Age Differences in Motion Perception and Specific Traffic Maneuver Problems

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Studies of age differences in motion perception abilities and accident involvement patterns are reviewed to predict the exaggerated difficulty for older drivers with specific traffic maneuvers and the expected ordering of older-driver accident involvement rates by type of maneuver. A rigorous analysis of police-reported accidents in Michigan and Pennsylvania used induced exposure methods to demonstrate the highest older-driver accident involvement rate for turning left against oncoming traffic; the next highest older-driver accident rate occurred when drivers were crossing or turning into a traffic stream, although the extent of overinvolvement was not as high as the first situation; and the lowest relative involvement rates for maneuvers in which an age-related motion perception deficit may be at issue were in situations in which vehicle headways are critical, such as overtaking. Mitigating factors such as older drivers' slower driving that may compensate for or minimize some of the problems found in laboratory tests are noted. Overall, the present review and analysis supports an interpretation that age differences in motion perception in critical traffic situations is an important factor in older drivers' overinvolvement in particular accident types.

Recent historical accident data, anecdotal evidence, and driver self-reports have suggested an exposure-corrected overrepresentation of older motorists for specific unsafe driving acts. Findings document a decline with advancing age in sensory/perceptual (especially visual) skills, a range of cognitive functions, and the speed of psychomotor responses involved in driving (*1*); however, traffic safety researchers have yet to account for differential accident experience in terms of performance deficits on critical driving tasks. The analyses in this paper are part of a broader effort to investigate the hypothesis that age differences in motion perception can explain older-driver overinvolvement in particular accident categories. On the basis of a review of laboratory tests of the perceptual skills of younger versus older drivers, predictions concerning relative involvement rates among varying types of police-reported collisions in two states are developed and confirmed.

AGE AND MOTION PERCEPTION

Prior investigations have addressed motion perception abilities pertinent to driving, including time-to-collision and gap-acceptance judgments, though only a subset has compared older and younger subjects. In time-to-collision (Tc) estimates, drivers estimate how long it takes them moving at a constant speed to reach specified points in their paths (*2*). They are hypothesized to be based either on an optic-flow process, in which the driver's analysis of the relative expansion rate of an image, such as an oncoming vehicle, over time provides the estimate of Tc directly (*3,4*), or on a cognitive process in which Tc is estimated using speed and distance information. In the former theoretical framework, the driver relies on two-dimensional information—that is, angular separation cues (the image gets larger—to estimate Tc; in the latter, the driver calculates Tc on the basis of three-dimensional information. Several studies (*5,6*) have supported the optic-flow model and the idea that two-dimensional, angular separation cues separate from background information suffice to allow drivers to estimate Tc.

Relative to younger subjects, a decline (possibly exponential) for older subjects in the ability to detect angular movement has been reported. Using a simulated change in the separation of taillights, indicating the overtaking of a vehicle, a threshold elevation greater than 100 percent was shown for drivers 70–75 years old versus those 20–29 years old for brief exposures at night (*7*). Older persons may in fact require twice the rate of movement to perceive that an object's motion-in-depth is approaching, given a brief (2.0 sec) duration of exposure. In related experiments, older persons required significantly longer to perceive that a vehicle was moving closer at constant speed: at 19 mph, decision times increased 0.5 sec between ages 20 and 75 (*8*). The age effect was not significant when the vehicle was moving away from the subject.

Next, research has indicated that, relative to younger subjects, older subjects underestimate approaching vehicle speeds (*9*). Furthermore, analysis of judgments of the "last possible safe moment" to cross in front of an oncoming vehicle has shown that older persons (especially men) allowed the shortest time margins at 60-mph approach speeds—older persons accepted a gap to cross at an average constant *distance* of slightly less than 500 ft, whereas younger men allowed a constant *time* gap and, thus, increased distance at higher speeds.

More generally, there is an increased sensitivity across age groups to longitudinal versus tangential movement. However, longitudinal movement is a greater problem for drivers because the same physical displacement of a vehicle has a much greater visual effect tangentially than longitudinally—that is, tangential movement results in greater relative motion (*10*). Other findings relevant to motion perception and accident involvement, though undifferentiated by age in research to date, include the following:

- There appears to be general underestimation of Tc, and as Tc increases, the error increases: in other words, as speeds go up, the error increases (*5*);

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- Tc estimates vary between experienced and inexperienced drivers: the former integrate time and distance to provide a safety margin, whereas inexperienced drivers use speed and distance perception alone (*6*);
- Drivers have greater sensitivity to movement toward them than away (*8,11*), and there is high sensitivity to discriminating between directions of movement. This implies that rear-end collisions more likely result from inattention and the inability to judge correctly the magnitude of relative motion rather than from a limitation in detecting its direction. Drivers know when they are gaining on a car, but may be unaware of how fast (*12*);
- An increase in the angular velocity is required for motion detection, with increasing separation between two objects (*11*); and
- Increases in the rate of conflict for merging maneuvers and conflict severity for turning maneuvers are related to increased variance in speeds in the traffic stream for which a driver is making gap-acceptance judgments (*13*) that is, a principal source of risk at intersections is the error of a turning driver in judging gaps in front of fast vehicles.

Collectively, the motion perception literature implies that older drivers should have more difficulty than younger drivers with specific traffic maneuvers: older drivers should have more accidents when (a) turning left against oncoming traffic; (b) when simply crossing or turning into a traffic stream, although the differential should not be as high as the first situation; and (c) where vehicle headways are important (e.g., in overtaking a lead vehicle).

AGE AND ACCIDENT EXPERIENCE BY DRIVING MANEUVER

A broad survey of findings published during the previous decade relating to trends in the accident experience of young and old drivers is summarized; all implied comparisons are typically with the general population.

- California: Men and women drivers older than 70 years had significantly higher accident rates, and right-of-way violations were the leading cause of injury accidents and the primary collision factor in 30 percent of fatal accidents in which older drivers were judged at fault (*14*).
- United States (nationwide): Increased accident rates at signalized intersections following adoption of right-turn-on-red are highest for drivers under 25 or over 55 (*15*).
- Toronto: A survey of motorists indicated that the frequency of collisions under peak-volume urban driving conditions on non-limited-access roadways was reported to be highest for drivers under 21 and over 60 (*16*).
- Iowa: Higher rates were reported for the 65–70 age group, and even higher for drivers 75 and older; the highest percentages of older-driver accidents were in the categories failure to yield, improper turn, and failure to obey traffic signs. Twenty percent of accident-involved drivers over 75 were attempting left-turning maneuvers when the collision occurred (*17*).
- Great Britain (nationwide): Seventeen–19-year-olds had the highest accident rates, although drivers 65 and older had roughly twice the expected number involving failure to obey intersection control and far higher numbers turning across traffic (*18*).
- New Brunswick: Analysis of 30,471 accidents during 10 years showed that drivers 60 and older had accident rates equal or worse than drivers under 25 and a higher at-fault rate; specific problems were failure to yield and improper turning and reversing (*19*).

