STATE OF CALIFORNIA
DEPARTMENT OF MOTOR VEHICLES

Teen and Senior Drivers

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14. ABSTRACT

This report updates statistical information on California teen and senior drivers as published in earlier reports prepared by the California Department of Motor Vehicles: *Teen Driver Facts* (Huston, 1986), *Senior Driver Facts* (Huston & Janke, 1986), *Teen and Senior Drivers* (Romanowicz & Gebers, 1990; Gebers, Romanowicz, & McKenzie, 1993; Aizenberg & McKenzie, 1997 [with the Beverly Foundation]; and Janke, Masten, McKenzie, Gebers, & Kelsey, 2003). The information is meant to assist highway safety administrators in making program and policy decisions affecting teen and senior drivers, and may also be of use to the insurance industry, traffic safety researchers, and the general public.

The report also summarizes international research on the driving safety and driving-related abilities of teen and senior drivers, and on crash countermeasures for these two groups.

15. SUBJECT TERMS

young drivers, aged drivers, driver attitudes, risk-taking, visual acuity, hazard perception

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PREFACE

This report updates information on teenaged and senior drivers previously published in a series of earlier California Department of Motor Vehicles (DMV) reports. The primary purpose of these reports has historically been to provide traffic safety administrators and legislators with useful information for formulating policy and law. A very important secondary purpose is to provide information on teenaged and senior drivers (in the context of the general driving population) to the insurance industry, researchers in the field of highway safety, and the general public.

The relationship between age and driving record has been explored for many years by numerous researchers, often under the auspices of the National Highway Traffic Safety Administration. These investigations have frequently been based on data from the national Fatality Analysis Reporting System (formerly Fatal Accident Reporting System), in which fatal crash rates for various age groups are expressed per person (driver or not) within age group, using census data. Probably one reason for this is that, where national age-group rates have been computed per driver rather than per person, they are subject to error due to unreliability of age-group driver license counts in some states (Federal Highway Administration, 2010). But a drawback of using per-person rates is that not all of the people counted in the denominator are drivers, and the percentage that are will vary with age. California driver license counts are relatively accurate (bearing in mind that people who are licensed do not necessarily drive, and that not all those driving on the road are licensed), so the present report gives incident rates per licensed driver as well as incident rates per driver per mile driven. In addition, the report presents an at-fault crash involvement ratio for each driver group, using a technique known as Quasi-Induced Exposure. This ratio is essentially an exposure adjusted crash rate, which is computed by dividing the percentage of at-fault drivers in the group by the percentage of innocent drivers in the group.

The crash and violation data in the present report came from two primary sources: (1) California Highway Patrol’s (CHP’s) crash record database (Statewide Integrated Traffic Records System, or SWITRS), and (2) DMV’s Driver Record Master (DRM) file.

ACKNOWLEDGMENTS

The authors would like to acknowledge the following individuals for their contributions to this project. The authors extend thanks to Roberta Tanger, Associate Governmental Program Analyst, of CHP's Information Services Unit, for providing SWITRS crash data; to Bill Schooling, Chief, and Mary Heim, Chief (retired), of the Demographics Unit, Department of Finance, for providing California population data; and to Mike Gebers, Research Scientist III, of DMV's Research and Development Branch for providing results of his analysis of crash and traffic violation data for a 1% random sample of licensed California drivers. The current report is the latest in a series of reports the department has published on teen and senior drivers. As such, its wording is very similar to that of the most recent prior report. Special recognition and thanks are given to Mary M. Janke, Research Scientist III (retired), the primary author of the earlier report on which the current report is based. Scott Masten, Research Manager II, and Bayliss Camp, Research Program Specialist II, both within DMV's Research and Development Branch, assisted in writing portions of the Research and Countermeasures sections of the report. This study was conducted under the supervision of Robert Hagge, Research Manager II, and the general direction of Dave DeYoung, Research Chief.

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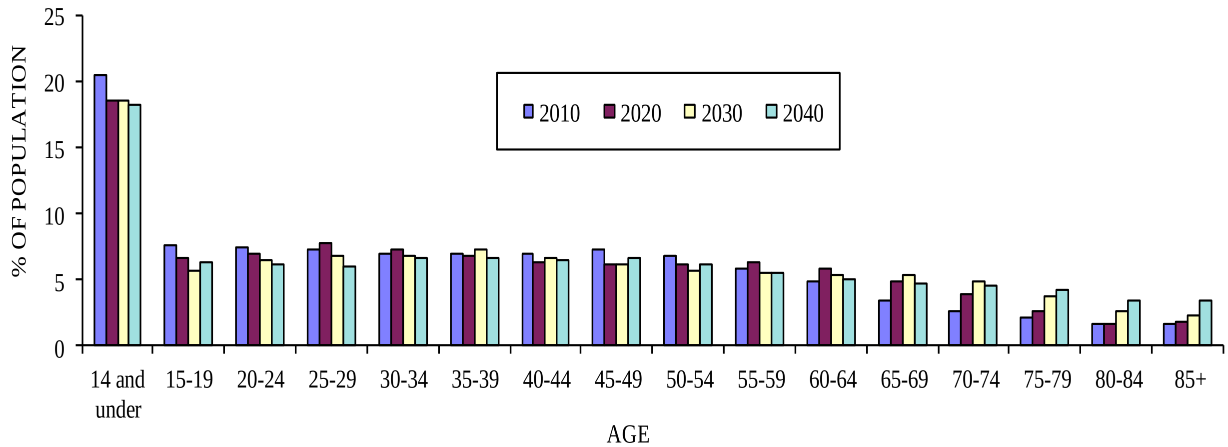
CALIFORNIA TRAFFIC DATA

California Driver Population

The relationship between age and driving behavior has interested highway safety researchers and administrators for many years. It is generally acknowledged that the greatest risk of crashes is among teenage drivers. Although teenagers represent the greatest safety problem because of their exceptionally high crash liability, senior drivers are also at increased risk compared to those in the middle age range. The number and visibility of crashes involving senior drivers can be expected to rise with growth in the older population (American Association of State Highway and Transportation Officials, 2012; TRB, 2004), increases in the percentage of older people who are licensed to drive (American Association of State Highway and Transportation Officials, 2012), and higher mileage for older drivers (Insurance Institute for Highway Safety, 2010b; LeRoy & Morse, 2008). According to researchers from the Insurance Institute for Highway Safety (Lyman, Ferguson, Braver, & Williams, 2002), by 2030 the number of involvements in police-reported motor vehicle crashes among senior drivers in the U.S. is expected to increase by almost 180%, while their fatal involvements are expected to increase by over 150%. Yet these drivers—who will largely come from the baby-boom generation—will still be underrepresented in crashes relative to their number in the population, the authors stated.

Table 1 and Figure 1 show actual (as of 2010) and projected (predicted) age distributions for the California population in years 2010, 2020, 2030, and 2040 (California Department of Finance, 2012). Over the next 30 years the population percentage of seniors is expected to increase in California as elsewhere, and by 2040 almost 31% of the population is projected to be 55 or older, with 20% aged 65 or older. The 20% figure includes all of the baby boomers, since in 2040 the oldest members of the cohort will turn 94 and the youngest members will turn 76.



Note. From California Department of Finance, May 2012, Interim Projections of Population for California: State and Counties, July 1, 2015 to 2050 (in 5-year increments), Sacramento, CA.

Figure 1. Actual and projected percentages of California population by age.

Table 1

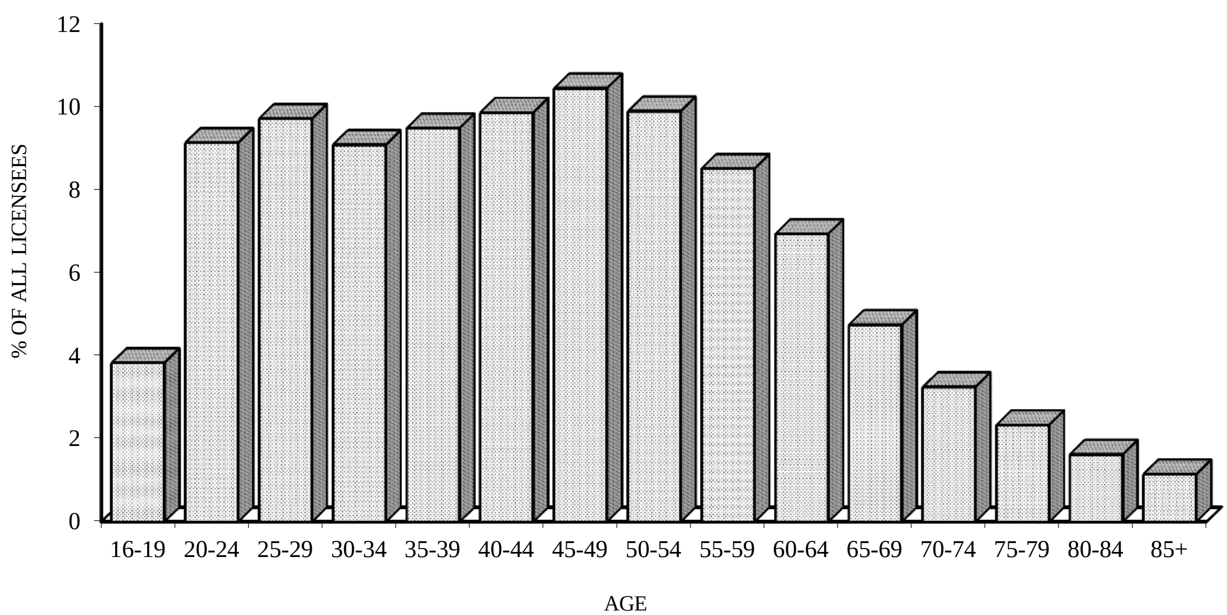
Actual (2010) and Projected Population Counts and Percentages of Total California Population by Age

	2010		2020		2030		2040	
Age	Population (thousands)	% of total population	Population (thousands)	% of total population	Population (thousands)	% of total population	Population (thousands)	% of total population
<15	7,640	20.48	7,567	18.54	8,299	18.62	8,795	18.33
15-19	2,828	7.58	2,711	6.64	2,566	5.76	2,998	6.25
20-24	2,770	7.42	2,831	6.94	2,883	6.47	2,945	6.14
25-29	2,749	7.37	3,159	7.74	3,052	6.85	2,868	5.98
30-34	2,578	6.91	2,977	7.29	3,063	6.87	3,156	6.58
35-39	2,578	6.91	2,801	6.86	3,248	7.29	3,166	6.60
40-44	2,613	7.00	2,564	6.28	2,977	6.68	3,090	6.44
45-49	2,694	7.22	2,511	6.15	2,744	6.16	3,199	6.67
50-54	2,567	6.88	2,540	6.22	2,509	5.63	2,921	6.09
55-59	2,208	5.92	2,596	6.36	2,443	5.48	2,682	5.59
60-64	1,835	4.92	2,410	5.90	2,408	5.40	2,403	5.01
65-69	1,306	3.50	2,021	4.95	2,400	5.38	2,291	4.78
70-74	973	2.61	1,614	3.95	2,142	4.81	2,176	4.54
75-79	768	2.06	1,067	2.61	1,666	3.74	2,021	4.21
80-84	604	1.62	704	1.72	1,175	2.64	1,610	3.36
85+	602	1.61	745	1.82	1,000	2.24	1,662	3.46
Total	37,313	100.00	40,818	100.00	44,575	100.00	47,984	100.00

Note. From California Department of Finance, May 2012, Interim Projections of Population for California: State and Counties, July 1, 2015 to 2050 (in 5-year increments), Sacramento, CA.

Improvements in health care, nutrition, education, and incomes have helped to increase the proportion of older adults who live more mobile and active lives. This trend should lead to a larger proportion of older persons who drive themselves, rather than carpooling or using public transportation, to meet their transportation needs (American Association of State Highway and Transportation Officials, 2012; Dobbs, 2008). For older drivers, driving remains the easiest, safest, and most convenient means of transportation (American Association of State Highway and Transportation Officials, 2012).

Figure 1 showed age groups' percentages of population, not percentages of drivers. Table 2 gives, for 2009, the number of licensed drivers in each age group as a percent of all California licensed drivers. These data are plotted in Figure 2. They were derived from a randomly selected 10% sample of the driving records of all individuals holding California driver licenses (California Department of Motor Vehicles, 2010). (People with only instruction permits are not included in these counts.) Of drivers licensed in 2009, 3.8% were teenagers aged 16-19 and 13.1% were seniors—that is, people aged at least 65.



Note. License data for 2009 are from California Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA.

Figure 2. Licensees in age group as a percentage of all California licensed drivers.

Table 2

Percentage of Licensed Drivers by Age and Sex

Age	Percent of all licensees	Men: Percent of all male licensees	Men: Percent of all licensees	Women: Percent of all female licensees	Women: Percent of all licensees
16	0.30	0.29	0.15	0.31	0.15
17	0.68	0.68	0.35	0.67	0.33
18	1.22	1.27	0.64	1.17	0.57
19	1.64	1.70	0.86	1.59	0.78
16-19	3.83	3.93	2.00	3.73	1.83
20-24	9.13	9.24	4.70	9.03	4.43
25-29	9.71	9.59	4.88	9.85	4.84
30-34	9.08	8.96	4.56	9.21	4.52
35-39	9.48	9.44	4.80	9.53	4.68
40-44	9.86	9.95	5.06	9.77	4.80
45-49	10.45	10.54	5.37	10.35	5.08
50-54	9.89	9.93	5.05	9.85	4.84
55-59	8.51	8.51	4.33	8.52	4.18
60-64	6.94	6.92	3.52	6.96	3.42
65-69	4.75	4.76	2.42	4.74	2.33
70-74	3.25	3.24	1.65	3.25	1.60
75-79	2.33	2.33	1.19	2.33	1.15
80-84	1.62	1.55	0.79	1.70	0.83
85 +	1.15	1.10	0.56	1.19	0.58
All ages	100.00	100.00	50.89	100.00	49.11

Note. License data for 2009 are from California Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. Data include a very small number of persons under 16 holding valid California driver's licenses, which slightly inflated the percentages shown for age 16.

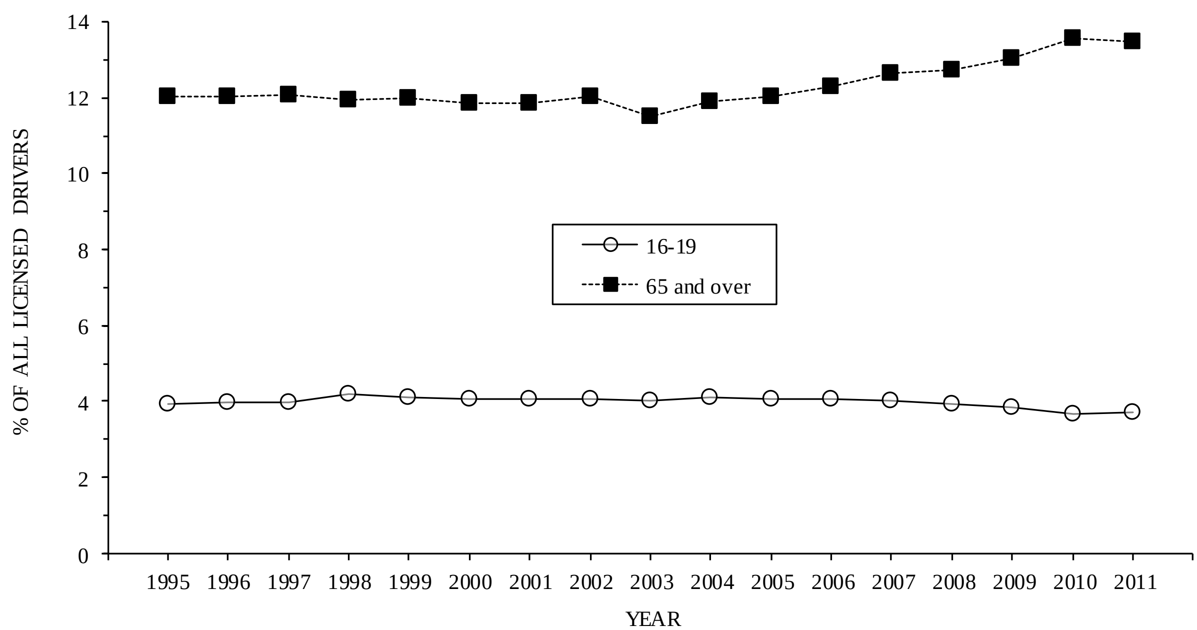
Table 3 and Figure 3 show, by year, the volumes of teenaged and senior drivers as percentages of the total licensed driver population over the years 1995 through 2011. The data are from the database of driving records for all California licensed drivers (California Department of Motor Vehicles, 1995-2011). Between 1995 and 2011, seniors' share of the licensed driving population increased from 12.0% to 13.5%, and teenagers' share decreased from 3.9% to 3.7%.

Table 3

Number and Percentage of Licensed Drivers by Year and Age

Year	All ages (thousands)	Age 16-19 (thousands)	%	Age 65+ (thousands)	%
1995	20,249	798	3.94	2,436	12.03
1996	20,278	802	3.96	2,439	12.03
1997	20,487	816	3.98	2,473	12.07
1998	20,735	873	4.21	2,476	11.94
1999	21,035	865	4.11	2,519	11.97
2000	21,404	873	4.08	2,541	11.87
2001	21,978	892	4.06	2,603	11.84
2002	22,606	915	4.05	2,720	12.03
2003	22,687	914	4.03	2,612	11.51
2004	22,843	941	4.12	2,722	11.92
2005	22,927	934	4.08	2,756	12.02
2006	23,237	939	4.04	2,861	12.31
2007	23,630	946	4.01	2,989	12.65
2008	23,719	934	3.94	3,018	12.73
2009	23,700	905	3.82	3,093	13.05
2010	23,800	875	3.68	3,226	13.56
2011	23,857	881	3.69	3,219	13.49

Note. License data are from California Department of Motor Vehicles, 1995-2011, *DL Information Report,* Sacramento, CA.



Note. License data are from California Department of Motor Vehicles, 1995-2011, *DL Information Report*, Sacramento, CA.

Figure 3. Percentage of licensed driver population by year and age of driver.

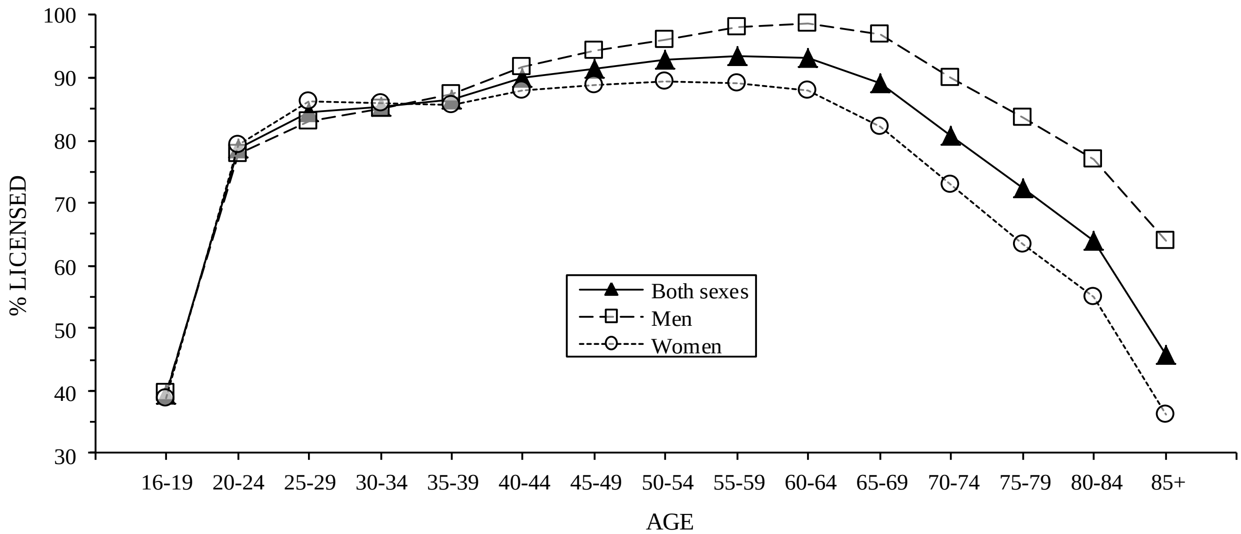
Almost all licensing and incident-involvement data presented below are for year 2009. Table 4 and Figure 4 show licensure rates by age—the estimated percentage of California residents in each age group who held a driver license as of January 1, 2010; that is, during 2009. Population estimates for 2009 are from California Department of Finance (2012). The licensing data, derived from counts of licenses in a 10% random sample of the driver record file in 2009, are from California Department of Motor Vehicles (January 2010). License rates are somewhat inflated by the inclusion of out-of-state residents and members of the military holding California licenses. Nevertheless, one can conclude broadly that an appreciably greater percentage of men than women are licensed within almost all age groups, and that from age 18 through somewhere in the eighties the majority of people hold driver licenses.

Table 4

Driver Licenses, California Residents, and Licensure Rate by Age and Sex

	Both sexes			Men			Women		
Age	Licenses[a] (thousands)	Residents[b] (thousands)	Licenses per 100 residents	Licenses (thousands)	Residents (thousands)	Licenses per 100 residents	Licenses (thousands)	Residents (thousands)	Licenses per 100 residents
16	70	571	12.27	34	294	11.68	36	276	12.89
17	160	579	27.61	82	299	27.38	78	280	27.85
18	288	583	49.42	152	302	50.47	136	281	48.28
19	389	577	67.38	204	300	68.18	184	277	66.51
16-19	906	2,309	39.25	473	1,196	39.58	433	1,113	38.90
20-24	2,160	2,746	78.67	1,112	1,426	77.99	1,048	1,320	79.40
25-29	2,297	2,716	84.56	1,154	1,390	83.00	1,143	1,327	86.20
30-34	2,148	2,512	85.51	1,078	1,268	85.04	1,070	1,244	86.00
35-39	2,243	2,589	86.62	1,136	1,298	87.52	1,107	1,291	85.72
40-44	2,332	2,595	89.88	1,197	1,305	91.77	1,135	1,290	87.97
45-49	2,470	2,700	91.49	1,269	1,346	94.25	1,201	1,354	88.74
50-54	2,339	2,521	92.80	1,195	1,243	96.14	1,144	1,278	89.55
55-59	2,013	2,151	93.56	1,024	1,042	98.21	989	1,109	89.18
60-64	1,641	1,761	93.18	833	844	98.78	808	918	88.04
65-69	1,123	1,261	89.09	572	590	97.02	551	671	82.12
70-74	768	952	80.70	390	434	90.00	378	518	72.91
75-79	551	763	72.31	281	335	83.77	271	428	63.33
80-84	383	599	63.96	186	242	77.02	197	357	55.11
85+	271	591	45.87	133	208	63.87	138	383	36.08
All ages	23,646	28,765	82.00	12,034	14,166	84.95	11,613	14,599	79.54

[a]License data for 2009 are from California Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. Data include a very small number of persons under 16 holding valid CA driver licenses. [b]Population data for 2009 are from California Department of Finance, August 2012, *2000-2010 Intercensal Population by Gender, Age, and Race/Ethnicity*.



Note. Licensing data for 2009 are from California DMV, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. Population data for 2009 are from California Department of Finance, August 2012, *2000-2010 Intercensal Population by Gender, Age, and Race/Ethnicity*.

Figure 4. Percentage of California licensed drivers by age and sex.

Total Traffic Crash Involvements and Citations

The information presented in the remainder of this report describes group averages, ignoring any variation—and there is always variation—among the differing members of the group. The average value for a group on any variable, by itself, is actuarial information of the type an insurance company might use to control its losses over the long run, and tells very little if anything about a particular group member. This point is probably obvious, but the tendency to think of individuals belonging to a particular group as being at their group's average is strong, so the point is made at the outset. In almost all cases, determining which Californians should have the driving privilege is done through an individualized testing process rather than use of actuarial information; more will be said about this below.

Past studies in California—as elsewhere—have shown that age and gender are related to driver record (e.g., Braitman, Chaudhary, & McCartt, 2011; Rice, Peek-Asa, & Kraus, 2003; Stutts, Martell, & Staplin, 2009). For instance, teenagers and men tend as groups to show higher crash and citation rates than, respectively, non-teenagers and women. This sort of statement may lead to a question of how crashes and citations are defined. Motor vehicle crashes are those officially reported to DMV; a crash is not required to be reported if no death, injury, or damage to a person's property amounting to more than $750 has occurred. Citations, in this context, are traffic tickets. The count of citations includes convictions of traffic violations (usually through forfeiting bail, which does not require an appearance at court), failure of a driver who has not deposited bail to appear in court to answer the charge, failure of a driver to pay a fine assessed in connection with the charge, and dismissal of the charge on condition that the driver attend a court-approved program.

DMV maintains an electronic database containing historical driving records for an ongoing 1% random sample of California licensed drivers for research purposes. Specifically, the 1% random sample contains the driving records of individuals with a valid driver license (including probationary and suspended/revoked drivers) or instruction permit, while excluding drivers with only a California Identification Card, or who are unlicensed or deceased. Data from this sample for the years 2004 through 2006 were used to calculate annual crash involvement and citation averages. These are shown in Tables 5 and 6 and Figures 5 and 6, and give a picture consistent with findings presented in earlier *Teen and Senior Drivers* reports. The tables and figures show each age/sex group's average yearly number of casualty plus non-casualty (that is, total) crash involvements—an involvement is counted for each driver involved in a crash—and average annual number of traffic citations. Both averages are given per 100 licensed drivers.

Some of the conclusions that can be drawn from Tables 5 and 6 and Figures 5 and 6 are the following:

- For each sex, the age group 16-19 shows the highest average annual crash and citation rates. The average annual crash rates and citation rates for both young men and young women peak at age 18.

- The average annual crash rate for combined sexes generally declines through somewhere between 70-74 and then increases, though it remains below the level for all ages combined (5.05 per 100 drivers, shown in Table 3).

- The average annual citation rate for combined sexes decreases strongly with age.

- At all ages, average annual crash and citation rates for men exceed those for women.

Table 5

Average Annual Crash Involvements per 100 Licensed Drivers by Age and Sex

Age	Both sexes (*n* = 238,741)	Men (*n* = 124,069)	Women (*n* = 114,672)
16	9.02	9.58	8.40
17	7.74	7.98	7.47
18	9.33	10.05	8.21
19	8.67	8.86	8.50
16-19	8.77	9.19	8.31
20-24	6.97	7.34	6.59
25-29	5.34	5.73	4.94
30-34	4.77	5.18	4.33
35-39	4.92	5.29	4.50
40-44	4.96	5.19	4.71
45-49	4.54	4.85	4.19
50-54	4.37	4.83	3.86
55-59	4.31	4.86	3.73
60-64	3.87	4.31	3.39
65-69	3.65	4.26	3.00
70-74	3.63	4.10	3.11
75-79	3.83	4.46	3.21
80-84	3.87	4.58	3.40
85+	3.98	4.72	3.43
All ages	5.05	5.45	4.61

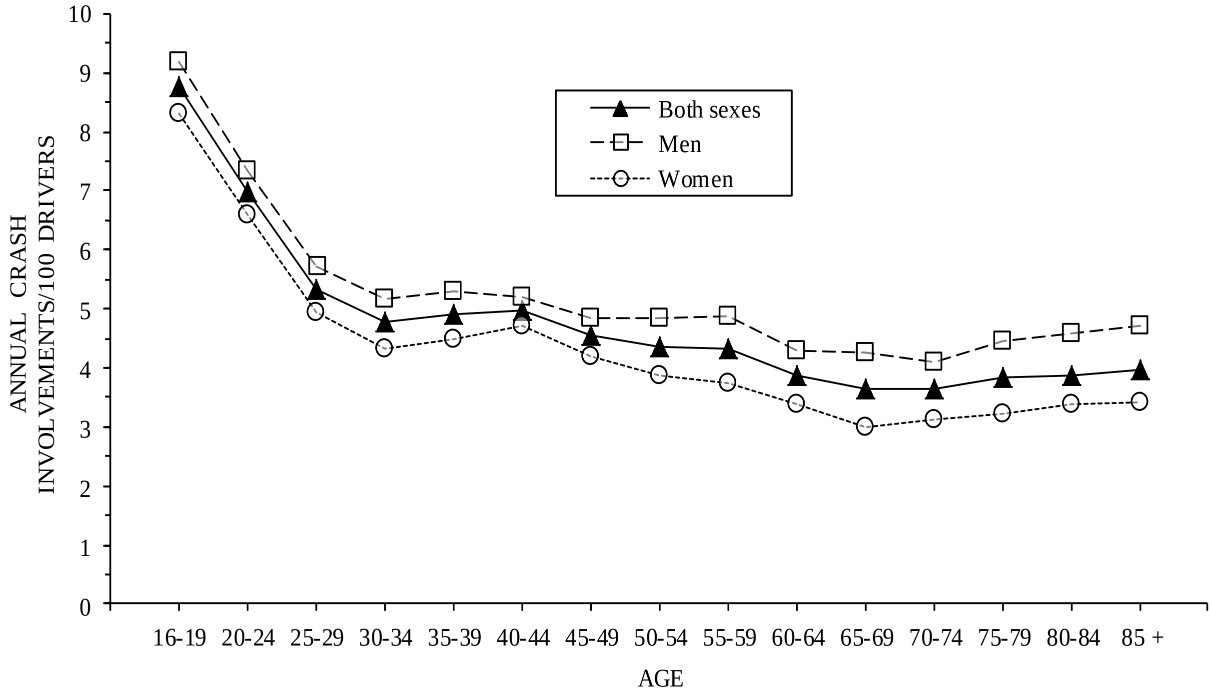
Note. Based on driver records of a 1% random sample of California licensed drivers. Annual averages (per 100 drivers) are for crashes occurring during the years 2004 through 2006.

