



# **MEDICAL CONDITIONS AND OTHER FACTORS IN DRIVER RISK**

**REPORT TO THE LEGISLATURE  
OF THE STATE OF CALIFORNIA**

**IN ACCORD WITH SENATE BILL 335  
CHAPTER 985, 2000 LEGISLATIVE SESSION**

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## EXECUTIVE SUMMARY

The Brandi Mitock Safe Drivers Act, SB 335 (Hayden, Ch. 985, Stats. 2000), requires the Department of Motor Vehicles (DMV) to evaluate the effects of physical conditions, ailments, and other factors on the ability to safely operate a motor vehicle. The department was to include in its evaluation indicators and predictors relating to the impairment of the ability to drive safely, including, but not limited to, driving records. In developing its evaluation, the department was to consider input from any interested party. The results of the evaluation were to be submitted to the Legislature on or before July 15, 2001.

Pursuant to SB 335, this report considers drivers known to the department as having a medical condition in terms of the average crash rates for six broad categories of physical or mental impairment in DMV's "P&M" program for such drivers. These are compared with the rate for the driving population as a whole. This information comes from departmental studies of the driver record database which, among many other elements, contains information on drivers' medical impairments and their motor

vehicle crashes. Some specific medical conditions—dementia and conditions causing lapses of consciousness—are reportable by law to the DMV. These conditions are considered at some length, along with departmental guidelines established to aid in making a licensing decision for drivers with them. Also discussed are various relatively common disorders, not mandatorily reportable, which have the potential to affect driving safety. The information presented on specific disorders comes from previously published departmental reviews of the scientific literature in this area, and from a review of recently published studies identified through a search in Medline, a medical information referencing system on the Internet.

As noted above, an evaluation of the following was required by SB 335:

- Effects of physical conditions, ailments, and other factors on the ability to safely operate a motor vehicle.
- Indicators and predictors relating to impairment of the ability to drive safely.
- Input from any interested parties.

In addition, the department believed that it was important to provide the Legislature with the following additional information not required by SB 335:

- Indicators and predictors of unsafe driving within the general driving population.
- Description of a more comprehensive licensing assessment system under study by the department.

A discussion of all five elements follows.

### *Medical Conditions as Predictors of Increased Risk (pages 4 to 62)*

Based on an extensive review as indicated above, many medical conditions have the potential to impair traffic safety when they reach a given level of severity. These are considered separately and constitute the greater part of the report.

Key elements:

- The effect of a medical condition on driving cannot be determined entirely from the diagnosis; it depends more fundamentally on the severity of functional impairments caused by the condition. These in turn depend to a great extent upon the stage of disease a driver has reached, as well as other factors.
- Significantly impaired vision, and cognitive ability that is reduced sufficiently to make the driver less capable (or even incapable) of making good and timely judgments of the best action to take in a traffic situation, are probably the most safety-relevant impairments caused by disease.
- There is no evidence that orthopedic impairments (such as a condition requiring hand controls, for example) reduce traffic safety.

*Medication Use as a Predictor of Increased Risk (pages 62 to 67)*

Key elements:

- The topic of medications and their interactions, as they relate to driving safety, is largely unexplored and too complex for consideration here in any depth.
- Benzodiazepines (e.g., Valium) are the class of drugs for which the clearest evidence of driving hazard exists.

*Input from Interested Parties*

The department conducted extensive research in this area, incorporating findings from the scientific literature and input from subject matter experts providing local, state, national, and international perspectives.

*Risk Factors in the General Driving Population (pages 1 to 4)*

Evaluation of this topic was not required by SB 335, since the risk factors involved do not impair the *ability* to drive safely, but rather other factors, such as the motivation or inclination to drive safely. Nevertheless, because the information was judged to be of interest to the Legislature, general risk factors were discussed briefly.

Key elements:

- Departmental research has established that an increased probability of accident involvement is associated with being young, being male, holding a commercial driver license, and having relatively many crashes and traffic citations on record.
- In response to the excess risk posed by youth and by drivers with a poor record, the department has established a graduated licensing program for novice drivers under age 18, and a negligent-operator treatment system based on traffic conviction and accident points for drivers with poor records.

*Three-Tier Testing: Toward an Improved Licensing Assessment System (pages 68 to 70)*

SB 335 did not ask for a description of the department's emerging assessment system, but it is included since it may be of interest to the Legislature. For some time it has been known that there is enough evidence of medically related crash risk to justify supplementing the department's present means of identifying medically impaired drivers with a system that will improve identification and assessment. Such a system has been studied since 1993, funded in part by the National Highway Traffic Safety Administration. As it is envisioned, most or all renewal applicants appearing in field offices would take brief screening tests in addition to the two standard licensing tests used now; only if their performance was poor on this "first tier" of tests would they proceed to further, more diagnostic, tests. Drivers reported to the department as having a presumed medical impairment would take all tests necessary to reliably evaluate their driving ability. The department's Research and Development Branch is currently studying the performance of the three-tier system in the field.

### Key elements:

- First tier – The system now being studied at DMV includes three tiers of tests—all shown to be related to impairment and/or road test score, and some to crashes. On the first tier, in addition to the usual visual acuity and knowledge tests, are structured observation of applicants by a technician who will record certain obvious signs of impairment, a question examining traffic judgment, and a test of low-contrast acuity; that is, ability to see clearly when there is little contrast between an object and its background. Applicants who passed all tests on the first tier would not go on to the second tier and would be licensed, though perhaps with a restriction—e.g., to driving only when using corrective lenses.
- Second tier – This would consist of automated tests of perceptual and information-processing speed and accuracy, as well as speed and accuracy in making a particular physical response to a particular stimulus. If the system was adopted, applicants who performed very well on second-tier tests, and applicants whose performance was so poor that they were judged to be a hazard on the road, would not proceed to the third tier. The first group would be licensed—though, based on their first-tier performance, restrictions would probably be imposed. The second group would lose the driving privilege. A third (probably the largest) group, those who performed neither very well nor very badly, would be tested on the road.
- Third tier – This would be a road test that was designed by the department especially for experienced but impaired drivers, and is in use now. It includes tests of cognitive functioning as well as orientation in space, ability to scan, and ability to handle the vehicle. In the three-tier system it would be the most important factor in deciding, for those taking it, whether they could be licensed with restrictions or should not be licensed.
- A potential advantage of the system is that drivers would not be selected for extensive testing on the basis of characteristics beyond their control, like age or sex. On the contrary, drivers would be selected on the basis of their performance on a battery of tests, and that battery will be finalized only after consideration of the tests' validities, reliabilities, and acceptability to the public.

