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Aging and the detection of imminent collisions under simulated fog conditions

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Abstract

The present study examined age-related differences in collision detection performance when contrast of the driving scene was reduced by simulated fog. Older and younger drivers were presented with a collision detection scenario in a simulator in which an object moved at a constant speed on a linear trajectory towards the driver. Drivers were shown part of the motion path of an approaching object that would eventually either collide with or pass by the driver and were required to determine whether or not the object would collide with the driver. Driver motion was either stationary or moving along a linear path down the roadway. A no fog condition and three different levels of fog were examined. Detection performance decreased when dense fog was simulated for older but not for younger observers. An age-related decrement was also found with shorter display durations (longer time to contact). When the vehicle was moving decrements in performance were observed for both younger and older drivers. These results suggest that under inclement weather conditions with reduced visibility, such as fog, older drivers may have an increased crash risk due to a decreased ability to detect impending collision events.

Keywords

Aging; driving; collision detection; fog; driving safety

An important and consistent finding regarding driving safety is the increased accident risk for older driver populations (Langford & Koppel, 2006; Evans, 2004; Owsley et al., 1991). For example, Evans (2004) examined data from the FARS (Fatality Analysis Reporting System) and found a steady increase in accident fatalities and rate of severe crashes for older drivers who were older than 60 years of age. This increased crash rate occurred for both men and women and was independent of miles driven.

The increased crash risk for older drivers could result from several age-related factors that range from sensory processing and perceptual processing to attention and cognitive ability. Age-related declines in sensory processing have been found in accommodation (Schachar, 2006), contrast sensitivity (Richards, 1977; Derefeldt, Lennerstrand, & Lundh, 1979; Owsley et al., 1983), dark adaptation (McFarland et al., 1980; Domey et al 1960), visual

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acuity (Chapanis, 1950; Kahn et al, 1977), spatial vision (Sekuler, Hutman, & Owsley, 1980), and dynamic visual acuity (Long & Crambert, 1990). Age-related changes in perceptual processing have been found in motion perception (Trick & Silverman, 1991; Gilmore et al., 1992; Andersen & Atchley, 1995; Betts et al., 2005; Bennett et al., 2007), optical flow (Andersen & Atchley, 1995; Andersen et al., 1999; Andersen & Enriquez, 2006) and depth perception (Norman et al., 2004; 2006).

Previous research has found that visual acuity is not a good predictor for crash risk (Wood and Owens, 2005). Instead, studies have found that dynamic acuity, contrast sensitivity, and useful field of view (Ball, Owsley, & Beard, 1990) are better predictor variables of crash risk. McGwin, Chapman, and Owsley (2000) found a relationship between contrast sensitivity for older drivers and specific driving conditions that are difficult for older drivers. The difficult driving conditions include driving at night and under inclement weather conditions.

In the current study, we examined age-related differences in detecting an impending collision under a specific type of inclement weather – fog. Failure to detect an impending collision can have serious consequences for the safety and well being of the driver as well as others in the immediate vicinity of the driver (i.e., passengers, other drivers or pedestrians). For example, if a driver fails to detect, with sufficient time to respond, an approaching vehicle that is on a collision path the driver might have inadequate time to avoid the impending collision or might overrespond resulting in a collision with other objects in the driving scene. Thus, understanding at ability of drivers to detect a collision with sufficient time to avoid a collision is an important and necessary issue in driving safety.

DeLucia et. al. (2003) studied the age-related differences in detecting collision events when a square object was moving towards the observer at a constant speed. The object travelled for 2 seconds and disappeared at either TTC (time to contact) of 1.5 or 3 seconds position. The participants were required to discriminate between collisions and misses. DeLucia et al. used a staircase methods to derive the 50% threshold or the point of subjective equality (PSE) in two response alternatives which indicates the collision detection performance. They found an age-related decrement in sensitivity for older females but not older males. In a more recent study, Andersen and Enriquez (2006) assessed age-related differences in detecting collision events under stationary and moving conditions. In their study, observers were presented a portion of the travel path of the spherical object, which either collided with or passed by the observer. They found that older observers, as compared to younger observers, were less sensitive to collision events and required more time to process the visual information. More important, however, is that their results suggest that older observers have more difficulty detecting imminent collision events when the observer is moving at a high speed and has a short viewing time.

