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Critical older driver errors in a national sample of serious U.S. crashes

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ABSTRACT

Objective: Older drivers are at increased risk of crash involvement per mile traveled. The purpose of this study was to examine older driver errors in serious crashes to determine which errors are most prevalent.
Methods: The National Highway Traffic Safety Administration's National Motor Vehicle Crash Causation Survey collected in-depth, on-scene data for a nationally representative sample of 5470 U.S. police-reported passenger vehicle crashes during 2005–2007 for which emergency medical services were dispatched. There were 620 crashes involving 647 drivers aged 70 and older, representing 250,504 crash-involved older drivers. The proportion of various critical errors made by drivers aged 70 and older were compared with those made by drivers aged 35–54.
Results: Driver error was the critical reason for 97% of crashes involving older drivers. Among older drivers who made critical errors, the most common were inadequate surveillance (33%) and misjudgment of the length of a gap between vehicles or of another vehicle's speed, illegal maneuvers, medical events, and daydreaming (6% each). Inadequate surveillance (33% vs. 22%) and gap or speed misjudgment errors (6% vs. 3%) were more prevalent among older drivers than middle-aged drivers. Seventy-one percent of older drivers' inadequate surveillance errors were due to looking and not seeing another vehicle or failing to see a traffic control rather than failing to look, compared with 40% of inadequate surveillance errors among middle-aged drivers. About two-thirds (66%) of older drivers' inadequate surveillance errors and 77% of their gap or speed misjudgment errors were made when turning left at intersections. When older drivers traveled off the edge of the road or traveled over the lane line, this was most commonly due to non-performance errors such as medical events (51% and 44%, respectively), whereas middle-aged drivers were involved in these crash types for other reasons. Gap or speed misjudgment errors and inadequate surveillance errors were significantly more prevalent among female older drivers than among female middle-aged drivers, but the prevalence of these errors did not differ significantly between older and middle-aged male drivers. These errors comprised 51% of errors among older female drivers but only 31% among older male drivers.
Conclusions: Efforts to reduce older driver crash involvements should focus on diminishing the likelihood of the most common driver errors. Countermeasures that simplify or remove the need to make left turns across traffic such as roundabouts, protected left turn signals, and diverging diamond intersection designs could decrease the frequency of inadequate surveillance and gap or speed misjudgment errors. In the future, vehicle-to-vehicle and vehicle-to-infrastructure communications may also help protect older drivers from these errors.

1. Introduction

Progress has been made in reducing crash involvement rates for drivers 70 and older since the mid-1990s (Cicchino and McCartt, 2014). Nevertheless, insurance claim rates begin to rise at age 65 (Highway Loss Data Institute, 2014), and police-reported crash risk per mile traveled begins to increase at age 70 (Cicchino and McCartt, 2014). The number of adults aged 70 and older in the United States is expected to increase considerably, from 10% of the population in 2013 to 15% in 2030 (U.S. Census Bureau, 2014a,b), leading to continued interest in reducing crashes among older drivers.

To develop effective countermeasures to reduce crashes among older drivers, it is essential to understand the types of crashes in which they are involved and the circumstances that lead to their crashes. It is well-established that older drivers are over-involved in angle, overtaking, merging, and intersection crashes in particular, especially those where the older driver was turning

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left (Mayhew et al., 2006). Age-related cognitive, visual, and physical impairments can affect the ability to perform driving tasks and navigate the kinds of complex roadway situations where older drivers' crashes often occur (Anstey et al., 2005).

Evidence from experimental studies give insight into the types of errors older drivers make that can potentially lead to crashes. When briefly viewing photos of traffic scenes, drivers aged 65 and older were more likely than younger drivers to judge that it was safe to continue through an intersection after a hazard entered the scene that made proceeding unsafe (Caird et al., 2005). Among drivers 65 and older, reaction time to traffic hazards presented in a video increased with age and with declines in cognitive and perceptual abilities (Horswill et al., 2008). In simulator studies, older drivers turning left decreased the size of the gap in traffic they would accept as vehicle speeds increase more than younger drivers, suggesting that older drivers attend more to another vehicle's distance than to its speed when making gap acceptance decisions (Staplin, 1995; Yan et al., 2007).

Much of what is known about the errors that older drivers do make in crashes comes from examinations of police reports generated after a crash. In a review of traffic violations attributed to drivers aged 65 and older involved in daytime crashes in Florida during 2005, researchers determined that crashes were most often due to failure to yield (Classen et al., 2010). Clarke et al. (2010) studied intersection crashes involving drivers 60 and older that were reported to three midland police forces in the United Kingdom during 1994–2007. In these crashes, the most frequent error leading to crashes was visual search problems, followed by poor judgment of another vehicle's approach speed. Compared with crash-involved younger drivers, contributing factors to older drivers' crash involvements more often include failing to yield the right-of-way (Brar and Rickard, 2013; Finison and Dubrow, 2002; Griffin, 2004; Stutts et al., 2009), disobeying traffic controls (Baldock et al., 2002; Brar and Rickard, 2013; Griffin, 2004), inattention (Finison and Dubrow, 2002; Stutts et al., 2009), or impairment by illness (Griffin, 2004).