Table 6

Average Annual Traffic Citations per 100 Licensed Drivers by Age and Sex

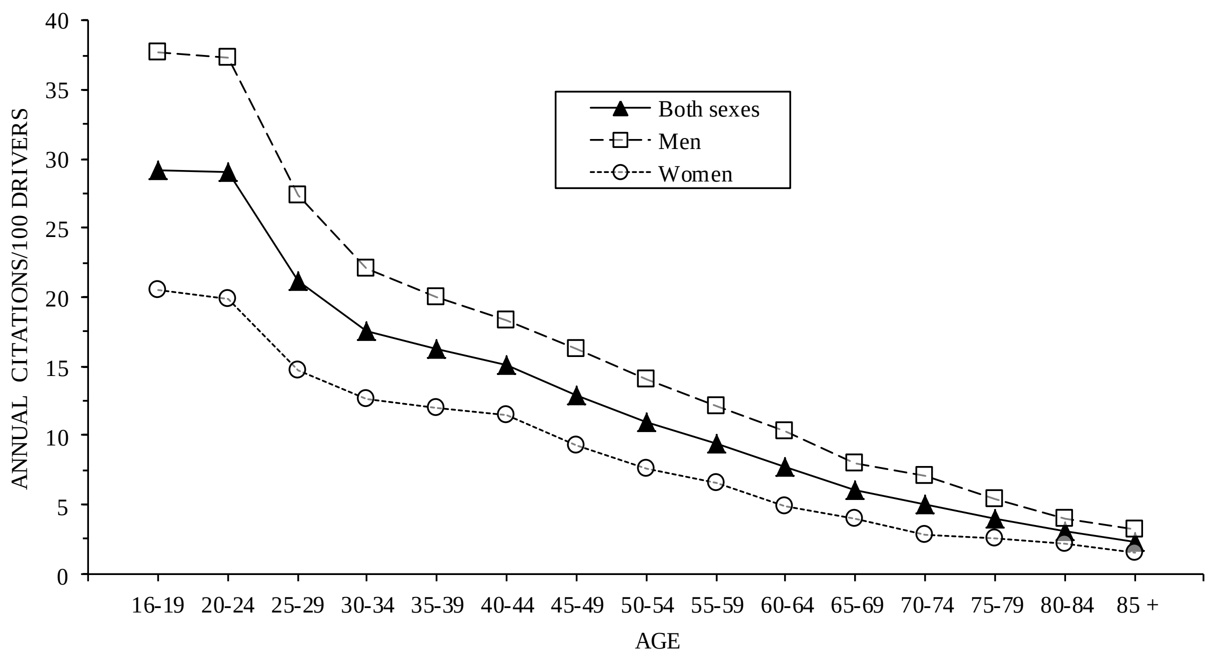
Age	Both sexes (*n* = 238,741)	Men (*n* = 124,069)	Women (*n* = 114,672)
16	15.21	19.15	10.89
17	26.06	33.36	17.93
18	34.75	45.49	24.70
19	34.57	44.24	22.65
16-19	29.14	37.66	20.49
20-24	29.02	37.31	19.88
25-29	21.16	27.41	14.65
30-34	17.56	22.09	12.60
35-39	16.22	19.96	11.95
40-44	15.07	18.27	11.44
45-49	12.92	16.21	9.30
50-54	10.94	14.06	7.54
55-59	9.47	12.15	6.62
60-64	7.76	10.37	4.93
65-69	6.06	7.94	4.04
70-74	5.03	7.14	2.76
75-79	4.02	5.44	2.62
80-84	3.05	3.92	2.23
85+	2.31	3.16	1.52
All ages	15.63	19.86	11.06

Note. Based on driver records of a 1% random sample of California licensed drivers. Annual averages (per 100 drivers) are for citations received during the years 2004 through 2006.



Note. Based on driver records of 1% sample of California licensed drivers. Annual averages (per 100 drivers) are based on crashes occurring during the years 2004 through 2006.

Figure 5. Average annual crash involvements per 100 licensed drivers by age and sex.



Note. Based on driver records of 1% sample of California licensed drivers. Annual averages (per 100 drivers) are based on citations occurring during the years 2004 through 2006.

Figure 6. Average annual traffic citations per 100 licensed drivers by age and sex.

The high average crash rate per year for young novice drivers justifies special efforts to make them safe members of the driving population, and these efforts are described below in the section Crash Countermeasures for Teenaged Drivers. Present-day senior drivers have a relatively low average annual crash rate, but this does not contradict the fact that driving performance eventually declines with age, though it may alleviate concerns that the group, as presently constituted, poses an unusually great threat to other road users. Senior drivers' underinvolvement in crashes despite a predictable average decline in driving skills caused by functional changes associated with aging and age-related disease indicates that most are aware, at least at some level, of their limitations and accordingly restrict the amount and conditions of their driving (American Association of State Highway and Transportation Officials, 2012; American Medical Association, 2010). For example, much research has shown that senior drivers tend to drive less than others, to avoid driving at night or in bad weather, and to forego driving when traffic is congested. In this sense, senior drivers as a group compensate for driving-related impairments, though any individual driver’s compensation may or may not be adequate. Since the average crash rate based on 2004-2006 data began to rise, however gradually, around age 75, that may mark a point—at least for the present cohort of seniors—at which there begins to be an increase in the number of drivers in the group whose impairments outstrip their compensatory abilities, thus raising the group average.

Traffic Crashes and Citations Adjusted for Mileage

The measures presented above are annual crash averages. Crash averages based on a fixed period of time may be used to indicate the average risk imposed by a particular group, collectively, on other road users, again collectively. That risk is a function of group members’ physical and mental abilities, motivations, experience, and other factors. Measures like crash rate per year have been used in reports like the present one to compare different age, sex, or driver record groups in terms of the societal hazard they pose (that is, the threat they pose to other road users); they are also widely used by insurance companies in setting auto insurance premiums. But they do not provide a clear picture of crash risk (invariably to the driver and possibly to others) when that driver is actually on the road, however little that may be.

It is desirable to have a measure of this sort of personal risk as well as societal risk. This section of the report uses a common method of adjustment for mileage to compare age/sex groups on crash and citation rates per average distance traveled, rather than per time period. The measure is meant to adjust for a group’s exposure to risk of crashes (or citations), because the greater the exposure (that is, the more and more challenging the driving), the greater the expected number of incidents. The adjustment is admittedly imperfect, because mileage is only a partial measure of exposure to risk. A perfect exposure measure would include additional variables to represent such things as the surrounding traffic environment, roadway type, lighting, and weather conditions. All these and more are factors that influence risk.

The youngest and oldest drivers have, as groups, the highest mileage-adjusted crash and citation rates (Baldock & McLean, 2005; Insurance Institute for Highway Safety, 2010b; Williams, 2003). The basic trends remain much the same as those reported in the earlier series of departmental studies conducted on teen and senior drivers (Aizenberg & McKenzie, 1997; Gebers, Romanowicz, & McKenzie, 1993; Janke, Masten, McKenzie, Gebers, & Kelsey, 2003). Typical trends are shown below in Table 7 and Figures 7 and 8, which give the expected crash and citation rates per 100,000 miles of driving. To determine these mileage-adjusted rates, an annual average (based for this report on the 3 years 2004 through 2006) of incident counts was computed for licensed drivers in the 1% random sample of California drivers mentioned above.

This gave annual crash and citation rates. Then the most recent available mileage data were obtained from the Nationwide Household Travel Survey (NHTS) (Federal Highway Administration, 2009). Statistical curve smoothing of the 2009 NHTS data was done to derive a stable annual mileage estimate for each age group (see Appendix for detail).

Following that, and using crashes as an example, the average annual crash rate for each age/sex group—average crashes per driver within the group per year—was divided by average mileage per driver within that group per year (from the 2009 NHTS data for California). The "year" term cancels out of both numerator and denominator, leaving average crashes per mile. This is an extremely small number for any group; for example, the average crash rate per mile for men aged 45-49 is only 0.0000029. Therefore the figure was multiplied by 100,000 for all groups to show average crashes per driver per mile within each group, times the factor 100,000.

An alternative way of looking at the result is that it shows average crashes per driver within each age/sex group over a hypothetical 100,000 miles of driving. Driving 100,000 miles would take members of different age/sex groups, if they were driving the average number of miles for their group annually, different numbers of years to accomplish. How many years might it take, on the average, for a member of one of the various groups being considered here? Six or seven is a reasonable minimum, 20 a reasonable maximum. Smoothed data for California from the 2009

NHTS show that teenagers drove on the average about 5,000 miles a year; drivers in their twenties through forties had averages ranging from about 11,900 to 13,600 miles a year, and thereafter average annual mileage declined to a low point of slightly over 4,500 miles a year for people aged 85 or more. These data are for combined sexes; more detailed information appears in the Appendix.

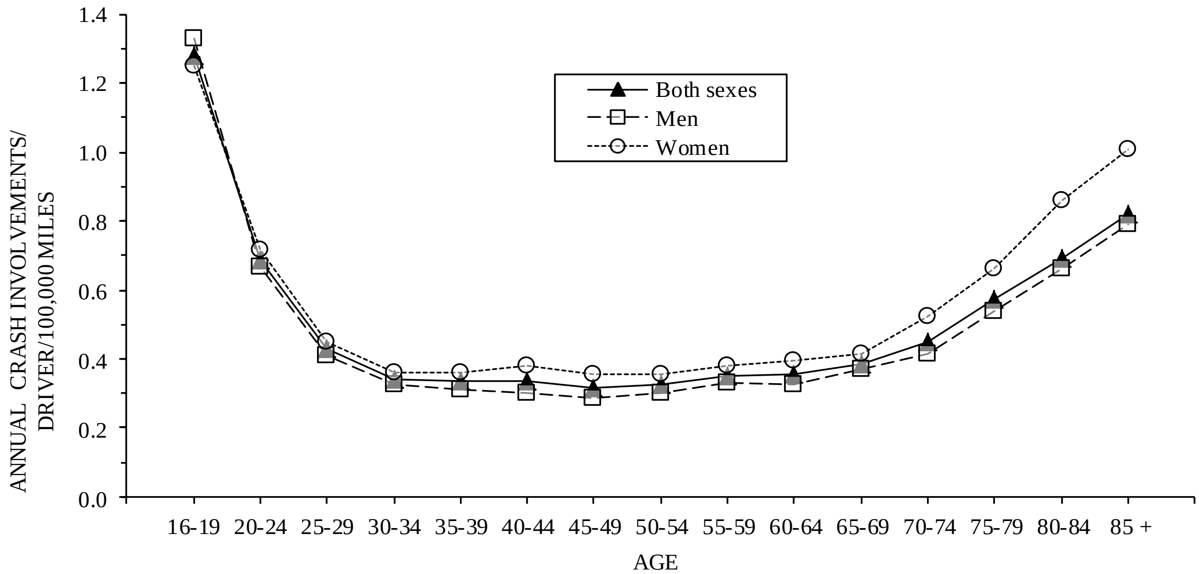
Importantly, the crash involvement rate per 100,000 miles of 1.28 for teenagers and 0.82 for age 85 and over does not mean that everyone who is a teenager, and just about everyone who is very old, will inevitably crash. The teenager can be expected to mature and become a safer, more experienced driver; the very old person can be expected to stop driving, for whatever reason. Neither do these rates mean that if a group of teenagers, or one of very old people, *collectively* drives 100,000 miles in a year, then every, or nearly every, individual in the group will have a crash. The rates are *averages per driver,* per 100,000 miles.

Table 7

Average Annual Crash Involvements and Traffic Citations per
Driver per 100,000 Miles by Age and Sex

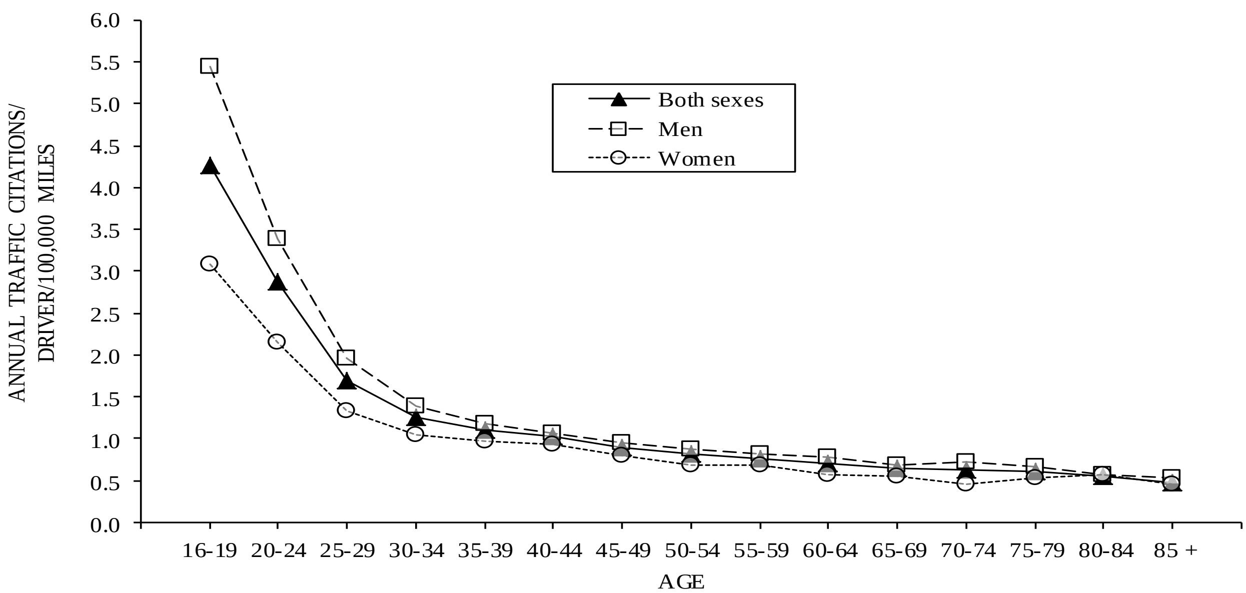
	Crash involvements			Citations		
Age	Both sexes	Men	Women	Both sexes	Men	Women
16-19	1.28	1.33	1.25	4.26	5.44	3.08
20-24	0.69	0.67	0.72	2.87	3.38	2.16
25-29	0.43	0.41	0.45	1.70	1.96	1.34
30-34	0.34	0.33	0.36	1.26	1.39	1.05
35-39	0.34	0.31	0.36	1.11	1.18	0.96
40-44	0.34	0.30	0.38	1.02	1.06	0.93
45-49	0.32	0.29	0.36	0.90	0.96	0.79
50-54	0.32	0.30	0.35	0.81	0.88	0.69
55-59	0.35	0.33	0.38	0.77	0.82	0.68
60-64	0.35	0.33	0.40	0.71	0.79	0.58
65-69	0.39	0.37	0.41	0.64	0.69	0.56
70-74	0.45	0.42	0.52	0.63	0.73	0.46
75-79	0.57	0.54	0.66	0.60	0.66	0.54
80-84	0.69	0.66	0.86	0.54	0.57	0.56
85 +	0.82	0.79	1.01	0.48	0.53	0.45
All ages	0.48	0.44	0.53	1.48	1.61	1.28

Note. Based on driver records of a 1% random sample of California licensed drivers. Averages based on crashes and citations occurring during the years 2004 through 2006. Mileage estimates are based on data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey, Estimated Average Annual Mileage by Age Group and Sex for the California Sample*, Washington, D.C.: U.S. Department of Transportation.



Note. Based on driver records of a 1% random sample of California licensed drivers. Averages based on crashes and citations occurring during the years 2004 through 2006. Mileage estimates are based on data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey*, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*, Washington, D.C.: U.S. Department of Transportation.

Figure 7. Average annual crash involvements per licensed driver per 100,000 miles by age and sex.



Note. Based on driver records of a 1% random sample of California licensed drivers. Averages based on crashes and citations occurring during the years 2004 through 2006. Mileage estimates are based on data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey*, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*, Washington, D.C.: U.S. Department of Transportation.

Figure 8. Average annual traffic citations per driver per 100,000 miles by age and sex.

Table 7, and Figures 7 and 8, show mileage-adjusted crash and citation rates. Conclusions that can be drawn from the table and figures include the following:

- In agreement with other studies, the youngest and oldest drivers have the highest average mileage-adjusted crash rates. The curve in Figure 7 has often been described as “U-shaped.”

- For both sexes, the average mileage-adjusted citation rate is highest for drivers aged 16-19, and diminishes with age. The rate for young men exceeds that for young women.

- The average mileage-adjusted crash rate for older women is considerably higher than the corresponding rate for older men. This may be in part a consequence, as discussed below, of women’s much lower mileage (about half as great as men’s, see Appendix) in the age range where the men-women disparity is most apparent; in part it may be due to recent widows or spouses of recently disabled men, who were not previously active drivers, joining the driving population. Related factors probably enter in as well; Stamatiadis and Deacon (1995), who used a different method of adjusting for exposure and found a similar result, discussed the relative lack of driving experience gained by present cohorts of older women—as compared to men—during their younger years.

It should be noted that, as group mileage rises, it is predictable that the group’s rate of crashes per mile will fall. The empirical curve representing crashes as a function of miles rises very steeply at first when mileage is low, and then levels off to a gradual increase as mileage becomes high. This makes crashes per mile misleading as a measure of crash risk (Janke, 1991)—if it is assumed, for example, that a group driving twice the number of miles on average should have twice the crash rate. Actually they will have less than that. Probably part of the reason for the empirical curve findings is that unfit groups tend to drive less and also to experience proportionately more crashes when they drive. But another part may be that groups with relatively low average mileage tend to accumulate more of their miles on congested city streets with two-way traffic, including pedestrians and non-motorized vehicles, and no restriction of access. High-mileage groups, on the other hand, typically accumulate a substantial proportion of their miles on divided multilane highways with no cross-traffic and limited access. At least after merging onto the highway has been accomplished, the driving task on these “freeways” is simpler (less exposure to risk), and the crash rate per mile is lower. Janke (1991) cited data from the California Business, Transportation and Housing Agency (1985) which indicated that there were 2.75 times as many crashes per mile driven on non-freeways as on freeways. Even if two groups are equally competent on the average, a group driving half the mileage of another would be expected to have more than half the rate of crashes per mile, simply because of their proportionally greater exposure to higher-risk driving conditions.

An alternative method of estimating exposure-adjusted crash risk that does not rely directly on miles driven was applied to the 2007 through 2009 fatal/injury crash data as part of this study. A description of that analysis and the results are presented in the section Traffic Crashes Adjusted for Exposure.

Fatal/Injury and Fatal Crashes

The heading refers to casualty crashes—that is, those involving someone's injury or death. "Fatal/injury" refers to the sum of fatal and nonfatal injury crashes. These are not as common as "property-damage-only" crashes, but because of their severity are much more likely to be investigated by police and reported to the DMV. Fatal and fatal/injury (F/I) crash rates are especially high for the group of drivers less than 25 years old, and in addition the average rate of involvement in fatal crashes is considerably elevated for the very aged when compared to middle-aged people, though not as high as for the young. A non-ability factor that magnifies older people's casualty rate is their vulnerability to being injured or dying from the crash (American Association of State Highway and Transportation Officials, 2012); evidence for this, and its implications, will be discussed in the section Research on Senior Drivers.

Average F/I and fatal crash involvement rates per 1,000 licensed California drivers for each age/sex group during 2009 are shown in Table 8. California crash data for 2009 are from the California Highway Patrol (CHP). (The number of crash involvements for each group is shown in Table 9 of this report). They are exhaustive, including not only crash involvements of California-licensed drivers within the state, but also involvements in California of unlicensed drivers and those holding out-of-state licenses. State licensing data for 2009 are from DMV.

The average F/I and fatal crash involvement rates shown here were derived by dividing aggregated CHP crash data from SWITRS by the count of all licensed drivers. It is important for the reader to know that this approach is somewhat different from that used to obtain crash and citation rates based on the 1% sample of driver records presented in a prior section of this report. Those rates were estimated based only on incidents on California's DRM record information for validly licensed drivers (minus deceased drivers and those with expired licenses) and drivers who were issued an instructor permit.

Fatal crashes are much less common than crashes resulting in only nonfatal injuries; during 2009, there were 2,805 fatal collisions and 163,524 nonfatal injury collisions in California (California Highway Patrol, 2009). Table 8 shows that in 2009, combining sexes and ages, the crash involvement rate (per 1,000 drivers) for F/I crashes (12.08) was 71 times that for fatal crashes (0.17).

Table 8

Fatal/Injury and Fatal Crash Involvements per 1,000 Drivers by Age and Sex

	Fatal/injury			Fatal		
Age	Both sexes	Men	Women	Both sexes	Men	Women
16	30.31	32.41	28.27	0.26	0.44	0.08
17	28.49	30.21	26.68	0.33	0.49	0.15
18	30.49	32.63	28.08	0.40	0.49	0.29
19	25.07	26.68	23.28	0.29	0.40	0.18
16-19	27.80	29.62	25.80	0.33	0.45	0.20
20-24	19.39	21.43	17.23	0.29	0.45	0.13
25-29	15.06	16.85	13.26	0.22	0.31	0.13
30-34	12.82	14.29	11.34	0.15	0.23	0.08
35-39	11.99	13.23	10.72	0.16	0.23	0.09
40-44	11.41	12.83	9.92	0.15	0.21	0.09
45-49	10.71	12.05	9.30	0.15	0.21	0.08
50-54	9.85	11.42	8.20	0.15	0.23	0.07
55-59	8.91	10.29	7.48	0.13	0.19	0.07
60-64	7.94	9.26	6.58	0.12	0.19	0.06
65-69	7.35	8.46	6.20	0.12	0.16	0.07
70-74	7.12	8.29	5.91	0.10	0.14	0.07
75-79	7.01	8.07	5.92	0.11	0.15	0.07
80-84	7.46	8.85	6.15	0.17	0.23	0.12
85 +	7.28	8.84	5.77	0.22	0.33	0.11
All ages	12.08	13.58	10.52	0.17	0.25	0.09

Note. Crash data are from CHP, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA.

Table 9 gives indexes of relative involvement in F/I and fatal crashes, during 2009, for drivers grouped by age and sex. What is called a relative involvement index was calculated for each age/sex group by dividing the percent the group represented of *all drivers involved in F/I (or fatal) crashes* by the percent it represented of *all licensed drivers*. This type of index is general; it can be used for total crashes as well. It is meant to answer the question: Considering how large a group is, as a percent of the driving population, is the group overinvolved or underinvolved in crashes? The expected index for any group would be 1.00—if a group is 10% of the driving population, for instance, one would expect drivers in it to have 10% of the crash involvements, everything else being equal. If another age/sex group contained 4% of the drivers involved in F/I crashes but only 2% of all licensed drivers in California, its relative involvement index would be 2.0, indicating that the group had twice as many F/I crash involvements as expected. Similarly, a group that contained 2% of the drivers involved in F/I crashes but was 4% of the driving population would have had half as many casualty crash involvements as expected, with a relative involvement index of 0.5.

Some caution should be used in making quantitative inferences about California licensees based on the data of Table 8. That is because, as noted, out-of-state and unlicensed drivers involved in California crashes are included in CHP's data. Such drivers probably represent a relatively small part of the total group. But the distortion caused by this source of error could make the licensed members of a particular age group look more hazardous than they really are, if the group contains many people who are unlicensed (at least, unlicensed in California), but drive and experience crashes nonetheless. This may be particularly true of teenagers. Conversely, if members of an age group are licensed in California but do not actually drive, this would reduce the group's relative involvement rate. This may be especially likely in the case of non-driving seniors keeping their licenses for personal reasons only.

Table 8 shows relative involvement indexes at each age level for male and female drivers separately and combined. The indexes given for men and women separately reflect both age and sex differences—so that women, say, are compared to the driving population as a whole (all ages, both sexes), and not just to other women. As an example, the 1.10 fatal/injury relative involvement index for women aged 25-29 means that women in this age group have, on the average, a relative involvement in fatal/injury crashes that is 10% greater than the relative involvement index for all drivers, defined as 1.00. Relative involvement indexes can also be made sex-specific (with men compared only to men, for example) by dividing each age/sex group's index by the "all ages" index for that sex, shown at the bottom of the table. The "all ages" F/I index for men is 1.12, so a sex-specific F/I index for men aged 25-29 would be 1.40/1.12 = 1.25. This means that, for that age/sex group, the relative involvement in F/I crashes is 25% greater than it is for men in general.

Table 9

Relative Involvement in Fatal/Injury and Fatal Crashes by Age and Sex

				Fatal/injury						Fatal					
	Group as % of all licensed drivers[a]			Group as % of all involved drivers[b]			Relative involvement index[c]			Group as % of all involved drivers			Relative involvement index		
Age	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women
16	0.30	0.15	0.15	0.74	0.39	0.35	2.51	2.68	2.34	0.44	0.37	0.07	1.50	2.54	0.49
17	0.68	0.35	0.33	1.59	0.87	0.73	2.36	2.50	2.21	1.28	0.99	0.30	1.90	2.84	0.90
18	1.22	0.64	0.57	3.07	1.74	1.33	2.52	2.70	2.32	2.81	1.85	0.96	2.31	2.87	1.68
19	1.64	0.86	0.78	3.41	1.91	1.50	2.08	2.21	1.93	2.81	2.00	0.81	1.71	2.31	1.04
16-19	3.83	2.00	1.83	8.82	4.91	3.91	2.30	2.45	2.14	7.34	5.20	2.14	1.92	2.60	1.17
20-24	9.13	4.70	4.43	14.67	8.34	6.32	1.61	1.77	1.43	15.65	12.32	3.33	1.71	2.62	0.75
25-29	9.71	4.88	4.84	12.11	6.81	5.31	1.25	1.40	1.10	12.37	8.82	3.55	1.27	1.81	0.73
30-34	9.08	4.56	4.52	9.64	5.40	4.25	1.06	1.18	0.94	8.03	5.99	2.05	0.88	1.31	0.45
35-39	9.48	4.80	4.68	9.41	5.26	4.15	0.99	1.10	0.89	8.77	6.38	2.39	0.93	1.33	0.51
40-44	9.86	5.06	4.80	9.32	5.38	3.94	0.94	1.06	0.82	8.70	6.21	2.49	0.88	1.23	0.52
45-49	10.45	5.37	5.08	9.26	5.35	3.91	0.89	1.00	0.77	9.09	6.70	2.39	0.87	1.25	0.47
50-54	9.89	5.05	4.84	8.06	4.78	3.28	0.82	0.95	0.68	8.82	6.73	2.09	0.89	1.33	0.43
55-59	8.51	4.33	4.18	6.28	3.69	2.59	0.74	0.85	0.62	6.38	4.71	1.68	0.75	1.09	0.40
60-64	6.94	3.52	3.42	4.56	2.70	1.86	0.66	0.77	0.54	5.05	3.89	1.16	0.73	1.11	0.34
65-69	4.75	2.42	2.33	2.89	1.70	1.20	0.61	0.70	0.51	3.23	2.32	0.91	0.68	0.96	0.39
70-74	3.25	1.65	1.60	1.91	1.13	0.78	0.59	0.69	0.49	1.97	1.31	0.67	0.61	0.79	0.42
75-79	2.33	1.19	1.15	1.35	0.79	0.56	0.58	0.67	0.49	1.48	1.03	0.44	0.63	0.87	0.39
80-84	1.62	0.79	0.83	1.00	0.58	0.42	0.62	0.73	0.51	1.65	1.06	0.59	1.02	1.34	0.71
85+	1.15	0.56	0.58	0.69	0.31	0.28	0.60	0.73	0.48	1.45	1.08	0.37	1.27	1.93	0.63
All ages	100.00	50.89	49.11	100.00	57.23	42.77	1.00	1.12	0.87	100.00	73.76	26.24	1.00	1.45	0.53

[a]Licensing data for 2009 are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. [b]Crash data for 2009 are from CHP, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. [c]Relative involvement is the crash involvement for the age/sex group as a percent of such involvement for all drivers, divided by the percent of all licensed drivers represented by that group. Percentage may not sum to 100.00 due to rounding.