Previous epidemiology studies on driving safety have found a relationship between the age of the driver and crash rates under reduced visibility conditions due to weather or dusk/ nighttime conditions (Langford & Koppel, 2006; McGwin & Brown, 1999; Massie, Campbell & Williams, 1995; Stutts & Martell, 1992). Fog is one example of an inclement weather condition that can have a direct impact on the driver's vision. The presence of fog reduces the overall contrast and visibility of the driving scene, which results in reduced visible details as a function of increasing distance. Such reduced visibility of driving scene may lead to higher injury and death rates in crashes (Al-Ghamdi, 2007). Driving simulation studies have found evidence of decreased driving performance under simulated fog conditions. A recent study (Ni, Kang, & Andersen, 2010) found reduced car following performance, for older as compared to younger drivers, under simulated fog conditions. As discussed earlier, it is well documented in the literature that contrast sensitivity is reduced

with increased age (Richards, 1977; Derefeldt, Lennerstrand, & Lundh, 1979; Owsley et al., 1983). These results, considered together, suggest that older drivers may have more difficulty than younger drivers in detecting impending collisions under dense fog conditions.

In the present study we investigated collision detection when an object was approaching the observer at a constant speed on a linear trajectory. Under these conditions a collision event is defined by the combination of two sources of information: a constant bearing in the visual scene (i.e. the position of the object in the visual field is constant) and expansion of the object (Andersen, Cisneros, Atchley and Saidpour, 1999; See also Ni and Andersen, 2008). For this type of collision event two factors might affect the ability of drivers to detect a collision when fog is present. First, the reduced visibility of the scene may increase the difficulty in determining that the bearing of the object is constant. This possibility may occur because the reduction in contrast of the surrounding scene may remove information (e.g., the horizon, texture gradients or linear perspective) important for determining the position of the object. If the ability to determine bearing of the object is reduced then we expect a decline in collision detection performance under high fog conditions. Second, reduced visibility of the scene may result in increased difficulty in detecting expansion information under foggy conditions. This suggests that detecting the approaching object might be impaired under high fog conditions, resulting in a decrease in collision detection performance.

In the present study we investigated the effects of fog on collision detection performance when optical variables (i.e., visual angle and change in visual angle of the object, and the relative speed between the object and the vehicle) were constant. Drivers were presented with a driving simulation scene of a straight roadway in a suburban setting. A spherical object travelled on a linear trajectory towards the vehicle for nine seconds before it either collided with or passed the vehicle. The vehicle was either stationary (Experiment 1) or moved on a linear path at a constant speed (Experiment 2) while the relative speed between the object and the vehicle was constant. Only a part of the travel path was presented and the driver's task was to determine whether the object would collide with the vehicle or pass by the vehicle.

EXPERIMENT 1

Subjects

11 college students (age mean and standard deviation of 23.0 and 2.6, respectively) and 11 older subjects (age mean and standard deviation of 75 and 4.6, respectively) were recruited for the study and were paid for their participation. Prior to the experiment, all drivers were screened using visual and cognitive tests including Snellen static acuity, contrast sensitivity, WAIS-KBIT, and perceptual encoding. All reported normal or corrected-to-normal vision and were currently licensed drivers. All drivers had experience driving in fog and reported driving at least 3 days per week. All drivers were naïve with regard to the purpose of the experiment. Demographic information of the subjects and the results of the screening tests are presented in Table 1.

Design

Three independent variables were examined: Age (younger and older drivers), simulated fog density (no fog, mild fog, medium fog, or dense fog, corresponding to 0, 0.08, 0.16 or 0.24 in simulated density respectively), and the time to contact (TTC) on the last frame of the display (2, 4, or 6 seconds). Age was run as a between-subjects variable. All other variables were run as within-subject variables. Two within-subject variables produced 12 combinations, each of which was repeated 40 times in the experiment (20 times with a simulated collision event and 20 times with a simulated non-collision event), producing a total of 480 trials. The 480 trials were then divided evenly into 4 blocks, which were

completed within one single-hour session. These experimental blocks were preceded by a 16-trial demonstration and practice block. The order of the trials for each observer in each block was randomized individually.