Pursuant to SB 335, it is the intent of the Legislature to address the effects of medical conditions and medications on the ability to operate a motor vehicle safely. The findings of medically related crash risk from the literature and the crash rate data presented in the report provide support for supplementing the department's present licensing program with a system for improved identification and evaluation of drivers having physical or mental conditions that potentially impair driving.

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## MEDICAL CONDITIONS AND OTHER FACTORS IN DRIVER RISK

This report is submitted in accordance with Senate Bill 335 (Chapter 985, effective January 1, 2001), which requires an evaluation by the Department of Motor Vehicles (DMV) of the effects of physical conditions, ailments, and other factors on the ability to safely operate a motor vehicle. To be included in this evaluation are indicators and predictors, including driving records, relating to impairment of the ability to drive safely.

This wording appears to exclude predictors of unsafe driving for drivers who are physically and mentally capable of driving more safely but choose not to. Nevertheless, such predictors will be discussed briefly. The report will first touch on indicators and predictors of crashes (risk factors) within the general driving population, and on programs that have been established to mitigate the effects of those risk factors. Then the special population of medically impaired drivers will be considered, along with crash records for the six broad categories of physical or mental impairment in DMV's "P&M" program for such drivers, who show evidence of incapacity rather than inexperience or willful negligence. Some of the medical conditions are reportable by law to the DMV, and these will be considered at some length. Finally, descriptions of various relatively common disorders will be offered, along with evidence from the scientific literature concerning their effects on driving safety. It should be kept in mind that the effect of a medical condition on driving does not depend entirely on the diagnosis, but more fundamentally on the severity of functional impairments caused by the condition. These in turn depend to a great extent upon the stage of the disease a driver has reached, as well as other factors.

### General Indicators and Predictors of Crash Risk

The department's "negligent operator" program for monitoring driver safety uses a point system that assigns penalty points to various traffic law infractions or crashes and establishes a level of point accumulation at which a licensing action is taken. Point systems are widely used by driver licensing agencies, and their main purpose is to identify possibly hazardous drivers and initiate driver improvement or license control actions against those drivers who, judging from their past performance, are most likely to become accident-involved in the future. A secondary purpose of point systems is more general—to discourage, within the general driving population, illegal and unsafe driving that leads to point accumulation and possible loss of license.

The California system assigns one point to most moving violations and two points to the most serious offenses, like drunk or reckless driving. An accident for which the driver is responsible is assigned one point. At present a driver is considered a *prima facie* negligent operator upon receiving four points in 1 year, six in 2 years, or eight in 3 years (California Vehicle Code [CVC] Section 12810.5). Before that level is reached, the department sends a warning letter to the driver when two points have been accumulated in a year, and a notice of intent to suspend when three have been accumulated. When the negligent-operator level has been reached, drivers are suspended for a time, after which their driving privilege is placed on probation. Those who violate probation by continuing to offend may have their driving privileges revoked.

For many years DMV has monitored the driving records of the drivers it licenses. Crashes, citations, and negligent-operator points have consistently been shown to be major predictors of future crashes for driver groups formed on the basis of traffic incident counts in a particular period of time. (They do not predict crash experience well for individuals, however.) To illustrate prediction of crashes for groups of drivers, Table 1 (from Gebers and Peck, 1987) appears below. It shows crash rates in a third year (in this case 1982) by number of negligent-operator points accumulated in the preceding 2 years (1980-81). The data were taken from a random 1% sample of the licensed driving population.

It should be noted that the fourth column of the table is labeled “times-as-many factor.” This is a relative crash rate. It was found by dividing the crash rate for each group with one or more negligent-operator points in 1980-81 by the rate for the group with zero points, giving a number that essentially tells how many times worse each group was in 1982 than the zero-point group.

Table 1  
Accident Rates in Third Year by Number of  
Negligent-Operator Points in Preceding 2 Years  
(1980-82; total sample = 143,624)

Negligent-operator point count (first 2 years)	Number of drivers	Mean accident rate (3 <sup>rd</sup> year)	Times-as-many factor (3 <sup>rd</sup> year)	Percent of drivers accident-free
0	102,214	.038	1.00	96.4
1	25,608	.061	1.61	94.1
2	9,038	.076	2.00	92.8
3	3,628	.093	2.45	91.4
4	1,542	.120	3.16	89.0
5	739	.119	3.13	88.6
6+	855	.135	3.55	88.0

Gebers (1999) further explored the prediction of accident risk by developing prediction equations that included not only negligent-operator points but also demographic and other factors as predictors. He concluded that an increased probability of accident involvement is associated with:

- being young,
- being male,
- holding a commercial driver license,
- having more citations on record, and
- having more accidents on record.

It is well known that young drivers, particularly young male drivers, are overrepresented in traffic accidents. For example, Aizenberg and McKenzie (1997) presented CHP data indicating that drivers aged 16 through 19 have a relative casualty (fatal or nonfatal injury) accident involvement index of 2.63—indicating that they have

163% more crashes than would be expected, considering the proportion of the driving population they represent. Male teenagers had 188% more than would be expected, and female teenagers 134% more. This excess is greater than for any other age group, and in fact all groups aged 35 or older have fewer casualty accidents than would be expected, considering how many drivers they represent. (That is, their relative involvement indices are all less than 1.00.)

According to Aizenberg and McKenzie, summarizing the work of other authors, most evidence suggests that risk taking is perhaps the major factor underlying the high collision rate among teens. Compared to other male drivers, young male drivers are found to be more willing to take risks and to perceive hazardous situations as being less dangerous than they really are. More accurate risk perception comes with age and experience. Even after the teen years, male drivers aged 18-24 perceive themselves as being less likely than other drivers their age to be involved in a collision; this is not the case for age groups beyond 24. Some of this is probably a function of inexperience. A study reported by Simpson and Mayhew (1992) found that experience was associated with decreased collision rates both for 20-year-old and 30-year-old drivers. However, the authors suggested that some of the benefits of experience are counterbalanced by age-related risk factors like thrill-seeking, peer pressure, and feelings of immortality. Recognizing the problem, DMV has instituted a graduated licensing program for drivers under 18, which contains elements of delaying licensure to accommodate more thorough practice, limiting the hours of nighttime driving and the age of passengers, and intervening earlier than is done in the general negligent-operator program when a young driver's record shows citations or crashes.