This overview is a preliminary confirmation of the prediction that the relative accident involvement rates of older drivers can be ordered according to traffic maneuvers in which motion perception difficulties will most strongly influence their safety. The following rigorous analysis of accident data in two states controls for (induced) exposure and accident factors extraneous to driver age to further increase our understanding of these relationships.

OLDER-DRIVER ACCIDENT INVOLVEMENT ANALYSES

Analyses of police-reported accidents in Michigan and Pennsylvania sought to focus on accidents in which drivers' motion perception was a significant contributing or causative factor. Accidents involving drinking drivers or vehicle equipment defects were excluded from consideration. Field reports that coded *Driver 1* as the driver more at fault (or more causative of an accident) and *Driver 2* as the one less at fault formed the basis for calculating relative involvement rates, that is, the cross tabulation of event frequencies as Driver 1/Driver 2 ratios, by driver age group. Four age groups were analyzed: 26 and younger, 27–55, 56–75, and 76 and older.

Michigan Accident Analysis

Michigan accident reports for 1986 through 1988 were examined. Accident report data were merged with other files to create records for analysis that contained entries describing the accident location (e.g., geometry), ambient environmental conditions, the crash occurrence and severity, driver and passenger(s), traffic citations associated with the event, and the vehicles involved and their drivers' intentions. Accident records associated with five specific maneuver types were examined: (a) merging and weaving maneuvers on limited-access highways, (b) lane change maneuvers on limited-access highways, (c) left turns against traffic, (d) crossing (gap-acceptance) maneuvers on non-limited-access highways, and (e) overtaking and passing on two-lane, two-way rural roads. The accident records were analyzed in comparison with base conditions and defined by explicit variable limits.

Merging and Weaving Maneuvers on Limited-Access Highways.

Only accidents that occurred on or near ramps in the vicinity of intersections with the limited-access facility were considered in the analyses for this maneuver. Also, accidents were eliminated, for example, when the vehicles were stopped and in situations in which it wasn't clear what maneuvers were occurring. Finally, driver intentions were also considered. Valid intentions included going straight, passing, changing lanes, and starting up. Eliminated intentions included making a right turn and backing. The resulting analysis set included 1,682 accidents.

Unfortunately, only 27 (1.5 percent) of the 1,682 accidents involved Driver 1s 76 and older. Furthermore, there were only 17 Driver 2s in this age group. In the 56–75 group, there were 174 Driver 1s and 289 Driver 2s. Subject to this caveat, cross tabulations for driver intention (i.e., Driver-1 age by intention) showed that the preponderance of Driver-1 intentions for all age groups was to go straight or change lanes; drivers under 55 showed virtually identical distributions (68 percent straight, 28 percent change); and drivers 56–75 were more likely to have the intention to change lanes (59 percent straight, 40 percent change). However, the distributions for Driver-2 intentions were far more similar to one another (variations on the order of 1 to 2 percent versus 10 percent for Driver 1).

Table 1 presents data in a matrix (cross tabulation) of Driver-1 age by Driver-2 age for specified conditions. If Driver 1 is at fault and Driver 2 is innocent (i.e., Driver 1 caused the accident and Driver 2 just happened to be there), it is argued that Driver 2 characteristics are implicit measures of exposure. Thus, the ratio of Driver 1 to Driver 2 characteristics is indicative of relative over- or underrepresentation (marginal row proportions divided by marginal column proportions); for example, if the proportion of Driver 1s 26 and younger is greater than the proportion of Driver 2s 26 and younger, then this age group is overrepresented in accidents relative to their exposure. This approach is discussed elsewhere in the context of quasi-induced exposure (*20*).

In general, Table 1 data indicate that the 26-and-younger group is overrepresented and the 27–55 and 56–75 groups are underrepresented. The involvement ratios are 1.5, 0.8, and 0.9, respectively, and 2.3 for the oldest group. The small number of older drivers makes conclusions problematic, but the ratio is more than 1.0, indicating overinvolvement.

Of further interest is cross tabulation of violations for Driver 1 by age (Table 2), which shows that different age groups committed different violations. Drivers 26 and under were far more likely to follow too closely and speed than drivers over 26. As older groups are examined, the tendencies shift: speeding becomes less likely, failing to yield more likely, improper use of lanes more likely, and following too closely less likely. Notwithstanding sample size, these trends carry over to the oldest driver group, which was least likely to speed and most likely to fail to yield and to use lanes improperly.

Next, as a comparison to a base condition, merging and weaving accidents were also compared with all accidents that occurred on limited-access highways. Among the most interesting findings, 38.4 percent of merging and weaving rear-end collisions involved Driver 1s 26 or younger, versus 40.8 percent of all rear-end accidents on limited-access highways. The two oldest groups accounted for more rear-end, merging and weaving accidents than they did for all rear-end accidents (11.7 percent versus 9.3 percent). However, for Driver 1s 26 and younger, approximately 4.5 percent of all limited-access highway accidents were classified as merging and weaving accidents; for Driver 1s 27–55, approximately 4.9 percent; for Driver 1s 56–75, approximately 4.8 percent; and for Driver 1s 76 and older, 4.6 percent. That is, merging and weaving accidents do not appear to be overrepresented, in comparison with all accidents on limited-access highways, for any age group.

In summary, notwithstanding the small number of the oldest drivers in this analysis set, drivers in different age groups appear to make somewhat different errors in merging and weaving accident situations: younger drivers are more likely to speed and follow too closely than older drivers, and older drivers are more likely to fail to yield the right-of-way and

TABLE 1 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE, MERGING AND WEAVING ON LIMITED-ACCESS HIGHWAYS

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	155 (24.1)[1]	418 (65.1)	63 (9.8)	6 (0.9)	642 (38.2)
27-55	216 (25.5)	519 (61.2)	110 (13.0)	3 (0.4)	848 (50.4)
56-75	43 (26.1)	103 (62.4)	16 (9.7)	3 (1.8)	165 (9.8)
76-98	4 (14.8)	20 (74.1)	3 (11.1)	0 (0.0)	27 (1.6)
totals	418 (24.9)	1060 (63.0)	192 (11.4)	12 (0.7)	1682

note : [1] cell entries: number of accidents (row percentage)

TABLE 2 CROSS TABULATION OF DRIVER-1 AGE BY VIOLATION, MERGING AND WEAVING ON LIMITED-ACCESS HIGHWAYS

driver-1 age	violation[1]				
	speeding	fail yield	lane usage	following	other
≤26	102 (14.8)[2]	52 (7.5)	152 (22.1)	358 (52.0)	25 (3.6)
27-55	128 (14.3)	96 (10.8)	217 (24.3)	429 (48.0)	23 (2.5)
56-75	21 (12.1)	33 (19.0)	54 (31.0)	60 (34.5)	6 (3.5)
76-98	2 (7.4)	8 (29.6)	9 (33.3)	7 (25.9)	1 (3.7)
totals	253 (14.2)	189 (10.6)	432 (24.2)	854 (47.9)	55 (3.1)

notes: [1] violations: speeding, failure to yield right of way, improper lane usage, following too closely
[2] number of accidents and (row percentage)

use lanes improperly. Moreover, the shift from one violation to another appears to occur with increasing age. However, following too closely is still the most likely violation for all but the oldest drivers.