Apparatus

The displays were generated by a Dell PC computer system and were presented on a 23-inch ViewSonic VP230mb flat monitor, with the dimension of 47cm (width) by 35cm (height), with the refresh rate at 60 Hz and the resolution at 1024 by 768. Subjects viewed the displays binocularly through a 19 cm diameter glass collimation lens. Head position was fixed using a chinrest. The purpose of the collimating lens was to remove accommodation cues of distance to the monitor. The distance between the eye and the lens was approximately 10 cm and the distance from the eye to the monitor was 45 cm.

Stimuli

The displays simulated a 3-D scene consisting of a roadway, roadway strip, and textured ground (See Figure 1). The total dimensions of the simulated space were 2400 by 1200 m. The roadway was 7.2 m horizontally and extended the entire depth of the simulated space. A black and white gravel texture pattern was used to simulate asphalt. A solid, yellow line was projected down the length of the roadway. An irregular green texture pattern was presented to the left and right of the roadway. The viewpoint was 1.2 m above the ground plane. The approaching bright red spherical object (2.4 m diameter) translated towards the observer at a speed of 90 km/h. The object motion trajectories were generated using the same method employed in previous research (Andersen and Enriquez, 2006; Ni and Andersen, 2008). The initial position of the object was chosen randomly from an arc (± 20 degrees from the center of the display) at a fixed distance of 223 m from the viewpoint. The end position of the object was 50 m, 100 m, or 150 m from the view point for TTC of 2, 4, and 6 s, respectively. The 3D velocity for collision and non-collision events was constant.

The projected size of the sphere varied as a function of distance, with the smallest projected size as 0.9° . Average luminance (measured using a Photo Research PR-524 LiteMate™ photometer and based on luminance measures of 20 random locations in the display) of the scene was 12.06 cd/m² under the dense fog condition and 19.13 cd/m² under no fog condition. The contrast of the moving object was varied as a function of the level of simulated fog and the TTC (associated with the distance of the object from the driver). For example, the Michaelson contrast of the object at the end of the display under dense fog condition was 0.16, 0.16, and 0.22 for the 2 sec, 4 sec, and 6 sec TTC condition, respectively (see Table 2 for a complete list of contrast values under each condition). The Michaelson contrast of the object at the beginning of the motion was 0.53, 0.13, 0.11, and 0.08 for no fog, light fog, medium fog, and dense fog conditions, respectively. All observers reported during debriefing that they were able to see the sphere in all conditions.

Simulated Fog—To simulate realistic effects of fog the computer simulation used the formula

$$L(s, \theta) = L_o F_{ex}(s) + L_{in}(S, \theta), \quad (1)$$

Where L_o represents the light reflected from the object, $F_{ex}(s)$ is the amount of light that reaches the observer divided by the amount of light decay that occurs with distance ($F_{ex}(s)$ can be replaced with e^{-bms} to represent the decay factor for fog using a Mei-scattering criterion), and $L_{in}(S, \theta)$ represents the scattering of light from fog. This function is the industry standard for simulating fog in computer graphics and visualization (Klassen, 1987; Nishita, 1998; Hoffman and Preetham, 2003) and produces a contrast gradient that varies

exponentially as a function of distance. The specific fog values in the simulation, using this equation, were 0.0, .008, 0.16 and 0.24. These values were selected to represent a range of conditions from high visibility (0.0 fog condition) to low visibility (0.24 fog condition). The low visibility condition was selected based on informal observations indicating that under this condition the visibility of the object was considerably reduced while still visible at the original position.