Holding a commercial driver license is an indicator of increased accident risk primarily because of the great number of miles commercial drivers must travel, exposing them to a relatively higher risk of crashes. Some other factors making for enhanced risk are their having to drive regardless of weather conditions for many hours, often without sufficient sleep.

### **Medical Conditions and Crash Risk**

Gebers did not study medically impaired drivers (a fairly small group), or include medical impairment as a possible predictor. In fact most medically impaired drivers are not young, nor do they drive commercially. They will be identified as higher risks by the point system if their prior driving records are poor, but most do not have poor prior records—in part because they tend to limit their driving. Nevertheless, drivers known to DMV as having medical conditions have, as a group, a crash rate substantially higher than that of the general driving population average; evidence for this will be presented below. To monitor these drivers the department has what is called the “P&M” program—a program for drivers with physical and/or mental disorders that may affect driving safety. The program depends to a great extent on input from physicians and others, and there is evidence (e.g., Popkin & Waller, 1988) that the most serious cases in terms of driving impairment are the most likely to be identified.

Early studies of the role of medical conditions in causing accidents commonly focused on conditions causing sudden incapacitation of the driver. They concluded that sudden natural deaths at the wheel, and epileptic seizures at the wheel, cause accidents only

rarely (e.g., 6 in 10,000 and 1 in 10,000 respectively, as found in the Netherlands by Van der Lugt, 1975). Sudden acute illness of any sort was found to cause crashes more commonly but still fairly rarely—about 1 in 1,000, as found in Sweden by Herner, Smedby, and Ysander (1966). In California, Janke, Peck, and Dreyer (1978) inspected police-report data from the California Highway Patrol (CHP) on medical-condition involvement in fatal crashes. During 1977, there were 4,351 fatal crashes in the state, involving 6,265 drivers. Of these drivers, 18 (0.29%) were noted on the police report as being acutely ill or having a blackout. If one such driver per crash is assumed, then sudden illness or blackout was noted as a factor in 4.1 per 1,000 fatal crashes.

In a Swedish study of fatally crash-injured drivers, Sjogren, Eriksson, and Ostrom (1996) found that suddenly incapacitating medical conditions probably caused the fatal crash in 6% of the drivers studied. This conclusion was based on autopsy and medical records of the driver, police data giving the circumstances of the crash, and an estimate of the probability that the disease contributed to the crash which took into account both the severity of any medical condition revealed at autopsy and other likely causes (environmental, behavioral, intoxication-related, and vehicle-related). While older drivers were more likely than younger ones to show medical conditions that were probably causal factors in their crashes, statistical analyses controlling for age showed that the medical conditions, rather than the drivers' chronological age *per se*, were the important factors in initiating the crashes that killed them. Some of the medical factors discovered in study drivers and judged by a forensic pathologist (one of the study's authors) to be associated with a high risk of sudden incapacitation were poorly controlled diabetes, recent clotting in coronary arteries leading to death of part of the heart muscle (myocardial infarction), uncontrolled epilepsy, and hemorrhage in a brain tumor. A limitation of the study, which the authors recognized, was the fact that drivers' medical records did not necessarily furnish information on other conditions, like dementia, which might have contributed to their crashes. None of the diseases identified at autopsy were judged with certainty to have caused the fatal crash, although almost 25% of the drivers had disease conditions considered to put them at some risk of sudden incapacitation, the primary focus of Sjogren and his associates.

In cases of sudden loss of consciousness or an acute medical emergency the driver's condition can cause a crash directly, but chronic medical conditions can contribute indirectly to crashes—for example, by undermining a driver's ability to react appropriately in hazardous situations, and thus bringing about a crash which might otherwise have been avoided. Medications to treat a disease can also operate in this way. In the CHP data of Janke et al. (1978) for fatal crashes during 1977 (there were 4,351 of these, involving 6,265 drivers), 18 or 0.29% of the drivers were noted as being acutely ill or having a blackout. It is unlikely that any single fatal crash involved more than one such driver, so it can be concluded that sudden illness or blackout was noted as a factor in 0.41% of fatal crashes, about 4 in 1,000. Eleven drivers (in 0.25% of the crashes, if there was no more than one such driver per fatal crash) were noted as having "other" physical impairments, and 14 drivers (in 0.32% of the crashes, given the same assumption) were noted as being on medication for some condition. Forty-one drivers (in 0.94% of the crashes, given the assumption) were noted as being under the influence of other drugs, excluding alcohol; many if not most of these cases may have been instances of recreational drug use. The sum of the first three driver totals is 43;

0.69% of the 6,265 drivers involved in fatal crashes and perhaps about 1% of the 4,351 crashes. This is not a large number, and it seems likely that even severe disease states may not be reliably detected by investigating police officers.

Waller (1977), a physician, speculated on the risk of a person whose impairment is minimal except during times when the environmental task becomes unusually demanding. At such times, the individual has less spare capacity to deal with the challenge. Excluding alcohol from the discussion, he wrote, ". . . I estimate that other medical conditions play a contributory role either alone or in combination with environmental stresses in the initiation of between 15 and 25% of all crashes" (page 395).

Through their recommendations to the driver involved, physicians and family members can greatly influence a medically impaired person's decision to limit or even give up driving. Physicians, in particular, also give substantial input to state licensing agencies for their decision-making, and others may do so as well. However, the licensing agency has the ultimate gatekeeping responsibility with respect to the driving privilege. When that agency makes a determination as to whether or not to let a medically impaired person drive a private passenger vehicle (heavy-vehicle commercial driving will not be considered here), an attempt is made to balance considerations of public safety against the driver's need for personal mobility. In California, one option short of taking away the driving privilege is to monitor the person through a "medical probation," which generally requires regular physician reports on the driver's health status. Another option, which allows limited driving only, is to restrict driving to specific roadways or specific times of the day.