Drivers 26 and younger and 76 and older are overrepresented in merging and weaving accidents. Although generally underrepresented, the 56–75 group is overrepresented during rush hours and dawn and dusk periods. There is some evidence to suggest that older drivers restrict their driving during poor weather: the magnitude of the involvement ratio remains about the same, but the percentages of older drivers involved as Driver 1 and Driver 2 decrease during adverse weather as measured by road surface condition. There does not appear to be an interactive effect between merging and weaving and weather. Finally, this analysis indicated that older drivers appear to have more problems with trucks than with automobiles in merging and weaving situations.

Lane Changes on Limited-Access Highways.

More than 13,600 accidents occurred away from interchanges after eliminations (e.g., median crossings), but it proved difficult to isolate those that were high-speed lane-change accidents per se. Thus, all accidents occurring at operating speeds were considered relevant in which the accident reports specified intention of a lane change. An analysis set containing 10,398 records was thus defined.

The Driver 1/Driver 2 age matrix for this analysis (Table 3) indicates underrepresentation of drivers aged 27–55 and overrepresentation of the other three groups. An additional matrix for an accident subset predicated on the intention that Driver 1 was attempting to pass was also constructed, but, with only 554 accidents, there were several empty cells. Most interesting, though, was that the involvement ratio increased to 2.0 for younger drivers but dropped to about 0.5 for the 56–75 group. This may be due to the fact that older drivers drive more slowly and attempt to pass less.

The distribution of violations by Driver 1 age is shown in Table 4. Relative to merging and weaving maneuvers, there is a higher proportion of speeding violations for all groups (as expected), lower failure-to-yield violations, and lower lane-usage violations. Following-too-closely violations are about the same. However, age-group differences, versus merging and weaving, are greater: more younger drivers are speeding here, fewer younger drivers have lane-usage violations whereas there is a higher percentage for older drivers, and differences in following too closely are less pronounced for this maneuver.

Finally, when violation patterns for lane-change accidents on limited-access highways versus the base condition—all accidents on limited-access highways—were examined and then compared with the earlier findings for merging and weaving maneuver accidents, a general shift in driver errors was noted with increasing driver age. In maneuvers that involved a lane change, older drivers appeared to have more problems related to tracking and alignment of their vehicles. An alternative explanation for this is that older drivers simply do not drive as fast, so the percentage of involvements for lane-usage violations will increase. However, examination of the ratios of types of accidents to one another suggests that there is still some "real" shifting in the accident distributions that is not explained by older drivers' slower driving. For example, the ratio of following-too-closely to lane-usage accidents for the 26-and-younger group is about 2.7; for the 27–55 group, 1.8; for the 56–75 group, 1.2; and for the 76-and-older group, 0.7. This implies that different drivers are having problems apart from those caused by speed, although the trend is not as clear if the ratios between lane-usage and failure-to-yield accidents are considered.

As noted, the base-condition accidents were simply non-interchange accidents. For all Driver-1 groups, the percentage of accidents accounted for by age group was about the same

TABLE 3 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE, LANE CHANGE ON LIMITED-ACCESS HIGHWAYS

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	232 (28.5)[1]	501 (61.5)	79 (9.7)	3 (0.4)	815 (32.5)
27-55	380 (27.1)	872 (62.2)	139 (9.9)	11 (0.8)	1402 (55.9)
56-75	65 (24.3)	177 (66.3)	24 (9.0)	1 (0.4)	267 (10.7)
76-98	5 (22.7)	16 (72.7)	1 (4.5)	0 (0.0)	22 (0.9)
totals	682 (27.2)	1566 (62.5)	243 (9.7)	15 (0.6)	2506

note : [1] cell entries: number of accidents (row percentage)

TABLE 4 CROSS TABULATION OF DRIVER-1 AGE BY VIOLATION, LANE CHANGE ON LIMITED-ACCESS HIGHWAYS

driver-1 age	driver-1 violation[1]				
	speeding	fail yield	lane usage	following	other
≤26	995 (23.5)[2]	84 (2.0)	797 (18.9)	2131 (50.4)	219 (5.2)
27-55	1036 (18.2)	133 (2.3)	1494 (26.3)	2622 (46.1)	406 (7.1)
56-75	146 (17.0)	36 (4.2)	282 (32.8)	342 (39.7)	55 (6.4)
76-98	17 (20.0)	1 (2.3)	36 (42.4)	28 (32.9)	3 (3.5)
totals	2194 (24.9)	254 (2.3)	2609 (24.0)	5213 (47.2)	593 (5.5)

notes: [1] violations: speeding, failure to yield right of way, improper lane usage, following too closely
[2] number of accidents and (row percentage)

(less than 2 percent different) for both lane-change–related accidents and the base-condition accidents (e.g., the 27–55 group accounted for 52.4 percent of lane-change accidents and 50.7 percent of base accidents). Similar results were noted for Driver 2s. However, it appears that the oldest group of drivers is generally underinvolved in this type of accident. This was determined by dividing the number of lane-change accidents on limited-access highways by the number of base accidents for each group. The results showed that, for drivers 26 and younger, 59.6 percent of all noninterchange accidents were defined as lane-change accidents; drivers 27–55, 63.6 percent; drivers 56–75, 59.2 percent; and drivers 76 and older, 50.0 percent.

Additional results from comparing lane-change accidents and base accidents include (a) Driver-1 violations for lane-change accidents were more likely to be improper lane usage (24.0 percent versus 19.1 percent) or speeding (20.2 percent versus 16.0 percent) and less likely to be failure to yield (2.3 percent versus 5.2 percent) or following too closely (47.2 percent versus 54.2 percent); (b) lane-change accidents are just as likely to occur during the non-rush-day period, but more likely during non-rush-night period (38.5 percent versus 35.0 percent) and less likely during rush hour (29.9 percent versus 33.4 percent); (c) lane-change accidents were more likely to occur at night (72.7 percent versus 66.5 percent), less likely during daylight, and about the same for dawn and dusk; and (d) trucks were slightly more likely to be Vehicle 2 in lane-change accidents versus all accidents (20.4 percent versus 18.5 percent), with a significant shift with Driver-1 age (18.8 percent for 26 and younger, 26.5 percent for 76 and older).

In summary, because the lane-change maneuver on limited-access highways is hard to isolate, accidents that were clearly not lane changes were eliminated and the remainder were analyzed. Notwithstanding the small sample sizes for older drivers, findings and conclusions about lane changes on limited-access highways indicate that (a) drivers in different age groups appear to make different errors when they are involved in accidents: younger drivers tend to speed and follow too closely, older drivers tend to use lanes improperly; (b) the shift from one violation to the other occurs with increasing age, but following too closely is still the most prevalent violation for all age groups but the oldest. Furthermore, speeding violations are more likely than merging and weaving accidents across all age groups; lane usage was less of a problem for the younger drivers than were merging and weaving accidents but more of a problem for older drivers, as was following too closely. Failure to yield was not as much of a problem for any age group for lane-change accidents on limited-access highways.