Procedure

The experiment was run in a darkened room. The observer viewed the monitor binocularly through a collimating lens with their head in a chin rest. Subjects were informed that they would be shown a series of displays consisting of a 3D scene with a single object in the distance that was moving towards the observer. Their task was to determine whether the moving object would hit the observer. Observers were next shown a series of demonstration displays of collision and non-collision stimuli in which the complete motion trajectory was displayed. After observers understood the task they were presented with 8 practice trials with the complete 9-second event, half of which simulated a collision, and were asked to indicate whether or not the object was on a collision trajectory by pressing one of the two designated keys on a standard keyboard. Subjects pressed the number “6” key for non-collision responses and the number “4” key for collision responses. No feedback was given during the practice trials and experimental trials. Subjects were required to correctly identify 7 of the 8 practice trials before proceeding to the experimental trials. This was done to ensure that the subjects understood the task and response.

Following the practice trials observers were instructed that the experiment would include brief presentations of the collision and non-collision events. If they were uncertain of whether the display was a collision or non-collision event they should make the best judgment possible. Subjects were given 4 sessions of trials with 120 in each block presented in a random order. Subjects were given a brief break between sessions.

Results

The average proportion of hits (collision response for trials that simulated a collision) and false alarms (collision response for trials that did not simulate a collision) was calculated for each subject in each condition and used to derive sensitivity (d') and response bias (β) measures (Green & Swets, 1966). In conditions where observers performed perfectly (100% hit rate or 0% false alarm rate), d' and β were calculated assuming a single error.

Sensitivity—The d' values for each subject in each condition were analyzed in a 2 (age) by 4 (fog density) by 3 (TTC) ANOVA (Analysis of Variance). A main effect of age was found ($F(1, 20) = 5.0$, $MSE = 27.92$, $p < .05$), indicating that younger observers (mean $d' = 3.43$, $stdev = 0.21$) had greater sensitivity than older observers (mean $d' = 2.78$, $stdev = 0.21$). The main effect of fog was found to be significant ($F(3, 60) = 3.17$, $MSE = 0.43$, $p < .05$), as well as the interaction of age and fog ($F(3, 60) = 3.35$, $MSE = 0.46$, $p < .05$). As can be seen in Figure 2, an increase in fog density resulted in a decrease in sensitivity for older observers but not for younger observers.

The main effect of TTC was significant ($F(2, 40) = 48.0$, $MSE = 44.13$, $p < .01$), which was mediated by a significant interaction with age ($F(2, 40) = 5.48$, $MSE = 5.04$, $p < .01$). When the TTC was 2 seconds, older observers performed as well as younger observers. As the TTC increased, the sensitivity for both age groups decreased. However, older observers' sensitivity decreased at a greater rate than that of younger observers (Fig 3). The 3-way interaction between age, fog, and TTC was not significant ($F(6, 120) = 0.71$, $MSE = 0.10$, $p = .64$). No other interactions were significant ($p > .05$).

An important issue is whether the age-related decrements in collision detection were due to an inability of older observers to perform the task. To examine this issue we conducted an additional analysis to determine if the d' values for each observer in each condition were significantly greater than zero (chance) (Marascuilo, 1970). Younger observers' sensitivity was significantly greater than zero ($p < .05$) in all 12 combinations of fog and TTC. For the no fog, 0.08 fog density and 0.16 fog density displays, the number of older observers with greater than zero sensitivity was 11, 10, and 8 (out of 11) for the 2s, 4s, and 6s TTC, respectively. For the 0.24 fog density displays the number of older observers with greater than zero sensitivity was 11, 11, and 6 (out of 11) for the 2s, 4s, and 6s TTC, respectively. These results suggest that the age-related decrements in collision detection with fog at the 2 and 4 seconds of TTC were due to decreased sensitivity to detect collision events rather than due to inability to perform the collision detection task. Approximately half of the older observers were unable to detect collisions with better than chance performance when dense fog (0.24) was simulated and a 6 sec TTC was presented.

Bias—The β values for each subject in each condition were analyzed in a 2 (age) by 4 (fog density) by 3 (TTC) ANOVA (Analysis of Variance). The main effect of age group was not significant ($F(1, 20) = 0.23$, $MSE = 0.40$, $p = .63$), suggesting that both age groups were equally likely to respond that a collision was simulated. The main effect of fog density was not significant ($F(3, 60) = 2.56$, $MSE = 0.24$, $p = .06$), suggesting that the fog density did not bias the observers' likelihood to report a collision event. A significant main effect of TTC ($F(2, 40) = 3.69$, $MSE = 2.11$, $p < .05$) was found, suggesting that observers were more likely to make a collision judgment with increased TTC. No other significant main effects or interactions were obtained.

