

TRAFFIC-ENTRY BEHAVIOR AND CRASH RISK FOR OLDER DRIVERS WITH IMPAIRMENT OF SELECTIVE ATTENTION^{1,2}

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Summary.—Current research suggests that older drivers with declines in selective attention would make more unsafe traffic-entry judgments than would older drivers with normal attention. This hypothesis was tested using an instrumented vehicle and a LIDAR speed and range detector. Participants were 20 older drivers: 10 ($M=72.0$ yr.) had impairments of selective attention, measured with the Visual Attention Analyzer, Model 3000, and 10 were nonimpaired ($M=71.2$ yr.). Drivers pressed a button to indicate the last possible moment they could safely cross a road in front of an oncoming vehicle. The speed and distance of the oncoming vehicles were measured and time-to-contact was calculated. Each driver's time-to-cross the roadway was independently measured. Attention-impaired drivers showed shorter time-to-contact values (5.60 sec. versus 6.86 sec.), took longer to cross the roadway (5.41 sec. versus 4.84 sec.), and had shorter safety cushions (the difference between time-to-contact and time-to-cross the roadway). Monte Carlo simulation showed that these performance differences increased the crash risk of the impaired group by up to 17.9 times that of the nonimpaired group.

Drivers over the age of 65 years are a growing segment of the driving population, and many continue driving through their 9th and 10th decades (Jette & Branch, 1992). These drivers are at risk for age-related impairments in abilities critical to safe driving, which include perception, attention, memory, and decision-making and implementation. These impairments of perception, motor skills, and related abilities have clear implications for increased risk of crashes. Federal statistics show that crash incidence per miles driven is greater in older drivers than in young and middle-age drivers (Ryan, Legge, & Rosman, 1998). Some of these older drivers may be particularly unsafe because they are unaware of their driving performance impairments and fail to restrict their driving activity, placing them at higher risk for crashes. They may continue to drive in highly demanding situations—such as during rush hour, on busy interstate highways, and in poor weather—leading to greater risk of crashes, especially at intersections (Ball, Owsley,

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Sloane, Roenker, & Bruni, 1993; Ball, Owsley, Stalvey, Roenker, Sloane, & Graves, 1998; Owsley, Ball, McGwin, Sloane, Roenker, White, & Overley, 1998; Ryan, *et al.*, 1998; Stutts, Stewart, & Martell, 1998) and while entering and crossing traffic streams (Lyles & Staplin, 1991; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998; McGwin & Brown, 1999).

The goal of this study was to assess the specific effects of age-related impairments of selective attention on traffic-entry judgments. Older drivers with impairment of selective attention should select traffic-entry cushions less safe than those selected by nonimpaired older drivers. To assess traffic-entry judgments and risk-acceptance in these older drivers, an instrumented vehicle was used which was equipped with a speed/range-finding device, as described in Method below. A Monte Carlo simulation analysis extrapolated the experimental data to assess the safety of traffic-entry judgments.

METHOD

Participants

Twenty older drivers who were full-time residents of Iowa city, legally licensed and neurologically normal, participated in this experiment. Ten of these drivers ($M=72.3$ yr., $SD=7.3$) showed impairments of selective attention and 10 did not ($M=71.2$ yr., $SD=4.8$). Participants were classified as attention-impaired based upon impaired performance on at least one of the two selective attention subtests (Subtest 3 ≥ 350 msec.; Subtest 4 = 500 msec.) of the Useful Field of View (UFOV) test of the Visual Attention Analyzer (Model 3000, Vision Resources, Chicago, IL).