In the following, ways in which DMV learns of medically impaired drivers and aspects of DMV's P&M (physical and mental conditions) program are discussed. Analyses of relevant departmental data on P&M drivers are presented, as well as a review of the driving-related medical literature. The literature review is based in large part on two earlier reviews, Janke (1993) and Janke (1994), covering published reports of investigations into the relationship between medical conditions and driving. More recent studies on the same topic were accessed through a Medline search. Analyses of current driver records of selected groups of medically impaired and orthopedically disabled drivers come from a report by Mitchell and Gebers (2001). Its authors, Emilie Mitchell and Michael Gebers, are DMV researchers. It should be understood that the topic to be addressed is vast, and of necessity this report will be extremely limited in scope.

### **Mandated Physician Reporting**

There is a state reporting law for disorders causing possibly recurrent loss or lapse of consciousness, effective since 1939 but amended in 1988 to include Alzheimer's-related dementia as a reportable condition. California Health and Safety Code Section 103900 mandates that physicians report patients over age 13 with these disorders to local health officers, who in turn transmit the reports (Confidential Morbidity Reports, or CMRs) to DMV. Three departmental surveys of CMRs were conducted in 1978, 1980, and 1991; Table 2 shows the results.

Table 2  
Confidential Morbidity Report Surveys

Condition	1978 Survey 2/16/78-3/15/78 Total = 333		1980 Survey 10/1/80-10/28/80 Total = 557		1991 Survey 9/2/91-9/30/91 Total = 1,849	
	N	%	N	%	N <sup>1</sup>	% <sup>1</sup>
Seizure(s), seizure disorder	242	73	388	70	187 <sup>2</sup>	52
Loss/lapse of consciousness	41	12	91	16	27	8
Syncope	27	8	35	6	48	13
Alcohol intoxic./withdrawal	8	2	11	2	9	3
Narcolepsy	2	1	2	<1	1	<1
Dementia	2	1	3	1	21	6
Hemianopsia	2	1	1	<1	1	<1
Trauma, concussion			6	1	5	1
Altered awareness			5	1	4	1
Possible seizure					13	4
Stroke, CVA					11	3
Psychosis					8	2
Hypoglycemia, diabetes					5	1
Dizziness, vertigo					4	1
Drug dependence/abuse					3	1
Miscellaneous	9 <sup>3</sup>	3	15 <sup>4</sup>	3	10 <sup>5</sup>	3

<sup>1</sup> Based on 357 cases out of 1,849.

<sup>2</sup> In 2 cases seizure was noted as occurring while driving and in 1 of these a crash occurred.

<sup>3</sup> Included drug withdrawal, stroke, schizophrenia, vertigo.

<sup>4</sup> Included stroke, vertigo, amnesia, loss of motor control, possible syncope or concussion or seizure, brain tumor, confusion, hypoglycemia, illegible report.

<sup>5</sup> Included brain cancer, macular degeneration, coma, adjustment disorder, "rehab," hereditary lymphedema, Parkinson's disease, multiple sclerosis.

The group of reportable disorders, according to an early regulation, has always been meant to include many diseases. These included not only epilepsy and "episodes of marked confusion" (now specifically referred to in the law as Alzheimer's disease and, if serious enough, related disorders), but also cardiac arrhythmias causing syncope (sudden loss of consciousness and postural tone which may recur), sudden drug withdrawal which may cause lapses of consciousness, alcoholic blackouts, narcolepsy, and diabetic hypoglycemia (insulin reaction), among others. But many more reported conditions, as well as a much greater specificity and diversity of reported conditions, were found in the 1991 survey than in prior years. The increasing number of CMRs was in part a result of increasing population, but California's population increased by only about 26% between 1980 and 1991, while the number of reports received by DMV increased by a factor of more than three, 232%. Though it was still true in 1991, as formerly, that most reports were of unspecified seizure disorders, their percentage had

decreased from 70% in 1980 to 52% in 1991. (If “possible seizure” is included, seizure disorders were 56% of the total; this category did not appear in earlier surveys.)

Of reported seizure disorders, it is probably safe to assume that the majority involved epileptic seizures. There is some reason for state licensing agencies to be concerned about drivers with epilepsy; Spudis, Penry, and Gibson (1986) noted that no other condition abruptly causes complete disability within less than one second, as epilepsy can do. At the same time they wrote that fewer than 1 in 5,000 to 1 in 10,000 motor vehicle crashes are the result of suspected epileptic seizures. It is interesting to compare this figure with the Herner et al. (1966) observation that 12 out of 44,255 fatal Swedish crashes—approximately 1 in 3,700—were due to epileptic seizures. But the figures do not necessarily conflict since, for example, medications available for treatment of seizure disorders and monitoring of drug levels in the blood undoubtedly improved between 1966 and 1986.

According to Fisher and Krumholz (1988), approximately 5% of the United States population have had a single seizure, and approximately 1% have epilepsy. Given that the California population was a little over 34,000,000 in 2000, this translates to about 340,000 people with epilepsy in California. Of these, it is estimated that only about 40,000—a little over one-tenth of a percent of the population—are known to DMV. (Nondrivers—who might later apply for a driver’s license—are reported to DMV as well as drivers, though children under 14 are not.) The degree of incompleteness in identification may be a basis for concern. However, there is some evidence that cases of epilepsy known to a licensing agency have, as a group, a crash rate higher than that of cases not known to the agency (Popkin and Waller, 1988). In that study, epilepsy cases unknown to the North Carolina DMV had a crash rate only 10% higher than that of the general population, suggesting that the identification system for such drivers in North Carolina was working effectively to flag those at highest risk. (For example, cases identified by the DMV may be the more active drivers among those with the disease. Being therefore at higher crash risk, they would probably have had, as a group, more crashes or other driving incidents to bring them to the attention of the department.)

Syncope was the second most frequent reporting reason in 1991. Grubb, Wolfe, Samoil, Madu, Temesy-Armos, Hahn, and Elliot (1992) reported that the prevalence of the condition in men aged 35-55 is 0.7%, while in men aged 75 or older it is 5.6%. If it can be assumed that prevalence rates are similar for women, syncope appears to be overreported if anything, at 13%.