EXPERIMENT 2

As discussed earlier, one possible effect of fog on driving performance is difficulty judging vehicle speed because of a decreased ability to recover edge rate information from reduced contrast. Thus in Experiment 2 we examined the effects of fog on collision detection performance when the vehicle was moving and optical flow information is available. Three different vehicle speeds were examined. In order to simplify the design a no fog and high fog condition were examined.

Subjects

11 college students (age mean and standard deviation of 20.5 and 1.8, respectively) and 11 older subjects (age mean and standard deviation of 77 and 10.5, respectively) were recruited for the study and were paid for their participation. Prior to the experiment, all drivers were screened using visual and cognitive tests including Snellen static acuity, contrast sensitivity, WAIS-KBIT, and perceptual encoding. All reported normal or corrected-to-normal vision and were currently licensed drivers. All drivers had experience driving in fog and reported driving at least 3 days per week.

Design

Four independent variables were examined: Age (younger and older drivers), simulated fog density (no fog or dense fog, corresponding to 0 or 0.24 in fog density respectively), moving speed of the vehicle (20, 50, or 80 km/h), and TTC (2s, 4s, or 6s). Age was run as a between-subjects variable. All other variables were run as within-subject variables.

Apparatus

The apparatus was the same as in Experiment 1.

Stimuli

The stimuli were the same as in Experiment 1 with the following exception. The simulated speed of the vehicle was 20, 50, or 80 km/h. The relative speed between object and vehicle was kept constant (90 km/h) by using different speeds of object motion. Specifically the velocity of the object was 70, 40, or 10 km/h for the 20, 50 and 80 km/h vehicle speed conditions, respectively. The reason for using a constant relative speed is that it ensures that optical expansion of the object is constant across different vehicle speed conditions.

Simulated Fog—The fog was simulated using the same methods as in Experiment 1.

Procedure

The procedure was similar to that in Experiment 1. The observer viewed the monitor binocularly through a collimating lens with their head in a chin rest. In Experiment 2 there were 360 trials in total. The task was the same as in Experiment 1. In addition, the same demonstration and practice trials were used as in Experiment 1. All subjects successfully passed the practice session before participating in the experiment.

Following the practice trials subjects were instructed that the experiment would include brief presentations of the collision and non-collision events. If they were uncertain of whether the display was a collision or non-collision event they should make the best judgment possible. Subjects were given 4 sessions of trials with 10 replications of each of the 36 condition (2 fog condition by 2 collision event by 3 TTC by 3 moving speeds), presented in a random order. Subjects were given a brief break between sessions.

Results

The average proportion of hits (collision response for trials that simulated a collision) and false alarms (collision response for trials that did not simulate a collision) was calculated for each subject in each condition and used to derive sensitivity (d') and response bias (β) measures. For conditions in which observers performed perfectly (100% hit rate or 0% false alarm rate) d' and β were calculated using a single error.

Sensitivity—The d' values for each subject in each condition were analyzed in a 2 (age) by 2 (fog) by 3 (TTC) by 3 (moving speed) ANOVA (Analysis of Variance). A main effect of age was found ($F(1, 20) = 9.93$, $MSE = 27.37$, $p < .01$), indicating that younger observers (mean $d' = 2.65$, $stdev = 0.22$) had greater sensitivity than older observers (mean $d' = 2.13$, $stdev = 0.12$). The main effect of motion was found to be significant ($F(2, 40) = 4.58$, $MSE = 1.69$, $p < .05$), as well as the main effect of TTC ($F(2, 40) = 149.33$, $MSE = 101.25$, $p < .01$), and the interaction between age and TTC ($F(2, 40) = 4.27$, $MSE = 2.89$, $p < .05$). As can be seen in Figure 4, sensitivity for both age groups decreased with increased TTC. However, older observers' sensitivity decreased at a greater rate than younger observers.