A few studies have used additional data sources to examine the errors of crash-involved older drivers with greater specificity. Oxley et al. (2006) studied police crash reports and investigated sites of crashes involving drivers aged 65 and older that occurred at high-crash intersections in four jurisdictions in Australia and New Zealand. Inappropriate gap selection and high task complexity were contributing factors in the majority of crashes. Hakamies-Blomqvist (1993) conducted on-scene investigations of at-fault fatal crashes in Finland during 1984–1989 and determined that crashes of drivers aged 65 and older were more often caused by observation errors, defined as inattention or faulty perception, compared with crashes of drivers aged 26–40. Braitman et al. (2007) interviewed at-fault drivers aged 70 and older and aged 35–54 involved in intersection crashes in Connecticut in addition to examining police crash reports and photographs of the intersections. In failure-to-yield crashes, older drivers most often made search and detection errors, defined as errors leading to a failure to detect other vehicles or traffic control devices, or evaluation errors, defined as misjudgment of another vehicle's speed, intention, or direction, or failure to interpret an intersection's design.

The type of information available in crash reports and the consistency with which it is collected can be limited. Although Braitman et al. (2007),Hakamies-Blomqvist (1993), and Oxley et al. (2006) used richer information sources to examine driver error, their studies also have important limitations. Namely, Braitman et al. (2007) and Oxley et al. (2006) were limited in geographic scope, a weakness shared with other studies of U.S. state crash data, and their focus was restricted to intersection crashes. The investigation by Hakamies-Blomqvist (1993) focused on fatal crash involvements, which precluded interviewing many of the crash-involved drivers and provided information on only the most severe crashes.

In the National Motor Vehicle Crash Causation Survey (NMVCCS) conducted by the National Highway Traffic Safety Administration (NHTSA), a sample of U.S. crashes requiring emergency medical response were examined in-depth by investigators, who collected a variety of on-scene and other information. The current study examined errors in the NMVCCS database made by drivers 70 and older, the age at which police-reported crash risk per mile traveled begins to rise (Cicchino and McCartt, 2014), and compared them with those of middle-aged drivers aged 35–54. This study also examined how errors varied by crash type. Because of the variety of information collected by the NMVCCS, the standardized fashion in which it was collected, and the nationally representative sample, the NMVCCS overcomes some key limitations of prior studies examining older driver errors. Given that older women are more likely to be involved in intersection and left-turn crashes than older men (Chandraratna and Stamatiadis, 2003; Finison and Dubrow, 2002; Griffin, 2004; Stamatiadis, 1996), gender differences were additionally investigated.

2. Methods

2.1. NMVCCS database

The NMVCCS is a nationally representative sample of U.S. police-reported crashes on public roads involving at least one passenger vehicle towed from the scene, occurring between 6 a.m. and midnight, and for which emergency medical services were dispatched (NHTSA, 2008a). A total of 5470 crashes were investigated during July 2005–December 2007 in 24 primary sampling units representing combinations of geographic regions (Northeast, Midwest, South, or West) and extents of urbanization (central city, large county, or group of contiguous counties). The data were weighted by NHTSA using a comprehensive two-stage procedure that incorporated design weights and adjustments to make the NMVCCS sample representative of the more than 2 million crashes meeting the study criteria that occurred nationally during the study period. Further details on the sampling design and case weighting procedures is available in Choi et al. (2008). More than three-quarters (78%) of the weighted crashes involved injuries, including 18% that involved incapacitating injuries and 2% that involved fatalities.

Two trained investigators were assigned to each primary sampling unit, and each investigator responded to a maximum of two crashes per week. Investigators arrived on-scene at the crash and documented characteristics of the crash scene, photographed the crash scene and vehicles, and interviewed drivers, passengers, witnesses, and police and other first responders. Data were collected on more than 600 factors regarding drivers, vehicles, the roadway, and the environment. Complete datasets were generated for the first three vehicles involved in the collision, which were designated as case vehicles. To qualify for the study, one of the case vehicles must have been present when the investigator arrived at the crash scene, and a complete police crash report must have been available. Information from the crash investigation, the police crash report, and medical records from post-crash treatment when available were considered in the investigator's reconstruction of the crash circumstances. NHTSA (2008b) describes the protocol used in the field to document crashes, including detailed descriptions of all data elements collected.