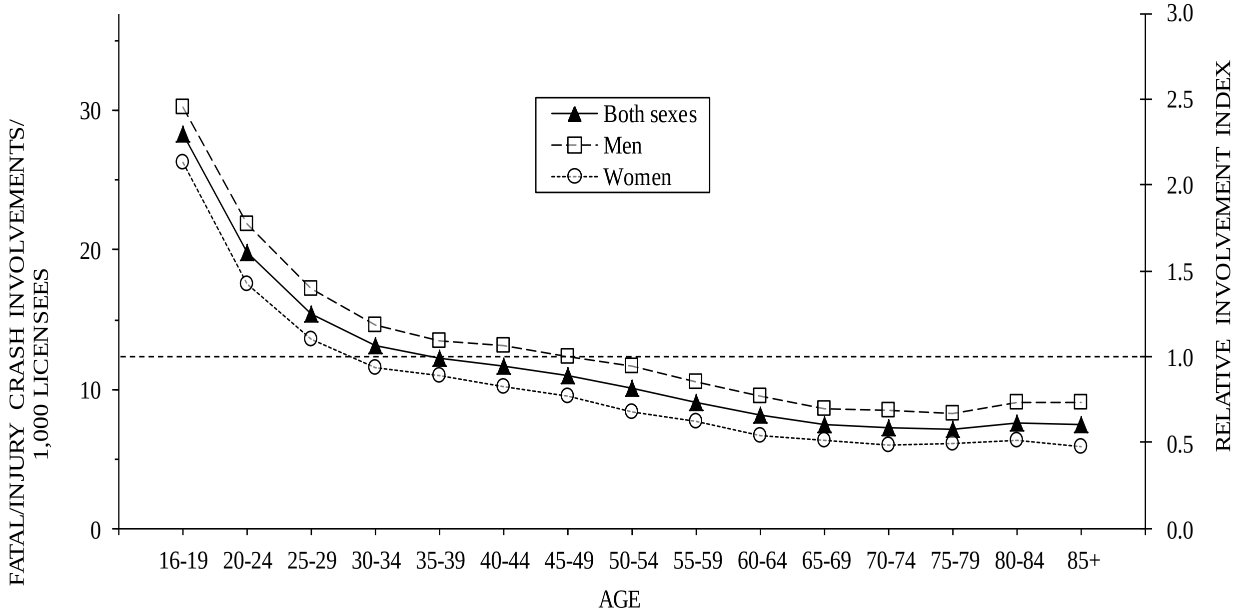
Given a measuring scale with a true zero point and equal intervals, relative information in the form of ratios (e.g., B is twice as heavy as C) can be inferred from scale readings (B weighs 8 lbs. and C weighs 4 lbs.). In a similar way, indexes of relative involvement for all age groups in a population can be inferred from the groups' separate involvement rates (the number of involvements for people in an age group divided by the number of people in that age group) and the average involvement rate for the entire population (the total number of involvements for all age groups divided by the total number of people in the population). Here we are concerned with traffic crashes of licensed drivers in the driving population. Because relative involvement index is a different way of presenting information that is already implicit in involvement rate, both the relative involvement indexes and the average group involvement rates for different age groups can be shown on the same graph. The actual curves are identical; only the numbers on the Y axis will be different, because one measure is a group's average rate of involvements per driver, and the other is a number that indicates a group's share of involvements compared to its share of drivers.

The graphing procedure requires using two Y-axes and drawing a horizontal line across the graph at the level of the average population crash-involvement rate on one of the Y axes. In the graphs below it is the left axis. The intersection of this line and the other Y axis, the one on the right, represents a relative involvement index of 1.00. Fixing the position of 1.00 establishes a unit distance and defines the relative involvement scale. Figures 9 and 10 show the result for F/I and fatal crashes, respectively. As mentioned, in each figure the Y-axis on the left represents crash involvement rate and the one on the right represents relative involvement index. The data are taken directly from Tables 8 and 9.

Tables 9 and 10, and Figures 9 and 10, indicate that:

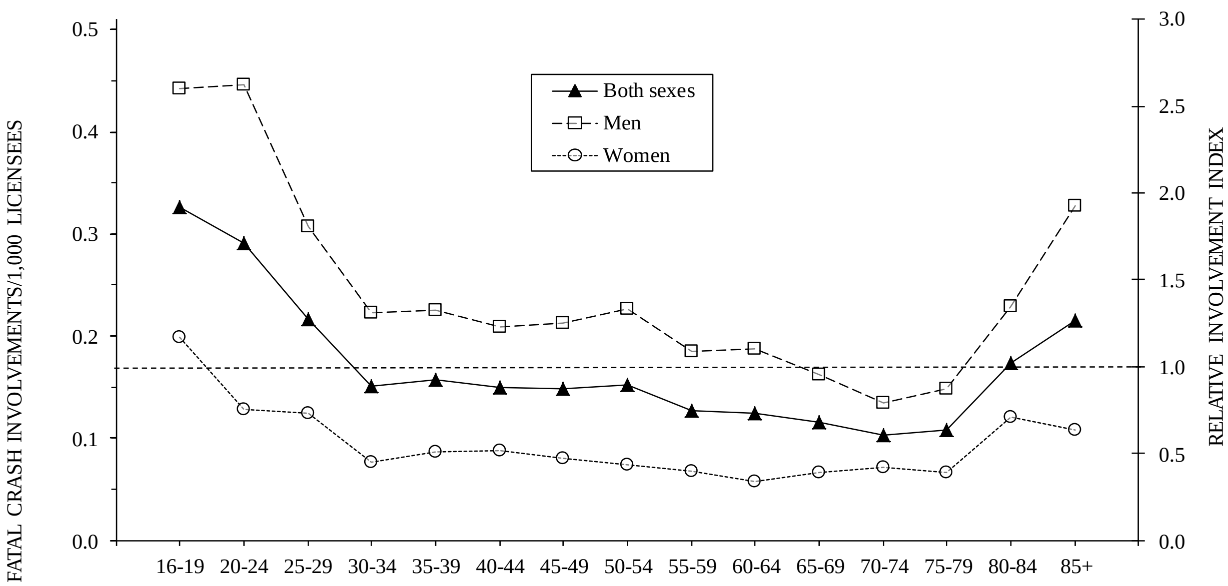
- As a group, teenaged drivers have the highest average F/I and fatal crash involvement rates. Within that group, 18-year-olds are at highest risk.

- As driver age increases, average involvement in F/I crashes decreases, reaches a low point at ages 75-79, and then rises slightly. The increase is by no means steep, despite seniors' greater physical and physiological vulnerability. However, vulnerability is a factor leading to an earlier increase in fatal crash involvement than is seen for F/I crash involvement; the increase in average fatal crash involvement begins after ages 70-74.



Note. Crash data for 2009 are from California Highway Patrol, 2011, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data for 2009 are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. The relative involvement is the crash involvement for the age/sex group as a percent of such involvement for all drivers, divided by the percent of all licensed drivers represented by that group.

Figure 9. Fatal/injury crash involvement rate and relative involvement index by age and sex.



Note. Crash data for 2009 are from California Highway Patrol, 2011, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data for 2009 are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. The relative involvement is the crash involvement for the age/sex group as a percent of such involvement for all drivers, divided by the percent of all licensed drivers represented by that group.

Figure 10. Fatal crash involvement rate and relative involvement index by age and sex.

- Within each age group, average F/I and fatal crash involvement rates of male drivers exceed those of female drivers.

- With all ages combined, the average involvement rate of men in fatal/injury crashes is 1.3 times (30% greater than) that of women.

- With all ages combined, the average involvement rate of men in fatal crashes is 2.7 times (170% greater than) that of women.

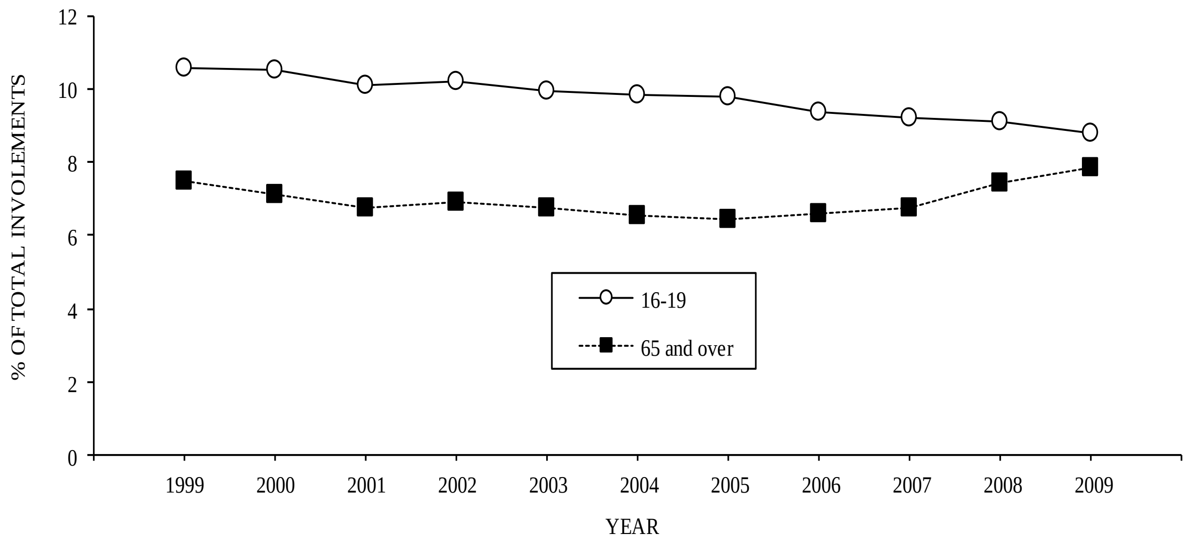
Table 10 and Figure 11 show the percentage of teenaged or senior drivers involved in F/I crashes from 1999 through 2009. Crash data are from CHP and disregard culpability for the crash. It is instructive to compare Figure 11 with the years 1999-2009 in Figure 3, which shows teenagers' and seniors' percentage shares of the licensed driver population. Figure 3 shows that licensed senior drivers had increased to about 13.1% by 2009, while licensed teenaged drivers had diminished to about 3.8% by 2009. Figure 11, picturing the groups' percentage shares of F/I crash involvements, shows for 2009 that teenagers (3.8% of licensees) were involved in about 8.8%, and seniors (13.1% of licensees) in about 7.8%, of F/I crashes. This indicates that the groups were over- and under-involved, respectively, in casualty crashes.

Table 10

Number and Percentage of Fatal/Injury Crash Involvements by Year and Age of Driver

Year	Total involvements	Age 16-19 involvements	% of total	Age 65+ involvements	% of total
1999	338,535	35,759	10.56	25,311	7.48
2000	357,081	37,532	10.51	25,395	7.11
2001	380,693	38,480	10.11	25,622	6.73
2002	385,923	39,505	10.24	26,629	6.90
2003	383,108	38,048	9.93	25,838	6.74
2004	383,137	37,727	9.85	25,111	6.55
2005	372,927	36,481	9.78	23,944	6.42
2006	355,014	33,257	9.37	23,505	6.62
2007	344,450	31,748	9.22	23,313	6.77
2008	297,221	27,129	9.13	22,167	7.46
2009	286,236	25,195	8.80	22,427	7.84

Note. Crash data for 1999-2009 are from California Highway Patrol 2000-2011, *1999-2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA.



Note. Crash data for 1999-2009 are from California Highway Patrol 2000-2011, *1999-2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA.

Figure 11. Percentage of fatal/injury crash involvements by year and age of driver.

Fatal/Injury and Fatal Crashes Adjusted for Mileage

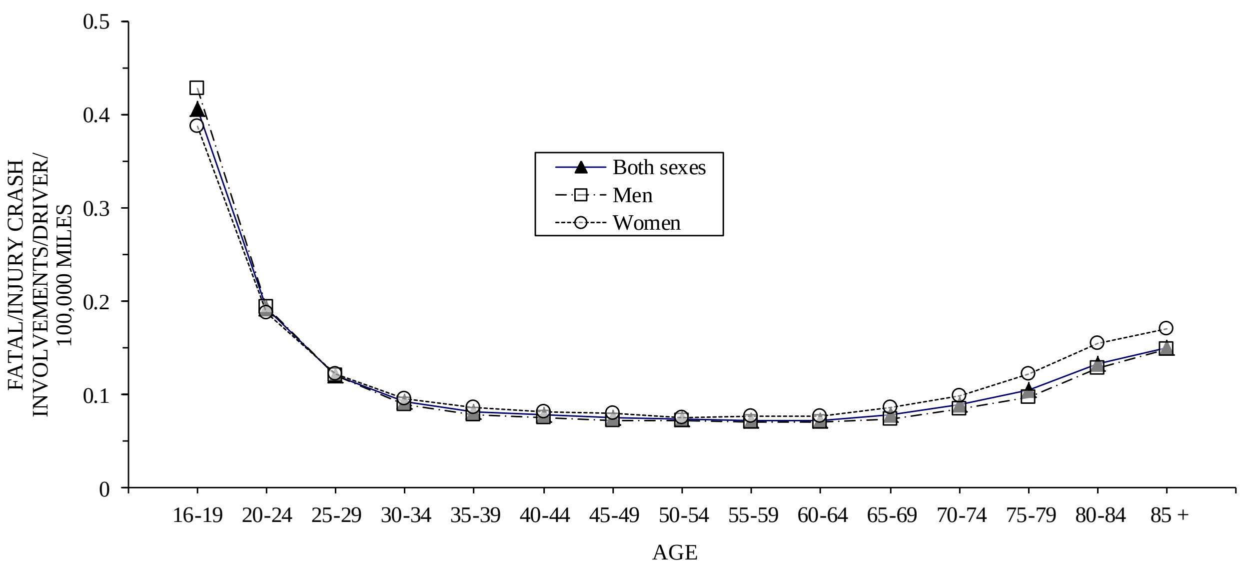
Table 11 and Figures 12 and 13 show the mileage-adjusted F/I and fatal crash involvements per driver per 100,000 miles (or simply the per-mile rates times 100,000) by age and sex. The mileage adjustments were obtained by applying the procedures previously described in section Traffic Crashes and Citations Adjusted for Mileage above. The same cautions on interpreting mileage-adjusted rates given in that section also apply here.

Table 11

Fatal/Injury and Fatal Crash Involvements per Driver per 100,000 Miles by Age and Sex

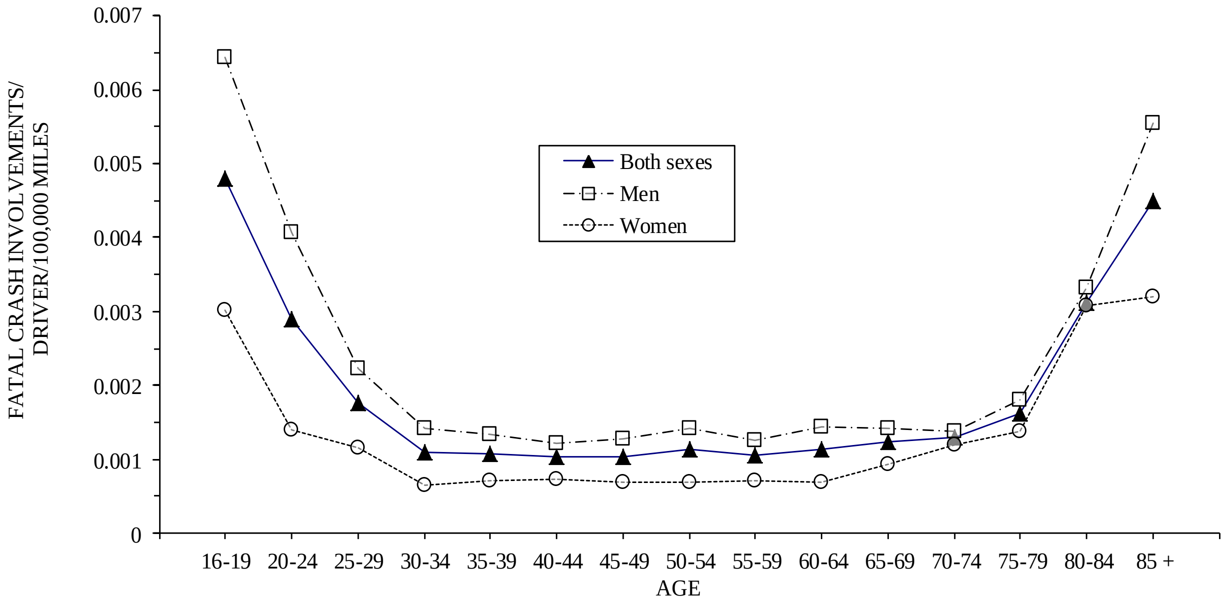
Age	Fatal/injury			Fatal		
	Both sexes	Men	Women	Both sexes	Men	Women
16-19	0.4062	0.4283	0.3881	0.0048	0.0064	0.0030
20-24	0.1916	0.1944	0.1872	0.0029	0.0041	0.0014
25-29	0.1210	0.1205	0.1211	0.0018	0.0022	0.0012
30-34	0.0921	0.0897	0.0946	0.0011	0.0014	0.0006
35-39	0.0818	0.0779	0.0864	0.0011	0.0013	0.0007
40-44	0.0774	0.0743	0.0807	0.0010	0.0012	0.0007
45-49	0.0748	0.0713	0.0790	0.0010	0.0013	0.0007
50-54	0.0731	0.0713	0.0753	0.0011	0.0014	0.0007
55-59	0.0723	0.0698	0.0764	0.0010	0.0013	0.0007
60-64	0.0725	0.0701	0.0771	0.0011	0.0014	0.0007
65-69	0.0775	0.0733	0.0858	0.0012	0.0014	0.0009
70-74	0.0885	0.0842	0.0990	0.0013	0.0014	0.0012
75-79	0.1045	0.0975	0.1221	0.0016	0.0018	0.0014
80-84	0.1331	0.1276	0.1553	0.0031	0.0033	0.0031
85 +	0.1503	0.1483	0.1696	0.0045	0.0055	0.0032
All ages	0.1143	0.1098	0.1215	0.0016	0.0020	0.0011

Note. Crash data are from CHP, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Repor*t, Sacramento, CA. Mileage estimates are based on 2009 data from the Federal Highway Administration, U.S. Department of Transportation, *2009 Nationwide Household Travel Survey*, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*, Washington, D.C.



Note. Crash data are from CHP, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. Mileage estimates are based on 2009 data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey*, Washington, D.C.: U.S. Department of Transportation, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*.

Figure 12. Fatal/injury crash involvement rate per driver per 100,000 miles by age and sex.



Note. Crash data are from CHP, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. Mileage estimates are based on 2009 data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey*, Washington, D.C.: U.S. Department of Transportation, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*.

Figure 13. Fatal crash involvement rate per driver per 100,000 miles by age and sex.

The mileage-adjusted F/I and fatal crash rates show the following:

- As with total crashes, the youngest and oldest drivers have the highest mileage-adjusted F/I and fatal crash rates, compared to middle-aged drivers.

- For combined sexes, mileage-adjusted F/I crash rates decline from the teenage years through about age 59. Thereafter they rise gradually, the increase becoming relatively steep between age groups 75-79 and 80-84. Nevertheless, the mileage-adjusted F/I crash rate for drivers aged 85 or more remains less than that for drivers through age 24.

- For combined sexes, mileage-adjusted fatal crash rates decline from the teenage years, reaching a low point that is mostly sustained from ages 30-34 through ages 65-69. They rise after that, with a sharp upturn starting at age 80-84. The rate for ages 85 and above is higher than all other age groups except teenagers, which is probably largely due to the greater vulnerability of very old drivers dying from injuries sustained in the crash.

Traffic Crashes Adjusted for Exposure

The mileage-adjusted crash rates presented above are limited in that they adjust only for the amount of driving; all time of day, roadway conditions, traffic levels, and other exposure factors are not considered. More recently, risk assessment methods have become available that estimate exposure directly from the crash data. Such methods, commonly referred to as induced exposure techniques, can produce exposure and risk estimates that are more reliable and less biased than what is possible through mileage adjustments and other means.

The concept of induced exposure and its use in estimating traffic crash risk was introduced in the mid-1960s by Thorpe (1964). Thorpe determined that the likelihood of a non-culpable (innocent) driver being involved in a crash is proportional to the likelihood of meeting that driver on the road. The quasi-induced exposure (QIE) technique used in the present study is based on a refinement of Thorpe's concept made by Carr (1969). Carr's method calculates the exposure-adjusted crash rate for a given group by dividing the group's proportion of all crash-involved at-fault drivers by the group's proportion of all crash-involved innocent drivers.

The QIE technique assumes that nonresponsible drivers involved in collisions are a statistically random (representative) sample of all drivers on the road (Chandraratna & Stamatiadis, 2009). If this assumption is met, then the exposure-adjusted crash risk for a certain type of driver can be determined by comparing how frequently drivers of this type appear among at-fault drivers to how frequently such drivers appear among innocent drivers (Carr, 1969; Lardelli-Claret et al., 2006).

The QIE technique was used in this study to analyze crashes in California from 2007 through 2009 that are recorded in SWITRS. The technique, as applied here, required that only certain types of crashes be included in the analyses. Specifically, to be included, a crash had to meet all of the following criteria: (1) involve only two vehicles (drivers); (2) have one at-fault driver and one not-at-fault driver; (3) have both drivers identified as having a valid age at or above 16; and (4) involve only passenger cars or pickup trucks as the driven vehicles. For purposes of the above selection, a driver was considered at-fault if they were listed as such in SWITRS, and not-at-fault otherwise. A crash was excluded from the analysis if neither of the two drivers was listed as being at-fault. Since SWITRS does not list more than one driver as being at-fault in any given crash, no crashes had to be eliminated due to both drivers being considered at-fault.

Crashes in which age was missing for either driver were also excluded.

The induced exposure method of estimating crash risk involves calculating the following ratios for each driver group of interest (Cerrelli, 1973).

$$\text{Liability Index} = \frac{\text{\% at-fault drivers in group}}{\text{\% group in driving population}}$$

$$\text{Relative Exposure Index} = \frac{\text{\% not-at-fault drivers in group}}{\text{\% group in driving population}}$$

$$\text{Hazard Index} = \frac{\text{Liability Index}}{\text{Relative Exposure Index}}$$

The induced exposure method can be used to determine exposure-adjusted crash rates when the proportion of the type of drivers of interest in the driving population is known. The QIE technique does not have this limitation because it doesn't correct for group representation in the population (DeYoung, Peck, & Helander, 1997). Instead, the QIE method calculates the exposure-adjusted crash rate for a given group by dividing the group's proportion of all crash-involved at-fault drivers by the group's proportion of all crash-involved innocent drivers as shown below.

$$\text{QIE Crash Involvement Ratio} = \frac{\text{\% at-fault drivers in group}}{\text{\% not-at-fault drivers in group}}$$

Age-sex group crash involvement ratios were computed for crashes recorded in SWITRS for 2007 through 2009 combined and that meet the criteria for inclusion described above. The group crash involvement ratio is essentially the crash involvement rate for the group, adjusted for the group's exposure. It is calculated by dividing the proportion of at-fault drivers in the group by the proportion of not-at-fault drivers in the group. A ratio greater than 1.0 indicates that drivers in the group, as a whole, are overinvolved as at-fault drivers relative to their exposure (as indicated by their percentage representation among innocent drivers). The age-sex group involvement ratios for total and fatal/injury crashes are presented in Table 12 and plotted in Figures 14 and 15.

Table 12

Total and Fatal/Injury Crash Involvement Ratio by Age and Sex for 2007 Through 2009

	Total crashes			F/I crashes		
Age	Both sexes	Men	Women	Both sexes	Men	Women
16	2.56	2.52	2.46	2.52	2.52	2.87
17	2.16	2.18	2.08	1.86	1.71	1.89
18	2.17	2.23	2.13	1.81	1.69	1.88
19	1.86	1.90	1.82	1.59	1.51	1.70
16-19	2.08	2.11	2.04	1.79	1.67	1.90
20-24	1.42	1.55	1.31	1.28	1.38	1.20
25-29	1.06	1.13	0.99	1.00	1.05	0.90
30-34	0.88	0.91	0.84	0.88	0.95	0.79
35-39	0.78	0.79	0.78	0.78	0.78	0.84
40-44	0.75	0.76	0.74	0.74	0.77	0.75
45-49	0.71	0.70	0.74	0.71	0.66	0.77
50-54	0.72	0.69	0.75	0.71	0.67	0.70
55-59	0.73	0.71	0.76	0.76	0.75	0.78
60-64	0.78	0.71	0.85	0.77	0.72	0.81
65-69	0.89	0.83	0.98	1.00	0.91	1.01
70-74	1.08	0.95	1.26	1.22	1.05	1.36
75-79	1.43	1.34	1.65	1.58	1.74	1.80
80-84	2.01	1.82	2.33	2.12	2.04	2.55
85 +	2.80	2.55	3.15	2.87	2.61	2.69

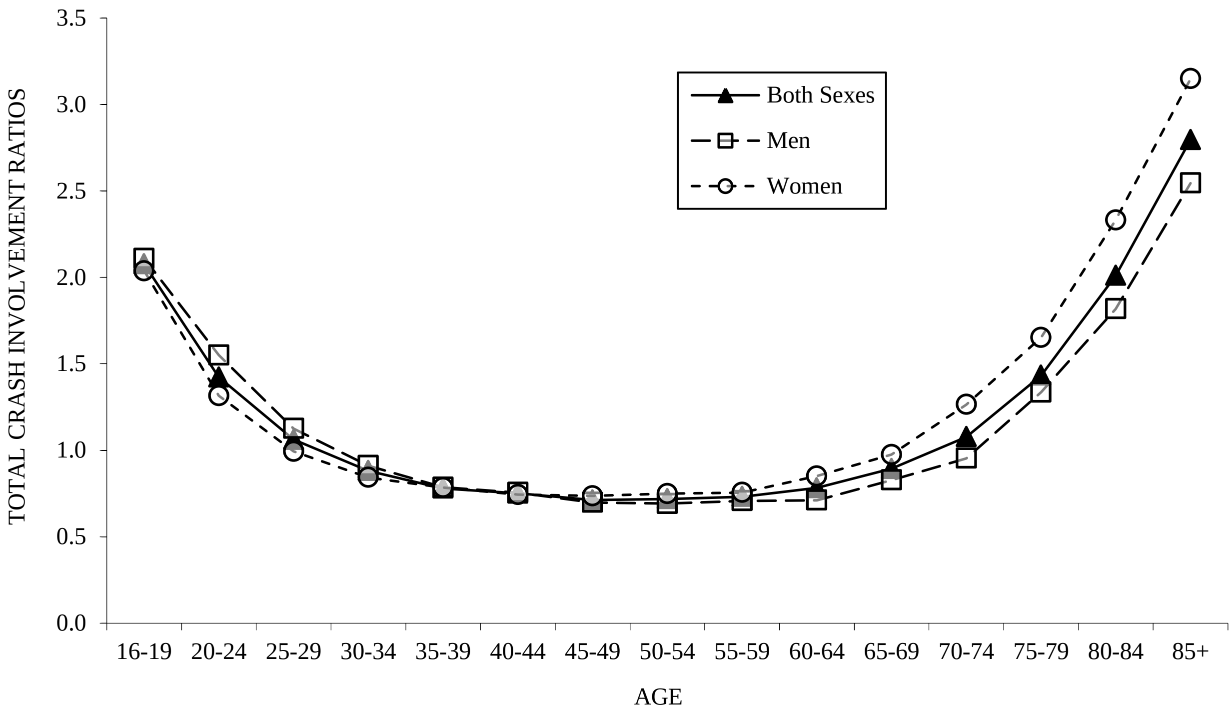
Note. Crash data for 2007 through 2009 are from California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS). Group crash involvement ratio = percentage of drivers at-fault in the group divided by percentage of drivers not-at-fault in the group.

The crash involvement ratios show the following for both total and F/I crashes:

- As with mileage-adjusted crash rates, the youngest and oldest drivers have higher crash involvement ratios than do middle-aged drivers.

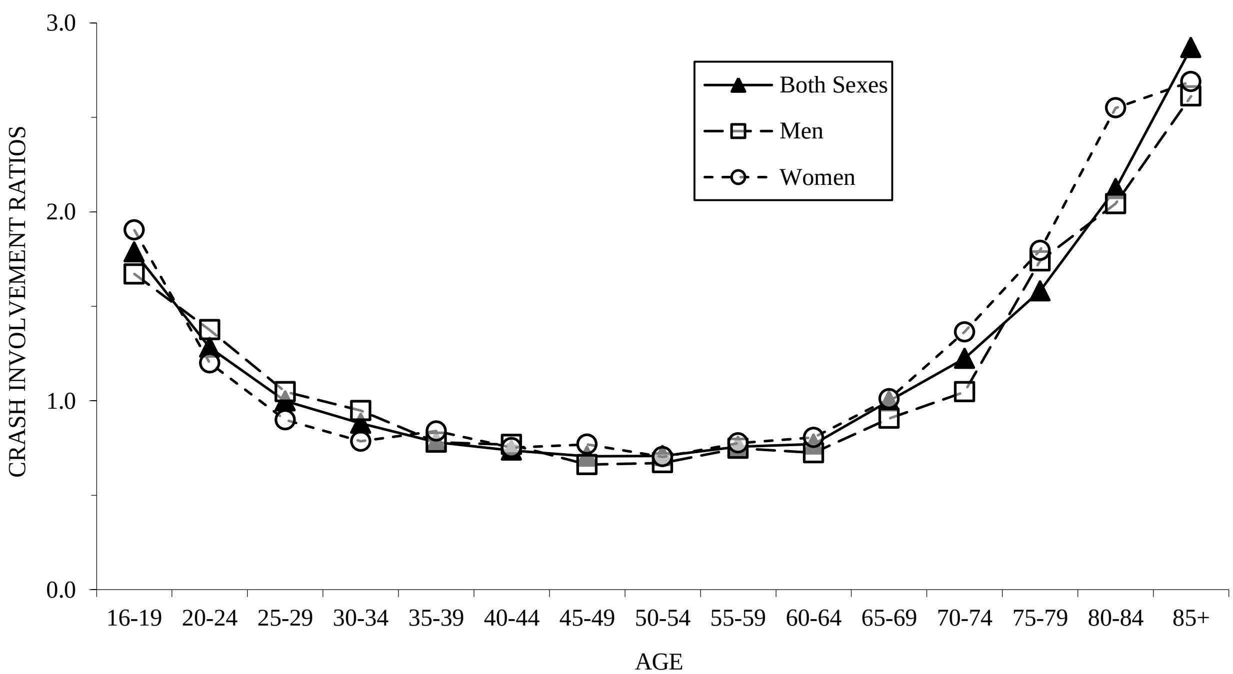
- The crash involvement ratios decrease with age until they begin to rise somewhere around age 50-60, the increase becoming relatively steep after age 70.