Drivers 26 and younger and 76 and older appear to be overrepresented for lane-change accidents. Overrepresentation of drivers 26 and younger is about the same as it is for merging and weaving accidents, but older groups appear to have fewer problems with lane-change accidents. Weather and time of day do not seem to have the impact on lane-change accidents that they do on merging and weaving accidents. Similar to merging and weaving accidents, older drivers appear to have more problems with trucks than younger drivers. However, when merging and weaving accidents were considered, there appeared to be a clearer trend with increasing age: with lane-change accidents there were only modest increases for the three youngest groups, and the oldest group had the most problems. However, all age groups have more involvement with trucks in lane-change situations than they do in general on limited-access roads.

Left Turns Against Traffic (Non-Limited-Access Highways).

Given a large sample size, fairly specific accidents in this category can be identified by driver intention; that is, one of the two drivers in an accident was turning left. This resulted in an analysis set containing about 15,500 accidents, and just more than 80 percent of the Driver 1s were turning left. The distribution of combinations of Driver-1 and Driver-2 intentions were (a) Driver 1 was turning left and Driver 2 was going straight (10,708), (b) Driver 1 was going straight and Driver 2 was turning left (1,863), (c) Driver 1 was passing and Driver 2 was turning left (about 600), and (d) both drivers were turning left (about 400). There was a scattering of other combinations. Analysis of only the first two, most frequent combinations in this list is reported. For the most part, signalized and unsignalized intersections were not separated because left turns against traffic involve the same judgments whether the signal is green or not there. Almost 75 percent of the accidents occurred during the day, 20 percent occurred at night, and the rest during dawn and dusk. About 70 percent occurred on dry pavement, more than 80 percent during clear or cloudy conditions. About 56 percent occurred in urban areas. More than 80 percent of the vehicles involved were automobiles, about 12 percent were trucks.

There were fundamental differences in the age distributions for drivers in the left-turn accidents. It may be recalled that for merging and weaving and lane-change accidents on limited-access highways, the Driver-1 age distributions were roughly the same—from the youngest to oldest group they were 38 percent, 50 to 52 percent, 8 to 9 percent, and 0.8 to 1.6 percent—and the first two age groups had accounted for more than 90 percent of the accidents. For left turns against traffic, these two groups account for less than 80 percent. Although it would thus appear that older drivers have substantially more problems with left turns than with merging and weaving and changing lanes, this factor may be tempered by exposure.

Examination of the Driver-2 age distributions shows that they also were virtually the same for merging and weaving and lane-change accidents, but different for left-turn-against-traffic accidents. This is illustrated in Table 5: relative to the maneuvers named previously, the percentages are higher for the 26-and-younger group, lower for the 27–55 group, and similar for the two oldest groups. On the basis of involvement ratios, both groups of older drivers are greatly overinvolved; only the 27–55 group is underinvolved. The net result shows that both groups of older drivers have a more serious problem with turning left than they do with merging and weaving and lane changing, whereas drivers 26 and younger have less of a problem.

The data in Table 6 are for accidents in which Driver 1 was going straight and Driver 2 was turning left. Only drivers 26 and younger appear to be overinvolved. Older drivers do not appear to have a problem with drivers turning left across their paths. Of course, there is a substantial difference in what is required of a given driver in one situation against another.

TABLE 5 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE (DRIVER 1 TURNING LEFT, DRIVER 2 GOING STRAIGHT), LEFT TURNS AGAINST TRAFFIC

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	1752 (39.5)[1]	2251 (50.8)	393 (8.9)	39 (0.9)	4435 (41.4)
27-55	1521 (39.5)	1958 (50.8)	350 (9.1)	26 (0.8)	3855 (36.0)
56-75	663 (38.2)	855 (49.2)	205 (11.8)	14 (0.8)	1737 (16.2)
76-98	249 (36.6)	347 (51.0)	75 (11.0)	10 (1.5)	681 (6.4)
totals	4185 (39.1)	5411 (50.5)	1023 (9.6)	89 (0.8)	10708

note : [1] cell entries: number of accidents (row percentage)

TABLE 6 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE (DRIVER 1 GOING STRAIGHT, DRIVER 2 TURNING LEFT), LEFT TURNS AGAINST TRAFFIC

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	359 (38.7)[1]	464 (50.1)	86 (9.3)	18 (1.9)	927 (49.8)
27-55	271 (36.6)	372 (50.2)	89 (50.2)	9 (1.2)	741 (39.8)
56-75	54 (32.1)	84 (50.0)	25 (14.9)	5 (3.0)	168 (9.0)
76-98	9 (33.3)	11 (40.7)	6 (22.2)	1 (3.7)	27 (1.4)
totals	693 (37.2)	931 (50.5)	206 (11.1)	33 (1.8)	1863

note : [1] cell entries: number of accidents (row percentage)

When Driver 1 is going straight and Driver 2 is turning left, Driver 1 is more likely to be moving and must see the vehicle turning left across his or her path and then decide whether to slow or stop to allow the other motorist to make the crossing maneuver. However, when making the left turn, Driver 1 is likely to be stopped and must estimate time-to-collision, assess whether a gap in the stream exists, then accelerate and turn the vehicle. Both the driver's task loading and frame of reference change from one situation to the other.

When further analysis of violation patterns indicated that the Driver-1 violation was failure to yield or improper turn (no signal), the results were quite similar to those in Table 5, in terms of proportions, indicating that these are high-incidence problems for the older groups. For other violations, older drivers had much lower relative-involvement ratios, though sample sizes were small.

During the non-rush-day period specifically, the two older groups were overrepresented. The 76-and-older group had a ratio more than 6.0, and the 26-and-younger group had an involvement ratio that was just more than 1.0. There was, in essence, a trade-off between these two groups for the rush-hour and non-rush-night periods. For the latter, the ratio of the 26-and-younger group had increased to about 1.2 and the 76-and-older group had decreased to 3.8. The involvement ratios for the two middle groups were roughly the same, regardless of time of day; the 27–55 group was underinvolved and the 56–75 group was overinvolved. The older groups were always overinvolved in left-turn accidents, and the 76-and-older group always had significantly more overinvolvement—especially during the day—with its worst problems occurring during non-rush-day periods. Finally, bad weather and darkness decreased the degree of overinvolvement for drivers 76 and older; involvement ratios were clearly higher for better environmental conditions. Also, older drivers' problems with trucks were not noted here.