In 1991, reports of dementia were no longer rare; this increase relative to earlier years may be largely, though perhaps not entirely, attributable to the 1988 law change. Even before 1988, the regulation interpreting what was then Health and Safety Code 410 called for report of individuals showing “episodes of marked confusion” or “senility.” Also it is well known that Alzheimer’s-type dementia is concentrated primarily in the elderly population, so the increasing number of elderly people in California may have played a role in the increase in reported cases.

According to Barclay, Weiss, Mattis, Bond, and Blass (1988), 15% of the population over age 65 show signs of dementia to some degree, as compared to 30% who have

cardiovascular disease. Given that people over 65 make up about 12% of the California population, there may be about 600,000 Californians with dementia overall—though certainly not all of these would be drivers, both because of the debility accompanying their disease in later stages and because the incidence of dementia is by far the greatest in people beyond 80, who are likely to have other impairments that keep them from driving.

The medical conditions cited in a 1991 sample of 1,744 CMRs have been tabulated separately by age group (Williams, Chang, and Graham, 1992). Williams et al. reported that 426 (about 24%) of the CMRs reported people aged 65 or more, who were thus, as 12% of the driving population, over-represented by approximately a factor of two. In these older individuals, seizure disorders and dementia each accounted for about one-third of the reports, with syncope accounting for 19% and stroke for 8%. In people younger than 65, seizure disorders accounted for fully three quarters of the reports, syncope for 13%, and dementia and stroke for less than 2% each.

### **Risk Groups of Reported Drivers**

In addition to CMRs, there are several other sources providing discretionary, as opposed to legally required, reports of medically impaired drivers to the DMV. Some of these are family members, acquaintances, law enforcement, and physicians (through letters rather than CMRs). When a person who is also a licensed driver is reported, he or she may be dealt with by means of the department's P&M (physical and mental conditions) program administered by Driver Safety or, in the case of many conditions or functional impairments, by Field Operations staff. Medical evaluations are generally solicited from drivers' physicians; the drivers themselves are examined by DMV's Field Operations and/or Driver Safety staff and, as the most extreme of the department's options, a suspension or revocation action can be taken against the driving privilege. On DMV's database of driver records, the records of P&M drivers are given a code designating one of six general P&M groups—Alcoholism, Mental Condition, Physical Condition, Lapses of Consciousness, Drug Addiction, and Lack of Knowledge or Skill. Within these broad categories, some new codes have recently been established to indicate a driver's principal diagnosis; these codes are now in use and should increase the precision of the department's information on the relationship between medical condition and driving record. (They will not, unfortunately, solve the problem of coexisting conditions which, together with the condition for which a driver was reported, affect his or her functional status.)

Do P&M drivers show inflated crash rates that justify a special program dealing with them? Not necessarily as individuals, but as a group they do. Figure 1, below, shows absolute and relative accident rates of the six broadly defined P&M categories. The data came from all drivers having a departmental P&M contact (e.g., reexamination, hearing) during 1991. For comparison purposes, one comparison group was randomly sampled from the driving population as a whole and another from the set of male drivers younger than 25, a relatively high-risk group within the "normal" driving population. The number of drivers in each sample is shown below the bar corresponding to that group.

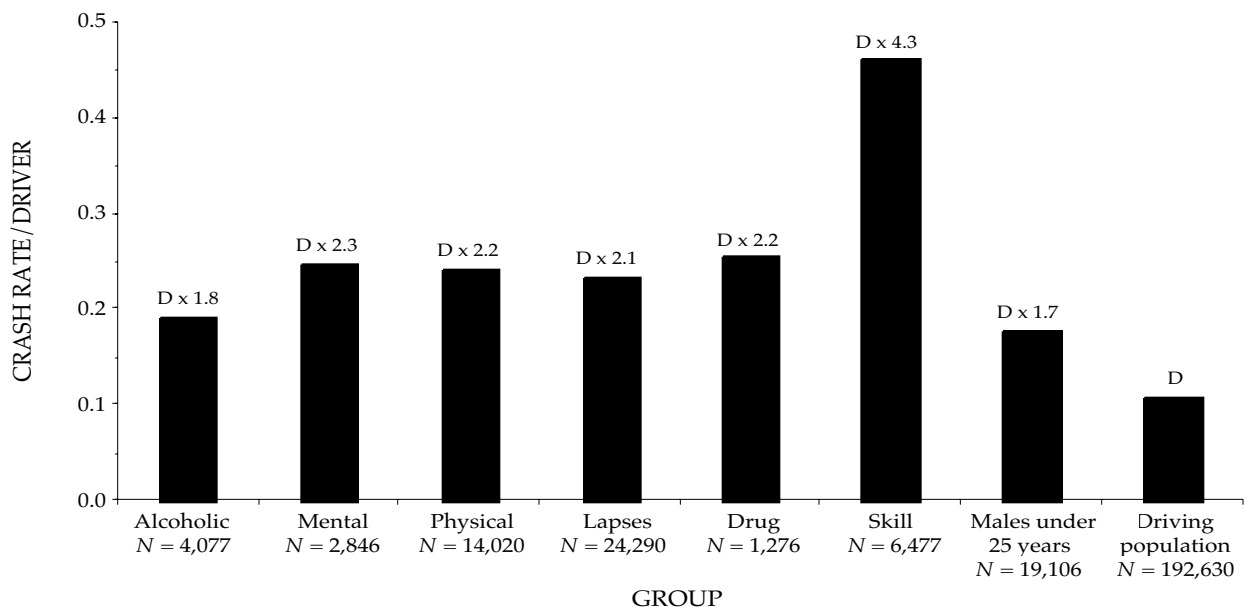
For P&M groups, the data shown here (Janke, 1993) represent accident rates during the 2 years preceding their 1991 P&M contact. Accident rates of the comparison groups are



for the 2-year period prior to a zero-date or “reference date” midway in 1991. The Y-axis of the graph shows accident rate per driver. The P&M and young male groups’ *relative* crash rates, shown as ratios of each group’s crash rate to that of the driving-population sample (here called D), each appear above the bar corresponding to that group. The rates and relative rates shown here may appear almost the same numerically (that is, the relative rates are about 10 times the rates shown on the Y-axis), but this is because the driving-population sample had an average 2-year crash rate close to 0.1.