The Useful Field of View test consists of four separate tasks; Task 1 measured how fast a subject can identify a single object such as the silhouette of a car or truck presented at central fixation. Task 2 was a divided attention task in which the subject had to identify a single object presented at central fixation while identifying a peripheral visual target. Task 3 measured how fast a subject can identify a single object, either the silhouette of a car or truck, presented at central fixation while identifying a peripheral visual target surrounded by 23 distractor shapes. Task 4 was a selective attention task like Task 3 but presented a more difficult center task that required a same-different discrimination. The dependent measure in each task was the threshold score (in seconds) at which a participant could identify 75% of the targets correctly. Recent work showed that these cutoff criteria correspond to cutoffs used in previous studies with high sensitivity (89%) and specificity (81%) for predicting crash involvement (Ball, *et al.*, 1993; Edwards, Vance, Wadley, Cissell, Roenker, & Ball, 2005). Reducing the Useful Field of View was a particularly good predictor of crashes given failure to yield at intersections (Owsley, Ball, Sloane, Roenker, & Bruni, 1991).

Driving Exposure

Driving exposure, described by days and miles driven per week, was assessed with a standardized questionnaire of driving habits (Owsley, Stalvey, Wells, & Sloane, 1999). Driving frequency, described by days driven, was similar for impaired ($M=6.0$ days, $SD=1.8$) and nonimpaired ($M=6.4$ days, $SD=1.0$) subjects. Impaired subjects ($M=159.0$ miles, $SD=138.6$) drove only a few more miles ($p=.09$) than nonimpaired subjects ($M=76.7$, $SD=37.8$).

Visual Assessment

All drivers were tested on a battery of visual and cognitive tasks. Contrast sensitivity was assessed using the Pelli-Robson chart (Pelli, Robson, & Wilkins, 1988). This test provides a measure of low-to-medium spatial frequency sensitivity, i.e., near the peak of the contrast sensitivity function. The best-corrected visual acuity was measured using the ETDRS chart for far visual acuity and the reduced Snellen chart for near visual acuity, both expressed as LogMAR (logarithm of the minimum angle of resolution), with 0 representing 20/20 vision. Perception of 3-dimensional structure from motion and of motion direction were both tested using computer-generated animation sequences (Nawrot & Blake, 1991).

Cognitive Assessment

The Rey-Osterreith Complex Figure Test–Copy Version required participants to copy a complex geometric figure; this test provided an index of visuoconstructional ability. The Recall Version of this test measured nonverbal anterograde memory; the subject was asked to draw the figure from memory 30 min. after copying the complex figure. The Block Design subtest from the Wechsler Adult Intelligence Scale provided an additional measure of visuoconstructional ability that correlated with performance IQ. The Benton Visual Retention Test put a demand on working memory, a key executive function. The Trail-Making Test subtest B also placed demands on executive functions, including working memory and attentional set shifting. The Rey Auditory Verbal Learning Test was a rigorous measure of anterograde verbal memory. Judgment of Line Orientation assessed visuospatial perception by requiring subjects to match lines of different orientation to a target. Difficulty increased on this test by varying the length of the matching lines. The Controlled Oral Word Association Test required subjects, within a 1-min. time limit, to generate as many words as possible that begin with a certain letter of the alphabet. These tasks are described in detail elsewhere (Spren & Strauss, 1991; Lezak, 1995).

Mobility was assessed using a shortened version of the “Get Up and Go” Task (Mathias, Nayak, & Isaacs, 1986; Podsiadlo & Richardson, 1991). Fine motor control was assessed with the Grooved Pegboard Test. Postural

stability was assessed with the Functional Reach Task (Duncan, Weiner, Chandler, & Studenski, 1990).

Traffic-entry Judgments

Traffic-entry judgments were tested in an instrumented vehicle (IV) known as ARGOS (Rizzo, Jermaland, & Severson, 2002). ARGOS is a mid-sized vehicle with extensive instrumentation and sensors hidden within its infrastructure to measure objectively critical aspects of drivers' control and safety behavior on the road (Rizzo, Stierman, Skaar, Dawson, Anderson, & Vecera, 2004).

The assessment of traffic-entry judgments in the instrumented vehicle was preceded by driver screening at curbside to test several fundamental requirements for driving, including locating the vehicle's controls and signals, inserting the key in the ignition, starting the car, shifting from park to drive, driving forward a short distance, and stopping. No participant failed the screening protocol.