A comparison of the left-turn-against-traffic accidents with all multivehicle accidents on US and state numbered routes (including limited-access highways) was conducted as the base-condition comparison. Overall, left-turn-against-traffic accidents accounted for 6.5 percent of the base-condition accidents for drivers 26 and younger, 6.0 percent for drivers 27–55, 8.9 percent for drivers 56–75, and 11.9 percent for drivers 76 and older. Although this comparison is based on frequencies, left-turn-against-traffic accidents are increasingly likely for older drivers.

Summarizing for other variables, left-turn-against-traffic accidents relative to base-condition accidents were more likely during daytime periods (30 percent versus 20 percent and good weather (by about 5 percent, equally likely in urban areas (56 percent), and somewhat less likely to involve trucks as either Vehicle 1 or Vehicle 2.

It must be reiterated that the accidents used for left-turn-against-traffic accident analysis were specifically selected by accident type and driver intention. In general, there was no differentiation made between signalized and nonsignalized intersections or by the number of lanes present. Nevertheless, older drivers evidenced serious problems making left-turn maneuvers against oncoming traffic. Conversely, older drivers confronted with a left-turning vehicle appeared to have no special problem. Interestingly, adverse environmental conditions did not demonstrate a deleterious effect in the accident records on the involvement of the older driver in left-turn-against-traffic–type accidents.

Crossing-Gap-Acceptance Maneuvers on Non-Limited-Access Highways.

For this maneuver, different types of crossing maneuvers were separated. Thus, nonsignalized intersections were isolated and mid-block, nonintersection accidents were not considered.

The difference between the two types of gap-acceptance maneuvers (left turn against traffic and crossing gap acceptance) was of central interest in this analysis. This was examined by first investigating the differences between Driver-1 violations by age. For crossing-gap-acceptance accidents, 90 to 95 percent of all violations were for failure to yield the right-of-way, versus 70 to 75 percent for left-turn-against-traffic accidents. Most of the shift, however, was due to citations for improper signaling of a turn; this was cited for 20 to 25 percent of the left-turn-against-traffic accidents but less than 4 percent for crossing-gap-acceptance accidents. For crossing-gap-acceptance accidents, it was fairly clear that the citations for failure to yield steadily increased with driver age, albeit over a fairly narrow range.

For time of day, the pattern was basically the same as reported earlier: there were differences between the two maneuvers, but the magnitudes and directions of difference were about the same. This leads to the conclusion that there is little difference by time of day. For road surface condition, the results were somewhat different: on dry roads, younger drivers were slightly more likely to be cited for failing to yield but there was little change for older drivers, and on roads that weren't dry, younger drivers shifted toward more speeding citations for crossing-gap-acceptance accidents but there was little change for older drivers.

Comparing results in Tables 5 (left-turn-against-traffic accidents) and 7 (crossing-gap-acceptance accidents) highlights some important differences. The involvement ratios for the left-turn accidents (1.1, 0.7, 1.7, and 8.0 for youngest to oldest age groups) are comparable to those for crossing, which are 1.3, 0.7, 1.2, and 4.6. There is minor unexpected variation in the Driver-2 age distributions: the left-turn maneuver accounts for a higher proportion of the accidents than the crossing maneuver, so turning left across traffic is a more serious problem for the older driver. This may be due to the contexts in which the drivers of the turning and crossing vehicles must perceive and react to the other vehicles: (a) for left turns across traffic, the conflicting vehicle is coming straight toward the turning driver, who must estimate time-to-collision with the oncoming vehicle or a gap between oncoming vehicles; and (b) for crossing maneuvers, the other vehicle is coming from the side. Similar judgments must be made in these situations, the views to the approaching vehicles are different, and angular movement is easier to detect in the latter case.

Examination of the vehicles encountered by the crossing driver revealed a slight tendency for drivers 76 and older to have more difficulties with trucks than with automobiles. The truck percentage (as Vehicle 2) was approximately two points higher than for any other age group (15.6 versus 13.1 to 13.8).

Overall, crossing-gap-acceptance accidents account for 3.1 percent of base condition accidents for drivers 26 and younger, 2.9 percent for drivers 27–55 group, 4.6 percent for drivers 56–75, and 7.4 percent for drivers 76 and older. Though crossing accidents appear to account for a high percentage of all accidents of older drivers, overinvolvement does not appear to be as great as it is for left-turn-against-traffic accidents.

A simple comparison of the percentage of accidents that each age group accounts for also shows that the representation of the two youngest groups is lower for crossing-gap-acceptance accidents than for the base condition (41.6 versus 44.2 percent for 26 and younger and 35.8 versus 41.2 percent for 27–55) and higher for the two oldest groups (15.7 versus 11.4 percent for 56–75, and 6.9 versus 3.1 percent for 76 and older). These percentages are very similar to those for left-turn-against-traffic accidents—about a point lower for the three youngest age groups and somewhat higher for the 76-and-older group. For the Driver-2 age distributions, there are only modest differences between the two maneuvers, less than 2 percent. In general, the involvement ratios are lower for two younger groups and higher for two older groups when crossing-gap-acceptance accidents are compared with the base condition. Compared with left-turn-against-traffic accidents, the involvement ratios for crossing-gap-acceptance accidents are higher for drivers 26 and younger and 56–75 and lower for the other two groups.

Comparisons between the crossing-gap-acceptance accidents and the base condition for other factors showed (a) about 26 percent of the intersection accidents and approximately 30 percent of the base accidents occurred during non-rush-night periods; (b) similar percentages of accidents occurred during clear or cloudy conditions, 81.5 percent for crossing gap acceptance and 78 percent for the base condition, and dry pavement accounted for 70 percent of the crossing-gap-acceptance accidents and 65 percent of base-condition accidents; (c) a somewhat higher percentage (52 percent) were rural accidents, versus the base condition, in which the percentage was approximately 44 percent; and (d) cars accounted for just more than 76 percent of the Vehicle 1s and about 82 percent of the Vehicle 2s in base-condition accidents whereas 83 to 84 percent of both Vehicle 1s and Vehicle 2s were cars for crossing-gap-acceptance accidents; trucks accounted for almost 17 percent of base-condition Vehicle 1s and 15 percent of base-condition Vehicle 2s, versus 13 to 14 percent for crossing-gap-acceptance accidents. Overall, the crossing-gap-

TABLE 7 CROSS TABULATION OF DRIVER-1 AGE BY DRIVER-2 AGE (ANGLE-STRAIGHT ACCIDENTS AT NONSIGNALIZED LOCATIONS), CROSSING TRAFFIC (GAP ACCEPTANCE)

driver-1 age	driver-2 age				
	≤26	27-55	56-75	76-98	totals
≤26	986 (33.8)[1]	1542 (52.8)	354 (12.1)	36 (1.2)	2918 (41.6)
27-55	794 (31.6)	1343 (53.5)	334 (13.3)	41 (1.6)	2512 (35.8)
56-75	355 (32.3)	586 (53.3)	132 (12.0)	26 (2.4)	1099 (15.7)
76-98	165 (34.0)	239 (49.2)	77 (15.8)	5 (1.0)	486 (6.9)
totals	2300 (32.8)	3710 (52.9)	897 (12.8)	108 (1.5)	70-15

note : [1] cell entries: number of accidents (row percentage) acceptance accidents (relative to base-condition accidents) tended to be more likely during daytime periods, good weather, and in rural areas, and less likely to involve trucks.