Prior to their P&M contacts in 1991, most of the P&M groups showed approximately twice the risk of the driving population as a whole. However, the “Skill” (Lack of Knowledge or Skill) group, consisting primarily of older drivers referred by DMV field office staff not because of a previously known medical condition but because of repeated licensing test failure presumably caused by a medical condition, showed more than four times the population risk for a crash. All P&M groups showed directionally higher crash risk than the young male comparison group, although in the case of the Alcoholic group the difference was negligible.

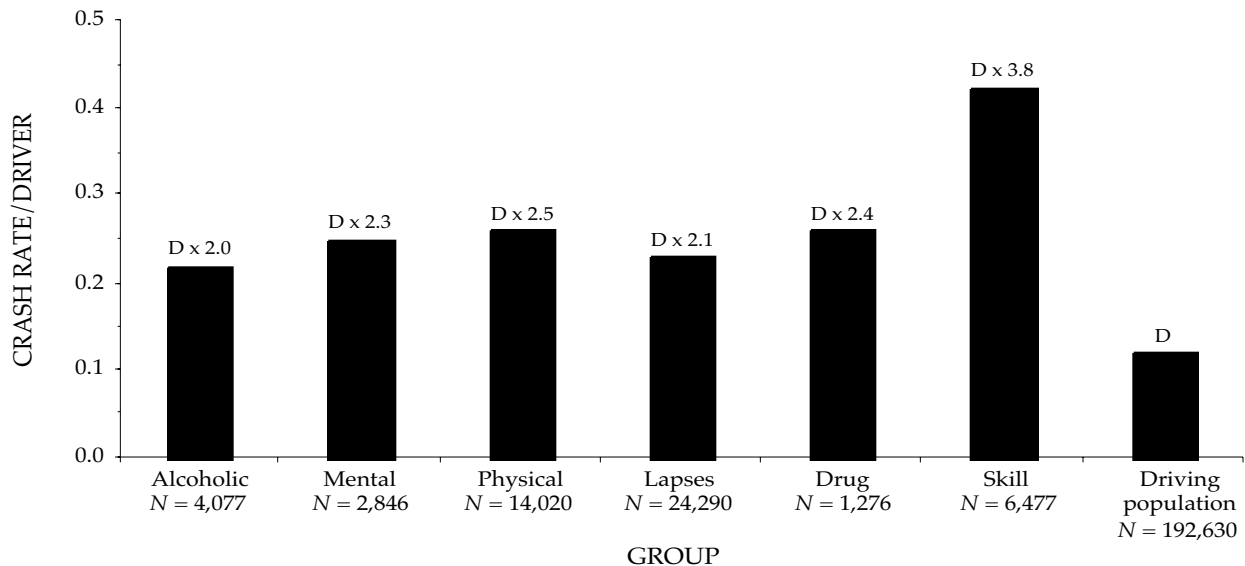
Some caveats are that all P&M drivers are cases known to DMV by definition, so they may be especially severe cases at higher crash risk than the average for their condition. Also, in interpreting the accident rates it should be kept in mind that some of these drivers’ contacts were scheduled precisely *because* they were involved in a possibly condition-related crash; this would inflate the prior accident rate for their group.



*Note.* D represents crash rate per driver for a sample randomly selected from the driving population. Entries above bars for the other groups show how many times larger each group’s crash rate per driver is than the population rate, D.

**Figure 1.** Prior 2-year crash rate by group for all drivers with a P&M contact during 1991 and comparison drivers.

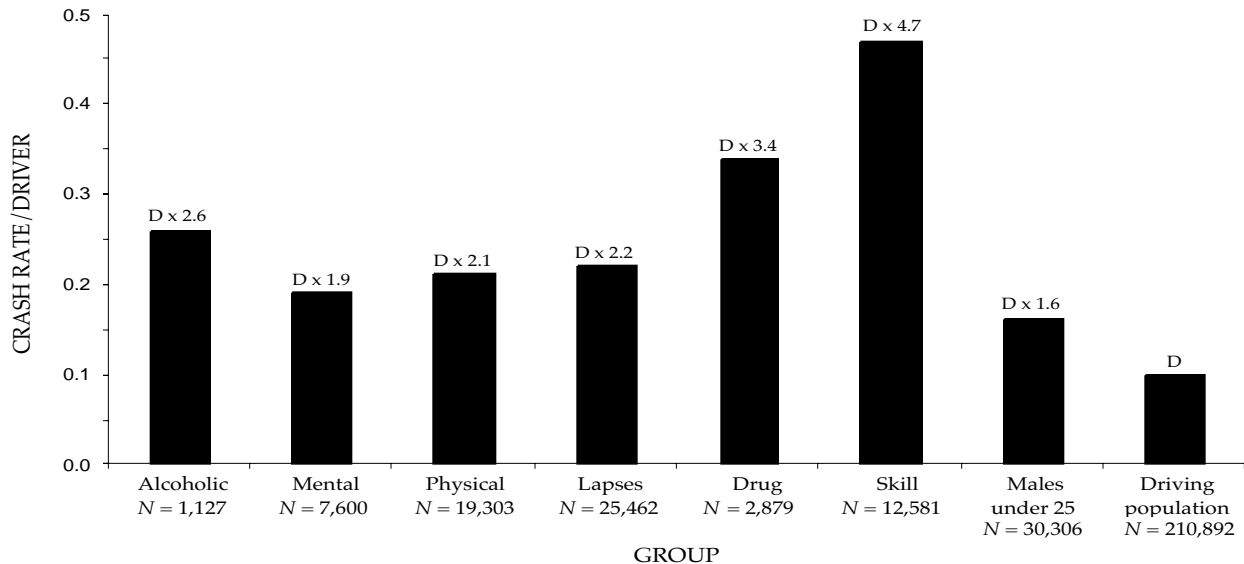
Figure 2 shows the result of standardizing accident rates to the age and sex distribution of the driving-population sample (only the age distribution in the case of the Drug group). This roughly equated the groups on demographic variables, so that between-group differences could be attributed to something other than age or sex. The Drug group's rate was standardized only by age because of a highly unstable mean in the cell representing older (55 and above) women, of whom there were only four. These four, with five accidents among them, had an extremely high accident rate which would have inflated the group's relative rate to 3.4. In general, standardization produced only minor changes in the risk profile of the groups.



Note. D represents crash rate per driver for a sample randomly selected from the driving population. Entries above bars for the other groups show how many times larger each group's crash rate per driver is than the population rate, D.