Using a method originally proposed by Perchonok (1972), the chain of events that preceded each case vehicle's involvement in the crash was reconstructed. An important element in this chain was the critical reason, defined as the immediate reason for the critical pre-crash event, or the event that made the first harmful event in the crash inevitable. The critical reason typically occurred or was encountered directly preceding the critical pre-crash event, which was typically the final event to occur prior to an avoidance maneuver or crash impact. The critical reason and critical pre-crash events cannot be interpreted as the causes of the crash, nor does the assignment of the critical reason imply fault or legal culpability. There could be earlier failures in the chain of events that were as important as or more important than the critical reason. However, because the critical reason represents a crucial failure in the chain of events that led to the crash, examining these failures and the resulting critical pre-crash events can shed insight on which significant errors are most common among crash-involved older drivers and in which situations these errors are made. More information on the data collection process and assessment of pre-crash factors can be found in NHTSA (2008a,b).

A single critical reason was assigned in each crash to one vehicle. Critical reasons were due to driver error or vehicle (e.g., tire or brake failure), roadway (e.g., missing or defective traffic signals, roadway designs that deviate from America Association of State Highway and Transportation Officials standards), or environmental (e.g., rain, glare) factors. Critical driver errors were classified into four broad categories:

- *Recognition errors* occurred when the driver failed to recognize a hazard and included daydreaming, when the driver failed to recognize a hazard due to focusing on internal thoughts; internal and external distraction, when the driver was distracted by something inside or outside the vehicle, respectively; and inadequate surveillance, when the driver was required to look to complete a maneuver and either failed to look in the appropriate place or looked but did not see another vehicle or traffic control. Errors were not coded as inadequate surveillance if the driver was inattentive because of daydreaming or internal/external distraction.
- *Decision errors* occurred when the driver made an unsafe driving decision and included traveling too fast for conditions, to be able to respond to the unexpected actions of others, or for a curve or turn; gap/speed misjudgment, where the driver pulled out or turned inappropriately in front of another vehicle due to misjudging of the length of a gap between vehicles or the speed of the other vehicle; following too closely to respond to the unexpected actions of others; false assumption of others' actions; illegal maneuvers, which included failure to obey traffic controls, turning from the wrong lane, and other illegal acts; and turning with an obstructed view.
- *Non-performance errors* occurred when a physical factor impeded the driver's functioning and included sleeping and medical events.
- *Performance errors* occurred when a driver failed to properly execute a driving maneuver and included panic or freezing; overcompensation, as when a driver overcorrects; and poor directional control.

Although only one critical reason was assigned per crash, a critical pre-crash event was assigned to each vehicle involved in the first crash impact. In multi-vehicle crashes, which were 69% of the crashes investigated, the critical pre-crash event coded to each vehicle generally described the event that led to the first crash impact from that vehicle's perspective. For example, in a rear-end crash, the pre-crash event for the striking vehicle may be "another vehicle stopping, slowing, or traveling at a slow steady speed in the same lane," and the event for the struck vehicle may be "other vehicle traveling in same direction with higher speed."

There were 92 specific critical pre-crash events classified in the NMVCCS database that were grouped into four broad categories for the current study, four of which encompassed more than 90% of events for older and middle-aged drivers who were assigned critical reasons. The four broad categories included the vehicle departing its lane and traveling over the lane line into an adjacent lane (e.g., due to unintentional drifting or an intentional lane change), the vehicle traveling off the edge of the road, the vehicle turning at or crossing an intersection, and another vehicle stopping, slowing, or traveling at a slow steady speed in the same lane.

Among drivers for whom inadequate surveillance was the critical reason for the crash, the type of inadequate surveillance error was recorded in the database. Types of inadequate surveillance errors were categorized in this study as failing to look, or as looking and not seeing another vehicle or failing to see a traffic control. Among drivers for whom a medical event was the critical reason, the type of medical event was determined through review of the investigator's crash narrative. The presence of factors were additionally recorded by investigators. Factors were recorded if they were present, whether or not they appeared to contribute to the crash and regardless of the critical reason for the crash. The factors used in the current analyses included the lighting condition and the presence of driver visual impairment.

Lighting conditions included daylight, dawn, dusk, dark with an artificial light source present, and dark without an artificial light source present. Visual impairment was coded as present if the driver had a diagnosed impairment that was uncorrected by lenses when the crash occurred. The presence of a visual impairment was typically determined through the interview with the driver or their surrogate, or a review of vision-related restrictions listed on the driver's license, and less commonly was determined from medical records of the driver's post-crash treatment.

2.2. Analyses

Analyses focused on crashes involving older (aged 70 and older) and middle-aged (aged 35–54) passenger vehicle drivers. Weighted values were used in analyses; unweighted counts of crashes and driver crash involvements are also provided in the tables.