- The ratios for older driver's exceed that of teenagers at around age 80, with the ratio for 85+ being over 30% and 70% higher for total and F/I crashes, respectively.



Note. Crash data for 2007 through 2009 are from California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS).

Figure 14. Total crash involvement ratio by age and sex for 2007 through 2009.



Note. Crash data for 2007 through 2009 are from California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS).

Figure 15. Fatal/injury crash involvement ratio by age and sex for 2007 through 2009.

It should be noted that crash rates adjusted for mileage are entirely different metrics than QIE crash involvement ratios, and have entirely different meanings. The mileage-adjusted rate reflects the likelihood that drivers in the age-sex group will crash in every 100,000 miles of driving. The crash involvement ratio, on the other hand, is not a measure of risk per se, but rather the likelihood that drivers in the group will be at-fault rather innocent in their crashes. In addition, the latter measure is based on only those crashes that meet the requirement of the QIE technique as described above.

Had-Been-Drinking (HBD) Drivers in Fatal/Injury and Fatal Crashes

The HBD indicator is put on the crash report by the investigating officer to indicate that an involved driver 1) had been drinking and is still under the influence of alcohol (with a BAC of .08% or higher, or as determined by the officer from other evidence when blood alcohol is below .08%), 2) had been drinking but is not under the influence of alcohol, or 3) had been drinking but the degree of alcohol impairment is unknown by the officer. (The last possibility may arise, for example, if the driver is unconscious after the crash.) The term "HBD driver" will be used here to refer to a driver involved in a crash where some type of HBD indicator was put on the crash report because the investigating officer indicated the driver had been drinking—and for brevity, the crashes of such drivers will sometimes be referred to here as "HBD crashes."

Table 13 presents the F/I and fatal crash involvement rates of HBD drivers during 2009 by age and sex, and Table 14 gives the corresponding relative involvement indexes for such drivers. Figures 16 and 17 show these data graphically for HBD F/I and HBD fatal crashes, respectively. As before, the Y-axis on the left represents involvement rate per 10,000 licensed drivers, and the Y-axis on the right represents relative involvement index. Data on HBD crashes taking place in 2009 are from California Highway Patrol (2009), and licensing data for 2009, which were used to obtain relative involvement index, are from California Department of Motor Vehicles (2010). A cautionary note is that, due to the small number of HBD fatal crash involvements for the youngest and oldest drivers, particularly the women in those groups, group involvement rates are unstable and may vary considerably from year to year.

Tables 13 and 14, and Figures 16 and 17, indicate that:

- Drivers aged 20-24 are the age range most involved in HBD F/I and HBD fatal crashes.

- The high point of average HBD F/I crash involvement is reached at ages 20-24; thereafter involvement consistently goes down. (Buying or consuming alcoholic beverages does not become legal in California until age 21.)

- The decrease after ages 20-24 is consistent for HBD fatal crashes, with the exception of a slight upturn starting at 80-84, which is probably due to instability resulting from the small number of very old drivers being involved in HBD fatal crashes.

- On the average, the oldest drivers (85+) are the group with the fewest HBD F/I and HBD fatal crash involvements.

- Within each age group, men's average HBD crash involvement substantially exceeds that of women.

- Within the group of teenaged drivers, the average involvement rate for young men aged 16-19 in HBD F/I crashes is over 2.5 times that for young women (20.31 vs. 7.71).

- Within the group of teenaged drivers, the average involvement rate for young men aged 16-19 in HBD fatal crashes is almost 5 times that for young women (1.14 vs. 0.23).

Table 13

Had-Been-Drinking (HBD) Drivers in Fatal/Injury and Fatal Crashes Compared to All Drivers Involved in Casualty Crashes, and to All Licensed Drivers, by Age and Sex

Crash type	Number of crash-involved drivers			Number of crash-involved HBD drivers			% of crash-involved drivers identified as HBD			Crash-involved HBD drivers per 10,000 licensees		
Age	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women
Fatal/injury												
16	2,121	1,115	1,006	53	37	16	2.50	3.32	1.59	7.57	10.76	4.50
17	4,554	2,476	2,078	146	110	36	3.21	4.44	1.73	9.13	13.42	4.62
18	8,781	4,974	3,807	447	329	118	5.09	6.61	3.10	15.52	21.58	8.70
19	9,739	5,454	4,285	649	485	164	6.66	8.89	3.83	16.70	23.72	8.91
16-19	25,195	14,019	11,176	1,295	961	334	5.14	6.85	2.99	14.29	20.31	7.71
20-24	41,887	23,829	18,058	4,051	3,002	1,049	9.67	12.60	5.81	18.75	27.00	10.01
25-29	34,598	19,438	15,160	3,054	2,362	692	8.83	12.15	4.56	13.30	20.48	6.05
30-34	27,543	15,409	12,134	1,848	1,406	442	6.71	9.12	3.64	8.60	13.04	4.13
35-39	26,889	15,030	11,859	1,501	1,174	327	5.58	7.81	2.76	6.69	10.33	2.96
40-44	26,615	15,356	11,259	1,417	1,021	396	5.32	6.65	3.52	6.08	8.53	3.49
45-49	26,457	15,288	11,169	1,344	989	355	5.08	6.47	3.18	5.44	7.79	2.96
50-54	23,031	13,650	9,381	1,055	805	250	4.58	5.90	2.66	4.51	6.74	2.19
55-59	17,928	10,533	7,395	700	548	152	3.90	5.20	2.06	3.48	5.35	1.54
60-64	13,032	7,717	5,315	429	343	86	3.29	4.44	1.62	2.61	4.12	1.06
65-69	8,258	4,842	3,416	216	158	58	2.62	3.26	1.70	1.92	2.76	1.05
70-74	5,469	3,236	2,233	110	84	26	2.01	2.60	1.16	1.43	2.15	0.69
75-79	3,867	2,264	1,603	64	52	12	1.66	2.30	0.75	1.16	1.85	0.44
80-84	2,861	1,650	1,211	38	32	6	1.33	1.94	0.50	0.99	1.72	0.30
85+	1,972	1176	796	21	8	7	1.06	1.19	0.88	0.77	1.05	0.51
All ages	285,602	163,437	122,165	17,143	12,951	4,192	6.00	7.92	3.43	7.25	10.76	3.61
Fatal												
16	18	15	3	1	1	0	5.56	6.67	0.00	0.14	0.29	0.00
17	52	40	12	7	5	2	13.46	12.50	16.67	0.44	0.61	0.26
18	114	75	39	27	22	5	23.68	29.33	12.82	0.94	1.44	0.37
19	114	81	33	29	26	3	25.44	32.10	9.09	0.75	1.27	0.16
16-19	298	211	87	64	54	10	21.48	25.59	11.49	0.71	1.14	0.23
20-24	635	500	135	244	199	45	38.43	39.80	33.33	1.13	1.79	0.43
25-29	502	358	144	173	135	38	34.46	37.71	26.39	0.75	1.17	0.33
30-34	326	243	83	90	76	14	27.61	31.28	16.87	0.42	0.70	0.13
35-39	356	259	97	80	70	10	22.47	27.03	10.31	0.36	0.62	0.09
40-44	353	252	101	76	63	13	21.53	25.00	12.87	0.33	0.53	0.11
45-49	369	272	97	72	63	9	19.51	23.16	9.28	0.29	0.50	0.07
50-54	358	273	85	64	58	6	17.88	21.25	7.06	0.27	0.49	0.05
55-59	259	191	68	34	28	6	13.13	14.66	8.82	0.17	0.27	0.06
60-64	205	158	47	25	21	4	12.20	13.29	8.51	0.15	0.25	0.05
65-69	131	94	37	15	12	3	11.45	12.77	8.11	0.13	0.21	0.05
70-74	80	53	27	4	3	1	5.00	5.66	3.70	0.05	0.08	0.03
75-79	60	42	18	2	2	0	3.33	4.76	0.00	0.04	0.07	0.00
80-84	67	43	24	2	2	0	2.99	4.65	0.00	0.05	0.11	0.00
85+	59	44	15	3	2	1	5.08	4.55	6.67	0.11	0.15	0.07
All ages	4,058	2,993	1,065	948	788	160	23.36	26.33	15.02	0.40	0.65	0.14

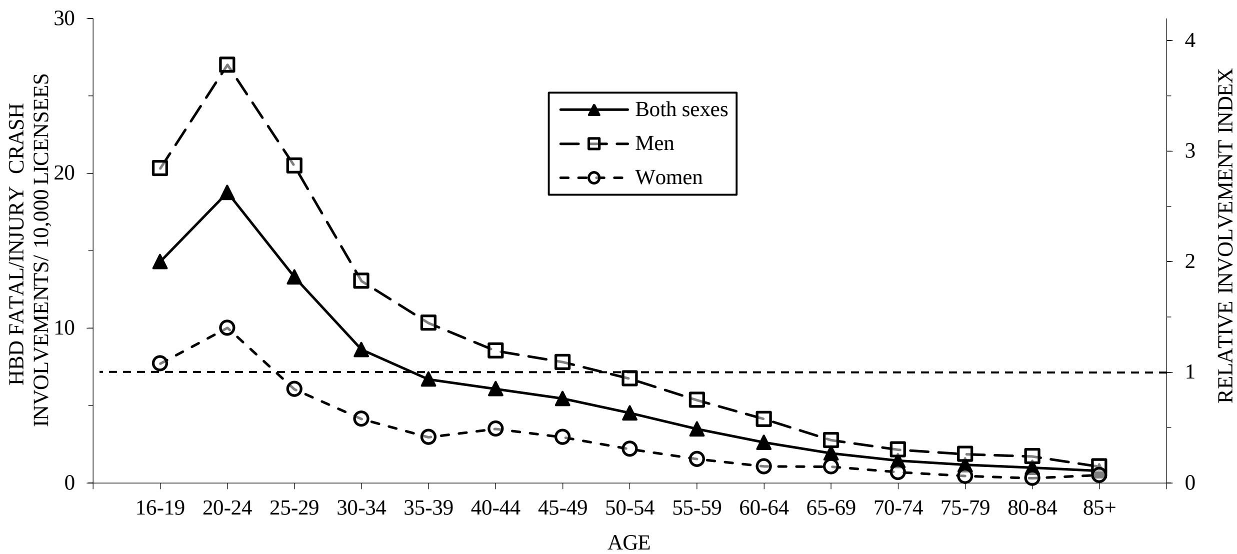
Note. Crash data for 2009 are from CHP, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data for 2009, used to compute percentages based on the number of licensed drivers within age/sex group, are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA.

Table 14

Relative Involvement in Had-Been-Drinking (HBD) Fatal/Injury and Fatal Crashes by Age and Sex

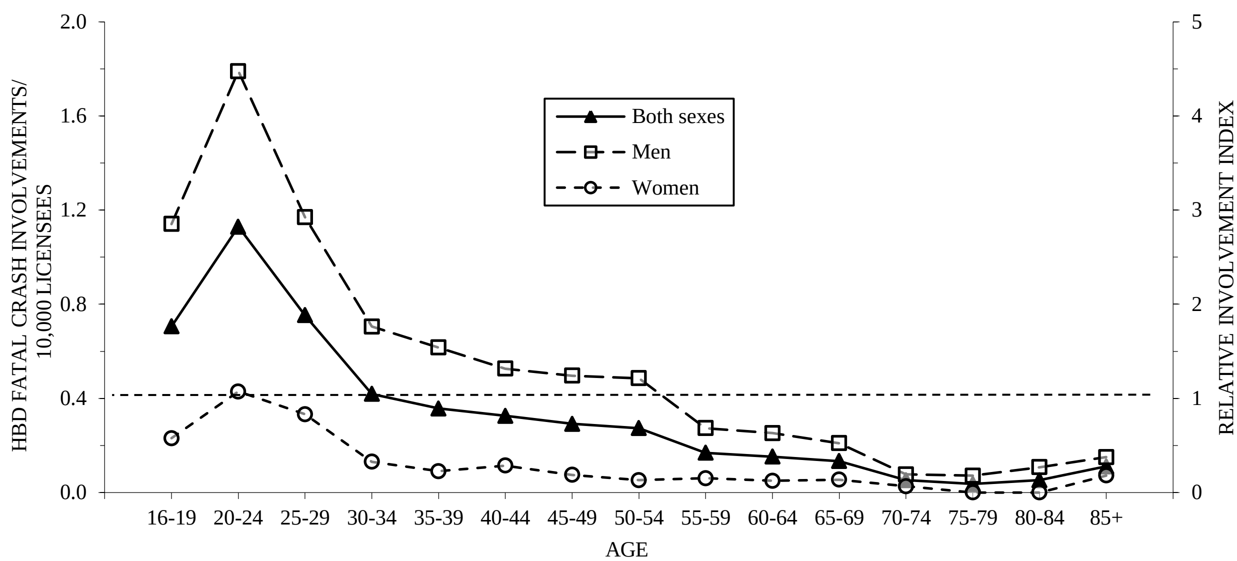
Age	Group as % of all licensed drivers[a]			Fatal/injury: Group as % of all involved drivers[b]			Fatal/injury: Relative involvement index[c]			Fatal: Group as % of all involved drivers			Fatal: Relative involvement index		
	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women	Both sexes	Men	Women
16	0.30	0.15	0.15	0.31	0.22	0.09	1.04	1.48	0.62	0.11	0.11	0.00	0.36	0.73	0.00
17	0.68	0.35	0.33	0.85	0.64	0.21	1.26	1.85	0.64	0.74	0.53	0.21	1.09	1.52	0.64
18	1.22	0.64	0.57	2.61	1.92	0.69	2.14	2.98	1.20	2.85	2.32	0.53	2.34	3.60	0.92
19	1.64	0.86	0.78	3.79	2.83	0.96	2.30	3.27	1.23	3.06	2.74	0.32	1.86	3.17	0.41
16-19	3.83	2.00	1.83	7.55	5.61	1.95	1.97	2.80	1.06	6.75	5.70	1.05	1.76	2.85	0.58
20-24	9.13	4.70	4.43	23.63	17.51	6.12	2.59	3.72	1.38	25.74	20.99	4.75	2.82	4.46	1.07
25-29	9.71	4.88	4.84	17.81	13.78	4.04	1.83	2.82	0.83	18.25	14.24	4.01	1.88	2.92	0.83
30-34	9.08	4.56	4.52	10.78	8.20	2.58	1.19	1.80	0.57	9.49	8.02	1.48	1.05	1.76	0.33
35-39	9.48	4.80	4.68	8.76	6.85	1.91	0.92	1.43	0.41	8.44	7.38	1.05	0.89	1.54	0.23
40-44	9.86	5.06	4.80	8.27	5.96	2.31	0.84	1.18	0.48	8.02	6.65	1.37	0.81	1.31	0.29
45-49	10.45	5.37	5.08	7.84	5.77	2.07	0.75	1.08	0.41	7.59	6.65	0.95	0.73	1.24	0.19
50-54	9.89	5.05	4.84	6.15	4.70	1.46	0.62	0.93	0.30	6.75	6.12	0.63	0.68	1.21	0.13
55-59	8.51	4.33	4.18	4.08	3.20	0.89	0.48	0.74	0.21	3.59	2.95	0.63	0.42	0.68	0.15
60-64	6.94	3.52	3.42	2.50	2.00	0.50	0.36	0.57	0.15	2.64	2.22	0.42	0.38	0.63	0.12
65-69	4.75	2.42	2.33	1.26	0.92	0.34	0.27	0.38	0.15	1.58	1.27	0.32	0.33	0.52	0.14
70-74	3.25	1.65	1.60	0.64	0.49	0.15	0.20	0.30	0.09	0.42	0.32	0.11	0.13	0.19	0.07
75-79	2.33	1.19	1.15	0.37	0.30	0.07	0.16	0.26	0.06	0.21	0.21	0.00	0.09	0.18	0.00
80-84	1.62	0.79	0.83	0.22	0.19	0.03	0.14	0.24	0.04	0.21	0.21	0.00	0.13	0.27	0.00
85+	1.15	0.56	0.58	0.12	0.08	0.04	0.11	0.15	0.07	0.32	0.21	0.11	0.28	0.38	0.18
All ages	100.00	50.89	49.11	100.00	75.55	24.45	1.00	1.48	0.50	100.00	83.12	16.88	1.00	1.63	0.34

[a]Licensing data for 2009 are from California Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. [b]Crash data for 2009 are from California Highway Patrol, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. [c]Relative involvement is the crash involvement for the age/sex group as a percent of such involvement for all drivers, divided by the percent of all licensed drivers represented by that group.



Note. Crash data for 2009 are from California Highway Patrol, 2011, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data for 2009 are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. The relative involvement is the crash involvement for the age/sex group as a percent of such involvement for all drivers, divided by the percent of all licensed drivers represented by that group.

Figure 16. Had-been-drinking (HBD) fatal/injury crash involvement rate and relative involvement index by age and sex.



Note. Crash data for 2009 are from California Highway Patrol, 2011, *2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions*, Sacramento, CA. Licensing data for 2009 are from CA Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. The relative involvement is the crash involvement for the age/sex group as a percent of such involvement for all drivers, divided by the percent of all licensed drivers represented by that group.

Figure 17. Had-been-drinking (HBD) fatal crash involvement rate and relative involvement index by age and sex.

Primary Collision Factors in Casualty Crashes

The primary collision factor in a crash is noted by the police officer on the crash report. This notation usually refers to an unlawful action taken by the driver "at fault"—that is, the driver considered by the investigating officer to be most responsible for the crash—or the condition of the driver, like drunkenness, when the crash occurred. The idea is that without the primary collision factor the crash would have been much less likely to occur, and perhaps would not have occurred. Tables 15 and 16 present the number and percent within age/sex group, respectively, of F/I and fatal crashes during 2009 by primary collision factor and age and sex of the driver at fault.

Table 15 shows that:

- Unsafe speed (which always refers here to driving too fast; driving too slowly would be cited as "impeding traffic" and is included in the "other" category) is most often the primary collision factor in F/I crashes for men of all ages combined, but its percentage contribution decreases as driver age increases. Violation of right-of-way becomes increasingly important in causing collisions, and becomes dominant for men aged 80 or more. This frequently involves crashing while trying to make a left turn, probably the most challenging maneuver for older drivers in general (Stutts, Martell, & Staplin, 2009).

- Unsafe speed is most often the primary collision factor in F/I crashes for women of all ages combined, as well. Violation of right-of-way is a very close second, and its percentage contribution becomes dominant for women after age 70.

- For all ages combined, right-of-way violation accounts for 10.4% of the fatal crashes of female drivers but only 6.1% of the fatal crashes of male drivers, for whom other causes are considerably more important. In order of relative importance, the most important causes of fatal crashes for women are improper turns, alcohol/drugs, and unsafe speed violation, while for men the most important are alcohol/drugs, improper turns, and unsafe speed.

Table 15

Number of Fatal/Injury and Fatal Crashes by Primary Collision Factor within Age and Sex of Driver at Fault

Crash type Sex	Primary collision factor[a]	All ages	16-19	20-29	30-39	40-49	50-59	60-69	70-79	80 +
Fatal/injury										
Men	All factors	79,089	9,653	24,08	13,351	12,445	9,825	5,304	2,661	1,802
	Alcohol/drugs	10,189	803	4,249	2,037	1,589	1,059	360	75	17
	Unsafe speed	27,130	3,556	8,365	4,670	4,402	3,371	1,613	708	445
	Wrong side of road	1,667	218	468	252	243	232	144	63	47
	Passing/lane change	3,481	360	1,014	623	605	488	250	94	47
	Improper turn	11,785	1,726	3,638	1,786	1,671	1,466	812	414	272
	Right-of-way	11,746	1,630	2,986	1,726	1,666	1,418	1,030	712	578
	Signs/signals	5,475	681	1,460	895	895	653	429	283	179
	Other moving violations	5,862	471	1,412	1,068	1,070	908	514	239	180
	All others	1,754	208	456	294	304	230	152	73	37
Women	All factors	53,797	7,020	16,014	9,449	8,147	6,233	3,642	1,977	1,315
	Alcohol/drugs	3,304	270	1,307	655	628	324	87	28	5
	Unsafe speed	16,559	2,387	5,140	3,058	2,441	1,801	976	467	289
	Wrong side of road	868	117	219	122	129	128	79	53	21
	Passing/lane change	2,268	274	724	387	362	276	142	63	40
	Improper turn	9,105	1,322	2,939	1,459	1,280	1,007	609	291	198
	Right-of-way	11,568	1,608	3,047	1,916	1,664	1,368	900	600	465
	Signs/signals	4,513	440	1,173	811	687	594	400	255	153
	Other moving violations	4,526	465	1,219	847	772	589	344	179	111
	All others	1,086	137	246	194	184	146	105	41	33
Fatal										
Men	All factors	1,648	167	546	248	243	213	124	52	53
	Alcohol/drugs	510	39	218	99	70	60	23	1	0
	Unsafe speed	338	45	122	53	46	43	17	6	6
	Wrong side of road	104	8	30	13	24	14	10	2	3
	Passing/lane change	57	6	18	8	7	9	7	1	1
	Improper turn	373	28	112	42	63	52	36	22	18
	Right-of-way	101	14	18	13	8	11	11	9	17
	Signs/signals	81	18	14	12	11	8	10	5	3
	Other moving violations	58	5	8	7	11	13	7	4	3
	All others	24	4	6	1	3	3	3	2	2
Women	All factors	521	51	163	76	82	59	43	22	25
	Alcohol/drugs	105	11	45	20	14	12	2	1	0
	Unsafe speed	65	7	22	9	12	6	6	3	0
	Wrong side of road	38	0	11	8	7	4	4	3	1
	Passing/lane change	37	6	15	5	4	3	3	0	1
	Improper turn	150	20	38	21	20	16	17	9	9
	Right-of-way	54	4	15	4	8	8	5	3	7
	Signs/signals	33	2	11	3	6	4	2	1	4
	Other moving violations	31	0	5	4	8	6	3	2	3
	All others	8	1	1	2	3	0	1	0	0

Note. Unpublished data for 2009 are from California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS).

[a]The factor "other moving violations" consists of infractions for impeding traffic, following too closely, right-of-way pedestrian, starting/backing, improper driving, and falling asleep. The factor "all others" consists of the infractions pedestrian violation, hazardous parking, unsafe equipment, other hazards, unknown, and "not stated."

Table 16

Percentage of Fatal/Injury and Fatal Crashes by Primary Collision Factor within Age and Sex of Driver at Fault

Crash type Sex	Primary collision factor[a]	All ages	16-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
Fatal/injury										
Men	All factors	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Alcohol/drugs	12.9	8.3	17.7	15.3	12.8	10.8	6.8	2.8	0.9
	Unsafe speed	34.3	36.8	34.8	35.0	35.4	34.3	30.4	26.6	24.7
	Wrong side of road	2.1	2.3	1.9	1.9	2.0	2.4	2.7	2.4	2.6
	Passing/lane change	4.4	3.7	4.2	4.7	4.9	5.0	4.7	3.5	2.6
	Improper turn	14.9	17.9	15.1	13.4	13.4	14.9	15.3	15.6	15.1
	Right-of-way	14.9	16.9	12.4	12.9	13.4	14.4	19.4	26.8	32.1
	Signs/signals	6.9	7.1	6.1	6.7	7.2	6.6	8.1	10.6	9.9
	Other moving violations	7.4	4.9	5.9	8.0	8.6	9.2	9.7	9.0	10.0
	All others	2.2	2.2	1.9	2.2	2.4	2.3	2.9	2.7	2.1
Women	All factors	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Alcohol/drugs	6.1	3.8	8.2	6.9	7.7	5.2	2.4	1.4	0.4
	Unsafe speed	30.8	34.0	32.1	32.4	30.0	28.9	26.8	23.6	22.0
	Wrong side of road	1.6	1.7	1.4	1.3	1.6	2.1	2.2	2.7	1.6
	Passing/lane change	4.2	3.9	4.5	4.1	4.4	4.4	3.9	3.2	3.0
	Improper turn	16.9	18.8	18.4	15.4	15.7	16.2	16.7	14.7	15.1
	Right-of-way	21.5	22.9	19.0	20.3	20.4	21.9	24.7	30.3	35.4
	Signs/signals	8.4	6.3	7.3	8.6	8.4	9.5	11.0	12.9	11.6
	Other moving violations	8.4	6.6	7.6	9.0	9.5	9.4	9.4	9.1	8.4
	All others	2.0	2.0	1.5	2.1	2.3	2.3	2.9	2.1	2.5
Fatal										
Men	All factors	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Alcohol/drugs	31.0	23.4	39.9	39.9	28.8	28.2	18.5	1.9	0.0
	Unsafe speed	20.5	26.9	22.3	21.4	18.9	20.2	13.7	11.5	11.3
	Wrong side of road	6.3	4.8	5.5	5.2	9.9	6.6	8.1	3.8	5.7
	Passing/lane change	3.5	3.6	3.3	3.2	2.9	4.2	5.6	1.9	1.9
	Improper turn	22.7	16.8	20.5	16.9	25.9	24.4	29.0	42.3	34.0
	Right-of-way	6.1	8.4	3.3	5.2	3.3	5.2	8.9	17.3	32.1
	Signs/signals	4.9	10.8	2.6	4.8	4.5	3.8	8.1	9.6	5.7
	Other moving violations	3.5	3.0	1.5	2.8	4.5	6.1	5.6	7.7	5.7
	All others	1.5	2.4	1.1	0.4	1.2	1.4	2.4	3.8	3.8
Women	All factors	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Alcohol/drugs	20.2	21.6	27.6	26.3	17.1	20.3	4.7	4.5	0.0
	Unsafe speed	12.5	13.7	13.5	11.8	14.6	10.2	14.0	13.6	0.0
	Wrong side of road	7.3	0.0	6.7	10.5	8.5	6.8	9.3	13.6	4.0
	Passing/lane change	7.1	11.8	9.2	6.6	4.9	5.1	7.0	0.0	4.0
	Improper turn	28.8	39.2	23.3	27.6	24.4	27.1	39.5	40.9	36.0
	Right-of-way	10.4	7.8	9.2	5.3	9.8	13.6	11.6	13.6	28.0
	Signs/signals	6.3	3.9	6.7	3.9	7.3	6.8	4.7	4.5	16.0
	Other moving violations	6.0	0.0	3.1	5.3	9.8	10.2	7.0	9.1	12.0
	All others	1.5	2.0	0.6	2.6	3.7	0.0	2.3	0.0	0.0

Note. Unpublished data for 2009 are from California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS).
[a]The factor "other moving violations" consists of infractions for impeding traffic, following too closely, right-of-way pedestrian, starting/backing, improper driving, and falling asleep. The factor "all others" consists of the infractions pedestrian violation, hazardous parking, unsafe equipment, other hazards, unknown, and "not stated."