**Figure 2.** Prior 2-year crash rate by group, standardized to comparison group by age and sex (drug group only by age), for all drivers with a P&M contact during 1991.

For purposes of the present report, Mitchell and Gebers (2001) replicated the Janke (1993) analysis. A pass through the driver license database identified all drivers who showed on their records a departmental contact during 2000 initiated by Driver Safety for a P&M reason. Two comparison samples were also randomly selected, one from the driving population and another from the set of males under age 25 within the driving population. P&M drivers again were separated by reason code into the six major P&M categories used by the department (Alcoholism, Mental Condition, Physical Condition, Lapses of Consciousness, Drug Addiction, and Lack of Knowledge or Skill). Each driver's earliest date of P&M contact within the year 2000 was taken as the zero point or reference date for the purpose of defining "prior" crash involvements, and comparison drivers were assigned reference dates equivalent to those of the P&M subjects. All individuals' driving records for the 2 years prior to reference date were accumulated. Crash rates and relative rates are shown by group in Figure 3, which can be compared with Figure 1.



Note. D represents crash rate per driver for a sample randomly selected from the driving population. Entries above bars for the other groups show how many times larger each group's crash rate per driver is than the population rate, D.

**Figure 3.** Prior 2-year crash rate by group for all drivers with a P&M contact during 2000 and comparison drivers.

Results for 2000 differ in certain respects from those for 1991. Considering first the Alcoholic and Drug groups, the percentage of drivers in the former decreased from 7.7% of drivers with P&M contacts in 1991 to only 1.6% in 2000, while that of the latter increased from 2.4% in 1991 to 4.2% in 2000. Relative crash rates of both groups increased substantially. These differences are difficult to interpret. The makeup of the Alcoholic and Drug P&M groups, and therefore their risk, is highly dependent on law, policy, and procedure changes. Therefore this issue will not be considered further in the present paper, especially since it has been firmly established that alcohol and drugs impair driving.

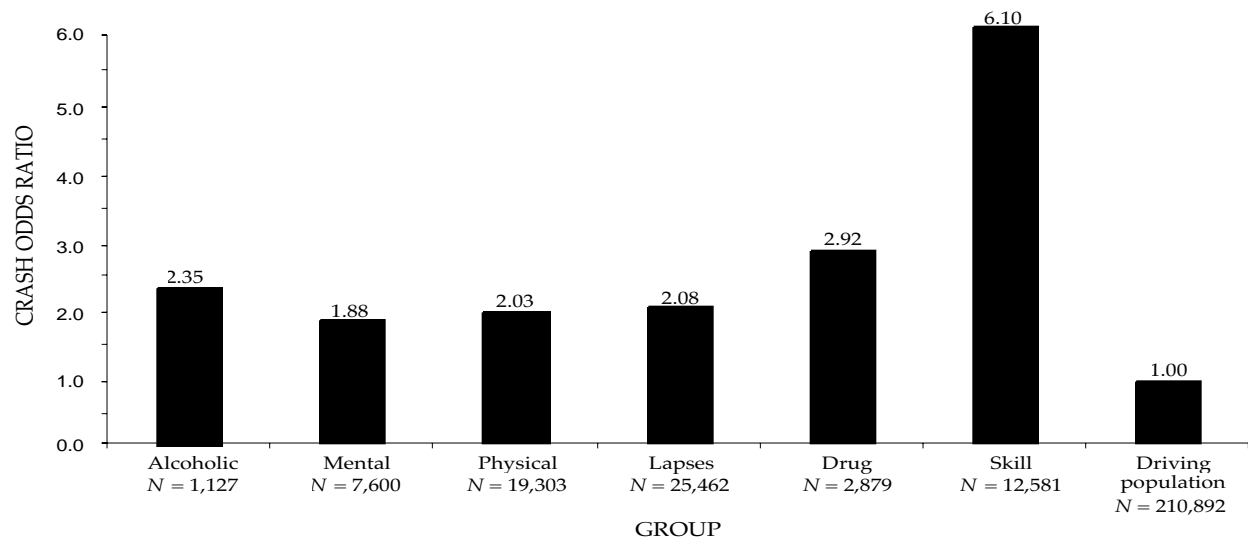
The Mental category includes dementia as well as mental illness, and the 1988 requirement that physicians report cases of Alzheimer's-type dementia, as well as the increasing number of elderly people, probably account for the greater part of the category's size increase since 1991. In 1991 the Mental category represented 5.4% of P&M contacts, while in 2000 it represented 11%, more than a twofold increase. The group's relative crash rate for the 2 years preceding a P&M contact, however, had decreased from its 1991 value. It was now lower than that of any other P&M group—possibly reflecting, in part, more widespread reporting of dementia cases at a very early stage of their disease.

Lack of Knowledge or Skill, called Skill in the figure, has consistently shown the highest relative crash rate of any P&M group. It represented 18.2% of drivers with P&M contacts in 2000, having been 12.2% in 1991. This 49% increase may reflect both more stringent DMV testing criteria and an increasing elderly population.

As mentioned, the Skill group is composed largely of older people; in 2000 the average age of the group was a little over 70 (Mitchell & Gebers, 2001). People entering it have sometimes been reported by law enforcement or other members of the public because of a perceived lack of driving skill and safety apparently not due to willful negligence, or they may find themselves in the group through failing licensing tests. For example, a driving test is required for three-time knowledge test failures (once they have finally passed the test on another license application). If, then, the driving test is failed their licenses can be revoked by the field office examiner—but, because they may request a hearing from Driver Safety, they will become part of the P&M program and placed in the Skill category. Skill cases generally have some notable medical impairment or a combination of medical impairments.

Relative crash rates for the Physical and Lapses categories differed only negligibly from their 1991 values. The groups' relative rates in 2000 were 2.1 and 2.2 times that of the driving population, respectively; the corresponding figures in 1991 had been 2.2 and 2.1. Lapses, the largest P&M group, comprised 36.9% of drivers with P&M contacts in 2000, 19% less than its 45.8% of such drivers in 1991. The Physical group, the second-largest P&M category, comprised 28.0% of drivers with P&M contacts in 2000, 5.7% more than its 26.5% of such drivers in 1991.