The proportions of crash-involved older drivers who made various critical errors and with other associated factors were compared with the proportions of crash-involved middle-aged drivers by calculating the ratios of these proportions and their associated 95% confidence intervals (CI). For simplicity, the ratio of proportions will be referred to as a rate ratio (RR). Similar analyses examined differences between older and middle-aged drivers for each gender. RRs greater than 1 indicate that the prevalence of a factor among older drivers was higher than the prevalence among middle-aged drivers. Middle-aged drivers were selected as a comparison group because they are not likely to have substantial age-related impairments or to exhibit the heightened risk-taking behaviors of the youngest drivers. Chi-square analyses ($p < 0.05$) were used to assess the statistical significance of differences in the distributions of characteristics between driver groups when more than two factors were considered. Analyses were conducted using PROC SURVEYFREQ in SAS (SAS Institute, 2011) to account for the complex sample design.

3. Results

There were 647 drivers aged 70 and older involved in 620 passenger vehicle crashes investigated during the study period, representing 250,504 drivers in 240,955 crashes nationally. Characteristics of older and middle-aged crash-involved drivers are summarized in Table 1. More than half of drivers in each age group were male, and more than 80% were involved in

Table 1
Characteristics of crash-involved drivers aged 70 and older and 35–54.

Characteristic	Ages 70 and older			Ages 35–54		
	Unweighted N	Weighted N	Weighted %	Unweighted N	Weighted N	Weighted %
Total	647	250,504	100	3113	1,130,405	100
Age						
70–74	242	110,203	44			
75–79	192	68,398	27			
80–84	124	49,774	20			
85 and older	89	22,128	9			
Gender						
Male	372	147,287	59	1722	616,180	55
Female	275	103,216	41	1391	514,225	45
Number of vehicles involved						
One	81	28,051	11	388	175,473	16
Two or more	566	222,452	89	2725	964,932	84

multiple-vehicle crashes; the distribution by gender and single- or multiple-vehicle crash involvement did not differ significantly between older and middle-aged crash-involved drivers. Forty-four percent of the older drivers were aged 70–74.

Ninety-seven percent of older drivers and 94% of middle-aged drivers were involved in crashes where driver error was the critical reason. Although these proportions were both high, they differed significantly (RR = 1.04, 95% CI = 1.02–1.05). Few older drivers were involved in crashes attributed to vehicle or roadway factors (1% each) or to environmental factors or unknown reasons (<1% each). Among drivers involved in crashes where driver error was the critical reason, a significantly larger proportion of older drivers (67%) were assigned the critical error than middle-aged drivers (49%) (RR = 1.38, 95% CI = 1.22–1.56).

3.1. Critical driver errors

The remaining analyses include crash involvements among older and middle-aged drivers where the critical reason for the crash was a driver error made by the older or middle-aged driver. Nearly half of critical older driver errors were recognition errors (48%), followed by decision errors (23%), non-performance errors (12%), and performance errors (5%) (Table 2). A significantly smaller proportion of the older driver critical errors than the middle-aged driver errors were decision errors (RR = 0.74, 95% CI = 0.61–0.90) or performance errors (RR = 0.46, 95% CI = 0.26–0.80).

Inadequate surveillance was by far the most common specific critical older driver error (33%) (Table 2). The next most frequent specific critical driver errors were misjudgment of the length of a gap between vehicles or another vehicle's speed (6%), illegal maneuvers (6%), medical events (6%; most often blackouts, followed by seizures, strokes, and other events), and daydreaming (6%). Among the specific driver errors, inadequate surveillance (RR = 1.47, 95% CI = 1.09–1.99) and gap or speed misjudgment (RR = 2.42, 95% CI = 1.35–4.39) were more prevalent among older drivers than middle-aged drivers. Older drivers were significantly less likely than middle-aged drivers to have driven too fast for conditions, a curve, or to respond to others' actions (RR = 0.31, 95% CI = 0.16–0.62), or to have made overcompensation errors (RR = 0.09, 95% CI = 0.02–0.52).

Table 2
Distribution of critical driver errors by driver age among drivers assigned the critical reason in the crash.

Critical driver error	Ages 70 and older		Ages 35–54	
	Unweighted N	Weighted %	Unweighted N	Weighted %
Total critical driver errors	422	100	1375	100
Recognition errors				
Inadequate surveillance	138	33	298	22
Daydreaming	20	6	73	4
Internal distraction	15	5	124	8
External distraction	21	4	65	4
Other/unknown recognition error	4	<1	32	2
Total	198	48	592	42
Decision errors				
Gap or speed misjudgment	33	6	53	3
Illegal maneuver	18	6	58	4
False assumption of other's action	24	4	73	5
Too fast for conditions/curve/to respond to others	12	3	118	11
Turned with obstructed view	14	2	37	2
Other/unknown decision error	9	1	94	7
Total	110	23	433	31
Non-performance errors				
Medical event	26	6	47	4
Sleeping, actually asleep	14	3	41	3
Other/unknown non-performance error	8	<1	27	2
Total	48	12	115	9
Performance errors				
Poor directional control	34	5	63	5
Overcompensation	3	<1	54	6
Other/unknown performance error	2	<1	13	1
Total	39	5	130	12
Type of driver error unknown	27	11	105	6

3.2. Factors associated with critical inadequate surveillance and gap or speed misjudgment errors

The prevalence of inadequate surveillance errors and gap or speed misjudgment errors among older drivers were examined by older driver age. Inadequate surveillance errors were somewhat more prevalent among drivers aged 70–74 (37%) than among drivers aged 75–79 (29%) or drivers 80 and older (31%), but not significantly so ($\chi^2[2] = 1.87$, $p = 0.39$). The prevalence of gap or speed misjudgment errors increased slightly with age, from 5% among drivers 70–74 to 8% each among drivers aged 75–79 and drivers 80 and older, but again these differences were not significant ($\chi^2[2] = 1.11$, $p = 0.57$).