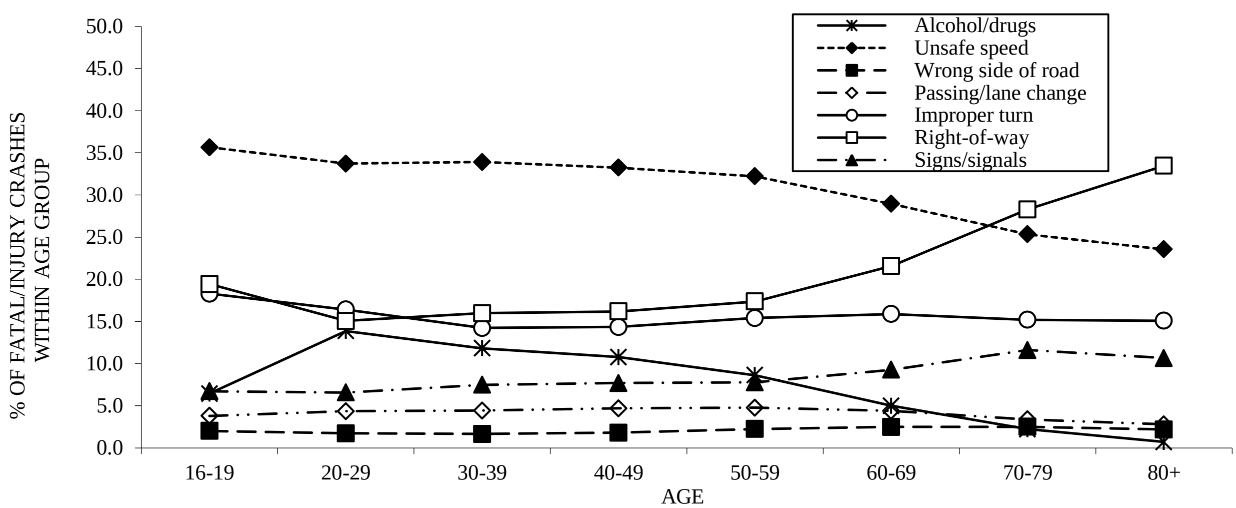
Table 17 presents primary collision factors within age group for responsible casualty crashes in the form of percentages. In this way it is like Table 16, but Table 17 does not break out the results separately by sex. Figures 18 and 19 plot the percentages from Table 17.

Table 17

Percentage of Fatal/Injury and Fatal Crashes for Combined Sexes by Primary Collision Factor within Age of Driver at Fault

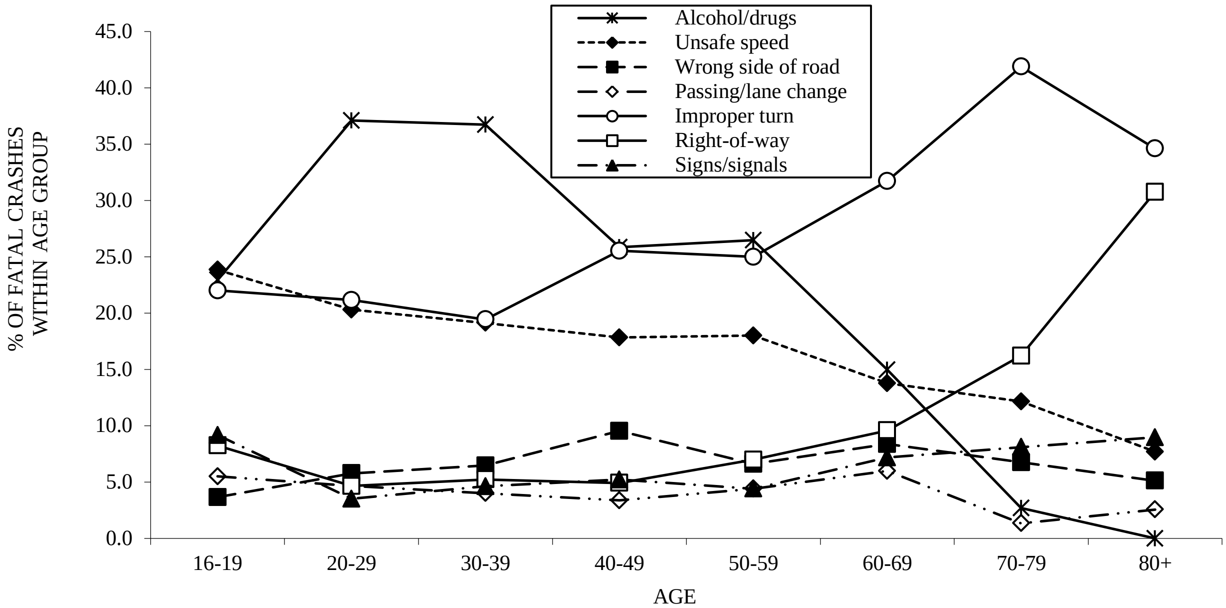
Crash type Primary collision factor[a]	All ages	16-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
Fatal/injury									
All factors	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Alcohol/drugs	10.2	6.4	13.9	11.8	10.8	8.6	5.0	2.2	0.7
Unsafe speed	32.9	35.6	33.7	33.9	33.2	32.2	28.9	25.3	23.5
Wrong side of road	1.9	2.0	1.7	1.6	1.8	2.2	2.5	2.5	2.2
Passing/lane change	4.3	3.8	4.3	4.4	4.7	4.8	4.4	3.4	2.8
Improper turn	15.7	18.3	16.4	14.2	14.3	15.4	15.9	15.2	15.1
Right-of-way	17.5	19.4	15.1	16.0	16.2	17.3	21.6	28.3	33.5
Signs/signals	7.5	6.7	6.6	7.5	7.7	7.8	9.3	11.6	10.7
Other moving	7.8	5.6	6.6	8.4	8.9	9.3	9.6	9.0	9.3
All others	2.1	2.1	1.8	2.1	2.4	2.3	2.9	2.5	2.2
Fatal									
All factors	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Alcohol/drugs	28.4	22.9	37.1	36.7	25.8	26.5	15.0	2.7	0.0
Unsafe speed	18.6	23.9	20.3	19.1	17.8	18.0	13.8	12.2	7.7
Wrong side of road	6.6	3.7	5.8	6.5	9.5	6.6	8.4	6.8	5.1
Passing/lane change	4.3	5.5	4.7	4.0	3.4	4.4	6.0	1.4	2.6
Improper turn	24.1	22.0	21.2	19.4	25.5	25.0	31.7	41.9	34.6
Right-of-way	7.1	8.3	4.7	5.2	4.9	7.0	9.6	16.2	30.8
Signs/signals	5.3	9.2	3.5	4.6	5.2	4.4	7.2	8.1	9.0
Other moving	4.1	2.3	1.8	3.4	5.8	7.0	6.0	8.1	7.7
All others	1.6	2.3	1.0	0.9	1.8	1.1	2.4	2.7	2.6

Note. Unpublished data for 2009 are from California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS).
[a]The factor "other moving violations" consists of infractions for impeding traffic, following too closely, right-of-way pedestrian, starting/backing, improper driving, and falling asleep. The factor "all others" consists of the infractions pedestrian violation, hazardous parking, unsafe equipment, other hazards, unknown, and "not stated."



Note. Unpublished data for 2009 are from California Highway Patrol, Statewide Integrated Traffic Records System (SWITRS). Percentages within age group do not add to 100.00 because only the most common collision factors were considered.

Figure 18. Percentage of responsible fatal/injury crashes within age group by primary collision factor and age of driver at fault.



Note. 2009 data are from California Highway Patrol's Statewide Integrated Traffic Records System (SWITRS), Sacramento, CA. Percentages within age group do not add to 100.00 because only the most common collision factors were considered.

Figure 19. Percentage of responsible fatal crashes within age group by primary collision factor and age of driver at fault.

The interpretation of Figures 18 and 19 may not immediately be evident. Within each age group, the percentages of that group's responsible F/I or fatal crashes attributable to the seven listed collision factors should add to approximately 90% when summed over all seven factors. (They do not add to 100.0% because of the exclusion of categories "other moving violations" and "all others," which make up roughly 10% of the total for many groups, especially when considering F/I collisions.) For example, within the age group 80 and above, right-of-way violations account for about 33.5% of group members' responsible F/I crashes; unsafe speed accounts for 23.5%. This is 57% of the group's responsible casualty crashes, while the other types of collision factors or violations play smaller roles. For the age group 30-39, unsafe speed accounts for about 33.9% of group members' responsible F/I crashes, and right-of-way violation is the next-largest contributor at 16.0%. These two violation types account for half of the group's responsible casualty crashes.

Graphs similar to these have sometimes been wrongly interpreted. Therefore it may be useful to stress that, for instance, Figure 18 should not be interpreted as implying that 33.5% of all casualty crashes are due to the right-of-way violations of drivers aged 80 or more, or that 33.9% of all casualty crashes are due to the unsafe speed of drivers between 30 and 39. The Y-axis is not percent of total casualty crashes attributable to specified collision factors, nor is it percent of drivers in an age group who are at fault in casualty crashes. It is percent share *within age group* of each specified primary collision factor in directly leading to the responsible casualty crashes of that particular age group's members, and thus it indicates the relative importance of each collision factor within the age group. The same is true for the fatal crash causes shown in Figure 19.

For F/I crashes, the chief primary collision factors are unsafe speed and right-of-way violation. Table 17 and Figure 18 show that:

- Unsafe speed is the most important factor in drivers' F/I crashes when all ages are combined, and in particular for drivers under age 70. Although its importance diminishes with age, it accounts for over 20% of F/I crashes even at ages 80 and above.

- Right-of-way violation exceeds speed by a wide margin as the primary collision factor in F/I crashes of drivers aged 80 or more. Though relatively less important at younger ages, it remains important at all ages as a cause of F/I crashes.

For fatal crashes, the most important primary collision factors and age-related trends are somewhat different from those for F/I crashes. Table 18 and Figure 19 show that:

- For all ages combined and for drivers less than age 60, alcohol/drug use is the predominant cause of fatal crashes. Its importance peaks for the age group 20-29, but even for teenagers—who cannot drink legally—it accounts for almost 23% of fatal crashes.

- Improper turn violation is the most important primary collision factor in fatal crashes of drivers aged 60 or more. It has always been important as a causal factor, though still exceeded percentagewise at most ages only by alcohol/drugs.

Traffic Violation Patterns and Age

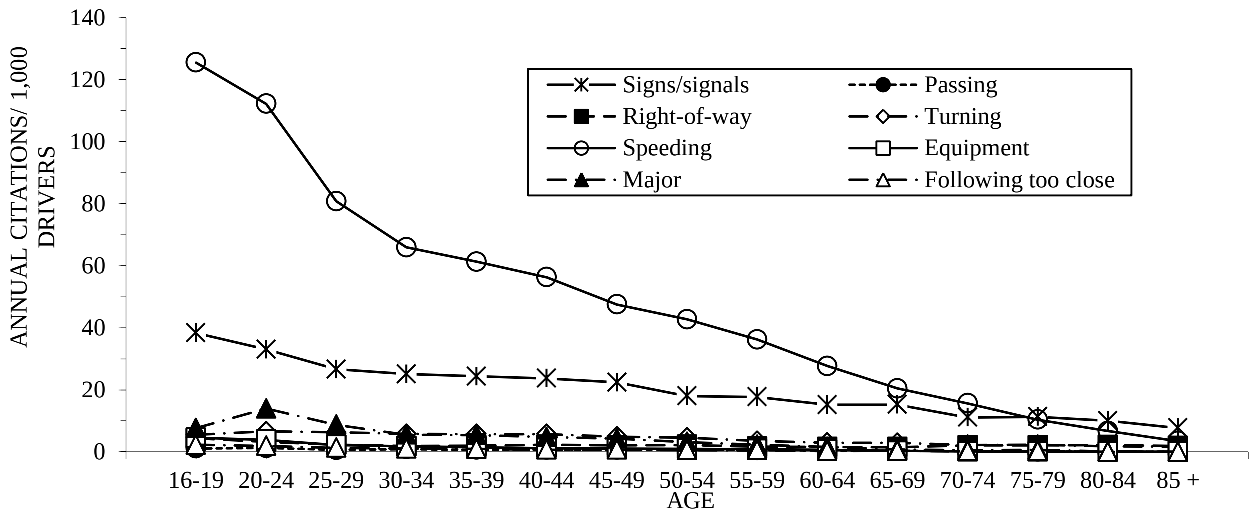
Abstracts of court records of conviction, and notices of citation dismissal contingent on completion of a court-approved program (usually a traffic violator school), are sent by the courts to DMV. These contain information on all violations recorded on traffic citations that arise from one traffic stop. (DMV's count of citations also includes failure of a driver who has not deposited bail to appear in court to answer the charge, and failure of a driver to pay a fine assessed in connection with the charge.) Dismissals in consideration of program attendance can be used for statistical purposes, but unless they become too frequent will not count against the driver in terms of assessing "negligent operator" demerit points or taking action against the license (which may be done based on the number of negligent operator points on the driver's record). Using DMV's citation data, Table 18 and Figure 20 show, by violation type and driver age, the citation rate per 1,000 drivers of selected violations occurring in California from 2003 through 2006. The information is not greatly different from that presented in terms of primary collision factors, since primary collision factors generally are, or imply, violations of traffic laws. But a salient difference is that when a primary collision factor is identified, there must first have been a crash.

Table 18

Average Annual Traffic Citations per 1,000 Licensed Drivers by Violation Type and Driver Age

	Violation type								
Age	Signs/ signals	Passing	Right-of-way	Turning	Speeding	Equipment	Major	Following too close	Total
16-19	38.37	1.10	4.35	5.52	125.54	4.56	7.64	2.29	189.38
20-24	33.04	1.25	3.25	6.61	112.20	3.86	13.95	1.94	176.11
25-29	26.65	0.63	2.28	6.29	80.83	2.23	8.72	1.28	128.90
30-34	25.08	0.90	1.88	5.78	65.95	1.76	5.51	1.05	107.90
35-39	24.35	0.70	2.03	5.75	61.32	1.50	5.41	0.91	101.98
40-44	23.69	0.66	2.31	5.73	56.29	1.20	4.76	0.66	95.30
45-49	22.40	0.74	2.05	4.89	47.55	1.10	4.25	0.69	83.68
50-54	18.00	0.81	2.21	4.61	42.74	0.97	3.15	0.55	73.03
55-59	17.70	0.53	1.67	3.54	36.23	0.87	2.28	0.47	63.27
60-64	15.17	0.45	1.57	2.95	27.67	0.68	1.57	0.29	50.36
65-69	15.25	0.30	1.49	2.91	20.44	0.34	0.78	0.34	41.84
70-74	11.11	0.24	2.06	2.25	15.67	0.13	0.59	0.15	32.20
75-79	11.29	0.13	2.09	2.30	10.37	0.05	0.66	0.20	27.08
80-84	10.01	0.00	2.20	1.80	6.71	0.10	0.10	0.00	20.92
85 +	7.71	0.00	1.88	1.65	3.49	0.07	0.00	0.00	14.80
All ages	23.10	0.72	2.26	4.98	59.73	1.64	5.31	0.91	98.66

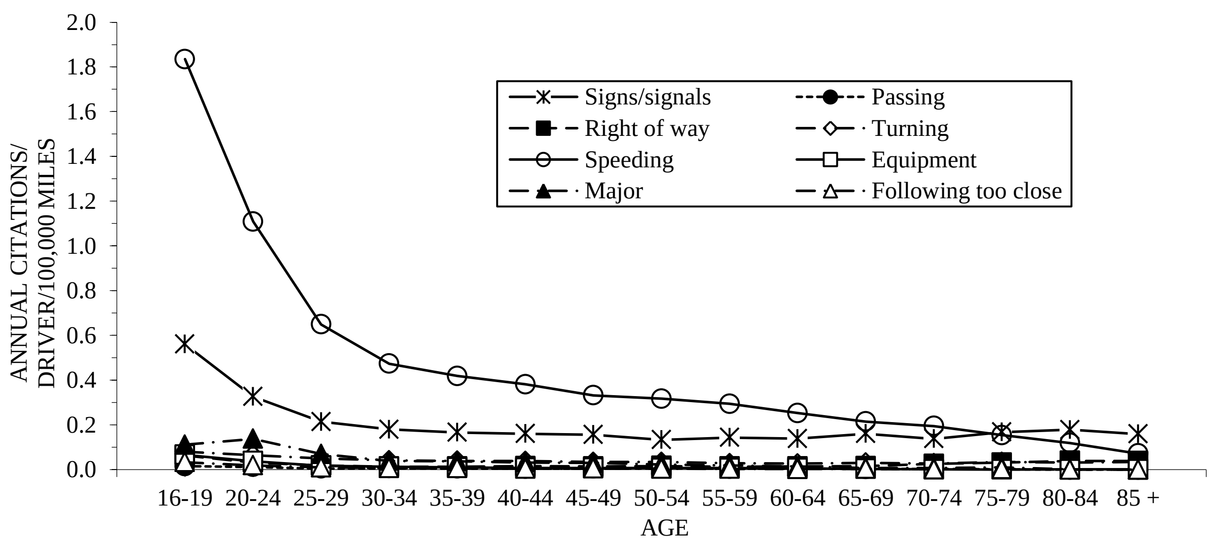
Note. Based on the driver records of a 1% random sample of California licensed drivers. Averages represent violations occurring during the years 2004 through 2006.



Note. Based on the driver records of a 1% random sample of licensed California drivers. Averages represent violations occurring during the years 2004 through 2006.

Figure 20. Average annual traffic citations per 1,000 licensed drivers by violation type and driver age.

Table 19 and Figure 21 show, by age and violation type, the mileage-adjusted rate of traffic citations per driver per 100,000 miles (or citations per mile times 100,000). Previous cautions raised regarding mileage-adjustment still apply.



Note. Based on driver records of a 1% random sample of California licensed drivers. Averages are based on citations occurring during the years 2004 through 2006. Mileage estimates are based on data from the Federal Highway Administration, U.S. Department of Transportation, *2009 Nationwide Household Travel Survey, Estimated Average Annual Mileage by Age Group and Sex for the California Sample*, Washington, D.C.

Figure 21. Average annual traffic citations per driver per 100,000 miles by violation type and driver age.

Table 19

Average Annual Traffic Citations per Driver per 100,000 Miles by Violation Type and Driver Age

Age	Violation type							
	Signs/ signals	Passing	Right-of-way	Turning	Speeding	Equipment	Major	Following too close
16-19	0.5607	0.0161	0.0635	0.0806	1.8347	0.0667	0.1117	0.0335
20-24	0.3264	0.0124	0.0321	0.0653	1.1085	0.0381	0.1378	0.0192
25-29	0.2142	0.0051	0.0183	0.0505	0.6495	0.0179	0.0701	0.0103
30-34	0.1802	0.0064	0.0135	0.0415	0.4738	0.0127	0.0396	0.0075
35-39	0.1662	0.0048	0.0138	0.0393	0.4186	0.0102	0.0369	0.0062
40-44	0.1606	0.0045	0.0156	0.0388	0.3817	0.0081	0.0323	0.0045
45-49	0.1565	0.0052	0.0143	0.0341	0.3321	0.0077	0.0297	0.0048
50-54	0.1336	0.0060	0.0164	0.0342	0.3172	0.0072	0.0234	0.0040
55-59	0.1438	0.0043	0.0136	0.0287	0.2942	0.0070	0.0185	0.0038
60-64	0.1386	0.0041	0.0144	0.0269	0.2527	0.0062	0.0144	0.0026
65-69	0.1607	0.0031	0.0157	0.0307	0.2153	0.0035	0.0083	0.0035
70-74	0.1382	0.0030	0.0256	0.0280	0.1948	0.0016	0.0073	0.0018
75-79	0.1682	0.0020	0.0311	0.0342	0.1545	0.0007	0.0098	0.0029
80-84	0.1785	0.0000	0.0392	0.0321	0.1196	0.0018	0.0018	0.0000
85 +	0.1593	0.0000	0.0388	0.0341	0.0721	0.0014	0.0000	0.0000
All ages	0.2187	0.0068	0.0214	0.0472	0.5654	0.0156	0.0502	0.0086

Note. Based on driver records of a 1% random sample of California licensed drivers. Averages are based on citations occurring during the years 2004 through 2006. Mileage estimates are based on data from the Federal Highway Administration, U.S. Department of Transportation, *2009 Nationwide Household Travel Survey, Estimated Average Annual Mileage by Age Group and Sex for the California Sample*, Washington, D.C.

Table 20 presents each violation type as a percentage of total traffic citations issued to each age group. Therefore it is similar to the tables on primary collision factors, showing age differences in the pattern, rather than the number, of violations. In this way Table 20 essentially gives a profile of each age group's traffic citation experience, disregarding the age differences in overall citation rate pictured in Figure 6.

Table 20

Violation Type as a Percentage of Total Traffic Citations for Age Group by Driver Age

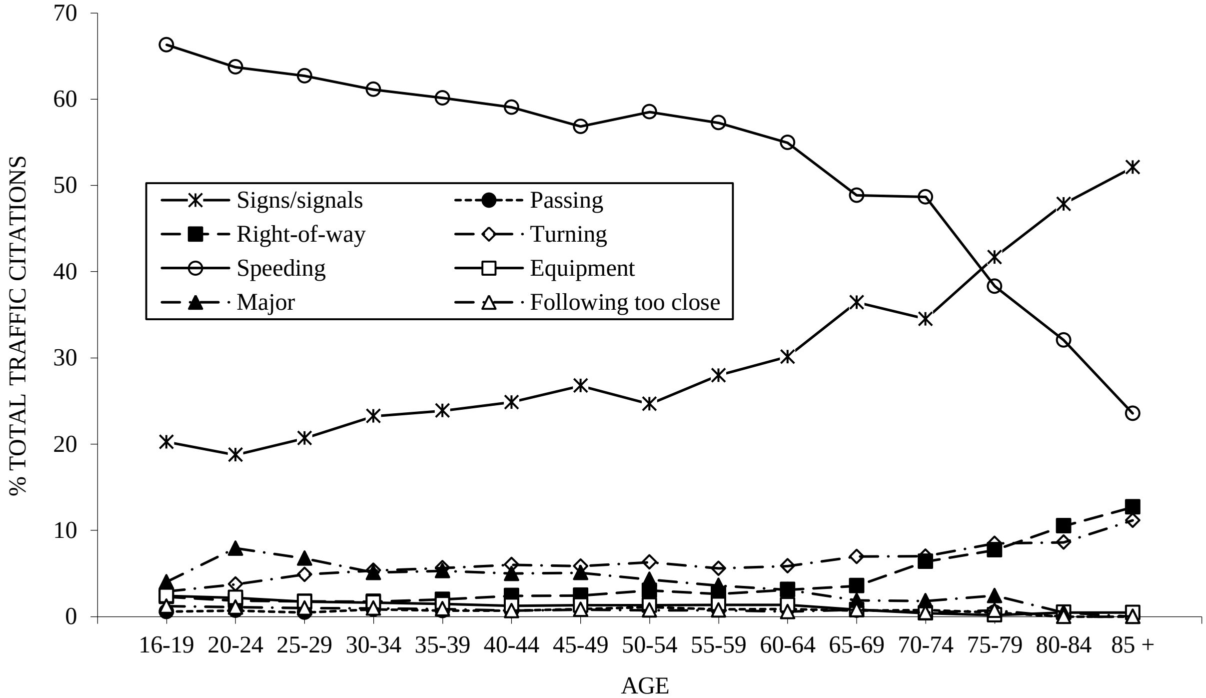
	Age														
Violation type	16-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85+
Signs/signals	20.26	18.76	20.68	23.24	23.88	24.86	26.77	24.65	27.97	30.13	36.45	34.52	41.69	47.85	52.10
Passing	0.58	0.71	0.49	0.83	0.69	0.70	0.89	1.11	0.83	0.88	0.71	0.76	0.48	0.00	0.00
Right-of-way	2.30	1.85	1.77	1.74	1.99	2.42	2.45	3.03	2.65	3.12	3.56	6.39	7.72	10.52	12.70
Turning	2.91	3.76	4.88	5.36	5.64	6.01	5.84	6.31	5.59	5.86	6.95	6.99	8.48	8.61	11.16
Speeding	66.29	63.71	62.70	61.12	60.13	59.06	56.82	58.52	57.25	54.96	48.84	48.66	38.29	32.06	23.57
Equipment	2.41	2.19	1.73	1.63	1.47	1.26	1.32	1.32	1.37	1.35	0.80	0.40	0.18	0.48	0.47
Major	4.04	7.92	6.77	5.11	5.30	5.00	5.08	4.31	3.60	3.12	1.87	1.82	2.42	0.48	0.00
Following too close	1.21	1.10	0.99	0.97	0.90	0.70	0.82	0.75	0.74	0.57	0.80	0.46	0.73	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Note. Based on the driver records of a 1% random sample of California licensed drivers. Averages represent violations occurring during the years 2004 through 2006. Percentages may not add to 100.00 due to rounding.

Readers may have noticed that there is no "miscellaneous violation" category in Table 20 and the eight violation types named add up to 100%. These are the types of violations tracked in departmental research involving the 1% random sample. That research is strongly concerned with the relationship between negligent operator point count and driver record, so the collection includes violations that carry different numbers of negligent operator points—two points for major violations including drunk driving and hit-and-run, one point for most of the others listed, which are moving violations but not "majors," and zero points for equipment violations.

The data in Table 20 are shown graphically in Figure 22. These tables and figures indicate that the average annual rates of specific types of cited violations, the average rates of these violations per 100,000 miles, and overall traffic violation patterns, are all related to driver age. The annual and mileage-adjusted rates shown in Tables 18 and 19, and Figures 20 and 21, indicate the following:

- Teenagers have the highest total citation rates annually, and seniors have the lowest. (This was also shown in Table 6 and Figure 6.)



Note. Based on the driver records of a 1% random sample of California licensed drivers. Averages represent violations occurring during the years 2004 through 2006.

Figure 22. Violation type as a percentage of total traffic citations for age group by driver age.

- The average annual rate of unsafe speed citations is high for most age groups but highest among teenagers; it generally decreases as age increases and reaches a very low value for drivers aged 85 or more.

- Teenagers have the highest average annual rate of citations for disregarding signs/signals, and drivers 50-54 have the lowest.

- Average citation rates for major violations—driving under the influence of alcohol or drugs, hit and run, and reckless driving—are not high when compared with rates for speed and signs/signals violations. But they are highest for drivers under 20-24 and lowest for seniors.

- For ages 75 and above, signs/signals citations are the type most frequently issued —though, like other citations for this age group, they are not common. Next most frequent within the group are citations for unsafe speed.

Table 20, giving violation percentages within age group, shows the relative importance of specific cited violation types at different ages. Since the contributions of the various types add to

100% for each age group (before rounding), the percentages (as discussed above) cannot be used to infer that one age group shows a higher rate of a particular type of violation than another. Nevertheless the patterns are interesting in themselves. Table 20 and Figure 22 show that:

- Speeding is unquestionably the dominant violation leading to citation for most age groups. Although its percentage contribution generally decreases as driver age increases, it is an important contributor for all groups.

- Signs/signals citations are the second most common type for most age groups, and become the dominant one for drivers aged 75 or more. They account for over half of the oldest (85+) group's citations.

- The relative importance of right-of-way violations is not great for drivers under age 75, but these violations are the third-highest generator of citations for the oldest (85+) group.

- Even at advanced ages, right-of-way violations are either overshadowed or closely rivaled by signs/signals violations and speeding. This is despite the important role of right-of-way violation as a primary collision factor in casualty crashes.

- Major violations like drunk driving, which constitute less than 8% of the citations within each age group, peak in their percentage contribution for drivers between 20 and 29. They are a negligible percentage of the total for drivers aged 65 or older.

Unsurprisingly, the above information on violation patterns will be seen as mostly consistent with the information on primary collision factors presented in Table 17. But the role of improper turning violation is a particularly interesting discrepancy. This is not a large share of total citations but, it is the most important collision factor in responsible fatal crashes of drivers aged 60 or more and is important for all age groups as a cause of F/I crashes. Improper turning violation also is a cause of responsible fatal crashes for women twice as often as for men. If it does not appear to be frequently cited, the reason may be that a citation for improper turning violation is rarely issued unless the violation has caused a crash.

<u>Arrests for Driving under the Influence of Alcohol/Drugs (DUI) and Hit-and-Run</u>

Table 21 shows the relative involvement indexes for DUI and hit-and-run felony and misdemeanor arrests in 2009 by driver age; arrest data come from the California Department of

Justice (2010). As mentioned in the preceding section, DUI and hit-and-run are both classified as major traffic violations, counting for two negligent operator points on a driver's record as opposed to the single point assessed for most moving (i.e., safety related) violations.

In California, neither purchase, possession, nor consumption of alcoholic beverages is legal until age 21. Therefore one might think that driving under the influence of alcohol would be negligible for teenagers. But a DUI conviction can be given on the basis of drug impairment alone, and even if there is no question of drugs, a minor can be convicted on a quasi-DUI charge (juvenile offense involving alcohol while driving, California Vehicle Code Section 23140) at a .05% blood alcohol level, considerably lower than the .08% level used for an adult. Unlike DUI, which is either a misdemeanor or a felony, the offense is considered an infraction, but conviction entails a 1-year license suspension. However, nothing in California law precludes a teenager who is detected driving with a BAC in excess of .08% from being convicted on misdemeanor or felony DUI charges in addition to the infraction of 23140. In fact, most teenagers detected as DUI are convicted under both 23140 and 23152. For simplicity, juvenile alcohol offenses while driving will generally be referred to in the following as DUI. Teenagers incur a substantial number of DUI convictions, and there is evidence that alcohol, in quantities above the legal limit for minors, is involved in most of them. Data for the year 2009 (Oulad Daoud & Tashima, 2012) showed a blood alcohol concentration, or BAC, for 10,985 convicted DUI offenders under age 21. The BACs of these offenders had an average value of 0.135%, 1.69 times higher than the 0.08% BAC level defining *per se* impairment (meaning that the BAC level *in itself* is sufficient evidence of impairment) at any age in California. It is 2.7 times higher than the 0.05% BAC level used for minors convicted of juvenile alcohol offenses. (The lower illegal BAC level for minors will be discussed more fully in the section <u>Crash Countermeasures for Teenaged Drivers</u>.) In fact, over 86% of these minors had BACs of 0.08% or above.

