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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.

An important and consistent finding regarding driving safety is the increased accident risk for older driver populations (Langford and 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 et al., 1979; Owsley et al., 1983), dark adaptation (McFarland et al., 1960; Domey et al., 1960), visual acuity (Chapanis, 1950; Kahn et al., 1977), spatial vision (Sekuler et al., 1980), and dynamic visual acuity (Long and Crambert, 1990). Age-related changes in perceptual processing have been found in motion perception (Trick and Silverman, 1991; Gilmore et al., 1992; Andersen and Atchley, 1995; Betts et al., 2005; Bennett et al., 2007), optical flow (Andersen and Atchley, 1995; Andersen et al., 1999; Andersen and 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 et al., 1990) are better predictor variables of crash risk. McGwin et al. (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 traveled for 2 s and disappeared at either TTC (time to contact) of 1.5 or 3 s position. The participants were required to discriminate between collisions and misses. DeLucia et al. used staircase methods to derive the 50% threshold or the point of subjective equality (PSE) in

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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 and Koppel, 2006; McGwin and Brown, 1999; Massie et al., 1995; Stutts and 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 et al., 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 et al., 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 et al., 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 traveled on a linear trajectory towards the vehicle for 9 s 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.

Table 1
Means and standard deviations of participants' demographic information and results from perceptual and cognitive tests in Experiments 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

[a] Differences between age groups were significant ($p \leq .05$).
[b] Contrast sensitivity was measured using the Pelli Robson test (Pelli et al., 1988).

1. Experiment

1.1. 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.

1.2. 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 s). 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.

1.3. Apparatus

The displays were generated by a Dell PC computer system and were presented on a 23-in. ViewSonic VP230 mb flat monitor, with the dimension of 47 cm (width) by 35 cm (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.