In summary, comparison of the involvement of different age groups of drivers in different types of gap-acceptance accidents showed that the older drivers are relatively overinvolved in both left-turn-against-traffic and crossing-gap-acceptance accidents. However, left turns across traffic appear to present more of a problem for drivers 76 and older than crossing or turning into traffic.

The principal violation for all age groups, increasing by age, is failure to yield right-of-way. There is not, however, the clear shift from one violation to another, as was apparent for the maneuvers on limited-access roads. Time of day appeared to have little importance in explaining differences between age groups, although road surface condition appeared related to an increased likelihood that younger drivers would be speeding. Explicit comparison of driver age group involvement in crossing versus left-turn accidents at unsignalized intersections showed that older drivers had more severe problems with turning left across traffic than with crossing the traffic stream. However, this does not mean that they have no problem with crossing maneuvers; they clearly have problems with both. Other factors that might make crossing gap acceptance more or less difficult were also examined: there appeared to be a volume-related effect, although it was not consistent, and there appeared to be a greater problem for the oldest group when interacting with trucks.

Overtaking and Passing on Two-Lane, Two-Way Rural Roads.

A severe problem with sample size was encountered after the stratifications had been made to clearly define passing accidents. It appears highly likely that there are more passing-related accidents than were isolated, but it is not clear how they can be identified. Of more than 230,000 accidents originally identified as meeting initial criteria, only 2.2 percent (fewer than 5,100) were identified in which Driver 1 intended to pass; after controlling for road type, fewer than 200 remained.

Distributions of Driver-1 age (by intention) show that for the base group, approximately 3.1 percent of the drivers are in the 76 and older group versus only 1.9 percent whose intention is to pass on a two-way, two-lane rural road (similar results were noted for the 56–75 group). This is probably indicative of the fact that older drivers drive more slowly and are less likely to overtake vehicles.

Single-vehicle accidents were also investigated, specifically, those in which the driver's intention was to pass. Sample sizes were small, but it was again clear that accidents in which the intention of Driver 1 was to pass had a far higher representation of drivers 26 and younger than any other. The sample was not stratified (e.g., urban and rural) because of its small size.

In summary, similar to the results for passing and overtaking maneuvers on limited-access highways, younger drivers appear to be overrepresented in these accidents. This is consistent with a distribution of driver speeds that has drivers 26 and younger traveling the fastest and average speeds decreasing by age. This would have the effect of the youngest drivers overtaking and passing drivers far more often than the oldest driver, who, generally speaking, would overtake very few drivers. Because of extreme problems in isolating accidents that clearly involved overtaking and passing maneuvers on two-lane, two-way rural highways, it was impossible to come to any definitive conclusions about problems specific to the older driver.

Pennsylvania Accident Analysis

Police-reported fatal accident records for the period 1977–1986 and nonfatal multiple-vehicle accident records from 1984–1986 in Pennsylvania Department of Transportation (PennDOT) databases served as the basis for a parallel analysis in search of convergent evidence for the accident-involvement patterns documented for Michigan drivers. These incidents were screened to remove cases in which the most-at-fault driver was known to have a blood alcohol content (BAC) of at least 0.10 percent or to have refused a breath test; this was done to focus analyses on driver judgment errors separate from the effects of intoxication. A total of 12,159 records were eligible for analysis under this criterion.

Calculations of relative accident involvement by the same four age groups of drivers examined in the Michigan analysis were performed, reflecting ratios of accident frequency counts for each group in which a group member was the most-at-fault driver (Driver 1) in the incident and those in which group members were the other involved operator (Driver 2, or the "victim"). For example, with respect to the overall accident record data base of 12,159 cases, drivers 26 and younger demonstrated a ratio of Driver 1–versus Driver 2 frequency counts of 4,903 to 3,833, or an overinvolvement rate of 28 percent. By comparison, the 27–55 group was underinvolved by 19 percent, and the 56–75 group was split nearly evenly with Driver-1 and Driver-2 frequencies of 1,722 and 1,742, respectively. For drivers 76 and older, 341 Driver 1 cases and 168 Driver 2 cases on these accident reports described an overinvolvement exceeding 50 percent.

The same cross-tabulation analysis approach was applied to relevant fields in the Pennsylvania accident records denoting sets of "vehicle movement" and "operator performance failure" contributing factors in each accident occurrence. The relative involvement rates by driver age group for accidents represented by vehicle movement categories of interest are shown in Figure 1, also including the "all accidents" trend described above. In Figure 2, relative accident involvement by age group for a range of pertinent operator performance failure factors is presented.

The results in Figure 1 demonstrate overinvolvement by drivers 26 and younger not only for all accidents examined, but also for incidents in which the vehicle movement before the "first harmful event of the accident" was described as turning left, changing lanes to the left, and changing lanes to the right, in increasing order of relative (Driver 1 versus Driver 2) involvement. As noted above, drivers 27–55 were proportionately underinvolved with respect to all vehicle movements considered. For the 56–75 age group, there was no