The presence of fog did not significantly affect overall sensitivity ($F(1, 20) = .37$, $MSE = 0.07$, $p = .55$). However, a significant interaction was found between motion and fog ($F(2, 40) = 6.40$, $MSE = 0.63$, $p < .01$), as well among motion, fog, and TTC ($F(4, 80) = 2.68$, $MSE = 0.31$, $p < .05$; see Figure 5). According to this three-way interaction, when TTC was 6 sec there was a significant interaction between motion and fog ($F(2, 40) = 6.55$, $p < .01$). Specifically, sensitivity to collision events was higher with no fog than with dense fog when a moving speed of 20km/h was simulated ($F(1, 20) = 13.06$, $p < .01$). The interaction between motion and fog did not reach significance when TTC was 4 sec ($F(2, 40) = 1.16$, $p = .32$) or 2 sec ($F(2, 40) < 1$, $p > .05$). There were no other significant effects ($p > .05$). When compared with the mean d' values obtained in Experiment 1, these results suggest that both

older and younger subjects had greater difficulty detecting collisions when observer motion was present---a finding previously reported by Andersen & Enriquez, 2006.

Similar to Experiment 1, we examined whether the age-related decrements in collision detection were due to an inability of older observers to perform the task using a test proposed by Marascuilo (1970). For each level of TTC, there were 12 different combinations of speed and fog density. Thus, the number of observers, with greater than chance performance, varied according to these conditions. When the TTC was 2 s or 4 s, the number of observers with greater than zero sensitivity was either 10 or 11 (out of 11) for both age groups. When the TTC was 6 s, the number of younger observers with greater than chance sensitivity varied between 8 and 11 (out of 11), and the number of older observers with greater than zero sensitivity varied between 4 and 8 (out of 11). Consistent with Experiment 1, these results suggest that the age-related decrements in collision detection were due to a decreased sensitivity to detect collision events, when fog was present and the TTC was either 2 or 4 sec, rather than due to an inability to detect a collision. For the 6-second TTC, about half of the older observers were unable to significantly detect collisions with better than chance performance.

Bias—The β values for each subject in each condition were analyzed in a 2 (age) by 2 (fog) by 3 (TTC) by 3 (moving speed) ANOVA (Analysis of Variance). The main effects of TTC ($F(2, 40) = 9.83$, $MSE = 23.70$, $p < .01$) and fog ($F(1, 20) = 5.91$, $MSE = 1.64$, $p < .05$) were significant. The interaction between TTC and vehicle speed was also significant ($F(4, 80) = 2.57$, $MSE = 0.93$, $p < .05$). No other effects were significant ($p > .05$). Consistent with Experiment 1, the results indicate that when fog was simulated or when the TTC was increased, observers were more likely to respond that a collision event was present.

General Discussion

In this study, we investigated age-related differences in the detection of collision events under simulated fog conditions. We examined two hypotheses. According to the contrast and bearing angle hypothesis, older drivers, as compared to younger drivers, will have more difficulty in perceiving constant bearing information under low contrast condition due to fog. The results in Experiment 1 provide evidence in support of this hypothesis. We found that older drivers, as compared to younger drivers, had decreased sensitivity to detection an imminent collision when high fog density was simulated. In addition, although a decrease in performance was found for both younger and older drivers with decreased display duration, older drivers showed greater decrements as a result of shorter display durations. This is a finding consistent with previous research (Andersen & Enriquez, 2006) and is likely due to the increased difficulty in determining the bearing angle with reduced contrast.

The results indicated that collision detection performance declined for both younger and older and that this decline was greater with increased speed of the vehicle. These results indicate that as edge rate increased the ability to detect a collision declined. The results of Experiment 2 were consistent with the results obtained in Experiment 1 in which performance decreased with a decrease in display duration. In Experiment 2, no significant effect of fog was found suggesting that the ability to use edge rate information was not affected by the presence of fog. One explanation for the lack of an effect is that the edge rate information in the present study was limited (i.e., no buildings, trees, or other objects were present in the display). It is possible that on the presence of fog may effect the utility of edge rate information that is present with more complex driving scenes. An important issue for future research will be to examine more complex driving scenes that contain more detailed edge rate information.