After being familiarized with the controls of the instrumented vehicle, participants drove approximately 3 miles of city driving to become proficient in the handling of the instrumented vehicle. The experimenter sat in the passenger seat throughout the drive and in subsequent testing of traffic-entry judgments.

Traffic-entry behavior was tested with the driver parked in an empty driveway perpendicular to a busy two-way 4-lane highway. This design allowed assessment of driver judgments with minimal exposure to a vehicular collision with oncoming vehicles. Speed, distance, and Time-to-Contact of each oncoming vehicle was gathered with the Stalker LIDAR (light detection and ranging) system (Plano, TX). Stalker LIDAR is a semiconductor laser device that measures the speed, distance, and direction vehicles are traveling relative to the device. The LIDAR was pointed directly at an oncoming vehicle by the experimenter sitting in the passenger seat (Fig. 1). The laser beam was directed at the license plate of the oncoming vehicle to ensure accurate results. Oncoming traffic rounding a curve entered the view of the experimenter and participant approximately 1,000 feet down the road.

Each driver was asked to press a button to mark the last possible moment he would cross the road in front of a specific oncoming vehicle. Each driver performed this judgment until 10 trials were completed. Data were streamed on-line from the LIDAR device to a laptop computer for data quality assessment, artifact detection, and calculation of Time-to-Contact for each button press. Trials were rejected when an extraneous passing vehicle unexpectedly occluded the LIDAR beam or when a participant had mechanical difficulty depressing the button.

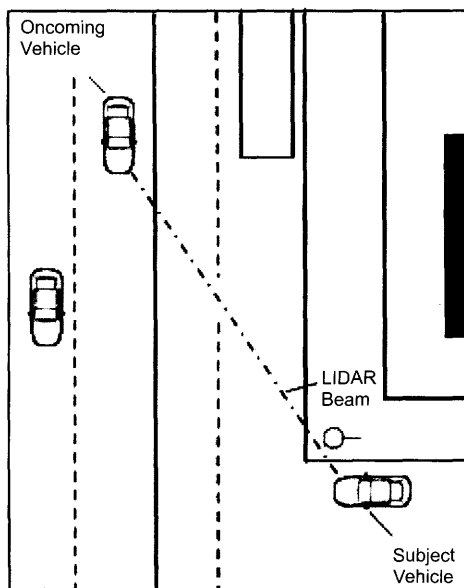


Fig. 1. Decision to enter traffic. Gap acceptance behavior in the instrumented vehicle was tested with the driver parked in an empty driveway perpendicular to a busy 4-lane highway (as in Skaar, *et al.*, 2003). Speed, distance, and time-to-contact of each oncoming vehicle were measured with the Stalker LIDAR system (Plano, TX). Independent estimates of the actual time each driver took to cross the road were also measured. When the road was clear of traffic, each driver crossed the roadway three times. Mean Safety Cushion was calculated as the difference between mean time-to-contact and mean time-to-cross for each driver.

Independent estimates of the actual time it took each driver to cross the road were obtained where the experiment was conducted. When the road was clear of traffic, each driver crossed the roadway three times. The average cushion of safety was calculated as the difference between the average Time-to-Contact and average Time-to-Cross for each driver.

A Monte Carlo simulation analysis was used to assess how potential differences between the attention-impaired and nonimpaired groups might influence traffic dynamics and the potential for crashes.