In addition to a possible conviction, there is a much more certain and immediate administrative penalty, driver license suspension, that follows arrest of adults (people aged 21 or more) with 0.08% of alcohol in their blood, and minors with 0.01% (California Vehicle Code Section 13353.2 and 23136; known as the "zero tolerance law"). A notice of "administrative per se" (APS) suspension is served at the time of arrest by the arresting officer; this notice contains the reason for and effective date of the suspension, along with other information. DMV subsequently determines what the facts of the case were, and takes the suspension if those facts are in order. Under the zero tolerance provision, the DMV is required to suspend for one year any driver under age 21 with a BAC of 0.01% or more as measured by an alcohol screening test, or who refuses or fails to complete the test. The zero tolerance law provides for a hardship restriction only if a BAC test was completed and the driver can demonstrate a critical need to drive. Minors found to have a BAC below 0.05%, who are detained under the zero tolerance law provisions need not be arrested or charged with a criminal DUI offense (either 23140 or 23152). DMV's determination of the facts for an APS suspension, and its subsequent action, are civil matters, completely separate from the person's later criminal conviction on the DUI charge except when the DUI charge is acquitted, which results in the DMV being required to vacate (set aside) the civil suspension. Drivers, who were arrested for DUI or hit-and-run, whether or not they were acquitted of the charge, appear in the data of Table 21 and Figure 23, below. Figure 23 plots, by age group, the relative involvement indexes from Table 21.

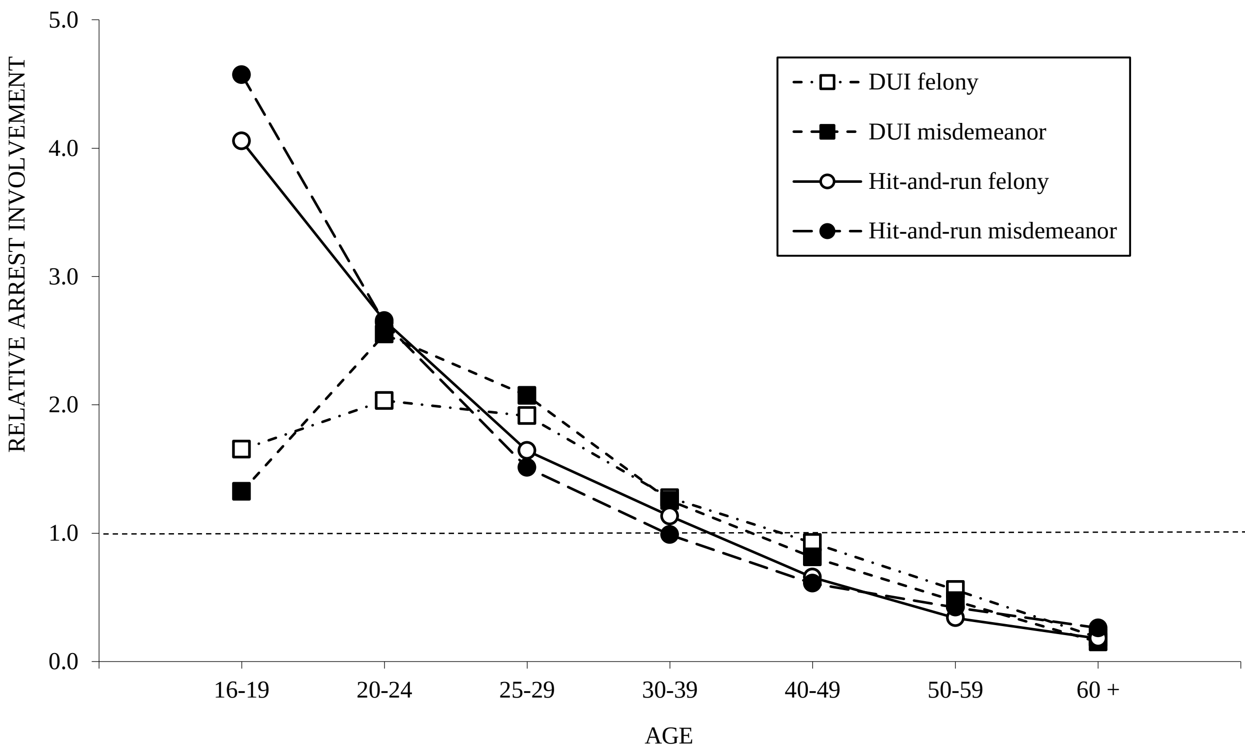
Table 21

Relative Involvement as Arrestee for Driving Under the Influence of Alcohol/Drugs (DUI) or Hit-and-Run by Age

		DUI[a]						Hit-and-run					
		Felony			Misdemeanor			Felony			Misdemeanor		
Age	% of licensed drivers[b]	Number[c]	%	Relative involve-ment index[d]	Number[c]	%	Relative involve-ment index[d]	Number[c]	%	Relative involve-ment index[d]	Number[c]	%	Relative involve-ment index[d]
16[e]	0.30	9	0.16	0.54	287	0.14	0.47	18	1.48	5.00	143	2.32	7.85
17	0.68	42	0.75	1.10	834	0.41	0.60	29	2.38	3.53	210	3.41	5.05
18	1.22	115	2.04	1.68	3,722	1.82	1.49	73	6.00	4.93	322	5.23	4.30
19	1.64	191	3.39	2.06	5,556	2.71	1.65	69	5.67	3.45	403	6.55	3.99
16-19	3.83	357	6.34	1.65	10,399	5.07	1.32	189	15.54	4.05	1,078	17.52	4.57
20-24	9.13	1,046	18.57	2.03	47,756	23.30	2.55	295	24.26	2.66	1,483	24.11	2.64
25-29	9.71	1,048	18.60	1.91	41,251	20.12	2.07	194	15.95	1.64	903	14.68	1.51
30-39	18.57	1,334	23.68	1.28	47,703	23.27	1.25	256	21.05	1.13	1,128	18.34	0.99
40-49	20.31	1,059	18.80	0.93	33,849	16.51	0.81	162	13.32	0.66	761	12.37	0.61
50-59	18.40	580	10.29	0.56	17,801	8.68	0.47	76	6.25	0.34	477	7.75	0.42
60 +	20.04	210	3.73	0.19	6,241	3.04	0.15	44	3.62	0.18	322	5.23	0.26
All ages	100.00	5,634	100.00	1.00	205,000	100.00	1.00	1,216	100.00	1.00	6,152	100.00	1.00

[a]The DUI includes juvenile offenses involving alcohol; see text. [b]The 2009 licensing data are from Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. [c]The 2009 arrest data are from California Department of Justice, 2010, *2009 Statewide Criminal Justice Profile*, Sacramento, CA. [d]Relative involvement is arrest involvement in the age/sex group as a percent of such involvements for all drivers, divided by the percent of all licensed drivers represented by that group. [e]Data in this row are for drivers aged 16 only. This table in previous published versions of this report included persons under age 16 in this age category. For purposes of comparing to prior reports, the numbers for 16 and under for 2009 arrests are DUI/Felony: 20, DUI/Misdemeanor: 368, Hit-and-run/Felony: 29, and Hit-and-run/Misdemeanor: 237. Percentages and relative involvement indexes for the 16 age group would change proportionally.

Table 21 shows that teenaged drivers as a group have a relative involvement index for DUI felony arrest—where there was a crash involving bodily injury—that is the third-highest among age groups, exceeded only by the indexes for drivers aged 20-24 and 25-29. For misdemeanor DUI arrest, the relative involvement index for teenagers as a group is the third-highest. The highest index for both types of DUI offense for drivers as a group is for those aged 20-24. (Those who are 20 years old are, like teenagers, under the minimum legal drinking age and for conviction purposes need only have a BAC of 0.05%—for administrative suspension purposes a BAC of 0.01%—rather than 0.08%. Therefore this subgroup may be more similar to 19-year-olds than to drivers of an age to drink legally. However, both 19-year-olds and drivers aged 20-24 are relatively high-risk groups for DUI and DUI crashes.) Figure 23 displays the relative involvement indexes from Table 21.



Note. Arrest data for 2009 are from California Department of Justice, *2009 Statewide Criminal Justice Profile*, Sacramento, CA. Licensing data are from Department of Motor Vehicles, January 2010, *State Summary Age and Sex Report*, Sacramento, CA. The relative involvement index is the arrest involvement for the age group as a percent of such involvement for all drivers, divided by the percent of all licensed drivers represented by that group.

Figure 23. Relative involvement as arrestee for driving under the influence of alcohol/drugs (DUI) or hit-and-run.

Figure 23 shows graphically that:

- Relative involvement as an arrestee for DUI is relatively high for teenagers and highest at ages 20-24. It declines thereafter, and the relative involvement of drivers aged 60 or more is close to zero.

- Teenagers have by far the highest relative involvement as arrestees for felony and misdemeanor hit-and-run. (This finding reflects alcohol-impaired behavior to some extent, because hit-and-run violations are frequently committed by drivers identified by the officer as HBD.)

- Hit-and-run arrest risk declines steeply with age. As with DUI, the relative hit-and-run arrest involvement of drivers aged 60 or more is close to zero.

RESEARCH AND COUNTERMEASURES

Research on Teenaged Drivers

The high average crash rate for teenagers as a group, shown for example in Table 3, is due to a number of factors. In the early stages of learning these include a fundamental lack of driving skill, but evidence suggests that poor vehicle control skills account for only 10% of teenaged novice driver crashes; the remaining 90% are accounted for by factors like inexperience, immaturity, inaccurate risk perception, overestimation of driving skill, and risk-taking (Edwards, 2001). Research addressing factors that contribute to the young driver group's high crash rate is discussed in this section of the report. The following section will describe countermeasures used to reduce their risk.

Hazard Perception, Risk Perception, and Risk-Taking

Teenagers are generally quick to learn the basic vehicle handling skills and knowledge they need to drive. But it takes much longer, and requires more varied experience, for them to develop the higher-level skills of hazard perception and risk perception in the driving environment (Arnett, 2002; Borowsky, Shinar, & Oron-Gilad, 2010). As it applies to driving, hazard perception depends upon perceptual and information-gathering skills, and involves properly identifying stimuli as potential threats. Risk perception involves subjectively assessing the degree of threat posed by a hazard, realistically assessing one's ability to effectively deal with that threat, and estimating the likelihood that a certain driving behavior will result in a given negative outcome (Arnett, 2002; Deery, 1999).

Hazard Perception. A multitude of skill-related factors contribute to teenage drivers' elevated crash risk, including failure to scan the traffic environment for potential hazards, poor speed management, incorrect assessment of roadway conditions, and driver distraction (Braitman, Kirley, McCartt, & Chaudhary, 2008). McKnight and McKnight (2003) studied hazard perception in novice drivers and found that novices in general failed to effectively scan the roadway for potential hazards, increasing the risk of a crash. The study found that failure to perform an adequate visual search before making left turns and not watching the car ahead explained some young and inexperienced drivers' crash involvements. Borowsky et al. (2010) found that hazards needed to be salient and pose an obvious threat before novice drivers decided to take action. Novices are also more likely to focus on individual details of the driving environment, and are less likely to continuously scan the road for hazards. More experienced drivers tend to view the driving situation as a whole, and were able to detect more potentially hazardous situations than novices (Borowsky et al., 2010). Young novices also tend to be less skilled than more experienced drivers in rapidly detecting potentially hazardous traffic situations, and may react slower to hazards pictured in driving simulations or fail to detect these hazards altogether (Lee et al., 2008; Sagberg and Bjornskau, 2006).

Risk Perception. Young novice drivers lack experience in handling hazardous driving situations and will often take unnecessary risks due to poor decision making, overestimation of their driving abilities, and underestimation of their vulnerability to crashing (Keating & Halper-Felsher, 2008; Williams, 2006). Drivers who believe themselves to be less vulnerable to crashing perceive less incentive to engage in any self-protective behaviors and therefore are actively at greater crash risk (Horswill & McKenna, 2004). Many young drivers have the perception that there are greater benefits to risky behavior, such as speeding, and are less likely to be aware of the potential costs (Dishion, Poulin, & Burraston, 2001). A study by Gardner and Steinberg (2005) found that when teens were in the presence of their peers, participants took more risks, and evaluated risky behavior more positively, compared to when they were driving alone. Furthermore, young drivers, particularly men, tend to believe themselves to be at lower risk of crashing than do older drivers (Harre, 2000) and teen women drivers (Ivers et al., 2009). For example, young men tend to underestimate the danger in high-risk driving situations that require fast reflexes or skilled vehicle handling, since they are overly confident in their abilities. They also tend to rate higher-risk driving behaviors, such as distracted driving, speeding, and driving after drinking, as being less risky than young female drivers (Sarkar & Andreas, 2004), and consider themselves to be more skillful than their age peers and older drivers (Delhomme & Meyer, 2000; Kinnear, 2011; OECD, 2006; Sarkar & Andreas, 2004).

Risk-Taking. As a result of their immaturity, their inexperience, and other factors, teenagers (especially males) tend to take more risks while driving than do other drivers (Gonzales, Dickinson, DiGuiseppi, & Lowenstein, 2005; Ivers et al., 2009). Risk-taking driving behaviors have been shown to be very important factors underlying the high crash rate of teenaged drivers as a group (Simons-Morton et al., 2011). Men generally tend to take more risks than do women when driving, which may be partly explained by the positive correlation that has been found between sensation seeking in general and testosterone levels (SafetyNet, 2009). Young drivers, especially men, are more likely than older drivers to engage in risky behaviors like speeding, tailgating, running red lights, violating traffic signs and signals, making illegal turns, passing dangerously, failing to yield to pedestrians, not wearing safety belts, using mobile phones and texting while driving, and driving after heavy drinking or marijuana use, all of which increase their crash risk (Braitman et al., 2008; Foss, Martell, Goodwin, & O'Brien, 2011; Gonzales et al., 2005; Ivers et al., 2009; Williams & Ferguson, 2002). Speeding, in particular, is strongly associated with youth (Foss et al., 2011; Williams & Ferguson, 2002). When young drivers crash, the types of crashes in which they are overinvolved also suggest risky driving. Crashes involving only one vehicle (where its driver is almost always at fault), intersection violations, speeding, following too closely, disobeying a traffic sign or signal, and unsafe passing have all been shown to be associated with youth (Foss et al., 2011; Gonzales et al., 2005; Ivers et al., 2009; Kirk & Stamatiadis, 2001).

Ample evidence suggests that the risky driving of teenagers may be part of a general risk-taking lifestyle (Bina, Federica, & Bonino, 2006; Hatakka, Keskinen, Gregersen, Glad, & Hernetkosk, 2002). For instance, teenagers who engage in risky activities outside the driving situation—such as smoking, use of illegal drugs, heavy drinking, comfort eating (overeating), and staying up late for whatever reason—tend to have a higher incidence of traffic crash involvement than do drivers who do not do these things (Bina et al., 2006).

Inexperience, Immaturity, and Their Interaction

On the other hand, teenage driving behavior that looks like intentional risk-taking may not always be so. It may instead be caused by their failure to appreciate the degree of risk in a situation due to their inexperience in driving (Arnett, 2002; SafetyNet, 2009; Williams & Ferguson, 2002). In fact, the majority of evidence suggests that driving inexperience is the second most important factor, after risk-taking, making young drivers more likely to crash. Immaturity and inexperience can act together in causing crashes, as when a young novice driver takes risks because of their immaturity, gets into a hazardous situation, and then fails to avoid a crash due to their inexperience (Mayhew & Simpson, 1999; Williams & Ferguson, 2002).

The influence of immaturity and inexperience on crash risk can change over time following licensure. There is evidence that crashes occurring earlier after licensure are due more to inexperience, whereas those that occur later are due more to risk-taking (Cooper, Pinili, & Chen, 1995; Harre, Brandt, & Dawe, 2000; McKnight & McKnight, 2003). These studies suggest that the effect of inexperience overshadows the effect of immaturity in causing teenagers' high crash risk in the first year of driving, while the effect of immaturity becomes the more important of the two later on, when they are somewhat older.

Some studies have tried more explicitly to disentangle the contributions of immaturity and inexperience in producing crashes. In the usual course of events, it is hard to separate the two factors. A study by Foss et al. (2011) found that the most dangerous period of driving for teenagers is immediately after they have been licensed, particularly in the first month. Specifically, the study found that during the first month of licensure, teen drivers were 50% more likely to be involved in a crash than they were after a full year of licensure, and nearly twice as likely to be involved in a crash as they were after 2 years of licensure. Over a longer period of time, crash rates have been shown to decline with increasing age, and the increasing driving experience and decreasing immaturity that comes with it (McCartt, Mayhew, Braitman, Ferguson, & Simpson, 2009).

Mayhew, Simpson, Desmond, and Williams (2003) analyzed the records of drivers aged 16 through 19 and drivers aged 20 and older during their first 2 years of licensure. Experience was measured by months of licensure, while maturity was measured indirectly by age. An age effect was clearly identified; as teenage drivers had higher crash rates than did older drivers at each month of licensure. A substantial experience effect was evident for both younger and older drivers with both age groups having the greatest declines in crashes during the first 7 months of driving. However, the effect was much stronger for younger drivers. The authors concluded that the effect of experience was greater for teenagers than it was for older drivers.

As reported by McCartt et al. (2009), in 2004 Mayhew and Simpson updated an earlier 1990 examination of crashes involving Ontario drivers. The authors found strong age effects for both male and female drivers, especially during the first year of licensure, with crash rates for older drivers being dramatically lower than those for teenage drivers. Beneficial post-license experience effects were also found among men drivers, with stronger effects for the younger ones. However, for both men and women drivers, especially those aged 16-19, the benefits of experience were substantially larger than those resulting from an additional year of age.

While the findings of both Mayhew et al. (2003) and Mayhew and Simpson (2004) suggest that experience is a stronger factor than immaturity in teenagers' crash rates, immaturity cannot be discounted entirely as a factor in teenage crashes. Even among beginning 16-17-year old drivers, the younger ones had higher crash rates than did the older ones (Insurance Institute for Highway Safety, 2010a). All of these new drivers were inexperienced, but the crash rates of immature beginners were higher than those of more mature beginners.

Situations of High Crash Risk for Teenagers

There are some situations in which teenagers have especially high risk. Although teenagers have higher average crash rates than do most other age groups under most conditions, their crash rates are disproportionately higher when driving with passengers, on weekends, at night, when impaired by alcohol or drugs, or while unbelted (Ferguson, 2003; Lin & Fearn, 2003; Williams, 2003). Some of these situations are discussed below.

Carrying Passengers. When drivers (of any age) carry passengers, clearly more people are at risk of injury or death if a crash occurs. But over and above that, for teenagers the risk of being in a crash when carrying passengers increases as well, especially when the passengers are their age peers. A study by Tefft, Williams, and Grabowski (2012) determined that, compared with having no passengers, the fatal crash risk for 16-17 year old drivers increased by 44% when having one passenger younger than 21, doubled when carrying two passengers younger than 21, and almost quadrupled when carrying three or more passengers younger than 21. However, when one passenger in the car was aged 35 or older, the 16-17 year old drivers fatal crash risk decreased by 62% (Tefft et al., 2012). Even for drivers as old as 24, risk increases when passengers of an equal or younger age are carried. What is striking about this is that the relationship apparently does not hold for older age groups. Passenger presence does not increase risk for older drivers, and even decreases it for drivers aged 30 and above (Oesch, 2005). Driving with passengers is especially problematic for teen drivers because passengers present unnecessary distractions for the teenaged driver who is inexperienced to start with and hence needs to pay full attention to the driving task (Oesch, 2005). Passengers who are age peers may encourage young drivers to take more risks, especially when young men are together since risky behaviors appear to be more common in this circumstance (Goodwin, Foss, & O'Brien, 2012; Reagan & Mitsopouls, 2001).

Night Driving. This is another especially risky situation for young drivers. The crash risk for teenagers when they drive at night is high even though their exposure to night driving is low (Williams, 2006). For teenagers, the majority of nighttime fatal crashes occur before midnight, with 32% of all 16-17 year-old driver fatal crashes occurring between 9 p.m. and 5:59 a.m. (Williams, 2007). The per-mile crash rate for teenaged drivers is twice as high from 9:00 p.m. to 6 a.m. than it is during daylight hours (Centers for Disease Control and Prevention, 2012; Insurance Institute for Highway Safety, 2003). The higher crash risk for teenagers at night is not surprising, considering driving is more difficult during darkness. Other factors that make night driving particularly problematic for teenagers is that they have had less experience driving at night (and driving, in general), may be sleep-deprived or fatigued, may be driving with teen passengers who increase distractions and encourage risk-taking behavior, and/or do more of their recreational driving, which often involves alcohol, at night (National Safety Council, 2007).

Alcohol Use. Driving under the influence of alcohol and/or drugs is a common cause of serious crashes; especially fatal ones (see Figure 17 for California data). The percentage of fatally injured 16-17 year old drivers who had a BAC at or above 0.08 percent decreased by 62 percent between 1982 and 2010 (Insurance Institute for Highway Safety, 2010). However, most of this decline occurred in the 1980's, and alcohol and drug use remain important factors in the high crash risk of young drivers—including teenagers, as Figures 16 and 17 show.

Being below the legal drinking age of 21 in all states and the District of Columbia, teenagers are less likely than some older age groups to drink and then drive, and when tested by law enforcement are less likely to have high blood alcohol concentration (BAC) levels. But teenagers who do drink and then drive are at much greater risk of serious collisions at all BAC levels when compared to older drivers (Bingham, Shope, Parow, and Raghunathan, 2009; Mayhew, Donelson, Beirness, & Simpson, 1986; Mayhew, Simpson, Sinhal, and Desmond, 2006; Zador, Krawchuk, & Voas, 2000).

Figure 17 shows that, in California, driving under the influence of alcohol or drugs caused the highest percentage of fatal crashes for all driver ages below 60, except for 16-19 year olds for which DUI was second only to speed as the primary cause. The U.S. Department of Transportation (2009) found that nationally, 33% of 15-20 year-old drivers who were killed in crashes had a BAC of 0.01% or higher, while 28% had a BAC of 0.08% or higher; the legal limit for adults in California. Bingham et al. (2009) determined that when all alcohol related crashes were considered together, teen drivers were twice as likely to crash as were adult drivers. Furthermore, when alcohol was added to other risky conditions, the risk of being in a fatal crash was 18 times greater for teen men drivers and 11 times greater for teen women drivers than it was for adults (Bingham et al., 2009). The same study found that the majority of teenagers' alcohol-related fatal and injury crashes occur at nighttime, on weekends, and with passengers present. In addition, the cumulative negative effects of lack of experience in drinking, lack of experience in driving, and lack of experience in doing these things together makes driving after drinking especially problematic for teenagers.

Other Drugs. While research focusing on the increased risks of crashing associated with drinking and driving is extensive, much less research has been done on specific drugs and their effects on driving. The research that has been conducted on drugged driving provides inconclusive results as to the precise dangers of mixing drugs and driving. This is primarily because the relationship between specific blood levels of drugs and driving impairment has not been determined (Compton, Vegega, and Smither, 2009; Stewart, 2006). However, fairly recent studies (Movig et al., 2004; Rapoport et al., 2009) have found that benzodiazepine users are at a higher risk of being involved in crashes than are non-users. Marijuana, the most common illicit drug (other than alcohol) used by teenagers, has also been linked to an increased risk of crashing. Blows et al. (2005) suggest that habitual users of marijuana have approximately a 10 times higher risk of car crash injury or death compared to infrequent or non-users. Patton and Brown (2002) conducted a survey indicating that some teenagers believe it is more acceptable to drive under the influence of marijuana than to drive under the influence of alcohol. This suggested to them a need for additional education about the dangers of driving and drug use. The respective roles of marijuana use versus a general pattern of risk-taking in causing crashes have not been disentangled, and there has been little research on other drugs, but the suggestion made by Patton and Brown is an example of one kind of possible crash countermeasure for young drivers. Other possible countermeasures are discussed below.

Crash Countermeasures for Teenaged Drivers

Regardless of the reasons why crash and violation rates are high for young drivers as a group, it is the responsibility of states and other accountable jurisdictions to attempt to reduce them. Countermeasures used to reduce crashes for teenaged drivers include driver education and training, modified driver licensing for teens, curfew laws, accelerated post-licensing control programs, and "zero-tolerance" (reduced BAC) alcohol laws. These treatments are discussed below.

Driver Education and Training

Driver education and training are commonly considered to have safety value for reducing teen crash and violation rates. But although it seems unquestionable that a novice must learn how to drive somehow, and preferably not by trial and error on the highway, research has failed to find evidence that formal driver training programs have a positive impact on traffic safety for teenagers (Chaudhary, Bayer, Ledingham, and Casanova, 2011; U.S. Department of Transportation, 2011). Perhaps the most frequently cited study of driver training efficacy was conducted in DeKalb, Georgia in the 1970's by Stock, Weaver, Ray, Brink, and Sadof (1983).

That study failed to find any long-term beneficial effect, for the trainee group as a whole, of training programs that included range training as well as other types of driver training. Peck (2011) reexamined the Georgia data and found that although the study did find evidence of small short term crash and violation reductions per licensed driver, there was a net increase in crashes when earlier licensure associated with the training was allowed to influence the crash and violation counts. Overall, several comprehensive reviews of the relevant scientific literature have concluded that most evidence does not demonstrate a reduction in subsequent crashes and violations for students who complete formal driver training programs of any sort, when compared to students who lack such training, and in some cases may even increase subsequent crashes (Chaudhary, Bayer, Ledingham, and Casanova, 2011; U.S. Department of Transportation, 2011). In addition, formal training often leads to earlier and more widespread licensure of young drivers (as found in the DaKalb study), resulting in more driving and, in turn more crashes and violations. This outcome may outweigh any safety benefits gained through increased driver competence that may result from the education and training. Experts have recommended that, to improve the courses, driver education and training should (a) be redesigned to reduce risk-taking behavior by teaching teenagers how to make good decisions and be aware of risks, (b) include increased parent-supervised driving practice, (c) be integrated with modified teenager licensing programs (see below), and (d) be multi-stage, with separate courses in the early learner and later transitional stages of licensing (Compton & Ellison-Potter, 2008; Mayhew & Simpson, 1996, 2002; NHTSA, 2009; Williams & Mayhew, 2003).

Modified Driver Licensing

Modified driver licensing programs for novice drivers in various jurisdictions are designed to reduce novices' crash risk by requiring them to gain driving experience under conditions of reduced risk before achieving full licensure. (These programs are sometimes referred to as provisional or graduated driver licensing [GDL] programs.) In the case of teenagers, this includes not only reducing their exposure to situations they lack sufficient experience to handle safely, but also to situations in which their immaturity puts them at higher risk. Modified licensing programs usually apply only to minors (under age 18), and consist of stages these teenagers must pass through before they are considered fully ready to hold regular licenses. NHTSA recommends a GDL program that involves a three-stage licensing system for teenagers that includes an instruction permit (IP) at stage one, a provisional license at stage two, and full licensure at stage three (Compton & Ellison-Potter, 2008). In the IP period there must be supervised practice behind the wheel before a provisional license can be granted, and restrictions are usually placed on the provisional license that prohibit driving at night and carrying young passengers. The initial license restrictions designed to keep risk at a lower level are phased out gradually, thus exposing young learner-drivers to higher-risk situations by degrees. License control actions like warning letters and license suspension are sometimes imposed at a lower violation or crash point level than the one used for regularly-licensed drivers.

The overwhelming majority of studies of single-state (i.e., one state or province) GDL program in the U.S., Canada, and New Zealand have found positive safety effects (Hedlund & Compton, 2004; Mayhew, Simpson, Singhal, & Desmond, 2006; Senserrick & Haworth, 2005; Shope, 2007). Of those studies showing a positive effect associated with GDL programs, the estimates of crash reductions range from 20–40% (Shope, 2007; Shope & Molnar, 2003). McCartt, Teoh, Fields, Braitman, & Hellinga (2010) reported that GDL programs are associated with reductions in fatal crashes for 15- to- 17-year olds, while Baker, Chen, and Li (2007) reported the most restrictive GDL programs have been associated with a 38% reduction in fatal crashes, and a 40% reduction in injury crashes among 16-year-old drivers. However, it should be noted that few of these studies evaluated the effect of GDL on older teens (18-19-year-olds) who are not subject to GDL requirements. Some of the studies that did so found that GDL was associated with increased crashes among these older teens. For example, Masten, Foss, Marshall (2011) found that stronger GDL programs (those with restrictions on nighttime driving and that allowed passengers) were reliably associated with substantially lower fatal crash involvement rates for 16-year-olds, but higher fatal crash rates for 18-year-olds. However, the same study found that GDL programs were associated with a net overall reduction in fatal crash involvements for 16-19-year-olds showing that the positive effects for younger teens under the program more than outweigh any negative effect it may have on older teens outside the program. Masten et al. suggested that the negative effect of GDL on 18-year-olds may be due in large part to younger teens waiting until after they turn 18 to obtain licensure to avoid GDL, making them less experienced as drivers, as a group, when they are 18.