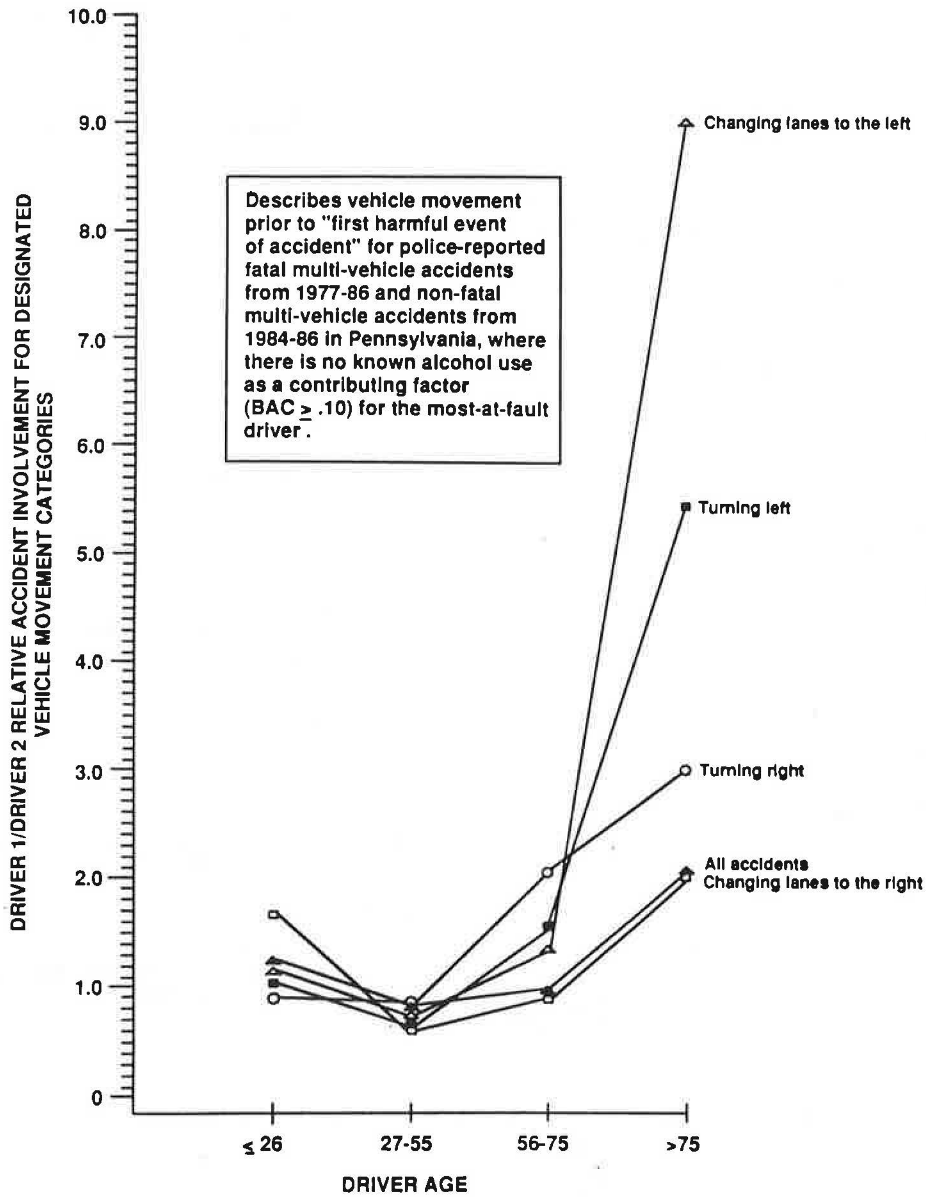

FIGURE 1 Relative accident involvement by driver age according to specified vehicle movement categories.

indicated overinvolvement for the changing-lanes-to-the-right category, but relatively higher Driver 1 frequencies were shown for accidents in which the vehicle movement was changing lanes to the left, turning left, and turning right. The most consistent and extreme overrepresentation in Driver 1 counts was noted for drivers 76 and older; turning left and changing lanes to the left were identified as the most problematic vehicle movements.

In Figure 2, age-related trends are shown for the frequency of involvement in accidents as the most-at-fault operator for whom a contributing factor was noted by police in one of seven categories—improper exit from roadway onto driveway or ramp, improper turning, careless lane change, improper entrance to roadway from driveway or ramp, improper car-following (tailgating), and careless passing—against the frequency of being identified as Driver 2 in such incidents. Considerable similarity to the results presented in Figure 1 is apparent. The 26-and-younger group is marginally underinvolved in improper entrance to and exit from the roadway as well as improper turning, and it is overinvolved in all other operator performance failure categories. Drivers 27–55 are either proportionately represented or underrepresented as driver 1 in all measures. Tailgating and careless-passing relative involvement rates remain low for drivers 56–75, but overinvolvement in all other performance failure categories is indicated, improper turning being the most prominent error. For drivers 76 and older, only the careless-passing relative involvement rate showed an underrepresentation for perfor-

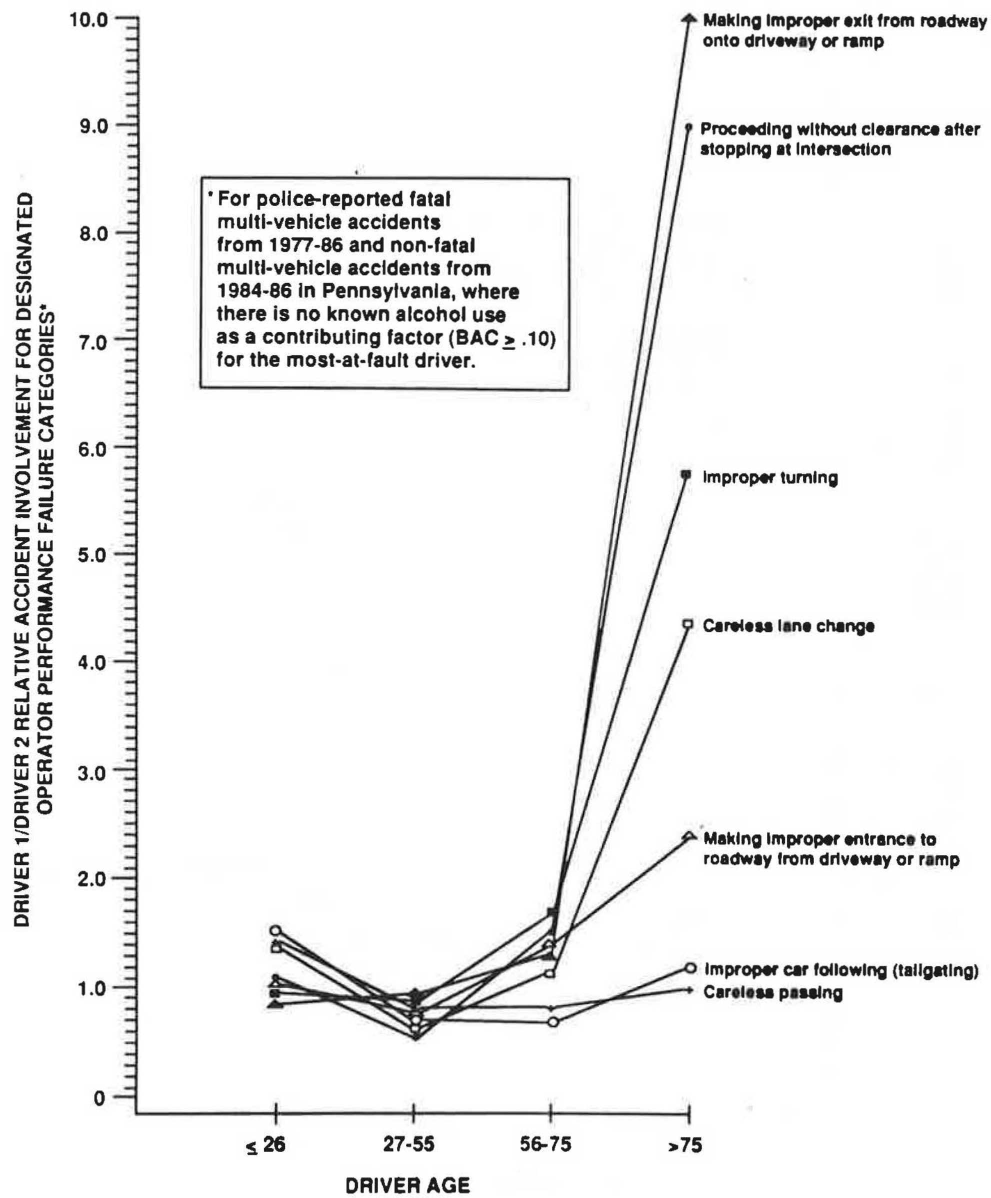

FIGURE 2 Relative accident involvement by driver age according to specified operator performance failure categories.

mance error; a modest increase in the Driver 1/Driver 2 ratio for tailgating and sharp to dramatic increases for all other problem behavior categories were shown for this group.