RESULTS

Despite differences in attentional abilities, the two groups showed few differences in visual, motor, and cognitive measures. Table 1 summarizes descriptive statistics for tests of cognitive, visual, and motor ability. The Wilcoxon Rank Sum test was used for between-group comparisons. The impaired and nonimpaired groups showed similar scores on all but one of the tests of cognitive, visual, and motor ability. Impaired subjects took 26.44 sec. longer to complete Subtest B of the Trail-Making Test, suggesting slight dif-

TABLE 1
COMPARISONS OF COGNITIVE, MOTOR, AND VISUAL MEASUREMENTS BETWEEN GROUPS ($n_s = 10$)

Demographic Measure	Impaired		Nonimpaired		<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
Age, yr.	72.30	7.30	71.20	4.85	0.33
Education, yr.	15.40	3.37	16.20	2.97	0.70
Cognitive Tests					
Auditory Verbal Learning Test	8.20	2.28	10.20	3.08	0.27
Benton Visual Retention Test	6.10	3.87	4.90	3.28	0.50
Complex Figure Task-Recall	15.80	6.23	17.35	5.26	0.66
Judgment of Line Orientation	24.90	5.17	24.90	3.21	0.67
Block Design	38.60	11.94	41.80	9.40	0.43
Complex Figure Task-Copy	29.30	5.60	29.65	3.51	0.87
Trail-Making Test Subtest B	94.55	29.34	68.01	19.21	0.03
Controlled Oral Word Association	38.80	9.93	42.80	8.95	0.41
Visual Tests					
Near Visual Acuity	0.023	0.040	0.021	0.040	0.93
Far Visual Acuity	-.038	.119	-.046	.112	0.99
Contrast Sensitivity	1.770	.221	1.770	0.197	1.00
Structure From Motion	9.98	3.11	9.49	2.12	0.74
Motor Tests					
Grooved Pegboard	95.14	17.66	80.27	10.14	0.06
Get Up and Go	10.43	2.08	9.99	1.73	0.69
Functional Reach	11.03	2.25	12.18	4.28	0.28
Useful Field of View					
Task 3, msec.	243.40	49.68	128.10	38.94	0.001
Task 4, msec.	442.20	85.16	250.20	99.22	0.001

Note.—Values were based on Wilcoxon Rank Sum test. Grooved Pegboard Test scores were calculated for means of both hand tests.

ferences in executive functions. Impaired drivers also tended to take longer to complete the Grooved Pegboard Test.

Age-adjusted multiple linear regression was used to compare Time-to-Contact, Time-to-Cross, and Cushion between groups. Compared to nonimpaired drivers, the attention-impaired drivers chose Cushion values that were 1.83 sec. shorter, and they took 0.57 sec. longer to cross the road. Impaired drivers chose entry gaps that were 1.26 sec. shorter than the nonimpaired group (Table 2). Despite their impairments, drivers in the selective attention-impaired group allowed themselves less safety cushion than those in the nonimpaired group. Spearman correlation analyses assessed the relations among visual attention, motor, and cognitive test performances and traffic-entry judgment outcome measures (Time-to-Cross, Time-to-Contact, and Cushion; see Table 3) across all 20 participants. Useful Field of View Subtest 3 thresholds (msec.) were negatively correlated with Time-to-Cross, Time-to-Contact, and Cushion. Thresholds for Subtest 4 were negatively correlated with Time-to-Cross and Cushion. Trends were observed for negative correlations between Subtest 4 performance and Time-to-Contact.

TABLE 2
COMPARISON OF TIME-TO-CROSS, TIME-TO-CONTACT, AND CUSHION
MEASURES FOR IMPAIRED AND NONIMPAIRED DRIVERS

Task	Group	<i>M</i>	<i>SD</i>	<i>p</i>
Time-to-Cross, sec.	Nonimpaired	4.84	0.37	.04
	Impaired	5.41	0.54	
Time-to-Contact, sec.	Nonimpaired	6.86	1.28	.08
	Impaired	5.60	1.64	
Cushion, sec.	Nonimpaired	2.02	1.43	.02
	Impaired	0.19	1.50	

Note.—Cushions were calculated as individual Time-to-Contact minus Time-to-Cross. *p* values were based on Wilcoxon Rank Sum test.