Among older drivers who made critical inadequate surveillance errors, 71% of the errors were attributed to looking but not seeing another vehicle or failing to see a traffic control as opposed to failing to look, compared with 40% of middle-aged drivers (RR = 1.75, 95% CI = 1.01–3.05). About a quarter (24%) of all older drivers who were assigned critical errors made inadequate surveillance errors attributed to looking and not seeing or failing to see a traffic control, which was 2.5 times as often as among the 9% of middle-aged drivers who made this error (RR = 2.58, 95% CI = 1.32–5.04).

Three percent of the older drivers who were assigned the critical reason for the crash were coded as having visual impairments, compared with 1% of middle-aged drivers (RR = 2.38, 95% CI = 0.95–5.98). Lighting conditions at the time of the crash differed significant between older and middle-aged drivers ($\chi^2[4] = 21.73$, $p = 0.002$). Among older drivers, crashes occurred most often during daylight (88%), followed by darkness with an artificial light source at the scene (7%) or without an artificial light source (3%), dusk (2%), and dawn (<1%); middle-aged drivers also crashed most often during daylight (70%), followed by darkness with (11%) or without (13%) an artificial light source present, dusk (3%), and dawn (3%). Seven times as many older drivers who made critical gap or speed misjudgment errors were visually impaired (16% vs. 2%, RR = 7.38, 95% CI = 2.52–21.61), and 9 times as many crashed on dark roads without artificial light (20% vs. 2%, RR = 8.79, 95% CI = 3.71–20.83), compared with older drivers who made different errors. Few older drivers who made critical inadequate surveillance errors were visually impaired (2%) and few crashed on roads that were dark and unlighted (1%).

3.3. Critical driver errors by type of critical pre-crash event

Among older drivers assigned a critical driver error in the crash, the most common critical pre-crash events assigned to them were turning and crossing at an intersection (58%); traveling off the edge of the road (16%); the other vehicle stopping, slowing, or traveling at a slow steady speed in the same lane (14%); and traveling over the lane line into the adjacent lane (8%). Older drivers coded a critical reason while traversing an intersection were most often turning left; 38% of the older crash-involved drivers who were assigned a critical reason were turning left at an intersection.

Broadly construed critical driver errors for these events are summarized in Table 3. The distribution of critical errors made by drivers who traveled off the edge of the road or over the lane line differed significantly between older and middle-aged drivers. Older drivers most frequently made non-performance errors in both event types. Older drivers' non-performance errors were most often due to sleeping (35%) and blackouts (34%) when they traveled off the edge of the road, and blackouts (54%) and seizures (27%) when they traveled over the lane line. For middle-aged drivers who traveled off the edge of the road, three-quarters of critical errors were evenly distributed between decision, performance, and non-performance errors; middle-aged drivers who traveled over the lane line made non-performance errors least frequently.

Table 3
Distribution of broadly categorized critical driver errors by most common critical pre-crash events and driver age.

Critical pre-crash event and critical driver error	Ages 70 and older		Ages 35–54	
	Unweighted N	Weighted %	Unweighted N	Weighted %
Turning at or crossing intersection				
Recognition error	138	58	321	60
Decision error	79	27	185	29
Non-performance error	1	1	8	2
Performance error	5	1	4	1
Type of error unknown	16	14	46	8
	$\chi^2[4] = 4.36$, $p = 0.36$			
Traveling off of edge of the road				
Recognition error	7	10	50	15
Decision error	4	7	69	26
Non-performance error	34	51	77	27
Performance error	16	22	72	27
Type of error unknown	5	10	20	5
	$\chi^2[4] = 13.95$, $p = 0.008$			
Other vehicle stopping, slowing, or traveling at slow steady speed in same lane				
Recognition error	38	71	149	60
Decision error	11	16	68	24
Non-performance error	3	4	13	5
Performance error	4	2	8	6
Type of error unknown	3	8	20	5
	$\chi^2[4] = 2.73$, $p = 0.60$			
Traveling over lane line into adjacent lane				
Recognition error	7	18	48	31
Decision error	5	16	43	30
Non-performance error	9	44	17	10
Performance error	7	11	20	21
Type of error unknown	3	11	17	9
	$\chi^2[4] = 21.92$, $p < 0.001$			

Table 4
Distribution of driver errors in all intersection crashes and in left turn crashes at intersections by driver age.