DISCUSSION AND CONCLUSIONS

The work reported in this paper began with a review of literature that indicated some fundamental differences in errors of motion judgment that drivers of different ages could be expected to make in the highway environment. It was also suggested that a driver's level of experience (and resulting differences in decisions about when and how to operate a vehicle) might compensate for at least some of the apparent differential in functional ability between older and younger drivers. These age differences generated hypotheses about the patterns of older versus younger driver involvement in accidents in which specific maneuvers were attempted by the driver at fault.

Examination of traffic-accident experience by driver age generally verified predictions of age-related overinvolvement in specific types of traffic accidents. The difference in magnitudes was not explicitly compared, but the ordering of the seriousness of the problem (by age) showed some general agreement. For example, where prior research suggested that older drivers would have problems judging left-turn and crossing maneuvers, the accident analysis showed the same results in the same order. The ordering (left-turns being worse than crossing) was expected on the basis of the relative difficulties (in the laboratory) with longitudinal versus tangential judgments of motion.

Left turns are clearly the most serious problem: older drivers have problems judging time-to-collision and acceptable gaps, and these problems are exacerbated by older drivers' generally slower response rates. When the highway environment is degraded, older drivers' experience makes them more cautious, which results in safer outcomes. With crossing maneuvers, older drivers have the same types of judgmental problems, but they are somewhat less severe because of the increased ease of successfully judging vehicle motion. Furthermore, the slower physical response is a little less critical, because the crossing maneuver takes less time to clear the path of an oncoming vehicle than the left-turn maneuver.

The problems older drivers were expected to have with overtaking and passing were not as clearly identified in the field data; this was arguably because of the older drivers' lower operating speeds and, consequently, fewer instances of overtaking other vehicles. Thus, though older drivers may have more serious problems than younger drivers in judging following distances, they simply overtake other vehicles much less often. As the proportion of older drivers in the population increases, however, the situation in which a slower lead vehicle and an overtaking vehicle both are operated by an older driver is likely to rise, and an increasing frequency of older Driver 1s in these accidents may be observed.

The review and analysis presented here serves as the starting point for rigorous laboratory and field testing of older and younger drivers' motion judgment capabilities as required to safely complete specific traffic maneuvers. Given testing situations that preserve an operationally meaningful context for drivers' maneuver decisions, in a realistic driving scene, highway engineering countermeasures and improved older-driver training programs emerging from such work have the potential to reduce older-driver overinvolvement in the accident categories highlighted in this report.

ACKNOWLEDGMENT

The work reported in this paper was sponsored by FHWA and undertaken by Ketron, Inc.

REFERENCES

1. L. Staplin, K. Lococo, and J. Sim. *Traffic Control Design Elements for Accommodating Drivers With Diminished Capability.* Report FHWA-RD-90-055, FHWA, U.S. Department of Transportation, 1990.
2. W. C. Purdy. *The Hypothesis of Psychophysical Correspondence in Space Perception.* Ph.D. thesis. Cornell University, Ithaca, N.Y., 1958.
3. J. J. Gibson. *The Senses Considered as Perceptual Systems.* Houghton Mifflin, Boston, Mass., 1966.
4. D. N. Lee. Visual Information During Locomotion. In *Perception: Essays in Honor of James J. Gibson* (R. B. McLeod and H. L. Pick, eds.), Cornell University Press, Ithaca, N.Y., 1974.
5. W. Schiff and M. L. Detwiler. Information Used in Judging Impending Collision. *Perception*, Vol. 8, 1979, pp. 647–658.
6. V. Cavallo, O. Laya, and M. Laurent. The Estimation of Time-to-Collision as a Function of Visual Stimulation. In *Vision in Vehicles* (A. G. Gale et al., eds.), Elsevior Science Publishers B.V., North Holland, 1986.
7. D. N. Lee. A Theory of Visual Control of Braking Based on Information About Time-to-Collision. *Perception*, Vol. 5, 1976, pp. 437–459.
8. B. L. Hills. *Some Studies of Movement Perception, Age and Accidents.* Report SR137. Department of the Environment, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1975.
9. B. L. Hills and L. Johnson. *Speed and Minimum Gap Acceptance Judgements at Two Rural Junctions.* Report SR515. Department of the Environment, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1980.
10. B. L. Hills. Vision, visibility and perception in driving. *Perception*, Vol. 9, 1980, pp. 183–216.
11. L. O. Harvey and J. A. Michon. Detectability of Relative Motion as a Function of Exposure Duration, Angular Separation and Background. *Experimental Psychology*, Vol. 103, No. 2, 1974, pp. 317–325.
12. L. Evans and R. Rothery. "Detection of the Sign of Relative Motion When Following a Vehicle." *Human Factors*, Vol. 16, No. 2, 1974, pp. 161–173.
13. D. F. Cooper, P. A. Storr, and J. Wennell. Traffic Studies at T-Junctions: 4. The Effect of Speed on Gap Acceptance and Conflict Rate. *Traffic Engineering and Control*, Vol. 18, No. 3, 1977, pp. 110–112.
14. R. E. Huston and M. K. Janke. *Senior Driver Facts.* Report CAL-DMV-RSS-86-82, 2nd ed. California Department of Motor Vehicles, Sacramento, 1986.
15. P. Zador, J. Moshman, and L. Marcus. Adoption of Right Turn on Red: Effects on Crashes at Signalized Intersections. *Accident Analysis and Prevention*, Vol. 14, 1982, pp. 219–234.
16. M. L. Chipman. The Role of Exposure, Experience and Demerit Point Levels in the Risk of Collision. *Accident Analysis and Prevention*, Vol. 14, No. 6, 1982.
17. *Older Driver Profile 1985–1986.* Iowa Department of Transportation, Des Moines, 1987.
18. R. L. Moore, I. P. Sedgley, and B. E. Sabey. Ages of Car Drivers Involved in Accidents, With Special Reference to Junctions. Transport and Road Research Laboratory Supplementary Report 718. Transport Studies Group, University College, London, England, 1982.
19. E. Hildebrand and F. R. Wilson. *An Assessment of Elderly Driver Accident Patterns.* Presented at 69th Annual Meeting of the Transportation Research Board, Washington, D.C., 1990.
20. R. Lyles, D. R. Lighthizer, and P. Stamatiadis. Quasi-Induced Exposure Revisited. *Accident Analysis and Prevention*, Vol. 23, No. 4, 1991.

All statements are solely the responsibility of the authors.

Publication of this paper sponsored by Task Force on Safety and Mobility of Older Drivers.