TABLE 3
SPEARMAN CORRELATION COEFFICIENTS FOR SIGNIFICANT UNIVARIATE PREDICTORS
OF TRAFFIC-ENTRY JUDGMENTS OUTCOME MEASURES

Outcome Measure	Predictive Variable	R_S^*	<i>p</i>
Time-to-Contact	UFOV Subtest 3	-.48	.03
	UFOV Subtest 4	.54	.01
Time-to-Cross	UFOV Subtest 3	.53	.02
	UFOV Subtest 4	.54	.01
Cushion	UFOV Subtest 3	-.61	.01
	UFOV Subtest 4	-.55	.01

*Spearman correlation coefficients.

Fig. 2 depicts gap distance judgments as a function of oncoming vehicle speed for attention-impaired and nonimpaired drivers. For each driver, Spearman correlation estimates tested the relationship between the gap distance chosen and the speed of oncoming vehicles. The correlation estimates of .24 [95% CI = (0.01, 0.47)] for the attention-impaired driver group and .13 [95% CI = (-0.11, 0.37)] for the nonimpaired driver group did not differ significantly ($p = .46$). To assess the difference in gap distance chosen between the groups, adjusting for the speed of oncoming vehicles, the speed of oncoming vehicles was categorized into two levels, 30–45 mph and 46–60 mph. Two-way analysis of variance showed that the attention-impaired drivers tended to choose shorter gap distances than the nonimpaired drivers ($F = 3.88$, $p = .06$), adjusting for the speed of oncoming vehicles and the status of attention impairment ($F = .02$, $p = .90$).

In a Monte Carlo analysis a simple simulation of the vehicle kinematics was developed to assess how the differences between the impaired and non-impaired groups might influence traffic dynamics and the potential for crashes. The Monte Carlo analysis (Shinar, Rotenberg, & Cohen, 1997; Brown, Lee, & McGehee, 2001) assumed the vehicle accelerated at a uniform rate to cross the intersection in the measured time. The model also assumed that the driver would begin to cross at the Time-to-Contact values reported in

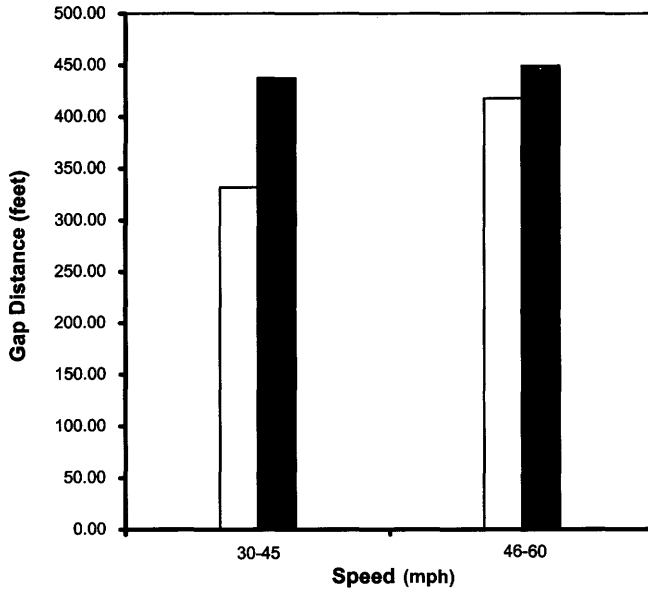


FIG. 2. Gap distance as a function of speed in impaired (□) and nonimpaired (■) drivers is shown. Bar heights represent mean gap distance (feet) of oncoming vehicles from the instrumented vehicle for both groups at speeds of 30–45 mph (Impaired: $M=331.93$, $SD=108.31$; Nonimpaired, $M=437.48$, $SD=83.95$) and 46–60 mph (Impaired: $M=417.82$, $SD=129.51$; Nonimpaired, $M=449.37$, $SD=107.50$).