Studies of GDL programs have differed greatly in the age groups studied (e.g., only 16-year-olds rather than 15–17-year-olds combined), length of follow-up (ranging from months to several years), types of crashes examined (e.g., fatal/injury, all crashes, at-fault only, etc.), specific crash metrics used (e.g., unadjusted counts, per capita rates, etc.), methodologies used to adjust for trends and other historical events (ranging from no adjustment to complex time series analyses), statistical methods used to estimate effects (ranging from simple differences in crash counts to complex statistical modeling), and the baseline crash rates to which GDL effects are compared.

One other relevant issue is that not much is known about which specific components of GDL programs are the most effective, or what calibrations of the components (e.g., length of permit period and hours of night restrictions) are associated with the largest crash reductions. Most studies of GDL programs evaluate the effects of the programs as a whole without an attempt to determine the effects of its specific components. However, there are some instances in which researchers have attempted to show that specific components were effective.

The results of additional studies of GDL programs in various states, some of which evaluated the effectiveness of specific GDL components, are presented below.

- *California* - This state's first modified licensing program for novice drivers under age 18 was implemented in October 1983. It included a mandatory 1-month instruction period, a teen-parent practice guide, parent certification of behind-the-wheel practice, waiting periods before retaking knowledge or driving tests that were failed, and license control actions at lower violation or crash point counts for teenagers aged 15-17. Hagge and Marsh (1988) evaluated this program and found, when teenage rates were compared with those of drivers aged 24 and older, that the program was associated with 5.3% lower crash rates for 15- to 17-year-olds and 23% lower violation rates for 16-year-old licensees. The program also decreased the percentage of 16- and 17-year-olds licensed to drive and increased the time they held IPs, thus avoiding excess crashes that might have been caused by early licensure.

  Enhancements to the 1983 program were added by legislation and implemented in July 1998. These included a 1-year driving curfew between 12:00 a.m. and 5:00 a.m.; increase of the mandatory IP period from 1 to 6 months; a requirement for parent certification of 50 hours of practice including 10 hours at night; and a restriction forbidding carrying passengers under age 20 for 6 months. Masten and Hagge (2003) evaluated this enhanced program. Based on an analysis of pre- and post-program monthly crash rates, they found no *overall* reduction in total crashes or fatal/injury crashes following program implementation. But their study did find that the program was associated with a 9.3% drop in total crashes, and a 9.6% drop in fatal/injury crashes, that involved drivers aged 15-17 and occurred during the driving curfew hours between midnight and 5:00 a.m. They also found the program was associated with reductions of 6.8% in total crashes, and 13.9% in fatal/injury crashes, that involved drivers aged 15-17 and passengers under the age of 20.

  Further enhancements to the July 1998 program were added by legislation and implemented in 2004 and 2006. Additional enhancements in 2004 included increasing the minimum learners permit age to 15½, and in 2006 the program was changed to start the nighttime restriction at 11:00 p.m. rather than midnight and to lengthen the period of the passenger restriction to 12 months rather than 6 months. The effects of these changes have yet to be evaluated.

- *Michigan* - Michigan implemented a modified licensing program in 1997. It includes a 6-month IP period, 50 hours of supervised driving practice, and a restriction forbidding driving between 12:00 a.m. and 5:00 a.m. Results from an evaluation of the program indicate that it was associated with statistically significant post-GDL crash reductions for 16-year-olds of 29% for all crashes, 44% for fatal crashes, 38% each for nonfatal injury crashes and fatal plus nonfatal injury crashes, 32% for day crashes, 31% for evening crashes, 59% for night crashes, 32% for single vehicle crashes, and 28% for multi vehicle crashes (Shope & Molnar, 2004).

- *New Jersey* – New Jersey implemented a modified licensing program in 2001. It includes a minimum age for a learners permit at 16, practice supervised driving for 6 months, a 1- year nighttime restriction of 11:00 a.m. to 5:00 a.m., and no more than 1 passenger under the age of 21 for 1 year. A recent evaluation of the program by Williams, Chaudhary, and Tison (2010) found that after the GDL program was implemented, relative to drivers aged 25-29, there were statistically significant reductions in the crash rates for both 17 and 18-year-olds relative to the rates for a comparison group of 25-29-year-olds. Specifically, they found that 17-year olds had a 16% reduction in total crashes, a 14% reduction in injury-only crashes, and a 25% reduction in fatal crashes. For 18-year-olds the study found a 10% reduction in total crashes as well as injury-only crashes.

- *North Carolina* - This modified licensing program, implemented in 1997, required all 15- to 17-year-old license applicants to hold an IP for a full year, an unusually long period. Additionally, teenagers in the program were prohibited from driving without supervision from 9:00 p.m. to 5:00 a.m. for the first 6 months. Initial evaluation results suggested average reductions for 16-year-old drivers in per-person total crashes (27%), fatal crashes (57%), injury crashes (28%), non-injury crashes (23%), nighttime crashes (43%), and daytime crashes (20%), when minors were compared to adults (Foss, Feaganes, & Rodgman, 2001). Again, the fact that the nighttime reduction was considerably larger than that for total or daytime crashes suggested that the program was at least partly responsible for reduced teenage crash rates. A more recent evaluation of this program, following a change in the program to prohibit the carrying of no more than 1 passenger under age 21, reported a 38.5% gradual permanent reduction in the rate of 16-year-old total crashes beginning 12 months after implementation of North Carolina's GDL program, a 46.8% reduction in crashes involving a fatality or an injury requiring medical attention, and a 32.1% reduction in crashes occurring during restricted nighttime hours (Foss, Masten, & Goodwin, 2007).

Curfew Laws

In the United States, all 50 states have nighttime driving restrictions with starting times generally ranging from 9 p.m. to 1 a.m., and one (Idaho) starting at sunset (Williams, Tefft, & Grabowski, 2012). As a component of modified driver licensing (GDL) programs, night driving curfews appear effective in preventing teenage crashes at night (e.g., Jiang and Lyles, 2011; Masten, 2011; McCartt et al., 2010). Their findings also suggested that longer curfew hours produce greater reductions in crashes, and that the start time of the curfew makes a difference. Showing the effect of start time, McCartt et al. (2010) found that nighttime driving restrictions beginning at 9 p.m. were associated with 18% lower fatal crash rates, compared to 12% for those starting at midnight. Furthermore, Masten (2011) found that only night restrictions beginning at 10 p.m. or earlier were associated with lower crash incidence.

Accelerated Post-Licensing Control Programs

Post-licensing control countermeasures—like warning letters, group driver improvement meetings, individual hearings, and license suspension or revocation—have been shown to be effective interventions for licensing agencies to use for reducing the crash and violation rates of licensed drivers in general (Masten & Peck, 2004). But there is some evidence that the traditional countermeasures used have a larger reduction effect on violations rather than on crashes. For example, Masten and Peck (2004) reported that driver improvement program studies have shown that most types of post-licensing control countermeasures reduce subsequent traffic violation for 6-24 months after treatment, and that treatment effects increase with increases in the severity of the intervention. However, they also reported that studies show weak correlations between post-licensing countermeasures and crash involvement, and interventions sometimes actually increase subsequent crash rates.

An evaluation of New Jersey's negligent driver interventions by Carnegie, Strawderman, and Li (2009) also provided evidence that specific countermeasures have positive safety effects, and that these treatment effects differ between novice and experienced drivers. The study found that of the post licensing control treatments used in New Jersey, the greatest overall reductions in violation and crash rates were achieved by a combination of license suspension and 1-year probation. Furthermore, the smallest reduction in violation rate was associated with New Jersey's driver re-education classes, which include a 3-point reduction in accumulated negligent operator points along with 1 year of probation. Finally, New Jersey's point advisory notices together with negligent driver fees appear to substantially reduce both violation and crash rates among all driver subgroups except teen drivers.

Imposition of post-licensing control actions at a lower violation/crash point count than that used for adults is characteristic of modified licensing programs for teenaged novice drivers. The intention of earlier intervention is to address bad driving habits before they become ingrained. A few studies have evaluated the effect of this sort of accelerated driver improvement program on teenagers, using as a comparison group teenagers who received driver improvement actions at the greater point level applied to all other drivers. One of them, evaluating Oregon's modified licensing program (Jones, 1994), found no added benefit of accelerated driver improvement for teenagers when its results were compared to those of a delayed-intervention program like that used for adults. However, there is other evidence that teenaged recipients of accelerated control show a greater improvement in their crash and/or violation record than do teenagers for whom driver control actions are delayed. California's early modified-licensing program for teenaged novices (like the enhanced program) included accelerated license control actions. Hagge and Marsh (1988) compared the effect of that to the effect of delayed interventions following the adult model, and found that this aspect of the program proved significantly superior in reducing subsequent 2-year rates of total and fatal/injury crash involvements for teenagers, and that the accelerated license control actions were increasingly more effective at higher point counts at which sanctions become more stringent.

<u>Alcohol Laws for Teenagers</u>

Since 1998, all States have implemented lower allowable BAC limits (sometimes called zero-tolerance laws) for persons younger than 21. Such laws have made it illegal for drivers under the age of 21 to drive after drinking alcohol; typically setting the BAC limit at 0.02% (U.S. Department of Transportation, 2011; Voas, Tippetts, & Fell, 2003). California's zero-tolerance law sets the BAC limit at 0.01% for all persons younger than 21 (California Vehicle Code Section 23136). Breaking these laws by being caught driving with a measurable BAC usually results in the offender's driver license being suspended or revoked (U.S. Department of Transportation, 2011). Most evidence suggests that zero-tolerance laws, lower BAC levels for teenagers, and raising the drinking age to 21 are effective in reducing their alcohol-related crashes (Compton & Ellison-Potter, 2008; Mayhew & Simpson, 1999). NHTSA has estimated that minimum drinking age and zero tolerance laws have reduced traffic fatalities for 18 to 20 year old drivers by 13% and have saved an estimated 25,509 lives since 1975 (Compton & Ellison-Potter, 2008). A review of six studies of lowered-BAC laws for young people found that all six, conducted in different jurisdictions, showed reductions in crashes associated with implementation of these laws (Zwerling & Jones, 1999). Estimates of the reductions in crashes and injuries ranged from 10% to 33%, with an average reduction of 20%. In general, the results suggested that where BAC laws were tougher, teen crash reductions were larger.

Research on Senior Drivers

Research on senior drivers has been conducted in at least two major ways. First, for many years there have been studies comparing the average performance of groups of varying ages on sensory, perceptual, motor, and cognitive tasks. The performance records being compared are collected during a single time period; if testing is done in 2012, for example, people who are young in 2012 are compared with people who are middle-aged and people who are old in that year. This method is called cross-sectional. When it is used, average scores for elderly people on most of the tasks studied are generally distinctly poorer than the averages for middle-aged or, particularly, young adult groups. Some of these findings will be presented here. There are also cross-sectional studies comparing the average performance of groups of varying age on specific driving outcome measures—generally crashes or road test performance. The findings for California have been presented above in tables and graphs, but results of studies in other jurisdictions will also be described in this section.

There is another major way to look at the effects of aging. That is, to look at people not at the same point in time, like 2012, but to follow groups in time as their members age and see how their performance changes. Different birth-cohorts—for instance, people born in the same decade—may be found to have different average scores when they are compared with people of identical age when tested but born in a different decade. An example would be a comparison of fifty-somethings who were born in the 1930s and tested in 1989 with fifty-somethings who were born in the 1950s and tested in 2009. This sort of investigation uses what is called a longitudinal method; it is difficult to accomplish and not frequently done, but one study that used the method will be discussed briefly.

In the following presentation of disabilities associated with aging, it should be remembered that no one individual will show all the disabilities listed, nor will each person show particular aging-related effects at the same chronological age. What the following does show is that there is a strong tendency for a variety of impairments to become more common within a group of individuals as their aging progresses, so that average group performance tends to decline.

Common Visual Changes

Vision is the most important source of information during driving, and worsening vision is a major factor contributing to driving difficulty and driving-related injuries (Subzwari et al., 2009). Numerous studies have determined that aging is associated with reduced peripheral vision, a need for more light in order to see, and increased difficulty in accommodation, or adjustment of the eyes' lenses for varying distances. Specifically, vision studies have found that:

- The relationship between static visual acuity and age, when the whole life span is considered (Pitts, 1982), takes the form of a curve. Average acuity is extremely poor at birth, improves to about 20/20 during the first year of life, remains relatively constant until about age 50, and then declines increasingly rapidly, with great variability in acuity at the older ages. Some usual physiological causes of the decline are reduction in pupil diameter, browning of the lens, and increased light-scattering by the ocular media—the glassy or watery material that fills the eyeball. Such changes result in greater sensitivity to glare—from, for instance, bright sunlight or vehicle headlights—and in lessened contrast sensitivity which, depending on its severity, can make detection of objects in fog or in low light extremely difficult. Other impairing factors arise from aging-related diseases, including cataracts, diabetic retinopathy, macular degeneration, and glaucoma.

- Additional practical consequences of common aging-related eye changes may be lessened ability to resolve visual detail, as in reading highway signs (Fozard, Wolf, Bell, McFarland, & Podolsky, 1977), and need of increased lighting due to changes in the lens and pupil (Nolan, 2002), making driving at night and dimly lit areas very difficult for older drivers.

- Investigators have reported that the binocular human visual field typically extends horizontally over approximately 180 degrees (Lockhart, Boyle, & Wilkinson, 2009), and a person's peripheral vision tends to narrow with increasing age (AAA, 2006). In a much-cited study (Owsley et al., 1998), it was found that drivers with a 40% or greater impairment in their useful field of view were more than twice as likely to be involved in a crash as were those with less or no impairment. Furthermore, a recent NHTSA-funded study by Lockhart et al. (2009) found that drivers with visual field loss showed more variability in lane maintenance on curves and when driving on freeways, as well as delayed accelerator release and reduced time to simulated collision during an unexpected hazard event.

- One aspect of vision that has repeatedly been found to be related to increased crash risk is the functional or useful field of view or UFOV (Ball & Owsley, 1993). UFOV is the visual field area over which information can be gathered without eye or head movements. UFOV can be described as the extent of visual field that is available to a person who is focusing straight ahead to perform a visual task, as might be done in driving. If a driver is looking ahead trying, for instance, to gauge the intentions of the driver in front, can that driver simultaneously perceive the approach of a hazard from the side, warning him or her to direct attention there? As this capability gets into the areas of perception and cognition, which are discussed below, it is quite different from sensory visual field. In some sense, it requires attention to be divided between the central task and the periphery, and it is another function that tends to diminish with age and has been related to crash experience in older drivers. Owsley, Ball, Sloane, Roenker, and Bruni (1991) measured what they saw as the three primary mechanisms underlying a restricted useful field of view: 1) reduced speed of processing visual information; 2) reduced ability to ignore irrelevant stimuli; and 3) reduced ability to divide attention. They found that, compared to other drivers, those with a severely restricted useful field of view had 3 to 4 times the general crash risk, and were 15 times more likely to be involved in an intersection crash. Cross et al. (2008) found UFOV impairment to be associated with a consistent increase in the motor vehicle crash rate for older drivers. Wood, Chaparro, Lacherez, and Hickson (2012) found that older drivers who performed better on the UFOV test performed significantly better in terms of overall driving performance and also experienced less interference from distracters.

- Hennessy (1995) investigated visual/perceptual tests as predictors of crashes in subjects of varying age. After statistical adjustment for sex, age within age group, and mileage, he found that such tests, including modules of the Useful Field of View test, showed crash-predictive value only for drivers aged 70 or older. Hennessy proposed an inadequate-compensation hypothesis to explain this result, positing that "vision-related driver record activity [crashes in this case] will generally be slight up to the ages when, on average, compensation is likely to be less than wholly adequate for worsening impairments of multiple visual abilities critical to safe driving" (p. 29; emphasis his). Departmental studies by Janke and Hirsch (1997) and Hennessy (2007) found that drivers who performed poorly on the UFOV test also tended to show worse performance on a standardized road test.

For these and other reasons, seniors often voluntarily self-regulate or give up driving at night and, more generally, under conditions of reduced visibility (Braitman & Williams, 2011; Molnar & Eby, 2008). In a more recent study, Okonkwo, Crowe, Wadley, & Ball (2008) found that older drivers were most likely to avoid driving in bad weather, at night, high traffic roads, unfamiliar areas, and making left hand turns across oncoming traffic. However, the results also showed that across all driving situations, a significant proportion of high risk drivers did not restrict their driving.

<u>Common Perceptual/Cognitive Changes</u>

Driving, being a complex decision-making process, is influenced by many cognitive and perceptual factors. One touched on above is the functional or useful field of view. Aside from this, many studies have found that information processing tends to slow as people age, making it more difficult for some senior drivers to choose a course of action and react in a timely manner to hazardous driving situations. Some points from these studies are:

- Searching and scanning is of particular importance in driving, and the process tends to become markedly less efficient with aging (Romoser & Fisher, 2009a; Staplin, Breton, Haimo, Farber, & Byrnes, 1987). The first of these two cited studies found that older drivers, as a group, were slower and made more errors than did younger ones in finding target stimuli within an array of irrelevant stimuli. The second study found among older drivers that cognitive (but not physical) decline was significantly correlated with a decrease in side-to-side scanning while turning. In driving, similar situations arise—for example, at intersections. Bao and Boyle (2009) found that older drivers fail to look left and right before making a turn at an intersection, compared to younger drivers. Romoser and Fisher (2009b) found that older drivers were more than 3 times as likely to execute secondary looks and 10 times more likely to turn too slowly at intersections, compared to younger drivers.

- Divided attention is required for the processing of multiple stimuli where more than one stimulus is relevant. It has been mentioned before in connection with the useful field of view. Staplin, Breton, Haimo, Farber, and Byrnes (1987) noted that complex divided-attention tasks, unlike simple ones, show average deficits beginning for groups of subjects in middle or old age. Rinalducci, Mouloua, and Smither (2003) found that older drivers showed increased times for visual processing, divided attention, and selective attention than did younger ones, and that the poorer the divided attention, the more likely participants were to leave the road, have crashes, and cross the median on a driving task. The ability to divide attention is necessary in driving situations where, for instance, a driver may recognize that one stimulus, the traffic light, has turned green for him, but at the same time another stimulus, a red-light runner, is approaching too fast to stop.

- In assessing driving performance with an interactive computer video, Schiff and Oldak (1993) found very little overall difference between age groups in response time when reacting to an event that was expected to happen, but drivers over 65 years of age generally required significantly more time to respond when the event was unexpected. An assessment of driving performance using an interactive driving simulator conducted by Fildes, Charlton, Muir, and Koppel (2007) found that compared to younger drivers, older drivers were consistently slower to fixate on hazardous stimuli in the driving environment and slower to respond to these hazards.

Effect of Medical Conditions

In addition to the usual normative changes of advancing age, elderly people are much more likely to incur medical problems that increase their risk or, if severe enough, influence them to stop driving. Examples are dementia, cardiovascular disease, diabetes, stroke, syncopal episodes, Parkinson's disease, and ailments that primarily affect flexibility, including arthritis and bursitis. Also, medications prescribed for some health problems can themselves have an adverse effect on driving ability, since the medication without undesirable side effects scarcely exists. Recent reviews of what is known about the effect of medical impairments on driving and cognitive predictors of unsafe driving include Florida's Department of Highway Safety & Motor Vehicles (2004), Dobbs (2005), and Mathias and Lucas (2009). Some additional findings on medical conditions and driving that primarily focus on the elderly include the following:

- The vast majority of dementia patients involved in traffic crashes continue to drive. Man-Son-Hing, Marshall, Molnar, and Wilson (2007) conducted a systematic literature review on the crash risk of drivers with dementia, and found that the probability of a person with dementia to be involved in a crash was 2 to 8 times higher than the risk for age matched controls. Furthermore, all studies that used road performance, driver simulator, or caregiver reports showed that drivers with dementia performed significantly worse than control subjects. Alzheimer's disease (AD), the most common form of dementia, is associated with an increased crash risk for older drivers. Dawson, Anderson, Uc, Dastrup, and Rizzo (2009) found that older drivers with AD performed more total safety errors, lane observance errors, and serious safety errors than do older drivers without AD.

- Duchek et al. (2003) followed a group of healthy controls, those with very mild AD, and a group with mild AD over a 2-year period and assessed their on-road driving performance every 6 months. The study found that participants with very mild or mild AD showed the most decline in driving performance compared to healthy subjects over the 2-year period. Specifically, participants with mild AD showed the most decline in driving performance compared to healthy subjects. Duchek et al. (2003) stated that driving evaluations should be conducted every 6 months for drivers diagnosed with AD.

- Lafont, Laumon, Helmer, Dartigues, and Fabrigoule (2008) found that visual problems, Parkinson disease, dementia, and stroke history were significantly related to cessation of driving. They also found that individuals with one or more of these conditions who continued to drive did not have more self-reported crashes compared to active drivers without these conditions.

- Physical functionality also plays a major role in driving performance. Differences in performance on driving tests for the elderly can also be due to loss of joint and skeletal flexibility, which makes the driving task much more difficult and makes the driver more susceptible to injury or death. National and international research shows that, starting around the age of 60 to 65, the risk of being involved in a vehicle crash starts to increase, along with the risk of being injured or dying in such a crash, though the risk of fatality increases much faster than the risk of injury with age (SafetyNet, 2009; US Department of Transportation, National Highway Traffic Safety Administration, 2009b). Marottoli et al. (2007) suggested that many elderly drivers can improve their flexibility through exercise. In their study, the authors found that the driving performance of participants in the exercise regimen was maintained over the study period, while it declined for those in the control group.

<u>Older Driver Safety</u>

The findings above constitute a litany of potential problems lying in wait for aging people who want to drive safely as long as they can. Seniors are largely aware of such problems, and tend to compensate for them by driving fewer miles, slower, and less aggressively; avoiding driving situations that have become too challenging, like darkness or inclement weather; and in many other ways (e.g., Donorfio, Mohyde, Coughlin, & D'Ambrosio, 2008). Thus most avoid crashing, and the average crash rate per year for California seniors is relatively low (Table 5). That is a finding not limited to this state; the Insurance Institute for Highway Safety (2012b), pointed out that while older drivers nationally have on average about a threefold increased risk of crashing per mile driven, they drive markedly less than do middle-aged drivers, making their average *annual* risk of crashing the same as that for the latter group. Evidence that older drivers as a group do not pose a disproportionate threat to others on the road (based on an annual risk metric) has also been found in studies by Dellinger, Kresnow, White, and Sehgal (2004); Eberhard, 2008; Langford, Bohensky, Koppel, and Newstead (2008b); Li, Braver, and Chen (2003); and Tefft (2008). However, using a quasi induced exposure technique, for both total and fatal/injury crashes, as with mileage-adjusted crash rates, the oldest drivers have higher crash involvement ratios than do middle-aged drivers. As shown in Table 12, the crash involvement ratios decrease with age until they begin to rise somewhere around age 50-60, the increase becoming relatively steep after age 70. The ratios for older driver's exceed that of teenagers at around age 80, with the ratio for 85+ being over 30% and 70% higher for total and F/I crashes, respectively.

While older drivers, as a group, do not appear to pose a disproportionate societal safety threat based on annual crash rates, they are at higher risk of dying in their crashes than are younger drivers in theirs. This greater fragility among older drivers may help explain the sharp upturn in mileage-adjusted fatal crash risk for the oldest drivers (as evident in Figure 10). Evidence of this fragility factor was found in a study by Li, Braver, and Chen (2003), which analyzed crashes in which a driver was killed. They found that driver death rates per mile of travel were higher for the youngest and oldest age groups than for middle-age drivers. Within the senior group, those aged 80 or more were on average the most fragile, but also on average the most crash-involved. Among older drivers overall, the authors concluded, fragility—which increased as early as age 60-64—explained higher proportions of deaths per mile driven than did crash over-involvement. In contrast, among drivers younger than 30, an age range when average fragility appears to be at its lowest point, driver death rates per mile were due almost entirely to excess crash involvement. A more recent study by Langford et al. (2008b) of drivers in Australia involved in fatal crashes during years 1988 through 2001 yielded similar findings. They found that the likelihood of a crash-involved driver being killed increased with age, with only 39% killed in the 17-24 age group compared to 64% killed among drivers aged 80 or above.

As mentioned above, another method of exploring age-group risk is longitudinal analysis, used for example by Evans (1993). In contrast with the more common cross-sectional analyses, in which groups of varying ages are compared at the same point in time, longitudinal analyses follow the same individuals over time as they age. Evans used data on fatal crashes from the years 1975-1990, monitoring the data for birth-cohorts of drivers as they aged over the 16-year period. The youngest cohort was born during 1967-1971; the oldest during 1892-1896. A striking finding was that, when crash rates were inspected for male drivers of the same age but from different birth cohorts, the more recently born drivers clearly and systematically had lower rates. (Data from men were emphasized because the amount and type of driving by women were judged to be still changing rapidly in the period studied.) Evans stated that there is every reason to expect similar ongoing declines in crash fatality rates, due to changes in the many factors that contribute to traffic safety—changes in roadways, vehicles, legislation, enforcement, education, and social norms, among others. These can all be considered crash countermeasures, and a few countermeasures specific to elderly drivers are discussed below.

Crash Countermeasures for Older Drivers

It was mentioned above that, although many older drivers have impairments that challenge their ability to drive safely, the majority are able to limit their risk to a reasonable level by driving more cautiously and by limiting the amount and conditions of their driving. Nevertheless, it cannot be assumed that every elderly person is aware of his or her limitations, knows how to compensate for them in the most effective way, and does so consistently. (The assumption may be especially suspect in the case of cognitively impaired individuals.) If not circumvented by compensatory techniques or removed by treatment (as cataracts, for example, can be), non-trivial limitations can be expected to increase risk. Considering this, and the projected great increase in numbers of elderly drivers, policymakers, administrators, and researchers have developed, implemented, and evaluated crash countermeasure programs targeting senior drivers, some of which are described below.

Education and Training

- Reviews of randomized clinical trial articles published from 2004-2008 found that a combination of an educational curriculum and on-road driver training improves older-driver knowledge and on-road driving performance but generally does not result in crash reduction (Bédard, Isherwood, Moore, Gibbons, & Lindstrom, 2004; Korner-Bitensky, Kua, von Zweck, & Van Benthem, 2009). Later studies using dissimilar education interventions, however, have shown different results. Ball, Edwards, Ross, and McGwin (2010) tested the effects of three types of cognitive training on subsequent crashes of over 900 older drivers. Two of the three types of training (speed-of-processing and reasoning training) lead to fewer at-fault crashes than did controls in the 6-year period after the intervention.

- Nasvadi and Vavrik (2007) evaluated a group of older drivers who attended a 55 Alive/Mature Driving training program in British Columbia using a matched pre-post comparison design. The program included such topics as rules of the road, adverse driving conditions, common hazards, older driver characteristics and experience, and physical conditions that relate to driving performance (e.g., vision, hearing, reaction time, and medication effects). The program increased knowledge of safe driving practices, traffic rules and regulations, hazardous driving situations, the effects of aging on driving, and offered compensation strategies for possible driving cessation. They found that attendees of the training course were more likely to have had at-fault crashes prior to attending and thus would be expected to have more than the controls without intervention. However, no significant differences in crash and violation rates were found between the training and control groups after the training intervention, except for the oldest male drivers (age 75+), who were 1.5 time more likely to have been involved in a crash. This education countermeasure was thus shown to be differentially effective based on age. The department evaluated the same type of program in California, which included the possibility of an auto insurance premium reduction for attending. The law establishing the program called for yearly comparisons of the records of drivers who had completed the course and drivers who had not. A series of annual studies (1988 through 1992) summarized by Janke (1994a) showed no consistent evidence that the program had reduced crashes among course graduates, although it had been shown to consistently reduce their citations.

- Vision diseases are a specific and very common form of medical impairment in older drivers. Owsley, McGwin, Phillips, McNeal, and Stalvey (2004) studied 403 older drivers who were licensed but visually impaired and crash-involved during the preceding year. They were randomly assigned to an educational intervention group or an eye-care-only group acting as a control. The goal of the educational curriculum was to help drivers realize how their impairment might affect their driving and what they could do about it, in terms of avoiding overly challenging driving situations. Though educational group drivers reported a higher frequency of self-regulation, which included such practices as making three right turns to avoid a left turn, after 2 years their collision rate did not differ significantly from the control group. It should be noted that some of the material taught in the educational treatment was probably similar to that taught in the Mature Driver Improvement Program (MDIP), which did not reduce crashes. But evidence suggested that one of the unforeseen results of the MDIP may have been an increase in driving leading to increased exposure to risk, and that apparently was not the case here. Also, specific practical techniques like "3 rights make a left" may not be taught in the MDIP.

- Since the best predictor of future crashes and convictions is a person's past driving record, a DMV outreach effort, aimed toward drivers aged 70 or more who have had recent (within the past 18 months) crash or violation activity on their records, was conducted in 2005. (These drivers had not accumulated enough points for DMV to classify them as negligent operators and impose sanctions.) Since the consequences of a crash can be so grave for frailer senior drivers, and since their recent traffic incidents might be influenced by declines in health and foreshadow even more serious declines, it was felt that early intervention could be of particular value. Educational material and positive reinforcement interventions seemed appropriate and more likely than threat of punishment to succeed in promoting safer driving.