Critical pre-crash event and critical driver error	Ages 70 and older		Ages 35–54	
	Unweighted N	Weighted %	Unweighted N	Weighted %
Turning at or crossing intersection				
Inadequate surveillance	122	50	233	45
Gap or speed misjudgment	30	10	40	5
Other error	87	40	291	50
Left turn at intersection				
Inadequate surveillance	83	58	141	50
Gap or speed misjudgment	26	13	33	8
Other error	58	29	142	43

Table 5
Distribution of critical inadequate surveillance errors and misjudgment of gap or speed errors by critical pre-crash event and driver age.

Critical driver error and critical pre-crash event	Ages 70 and older		Ages 35–54	
	Unweighted N	Weighted %	Unweighted N	Weighted %
Inadequate surveillance				
Left turn at intersection	83	66	141	48
Other intersection	39	21	92	26
Other circumstances	16	12	65	26
Gap or speed misjudgment				
Left turn at intersection	26	77	33	62
Other intersection	4	10	7	14
Other circumstances	3	13	13	24

The distribution of broadly construed critical reasons in crashes where drivers were turning at or crossing an intersection and in crashes where the other vehicle was stopping, slowing, or traveling at a slow steady speed in the same lane was nearly identical among older and middle-aged drivers (Table 3). Recognition errors were most common among drivers in both age groupings involved in these two crash types, followed by decision errors.

Although general categories of errors did not vary among older and middle-aged drivers assigned critical errors while turning at or crossing intersections, the prevalence of the two most common specific errors in intersection crashes were examined (Table 4). More than half (60%) of older drivers' errors when turning at or crossing intersections were inadequate surveillance errors (50%) or gap or speed misjudgment errors (10%), which was not significantly higher than the 50% of middle-aged drivers who made these errors while traversing intersections (RR = 1.19, 95% CI = 0.94–1.51). However, 71% of the critical errors of older drivers involved in intersection crashes when turning left were inadequate surveillance (58%) or gap or speed misjudgment errors (13%), which was a significantly higher percentage than the 57% for middle-aged drivers (RR = 1.24, 95% CI = 1.02–1.51).

The types of critical pre-crash events during which drivers most often made critical inadequate surveillance and gap or speed misjudgment errors were also examined. About two-thirds (66%) of older drivers' total inadequate surveillance errors were made when drivers were turning left at intersections, as opposed to during different driving maneuvers (Table 5). In comparison, about half of middle-aged drivers' total inadequate surveillance errors (48%) were made while turning left at intersections (total inadequate surveillance errors: RR = 1.38, 95% CI = 1.00–1.91). Seventy-seven percent of older drivers' gap or speed misjudgment errors occurred when drivers were turning left at intersections, which was higher than the prevalence among middle-aged drivers (62%) but not significantly so (RR = 1.23, 95% CI = 0.94–1.62).

Table 6
Differences in prevalence of critical driver errors by driver and gender and age.

Critical driver error and gender	Ages 70 and older		Ages 35–54		
	Unweighted N	Weighted %	Unweighted N	Weighted %	RR (95% CI)
Females					
Total critical errors	189	100	624	100	
Total recognition errors	107	59	293	44	1.34 (1.21–1.48)
Total inadequate surveillance errors	73	41	149	24	1.71 (1.18–2.49)
Inadequate surveillance: looked but did not see	43	32	58	8	3.89 (1.61–9.39)
Gap or speed misjudgment	17	10	21	2	5.05 (2.17–11.75)
Medical event	7	3	18	4	0.71 (0.13–3.91)
Illegal maneuver	6	3	24	5	0.63 (0.32–1.23)
Males					
Total critical errors	233	100	751	100	
Total recognition errors	91	39	299	39	0.99 (0.76–1.29)
Total inadequate surveillance errors	65	27	149	21	1.28 (0.78–2.11)
Inadequate surveillance: looked but did not see	33	17	70	10	1.72 (0.81–3.65)
Gap or speed misjudgment	16	4	32	3	1.21 (0.41–3.52)
Medical event	19	9	29	4	2.18 (1.13–4.21)
Illegal maneuver	12	9	34	3	3.56 (1.38–9.19)

3.4. Gender differences in critical driver errors

The most prevalent specific critical driver errors among older female drivers were inadequate surveillance (41%), gap or speed misjudgment (10%), daydreaming (8%), and internal distraction (6%); among older male drivers, they were inadequate surveillance (27%), illegal maneuvers (9%), medical events (9%), poor directional control (5%), and driving too fast (5%).