Table 4. The initial velocity of the approaching vehicle was fixed at 65.6 ft. per sec. The Time-to-Contact and acceleration for each crossing were drawn from a normal distribution with standard deviation corresponding to the data in Table 4. Two general conditions were simulated. In the first, the approaching vehicle maintained a constant speed. In the second, the approaching vehicle reacted with a 0.3-g deceleration. In the simulation, the ap-

TABLE 4
SIMULATED CRASH RISK OF IMPAIRED AND NONIMPAIRED DRIVERS: PERCENT

Vehicle Condition	Measure	Group			
		Nonimpaired		Impaired	
		M	SD	M	SD
Without Braking	Time-to-Contact at edge of intersection	2.02	1.34	0.20	1.73
	% Below 2 sec.	49.3		84.8	
	% Below 1 sec.	22.9		67.5	
	% Crash	6.5		44.4	
With Braking	Time-to-Contact at edge of intersection	2.39	.99	0.73	2.58
	% Below 2 sec.	36.0		78.5	
	% Below 1 sec.	3.7		37.3	
	% Crash	0.9		16.1	

proaching vehicle began braking 1.5 sec. after the Time-to-Contact of the crossing vehicle dropped below 4 sec. Table 4 shows the results of 10,000 simulated crossing situations for each of the four conditions.

The top row of Table 4 showed that the Time-to-Contact when the crossing vehicle reached the edge of the intersection agreed with the time Cushion in Table 2. Impaired drivers have a much shorter time to collision than do the nonimpaired drivers. Table 4 also showed the percent of crossing situations in which the Time-to-Contact is less than 2 and 1 sec. These results were important because they represented situations in which drivers are likely to brake for the crossing vehicle. This braking behavior may disrupt the traffic stream and even induce a rear-end collision that could endanger the approaching vehicle. Table 4 also shows that the likelihood of a crash is much greater for impaired drivers—44.4% compared to only 6.5% for nonimpaired drivers. The bottom portion of Table 4 shows the results when the approaching vehicle brakes in response to the crossing vehicle. This situation is more representative of actual traffic conditions and showed that the overall rate of collisions drops substantially. The approaching vehicle collided with the crossing vehicle 16.1% of the time for the impaired drivers but only 0.9% for the nonimpaired drivers. Similarly, the safety cushion was much greater for the nonimpaired drivers. Only 3.7% of the nonimpaired drivers had a Time-to-Contact below 1 sec. as they crossed compared to 37.7% of the impaired drivers.

Overall, the Monte Carlo analysis shows that relatively small differences, in when impaired and nonimpaired drivers begin crossing an intersection and in how quickly they cross the intersection, can have a substantial effect on safety cushions and the probability of a crash. According to this analysis, impaired drivers are 6.8 times as likely to crash when the approaching vehicle does not brake and 17.9 times more likely when the approaching vehicle compensates for short Time-to-Contact values. Relatively small differences in the crossing decision criteria and the timing of the crossing maneuver can have a substantial effect on driver safety.

DISCUSSION

An on-board semiconductor laser device (LIDAR) was used to test whether drivers parked by the roadside in an instrumented vehicle could judge speed and distance of approaching vehicles and safely decide whether to enter traffic. Compared to 10 older drivers with no attentional impairment, a group of 10 drivers of similar age with impairment of selective visual attention chose marginally shorter traffic-entry times (based on Time-to-Contact) and took longer to enter traffic, leaving a smaller Cushion ($p < .05$, all cases) and indicating less safe judgments of traffic entry.

Neuropsychological, visual, and physical measures have been shown as

direct and indirect predictors of driver safety, in terms of crash risk based on individual crash history (Ball, *et al.*, 1993; Reger, Welsh, Watson, Cholerton, Baker, & Craft, 2004). The main difference between the driver groups in this study was in selective attention. Age-related decline of selective visual attention has been shown in multiple studies to be a predictor of real world vehicular crash (Ball & Owsley, 1991; Owsley & Ball, 1993; Owsley, 1994; Duchek, Hunt, Ball, Buckles, & Morris, 1998; Owsley, *et al.*, 1998; Owsley & McGwin, 1999; Carr, Duchek, & Morris, 2000; Ball, 2003; Duchek, Carr, Hunt, Roe, Xiong, Shah, & Morriss, 2003) and poor performance on road tests (Myers, Ball, Kalina, Roth, & Goode, 2000) and simulated driving tasks (Rizzo, Reinach, McGehee, & Dawson, 1997). However, specific effects of reduced visual attention on mechanisms of increased crash risk in demanding road segments and events, such as intersections and entering or crossing traffic streams, have generally not been quantified. Reasons for this include the lack of safe and effective procedures to assess performance in situations of high cognitive and attentional demand in a real-world setting.