  A federal grant was obtained through the Office of Traffic Safety to assess the feasibility, acceptance, and benefits of such an outreach. A sample of some 17,000 drivers aged 70 or older with recent incidents on record, and therefore having an above-average risk of future crashes (Gebers & Peck, 1992), was randomly divided into four groups. One got a letter from the DMV Director; one a letter and a list of resources for elder assistance and information; the third received both of these, plus a number of elder-targeted pamphlets on vision, drugs (prescription, over-the-counter, herbal supplements, and their potential interactions), bodily flexibility, compensation for age-related declines, defensive driving, and so on; and the fourth received no intervention. All three treated groups were mailed a quiz/questionnaire to assess their safety-related knowledge and driving habits; also included was a short assessment of their attitudes toward DMV.

  The materials were mailed out in January of 2003. There was an overall questionnaire return rate of 43% to 62%. Results from the pilot testing revealed that the increased average annual mileage for senior drivers, noted above, was supported by questionnaire results. A number of the respondents not only claimed to drive cars and trucks, but to pilot airplanes as well. The analysis compared the relative knowledge of the groups, compiled their comments, and followed their driving records for a year subsequent to the mailings. However, the amount of material sent had no significant impact on either subsequent crashes or traffic convictions, as of 12 months post intervention (Kelsey & Janke, 2005).

A related educational effort by the department was the development of a senior web site, which branches off from DMV's Internet home page. The web site, posted in 2007, collects information on senior issues in one place for ease of access and use by seniors and those concerned about them. Included are web pages (also available in Spanish) on driver licensing, alternative transportation choices, health, and safety, as well as a comprehensive Senior Guide for Safe Driving posted in 2011.

<u>Earlier Post-Licensing Intervention</u>

- Gebers and Peck (1992) introduced the idea of an age-mediated "negligent-operator" point system for elderly drivers with recent incidents on their driving records. The negligent-operator program as it presently exists in California assigns points to traffic convictions and at-fault crashes. When a driver of any age has accumulated a certain number of points in a certain period of time, there are sanctions that may be as benign as a warning letter or as severe as license suspension or revocation. Gebers and Peck plotted the expected number of crashes in a subsequent 3-year period against the total number of points accumulated in the preceding 3 years for drivers aged 60-69, 70 and above, and of any age. They found that at the lower point levels older-driver groups had crash risk equal to or less than that of the all-ages group, but around the 3-point level and above there was a steeper increase in the expected crash average for drivers 70 and above than for the other two groups. A similar trend was seen for drivers aged 60-69 who had more than five points in a 3-year period. Concerned that points on an older driver's record, which are fairly rare events, may be early warning signs of the onset of some driving-related impairment, the authors suggested that negligent operator interventions be invoked at a lower point level for older people than for younger ones, so long as the initial interventions were not punitive. An educational brochure or self-assessment guide was suggested to inform the driver of typical problems associated with aging, and encourage him or her to assess possibilities for remediation or self-restriction. An educational intervention applied to drivers aged 70 or with recent incidents on record, completed in 2005, is described above.

<u>Medical Review and Restrictions on the License</u>

License restrictions are by no means new, and in fact a restriction to driving only while wearing corrective lenses is very common. But DMV (and other jurisdictions) can also restrict the licenses of drivers with impairments that are not as readily corrected to driving only at particular times of the day, on particular routes, and the like. The rationale behind use of these less common restrictions is that, even for drivers chronically so impaired that their risk of having a crash in unrestricted driving is much higher than average, risk will be greatly reduced if their trips are few, short, and made under conditions that do not unduly challenge their limitations.

- Malfetti and Winter (1990) proposed guidelines for a conditional license for selected elderly drivers that would be similar to a restricted license and would be adapted to the driver's mode of living, driving needs, and driving ability. The system would allow impaired seniors to operate a motor vehicle only under conditions that would not exceed their abilities, and would identify and treat high-risk drivers without penalizing safe drivers of the same age. Recent studies found that older drivers with license restrictions kept their licenses, had fewer traffic violations, and were crash free longer compared to unrestricted drivers (Marshall, Spasoff, Nair, & van Walraven, 2002; Nasvadi & Wister, 2008).

- Popkin, Stewart, and Lacey (1983) examined the impact of an initial medical review on the subsequent driving records of individuals, most commonly elderly, identified as having medical impairments. The results indicated that persons in most of the impairment groups (cardiovascular diseases, diabetes/endocrine illnesses, vision impairments, and mental problems) were at significantly lower risk of crashing following the medical review. A similar study by Stewart and Rodgman (1995) looked at the records of drivers referred to the North Carolina Medical Evaluation Program, 40% of whom were age 66 years or older. The study found similar results to Popkin, Stewart, and Lacey (1983) in regards to violation rates, but opposite results for crash rates.

- In another study, the general effect of restricting the licenses of drivers with medical impairments was investigated in Saskatchewan, Canada by Marshall, Spasoff, Nair, and van Walraven (2002), though they did not look at the influence of specific restrictions or specific medical diagnoses. Saskatchewan Government Insurance, which provides insurance coverage to all drivers in the province, delivers a program that issues restricted licenses to people with medical impairments that may affect their driving ability. Restrictions include both driving restrictions (e.g., may drive only during daylight hours) and/or licensing restrictions (e.g., periodic eye examinations are required for licensure). The authors compared drivers with and without restrictions of either type. After adjustment for demographic variables, the group of drivers with any restriction had a significantly higher average crash rate than the group without restrictions, though the increases themselves were significantly lower than those associated with being male or living in an urban area. In contrast, restricted license holders had a significantly lower average traffic violation rate than did the group of drivers without restrictions. Saskatchewan has one item of information that California lacks–the date on which a restriction was imposed. So in a second analysis in the same study, Marshall et al. (2002) compared average rates of crashes and traffic violations before and after driving restrictions (not licensing restrictions) were imposed. In all instances, average rates decreased following imposition of restriction(s). This led to a conclusion that restricted licensing programs like that used in Saskatchewan appear to be effective. Nasvadi's thesis study (2007) made the same findings in British Columbia.

- California law specifies that patients with conditions that can cause recurrent lapses of consciousness, or with dementia, must be reported by physicians; these reports (which are confidential) go through the local health office to DMV. In addition, physicians, law enforcement officers, family members, and others can report drivers who may be unsafe directly to DMV. Those reported, either by law or otherwise, are commonly elderly. A full medical evaluation is generally obtained, and on the basis of this evaluation, interaction with the driver, and results from a law, vision, and/or road test administered to him or her, the department decides what the status of the driver's license should be. Sometimes the impairment is so severe that the license must be withdrawn. But for lesser degrees of impairment, where the person is judged to be able to drive safely within certain limits, those limits (restrictions) are placed on the license, as noted above. Perhaps an important point to make here is that DMV's decision to retest a driver, and DMV's decision with regard to a reexamined driver's license status, are made purely on the basis of such factors as medical review and driving performance, not on the basis of a non-individualized attribute like age. In this regard, California is in line with current recommendations and best practices (Langford, Bohensky, Koppel, & Newstead, 2008a).

<u>Enhanced Renewal Testing</u>

- Overall, there has been little research conducted on the effectiveness of various license renewal requirements for older drivers and on traffic crash and violation rates. Requiring license applicants to take adequate renewal tests (especially, perhaps, vision tests) should be safety-enhancing, but the evidence is mixed. Kelsey, Janke, Peck, and Ratz (1985) found that clean-record drivers aged 70 or older who were offered a 2-year license extension by mail, thereby avoiding all renewal tests, had significantly *fewer* crashes and citations than did a comparison group of similarly clean-record age peers who were required to go to DMV field offices and take these tests. Of the various license renewal requirements studied, including in-person renewal, mandatory testing, vision tests, road tests, and shorter license renewal terms, a reduction in fatalities could only be tied to in-person renewal for the oldest drivers (age 85+); no other provision demonstrated any safety benefits (Molnar & Eby, 2005).

- A countermeasure that should especially benefit the elderly, but does not target them as a special group, is an experimental assessment system recently studied by California DMV. The 3-Tier Assessment System that was evaluated had three levels or “tiers” of tests applied to a broad spectrum of drivers, including renewal applicants who were required to renew their license in a field office, and to take the written renewal test when doing so. This included all applicants above age 69 as well as customers of any age, called referrals, who are reported to DMV—by doctors, police, family members, or others—and referred to a field office for road testing; those with unsafe driving records; or those who had been identified as possessing one or more conditions that may affect safe driving. Two aims of the project were to see whether renewal applicants have acquired some physical or mental condition which should be evaluated on a road test, and to determine whether such a condition has progressed to the point where it would be too hazardous to take the driver out on the road. It was anticipated that this type of system would be more broadly acceptable with the public than a screening system based simply on age alone (Hennessy & Janke, 2009).

  The first tier of the 3-Tier Assessment System, as piloted (Camp, 2010b), consisted of a few brief screening tests, supplemented by a brief cognitive screening exercise and unobtrusive observations by DMV staff for impairment, designed to identify customers in need of further assessment of the safety of their driving, and to identify customers who might benefit from education regarding how to safely compensate for driving-relevant functional limitations. These brief screening tests cover the domains of vision, cognition, and physical function. As the system is envisioned, if the first tier is passed, the license is renewed. If the tier is failed, the driver may be given a referral for medical or vision assessment and best correction of his or her condition. Second-tier examination is required if correction of a problem discovered on the first tier is not adequate. The second tier consisted of longer tests designed to predict the performance of identified drivers on a road test; these included the written renewal test, and two computerized tests of information-processing ability including a computer-based test of perceptual response time (the PRT, a sub-test of the Useful Field of View battery; Clay, Wadley, Edwards, Roth, Roenker & Ball 2005), and a driving-habits survey. If performance is good, the license is renewed, possibly with restriction(s); if poor, there may be additional medical referrals and, afterward, either a road test—the third tier—or the determination that the driver is too unsafe to test on the road (with subsequent withdrawal of the driving privilege). It is also at the third tier that educational intervention is administered to customers who had been identified at Tiers 1 or 2 with one or more potential limitations that could affect safe driving; this education is tailored to the customer in reference to the specific limitation that had been identified.

The 3-Tier Assessment System was piloted by CA DMV in 2006-2007 in six field offices in the Northern California area (Camp, 2010a and 2010b). The full pilot study was undertaken after more limited pilot studies were conducted and reported by Janke (2001b). The Pilot examined how well the 3-Tier Assessment System identified functional impairments, extended the safe driving years for drivers of all ages, and reduced crashes and violations. The Pilot was quasi-experimental, so there are limitations to the interpretation of the data gathered during the pilot; these limitations include potential biases to the findings. To the extent possible, the limitations and biases to the interpretation of data gathered during the 3-Tier Pilot were identified and discussed in prior reports (Camp, 2010a, 2010b, and 2011).

Camp found the Pilot likely reduced the driving years for some drivers who were designated as extremely functionally limited, because they failed to renew their licenses. No longer having a driver license most likely reduced the number of crashes by discouraging extremely functionally-limited drivers from driving at all, and may have encouraged others to stop driving earlier than they otherwise might have done. Camp found weak (but not statistically significant) evidence that the 3-Tier Assessment System reduced subsequent at-fault injury and fatal crashes. The 3-Tier Assessment System was piloted in 2007 somewhat differently from the system originally proposed by Hennessy and Janke (2009); therefore the findings of the Pilot cannot be extended to the latter.

Given the lack of a demonstrated overall safety benefit of the pilot program, Camp did not recommend implementing the 3-Tier Assessment System, nor any of the constituent screening tests. He did recommend additional research on the materials and means to encourage safe driving (for instance education), on the relationship between preparation and outcomes on the drive test (including preparation under the advice of an occupational therapist or certified driving rehabilitation specialist), and a variety of other subjects such as screening tests for limitations in cognition and perception, and the predictors of, and process of, informal de-licensure.

If the 3-Tier Assessment System does eventually become operational, it will include a conditional licensing component that applies appropriate driving restrictions based on test performance and identified functional limitations of the driver. The use of license restrictions is most commonly applied to drivers who are not referrals, but to those who need corrective lenses to drive. The possibilities and effectiveness of license restrictions as applied to both referrals and non-referrals have not yet been adequately studied.

<u>Task Force on Older Adult Transportation</u>

- A comprehensive approach to traffic safety for senior drivers, passengers, and pedestrians was initiated by the 2-year (Feb 2001 through Jun 2002) Task Force on Older Adults and Traffic Safety (California Task Force on Older Adults and Traffic Safety, 2002). The task force, led by the Center for Injury Prevention Policy and Practice (www.eldersafety.org), gathered together 36 representatives from governmental agencies at the federal, state, and local levels, as well as universities and senior advocacy groups. It developed a strategic framework of recommendations for action to help coordinate statewide efforts to improve traffic safety for older Californians. Several recommendations emerged covering such items as traffic-related injury prevention: more effective driver assessment and licensing; improving older adult risk identification and risk reduction practices; better medical assessment of a patient’s traffic safety risks; safer roadway infrastructure and land use practices; and safer motor vehicle design. This led to the formation of “The Older Californian Traffic Safety Task Force” (led by California CHP), which later merged with the California Strategic Highway Safety Plan (SHSP) to initiate action on these recommendations.

- Other researchers, such as Eby and Molnar (2009), studied older adult safety and mobility and highlighted the research still needed on these issues. They discussed many of the areas the Task Force on Older Adults and Traffic Safety covered and included such items as approaches that might extend the years of safe driving, driving cessation, and the necessity of viable alternative transportation options for those who decide to or are required to cease driving. Dickerson et al. (2007) discuss current knowledge on older driver safety and mobility and describe a framework for transportation and safe mobility that meets the goals of crash prevention and mobility maintenance for older adults. The framework is based on a transportation continuum of Driving (with emphasis on crash prevention) to Transitioning (with emphasis on crash prevention and maintaining mobility) to Non-Driving (with emphasis on maintaining mobility). They discuss several key areas that must be addressed in each phase of the framework: screening and assessment; remediation and rehabilitation; vehicle design and modification; technological advancements; roadway design; transitioning to non-driving; and alternative transportation.

Most countermeasures discussed above have been aimed at the behavior of the driver, but it should also be recognized that the human-factor problems of aging may have solutions that are primarily technological rather than behavioral. Since all drivers, regardless of age, sometimes function well below an optimal level of mental alertness and physical efficiency, it can be expected that technological advances designed to counteract the impairments of aging will make the driving task easier and safer for all drivers (Janke, 1994b; Jenness, Lerner, Mazor, Osberg, & Tefft, 2008).

Roadway and Vehicle Factors

- Improvements in the driving environment, such as better lighting and clearer, more strategically placed signs and signals, would go a long way toward making the roads safer for elderly drivers, according to TRIP—a national transportation research group (TRIP, 2012). Lyman, Ferguson, Braver, and Williams (2002) recommended protected left-turn lanes and left-turn signals at intersections to reduce the kind of problems drivers experience in such situations, as identified by the Federal Highway Administration Office of Safety (2009). The emphasis should be on the word "protected," since a similar kind of traffic control, protected/permissive left turns (PPLT), can confuse drivers of any age, as Noyce and Kacir (2002) demonstrated. The problem is based on PPLT standards published in the Manual on Uniform Traffic Control Devices (MUTCD), 2009 Edition (Federal Highway Administration, 2009). Standards for PPLT signal phasing—which provides for a protected phase, in which left turns are made freely while opposing traffic is stopped, and a permissive phase, in which left-turners must yield to opposing traffic and make their turn only when it is clear—call for two signals to be illuminated simultaneously in the same signal face. For example, a separate signal face for the left-turn lane must simultaneously show both a green arrow and a red ball during the protected phase. The MUTCD *recommend*s using a protected left in areas with a large number of older drivers. Noyce and Kacir demonstrated driver confusion on the meaning of such signaling, conducting a large simulator study that presented left-turn scenarios with different traffic signal displays from the point of view of a driver in an exclusive left-turn lane. Subjects chose the most appropriate action in each scenario from among four possibilities: go; yield, wait for a gap; stop, then wait for a gap; and stop. All age groups did worse when a green arrow and red ball were shown simultaneously on the same signal face, but elderly people were particularly affected.

- There are many vehicle design and safety features that could be incorporated in vehicles to reduce or eliminate some of the hazards, and overcome some of the cognitive and sensory deficits, experienced by elderly drivers today. Molnar, Eby, and Miller (2003) note that these features are often integral parts of the integrated sensory and processing systems of newer vehicles, and could possibly be adapted for use on older vehicles. Such technologies alter the way the driver controls the vehicle. Adaptive cruise control extends the speed maintenance concept to include distance maintenance from other vehicles, accelerating or decelerating as required. Warning systems, based on radar or laser technology, alert the driver to possible collisions with obstacles in front of or behind the vehicle and can even alert the driver when they are drifting out of their lane. Night-vision systems, both low-light and infrared, are available to provide the driver with the ability to detect obstacles and hazards with visual information they would not have using only their eyes.

- Challenges resulting from age-related changes in functional abilities, such as the combination of a narrowing useful field of view and decreasing flexibility in turning one's heads to clear traffic when changing lanes or backing up, can be overcome with well-designed technology. Alert systems and visual aids, such as rear-view cameras or panoramic mirrors, can compensate for these changes, as long as the technology is suitable to the common abilities and characteristics of older drivers. Audio and visual aids must take into account the cognitive, vision, and hearing losses experienced by some older drivers. Visual displays and auditory devices must be simple and easy to interpret, visual aids must be bright and large enough for drivers with reduce vision capabilities to see, and audio cues must be loud and clear enough to be heard and understood (Molnar et al., 2003).

- Kahane (2004) studied the effectiveness of life-saving technologies that manufacturers voluntarily introduced or were required (by Federal Motor Vehicle Safety Standards (FMVSS)) to implement in passenger cars, light trucks, and vans from 1960 to the late 1990s. They estimated from FARS data that 328,551 lives were saved by the introduction of vehicle safety technologies from 1960 through 2002. The combined effectiveness (percent of potential fatalities saved) of these technologies ranged from less than 1% in 1960 to almost

43% in 2002. These technologies included safety belts and airbags, energy-absorbing steering assemblies, upgraded locks and latches, disk brakes, windshield improvements, and a variety of structural reinforcements. Glassbrenner (2012) addressed recent improvements in vehicle crash avoidance and the car's ability to withstand a crash without serious occupant injury, attempting to answer the question "How much safer are newer vehicles." Their study isolated the vehicle factor from the human and environmental factors in the 26% reduction in fatalities and 38% reduction in injuries shown in FARS data over the 10-year period from 1999 to 2009. There are additional life-saving technologies that could be implemented, however. Li et al. (2003) suggested that depowered airbags and force-limiting safety belts would give better protection to the fragile bodies of older vehicle occupants and reduce their injuries and deaths if a crash should occur. FMVSS No. 208 required full implementation of "smart" or "advanced" airbags in 2007 and later passenger vehicles. These airbag systems include multi-stage inflators, pretensioners, occupant sensors, and deployment algorithms that either suppress or deploy the air bag in a low risk manner (Gabler & Hinch, 2008). Li et al. (2003) also noted that crash forces could be reduced if the crush zones of passenger vehicles were lengthened in conjunction with reducing the stiffness of vehicle front ends.

- Evans (1991) wrote in his book, *Traffic Safety and the Driver*, that he expected the risk level of drivers in general to decline in response to positive changes in factors contributing to traffic safety. In addition to improved roadway and vehicle design he mentioned legislation, law enforcement, education, social norms, and medical and emergency care. He also speculated that additional improvements in highway safety will come from health-enhancing behavioral changes regarding hygiene, diet, exercise, and avoidance of alcohol and tobacco. More recently, Evans emphasized that, though vehicle factors are important in overall traffic safety, driver behavior is much more important and that U. S. policy must address aberrant driver behavior, effectively changing our traffic safety culture, to avoid needless deaths and injuries (Evans, 2004).

Care must sometimes be taken, though, in characterizing a particular change as positive. Noland (2003), analyzing the effect of roadway (infrastructure) upgrades on traffic fatalities and injuries, pointed out that such upgrades as increasing the number and width of lanes have been commonly assumed to be safety measures. It is true, he acknowledged, that roadway upgrades have increased, and fatalities per mile have decreased, in the U.S. over the last 30-40 years. But he warned that drawing a conclusion that the former caused the latter ignores behavioral reactions to safety "improvements" that may affect fatality reduction goals adversely. Noland's study results do not, of course, imply that there is no safety payoff in trying to improve roadways and devices associated with their use. Aside from the type of upgrades he studied, other infrastructure changes like increasing shoulder widths or separating lanes with medians, and improvements in signage, signals, and lighting, might be expected to benefit all—perhaps especially senior—drivers.

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APPENDIX

Statistical Curve Smoothing of the 2009 Nationwide Household Travel Survey Mileage Data for California

The mileage estimates utilized in this report are based on California data (N = 28,198) from the Nationwide Household Travel Survey (NHTS) conducted by the Federal Highway Administration (2009). An examination of the mileage rates by age and gender indicated that the data, for both sexes separately as well as combined, could be best described as reflecting a cubic polynomial trend.

A cubic trend describes a relationship in which there are two “bends” in the data. Therefore, it was decided to apply curvilinear regression models to these data in order to obtain “smoothed” mileage estimates for each age and sex group. The advantage of this approach over using the raw age group means is that the estimates tend to be more accurate and stable. The results of the curve fitting statistical tests indicate that the cubic curve provided a statistically significantly ($p < .05$) better fit to the mileage data than did either a quadratic polynomial equation or a linear equation.

The following polynomial regression models or equations were applied to the NHTS California group mileage rates to obtain the predicted mileage rate for each group. The estimated rates are displayed in the attached Table A1. The attached Figure A1 illustrates the actual and modeled mileage rates for both sexes combined, while Figure A2 illustrates the actual and modeled mileage rates for males and females separately.

Estimated mileage for both sexes = $2{,}499.62 + 4{,}910.99(X) - 585.80(X^2) + 17.92(X^3)$

Estimated mileage for men = $1{,}536.10 + 6{,}058.69(X) - 698.93(X^2) + 20.98(X^3)$

Estimated mileage for women = $3{,}193.74 + 3{,}936.99(X) - 497.80(X^2) + 15.75(X^3)$

In the above equations, X is an integer representing a specific age group (identified on the horizontal axis on Figure A1). X^2 and X^3 are the values of X raised to the 2nd and 3rd powers, respectively. For example, the estimated mileage rate for both sexes in the 6th age group (drivers aged 40-44) is computed as follows:

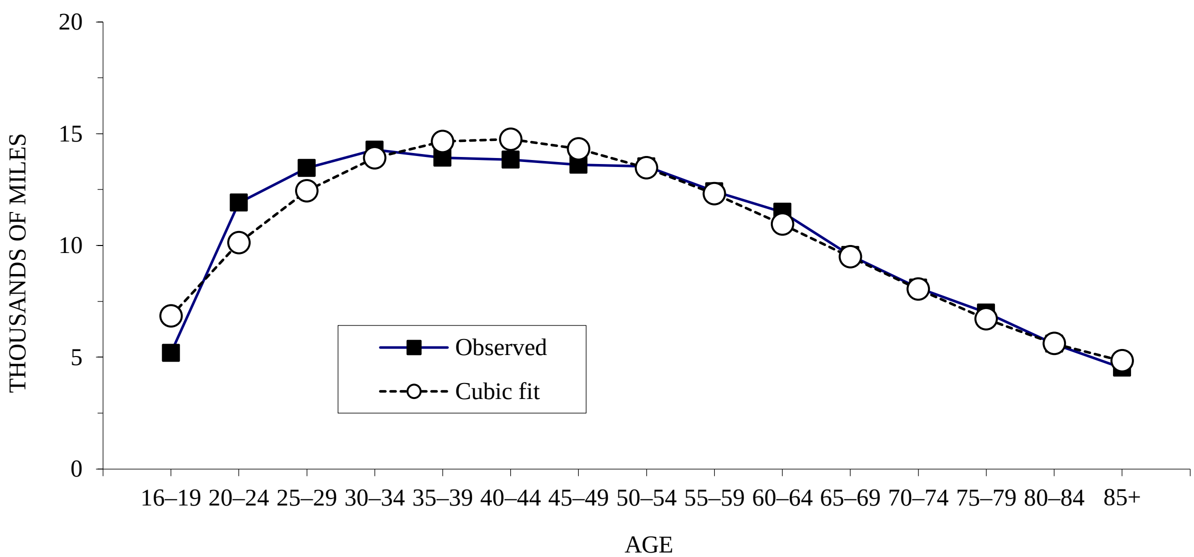
$2{,}499.62 + 4{,}910.99(6) - 585.80(36) + 17.92(216) = 14{,}747.5$ miles

Table A1

Observed and Estimated California Average Annual Mileage by Age and Sex

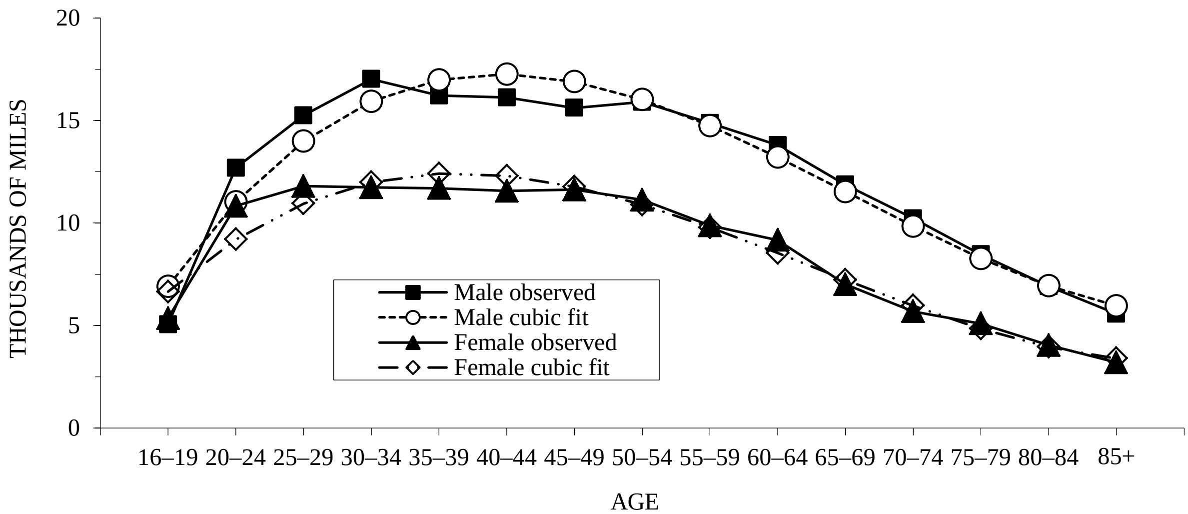
	Mileage					
	Both sexes		Male		Female	
Age	Observed	Cubic fit	Observed	Cubic fit	Observed	Cubic fit
16 – 19	5,189	6,843	5,061	6,917	5,353	6,649
20 – 24	11,912	10,122	12,684	11,026	10,830	9,203
25 – 29	13,462	12,444	15,243	13,988	11,794	10,950
30 – 34	14,279	13,918	17,014	15,931	11,735	11,985
35 – 39	13,922	14,650	16,215	16,979	11,695	12,402
40 – 44	13,835	14,747	16,116	17,258	11,565	12,297
45 – 49	13,604	14,319	15,615	16,896	11,627	11,763
50 – 54	13,530	13,471	15,900	16,016	11,125	10,894
55 – 59	12,416	12,312	14,875	14,745	9,877	9,787
60 – 64	11,493	10,950	13,798	13,210	9,165	8,534
65 – 69	9,558	9,490	11,869	11,536	7,010	7,230
70 – 74	8,102	8,042	10,223	9,848	5,688	5,970
75 – 79	6,988	6,713	8,464	8,273	5,098	4,849
80 – 84	5,592	5,609	6,911	6,937	4,040	3,961
85 +	4,524	4,839	5,576	5,965	3,201	3,400
All ages	10,560	10,565	12,371	12,368	8,654	8,658

Note. California mileage estimates are based on data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey*, Washington DC: U.S. Department of Transportation, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*. California data are smoothed by a series of cubic polynomial regression models to provide more accurate and stable estimates for age groups than provided by the raw mileage data.



Note. California mileage estimates are based on data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey*, Washington DC: U.S. Department of Transportation, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*. California data are smoothed by a series of cubic polynomial regression models to provide more accurate and stable estimates for age groups than provided by the raw mileage data.

Figure A1. Observed and estimated California average annual miles by driver age.



Note. California mileage estimates are based on data from the Federal Highway Administration, 2009, *Nationwide Household Travel Survey*, Washington DC: U.S. Department of Transportation, *Estimated Average Annual Mileage by Age Group and Sex for the California Sample*. California data are smoothed by a series of cubic polynomial regression models to provide more accurate and stable estimates for age groups than provided by the raw mileage data.

Figure A2. Observed and estimated California average annual miles by driver age and sex.