Critical driver errors that were significantly more prevalent for older drivers of only one gender, compared with middle-aged drivers of the same gender, are summarized in Table 6. Total recognition errors, inadequate surveillance errors attributed to looking and not seeing, and gap or speed misjudgment errors were significantly more prevalent among older female drivers than middle-aged female drivers but did not differ significantly by age for male drivers. Critical errors due to medical events and illegal maneuvers occurred significantly more often among older male drivers than middle-aged male drivers.

4. Discussion

Similar to serious crashes involving drivers of all ages (NHTSA, 2015), driver error is the final failure in the chain of events precipitating a crash in the vast majority of crashes involving older drivers. The current study found that inadequate surveillance errors are the most common errors made by older drivers, and that the prevalence of inadequate surveillance and of gap or speed misjudgment errors was significantly higher among older than middle-aged drivers assigned critical errors. These two errors accounted for 33% and 6%, respectively, of the total errors among crash-involved older drivers assigned critical errors, and 58% and 13%, respectively, of the critical errors made by crash-involved older drivers while turning left at intersections.

The current findings support results of other studies that have examined the prevalence of related errors among older drivers and have also found errors comparable with surveillance and gap acceptance to be among the most common (Braitman et al., 2007; Clarke et al., 2010; Hakamies-Blomqvist, 1993; Oxley et al., 2006). Specific frequencies of similar errors have varied among studies. Greater proportions of errors comparable with gap or speed misjudgment in intersection crashes were reported by Oxley et al. (2006) among drivers aged 65 and older and by Braitman et al. (2007) among drivers aged 70–79 than seen in the current study. Variation in definitions of errors, the number of errors attributed to individual drivers, and the sources of information on crashes available for review among studies could have contributed to differences in results.

Some of the errors most prevalent among older drivers may result from age-related cognitive, perceptual, and physical declines. Specifically, inadequate surveillance errors, which among older drivers in this study were primarily due to looking and not seeing, may be related to diminishing abilities to divide visual attention and reductions in information processing speed. Poor performance on the divided attention subtest (subtest 2) of the useful field of view (UFOV) test is associated with increased risk of at-fault motor vehicle crashes (Ball et al., 2006) and has been associated with looking and not seeing in experimental tasks assessing the ability to rapidly detect changes to visual scenes (Hoffman et al., 2005; Matas et al., 2014). Slower information processing speeds linked with aging are also related to poorer performance in change detection experiments (Costello et al., 2010). On-road studies have indicated that older drivers do not scan as thoroughly at intersections as middle-aged drivers (Bao and Boyle, 2009; Staplin et al., 1998), which could exacerbate problems with information gathering and processing.

Age-related cognitive impairments likely also contribute to older drivers' difficulties in selecting appropriate gaps in traffic. Performance on subtest 1 of the UFOV, which assesses visual processing speed, has been associated with gap selection ability in an on-road course and driving simulator (Bowers et al., 2005; Jongen et al., 2012). Slower reaction times and problems with motion perception associated with aging (Der and Deary, 2006; Snowden and Kavanagh, 2006) can also contribute to difficulties in identifying gaps and entering the traffic stream in sufficient time when gaps are identified.

The current study suggests that visual impairments and driving in darkness are related to the ability to judge gaps or other vehicles' speeds, as older drivers who made this critical error were 7 times as likely to be visually impaired and 9 times as likely to have crashed on dark and unlit roads as older drivers making other critical errors. The mechanism underlying this relationship is unclear. Especially given that older drivers may attend more to another vehicle's distance than speed when deciding to pull out in traffic (Staplin, 1995; Yan et al., 2007), distance perception (stereoacuity) could play a role in older drivers' gap judgments. However, poor stereoacuity has generally not been associated with increased crash risk (Owsley et al., 1998; Owsley and McGwin, 2010; Rubin et al., 2007). The specific visual impairments that were experienced by drivers assigned this factor were unknown. It is possible that difficulties seeing other vehicles at a distance because of visual impairments or darkness made it more likely that drivers would detect vehicles too late, after they had decided to turn.

Changes in the distribution of errors with age differed strikingly by gender. Older men were involved in more crashes than older women in which they made a critical error. However, older women were nearly 4 times as likely as middle-aged women to look but not see and 5 times as likely to misjudge another vehicle's speed or the gap between vehicles, whereas the prevalence of these errors did not differ significantly between older and middle-aged men. As surveillance and gap misjudgment errors were made most often when older drivers turned left at intersections, this finding is consistent with previous research demonstrating that older women are more frequently involved in intersection and left-turn crashes compared with older men (Chandraratna and Stamatiadis, 2003; Finison and Dubrow, 2002; Griffin, 2004; Stamatiadis, 1996).

Differences in driving patterns could help explain gender differences in driver errors. Older women drive fewer miles than older men (Federal Highway Administration, 2009), and it is likely that low-mileage drivers travel a larger percentage of their miles on local roads, where they would encounter more intersections where gap misjudgment errors and surveillance often occur (Langford et al., 2006). Similarly, older female drivers are more likely than older male drivers to report self-regulating their driving by avoiding expressways or driving only on local roads (Molnar and Eby, 2008).