The results of this study resemble those of a previous study of Japanese drivers. Keskinen, Ota, and Katila (1998) studied the on-road driving behavior of younger and older adult men. Their study indicated that older drivers accepted smaller time gaps when turning in front of younger motorists, an occurrence common to any city roadway. While the data provided insight into the behaviors and circumstances at intersections that contribute to increased crash risk, there were some limitations. Subject information was limited to sex and estimated age; as a result, drivers belonging to at-risk subgroups such as the attention- and cognitive-impaired could not be identified. While the study reported no differences in attention behavior between older and younger adults, inferences of attention were limited to observations of driver head checks to the right and left. There was also no information on the speed and distance of oncoming vehicles being observed by the drivers.

In a simulator study of gap acceptance in older female drivers, Guerrier, Manivannan, and Nair (1999) found that working memory, indexed by a mental addition task (Foos, 1989), was a predictor of reaction time and time gap. Drivers with greater working memory capacity chose larger entry gaps. These relationships are similar to those found between visual information processing capabilities and safety cushion in the current study. Working memory (the process of brief storage of information until it is available for use), attention (operating on contents of working memory), and executive functions (response selection and implementation) are key determinants of drivers' strategies and tactics. This includes judgments of traffic entry.

Hills and Johnson (1980) reported older drivers tend to choose constant distance gaps when entering traffic given high or low speeds compared to younger adult drivers, who make their decisions based on speed. Staplin

(1995) reported that older drivers use distance cues while estimating left-hand turns given high or low speed. These studies did not assess Time-to-Contact of oncoming vehicles and maintained that drivers were unsafe when not changing gap distance based on the speed of oncoming vehicles. Hills and Johnson (1980) suggested that older drivers choose constant distance gaps when entering traffic whether that traffic is moving at high or low speeds, whereas younger adult drivers adjust their decisions on traffic entry based on ambient traffic speed. Staplin (1995) reported that older drivers use distance cues while deciding when to make left-hand turns given high or low speed of oncoming vehicles. The concern raised by these studies was that drivers who do not adjust their traffic-entry or traffic-crossing decisions based on the speed of oncoming vehicles are unsafe. The results of the current study, although preliminary, suggest a related safety concern. Given equivalent oncoming vehicle speed, nonimpaired older drivers tended to choose greater traffic-entry gap distances than attention-impaired older drivers did, even though the latter group are less capable of reacting to other vehicles than normal older or younger drivers.

Selective attention may impair driving more than other aspects of attention (Parasuraman & Nestor, 1991; Duchek, *et al.*, 1998). This study finds evidence that drivers with selective attention impairment do not accommodate for deficits and choose shorter entry gaps, and thereby shorter safety cushions, than nonimpaired drivers. Further, driving exposure was similar between groups, suggesting that drivers with selective attention deficits may not be aware of their impairment and fail to self-adjust. Individuals who fail to accommodate for their decreased driving skills may place themselves at greater risk for crash. Although preliminary, these results suggest that selective attention impairments may compromise driving safety by undermining drivers' ability to adapt their decision criteria to their diminished perceptual and motor skills. Such adaptation in nonimpaired drivers contributes to safe outcomes in the face of substantial differences in decision criteria (van Winsum, 1998). Results of the Monte Carlo analysis suggest that relatively small differences in decision criteria for traffic-crossing and in the timing of the crossing maneuver by attention-impaired drivers may have substantial effects on public safety.

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