The current study adds to the growing body of literature indicating that a decreased ability to process visual information associated with aging may lead to an increased risk of crashes (e.g., Andersen et al., 2000; Andersen & Enriquez, 2006; De Lucia, et al. 2003). The results of the present study suggest that under inclement weather conditions, such as fog, older drivers may be subject to an increased crash risk due to a decreased ability to detect an impending collision. An important finding of the present study was the interaction of age and display duration. According to this result, there was a considerable decline in collision detection performance for older drivers for the 6 sec TTC condition (allowing for a 3 sec presentation of the display). Given the well documented finding of slower reaction time and reduce divided attention capacity with age this result suggests that older drivers may be at considerable risk of a collision because of the additional time needed to detect a collision.

The results of the present study suggest two human factors applications for improving driving safety among older drivers. The first application concerns driving assistance systems. Major automobile manufacturers have developed intelligent safety systems (e.g. “Crash Mitigation Braking System” from Honda, Volvo’s “City Safety”, Toyota’s “Pre-crash System”, and Mercedes Benz’s “Distronic Plus” system) to reduce crash risk. Many of these systems were tested on younger drivers and thus do not consider the perceptual limitations of older drivers. A second application concerns the use of training methodologies to improve performance of older drivers. Andersen et al. (2010) found that following training with near threshold stimuli resulted in dramatic improvement of performance for older observers in a texture discrimination task. The improvement resulted in performance levels similar to younger observers who did not receive training and the improved performance was retained for up to 3 months. Indeed, the training, which occurred over a 2 day period, resulted in performance equal to the performance of college age observers before training. Other research (Richards et. al., 2006) found that older observers could improve their performance in divided attention through repeated training with the UFOV (useful field of view) task. An important topic for future research would be to investigate whether older observers can improve collision detection performance through the use of similar training techniques. For example, training older drivers with difficult detection conditions (e.g., impending collisions with simulated dense fog and short viewing time) might result in improved detection performance under these conditions. As a result drivers may become more optimal in detecting a collision with less viewing time allowing for a greater amount of time to initiate a control response to avoid a collision. Such training methods thus might serve to reduce crash risk among older drivers.

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a

b

Figure 1.
Example of stimuli with nofog (a) and simulated fog (b) present.

Figure 2.
The mean sensitivity (d') as a function of age and fog density from Experiment 1.

Figure 3.
The mean sensitivity (d') as a function of age and TTC from Experiment 1.

Figure 4.
The mean sensitivity (d') as a function of age and TTC from Experiment 2.

Figure 5.
The mean sensitivity (d') as a function of fog density, moving speed and TTC from Experiment 2.

Table 1

Means and Standard Deviations of Participants' Demographic Information and Results From Perceptual and Cognitive Tests in Experiment 1 and 2

Variable	Younger		Older	
	M	SD	M	SD
Age (years) ^a	23.0	2.6	75.0	4.6
Years of education ^a	14.5	1.3	16.4	2.4
Snellen Letter Acuity	10/10.8	1.2	10/12.4	2.2
Log Contrast Sensitivity ^{a, b}	1.78	0.14	1.64	0.23
Digit Span Forward	10.8	2.3	11.3	2.6
Digit Span Backward	8.4	1.4	7.1	1.5
Perceptual Encoding Manual ^a	87.9	15.1	54.7	16.3
Kaufman Brief Intelligence Test	23.9	3.4	26.7	5.2

^aDifferences between age groups were significant ($p < .05$).

^bContrast sensitivity was measured groups were using the Pelli Robson test (Pelli, Robson, & Wilkins, 1988)

Table 2

Michaelson contrast of the object at the end of the motion

Fog condition	TTC = 2s	TTC = 4s	TTC = 6s
No Fog	0.53	0.54	0.61
Light Fog	0.17	0.18	0.34
Medium Fog	0.15	0.16	0.25
Dense Fog	0.16	0.16	0.22