It also is possible that misjudgment and surveillance errors were elevated among older women and not men because of gender differences in abilities that decline with age. For instance, men are more accurate at predicting time-to-collision than women (Caird and Hancock, 1994), and although motion perception abilities decline for both genders with age, older women's skills remain worse than older men's (Snowden and Kavanagh, 2006). Reaction time also increases more rapidly for women than men with age (Der and Deary, 2006). However, no gender differences were found in visual search and gap misjudgment errors during a recent study where drivers aged 65 and older were tested in a comprehensive driving evaluation (Classen et al., 2013). This could suggest that gender differences in functional abilities among the general population of older drivers do not affect driving skill when the route is prescribed.

The majority of critical events in which an older driver made a critical error occurred when maneuvering an intersection, but nearly a quarter occurred when older drivers left their lane by driving off the edge of the road or into an adjacent lane. Unlike middle-aged drivers, older drivers most often left their lanes due to non-performance errors, which most frequently were due to blackouts, drowsiness, or seizures. Medical conditions such as epilepsy and diabetes are associated with increased crash risk (Marshall, 2008), in part because they elevate the likelihood of sudden incapacitation. Medical events were significantly more prevalent among older men than middle-aged men with critical errors in the current study, but did not differ between older and middle-aged women. The prevalence of medical events among older male drivers may be a factor in why the proportion of their errors attributed to inadequate surveillance and gap or speed misjudgment were lower than among women. While older women's errors were heavily concentrated on those two most common errors, older men's errors were more evenly distributed.

Older drivers were turning left in the majority of crashes where they made inadequate surveillance and gap or speed misjudgment errors, and inadequate surveillance and gap or speed misjudgment errors were also the most common errors made when older drivers crashed while turning left. Countermeasures that simplify or eliminate left turns can reduce the frequency of these errors. Protected left turn lanes with green arrows make it unnecessary to perceive and judge the gaps in oncoming traffic and can make turning left at traffic lights less dangerous. Other roadway- and vehicle-based countermeasures that remove the need to make left turns or assist drivers while passing through intersections can be helpful. Converting intersections controlled by traffic signals or stop signs to roundabouts greatly reduces injury crashes (Persaud et al., 2001). Older drivers favor roundabouts somewhat less than younger drivers and may use alternate routes to avoid them (Hu et al., 2014; Retting et al., 2007), but adding features to roundabouts such as advanced warning signs or directional signs may encourage older drivers to use them (Lord et al., 2007).

New intersection designs such as diverging diamond interchanges also eliminate left turns across traffic. In the future, technologies in vehicles that communicate with infrastructure and other vehicles will provide information to drivers about gaps in traffic when they are turning and alert them to changes in traffic signals. Such systems were recently tested on-road in a year-long pilot study as part of the U.S. Department of Transportation's (2015) connected vehicle program.

Cognitive and visual screening tests for license renewal have been proposed as crash reduction countermeasures. However, while performance on various cognitive screening tests is associated with the likelihood of future crash involvement (Vanlaar et al., 2014), existing tests are not sufficiently accurate at identifying drivers with heightened crash risk without also falsely identifying drivers not at increased risk. Similarly, a review of the effectiveness of vision screening for older drivers in preventing crashes concluded that the effectiveness cannot be determined because existing evaluations are not of high enough quality (Desapriya et al., 2014).

Although the NMVCCS database overcomes several shortcomings of previous studies of older driver errors in crashes, it is not without limitations. The sample size of drivers aged 70 and older permitted only limited comparisons by gender and generally did not make it possible to draw comparisons by older driver age. The designation of the critical pre-crash event and its associated critical reason cannot be interpreted as causes of the crash. By design, these events occurred closest in time to the crash's first harmful event, but crashes are usually caused by multiple factors. It is possible that events or reasons that occurred earlier in the chain of events had a larger influence on the crash's occurrence than what was deemed the critical event and reason, and NHTSA (2008a) cautions that the assignment of the critical reason can be subjective. Some information from the crash investigations was collected through interviews, but not all crash participants could be interviewed, and some who were interviewed may have provided false or biased responses. Because of this limitation, it was a strength of this study that crash investigations were based on multiple sources of information. Analyses were limited to crash involvements where the critical error was assigned to an older or middle-aged driver, but assignment of the critical error also does not imply fault or legal culpability. There was no information available on the number of miles driven by crash-involved drivers, and the locations where they drive. As noted earlier, patterns of errors were likely influenced by where drivers travel.

A small number of critical driver errors are more often the critical reasons underlying the serious crashes of older drivers than of middle-aged drivers. By focusing on countermeasures that limit the opportunities to make these errors, particularly by altering the roadway environment to reduce conflict points and developing vehicle technologies to assist drivers at intersections, the effect of older drivers' age-related limitations on crashes can be diminished.

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