Mitchell and Gebers used a statistical technique to adjust for differences in the sex and age composition of the groups shown in Figure 3. The purpose of the adjustment was to measure and rule out their effects, so that conclusions could more readily be drawn about the effect of medical conditions *per se*. These sex- and age-adjusted results are shown in Figure 4.



*Note.* The number above each bar corresponding to a group is the same as the value shown on the Y-axis—i.e., the odds of a crash for that group compared with the odds of a crash for a group randomly selected from the driving population. The driving population group is compared with itself, so its odds ratio equals 1.00. For other groups, values less than 1.00 indicate less, and values more than 1.00 indicate more, than the population risk.

**Figure 4.** Ratio of P&M group's crash odds to driving population's crash odds for all drivers with a P&M contact during 2000, after adjustment for age and sex.

On the Y-axis of Figure 4 are ratios (called “odds ratios”) representing the odds of involvement in at least one crash during the prior-2-year criterion period for drivers in each P&M group, divided by the corresponding odds for the driving-population sample. The precise odds ratio for each group is shown above the bar corresponding to it. (The Mitchell & Gebers paper, “Technical Supplement to ‘Medical Conditions and Other Factors in Driver Risk’,” is available to interested readers through the Research and Development Branch within DMV’s Licensing Operations Division.)

In the remainder of the present paper, driving-related effects of a few specific medications and medical conditions (including orthopedic disabilities, not considered a P&M condition) will be discussed. The discussion will begin with some medical conditions reportable under California Health and Safety Code Section 103900 and continue with others that are not required by law to be reported, though of course they may be.

## **Reportable Conditions**

### **Epilepsy**

Among the conditions that California physicians are required to report to DMV, epilepsy may be the one most commonly reported, though not by that name. The word “epilepsy” comes from the Greek word for “seizure,” and basically refers to a type of event rather than a disease, since there can be many causes of seizures. These include brain tumors, brain trauma, and vascular malformations in the brain, while in many other cases the cause may be unknown. Whatever the cause, it is self-evident that if a driver suddenly loses consciousness at the wheel an accident is likely to happen, explaining the primacy of “loss or lapse of consciousness” in the reporting law. Hansotia and Broste (1991), considering the effect of epilepsy on crash risk, noted that early studies showing a greatly inflated risk are not completely applicable today because of medical advances. In addition, many earlier studies dealt with the presumably more severe cases of patients at specialized epilepsy clinics or, they added, with driver-patients who were known to licensing agencies and therefore might be expected to have had poorer driving records than the average for their condition. Hoping to get a truer picture of risk, the authors conducted a population-based study in Wisconsin, taking as subjects active driver-residents of seven contiguous ZIP-code areas in that state.

There were 241 active drivers with epilepsy in the region who constituted the epilepsy group. The remaining drivers, more than 30,000, became the comparison group for epilepsy. The study period included the 4 years 1985 through 1988. During this period, medical records showed, 19% of the epilepsy patients had three or more seizures and another 25% had one or two seizures, leaving 56% who experienced no seizure in the 4 years.

Age-standardized “mishap ratios” (SMRs; essentially odds ratios) were calculated for moving violations and accidents during the study period. Again, this standardization was done to make the epilepsy group and the comparison group comparable in terms of age composition, so that any differences in driver record between groups could not be attributed to age differences. For epilepsy patients compared to all drivers in the region not having epilepsy, “careless driving” violations, injury accidents, and driving-

under-the-influence (DUI) violations showed statistically significantly inflated SMRs of 1.57, 1.63, and 2.75, respectively. (Statistical significance of a result refers to the great unlikelihood of its having been due to chance.)

Since standardized mishap ratios estimate the risk of a certain type of unpleasant incident for the epilepsy group relative to that risk for the non-epilepsy comparison group, adjusting for age differences, an SMR greater than 1.0 indicates greater risk for the group in the numerator, the epilepsy group. Specifically, the SMR of 1.57 (for “careless driving” violations) indicates a risk 57% greater than “age-normal” for drivers with epilepsy, while the SMR of 2.75 (for DUI) indicates a risk 175% greater than “age-normal.” Hansotia and Broste felt that “careless driving” violations were more likely than willful violations to be a result of lapses of concentration, consciousness, or bodily control. They also noted that chronic alcohol and drug abuse might well play a part in both the causation and the medical management of epilepsy, lowering the threshold for seizures and reducing compliance with treatment. The first supposition is supported by evidence from Ng, Hauser, and Brust (1988), who reported that alcohol use in itself can cause seizures.

The statistically significant finding for injury accidents and the finding of no difference between groups for PDO (property-damage-only) accidents suggested to Hansotia and Broste that patients might not have reported their less serious accidents, though other explanations were tenable. Despite the evidence for increased violation and accident risk, the excess risk of epilepsy patients was not felt by the authors to be extreme. In fact, they considered it not great enough to warrant further restrictions on the driving privilege than those that already existed. They pointed up this conclusion by estimating that the excess risk associated with epilepsy accounted for about 13 of the 5,665 accidents occurring in the area over the 4-year study period, while drivers under the age of 25 (a much larger group than epilepsy patients) had 1,058 more accidents than would have been expected if the accident rate for all drivers of 25 or more had applied to them. Wisconsin later changed their required seizure-free period for driving to 3 months, but it is not known whether or not that was in response to the study.

Gastaut and Zifkin (1987) appeared to paint a different picture, though they warned that their results could not be used to predict the frequency of seizures while driving for epileptic drivers, or for that matter the overall accident risk of an unselected sample of drivers with epilepsy. They studied 400 drivers attending a specialized epilepsy center in France, presumably more severe cases than average. Out of these 400, one third (133 patients) admitted to a seizure behind the wheel at some time, with 69 or 52% of the 133 having a resultant crash. In 82 driver-patients a seizure of a defined type was witnessed by a third party, and the experience of these drivers was studied more intensively. Among the 82 there had been 109 seizures at the wheel, and 60 (55%) of the 109 seizures had led to a crash for 43 (52%) of the 82 drivers. These 60 crashes definitely caused by seizures injured 13 people, two of them fatally. By far the most common seizure type involved in crashes (53 of the 60 seizures, or 88%) was complex partial (i.e., not generalized) seizure, or CPS. This was due in great part to the frequency of that type of temporal lobe seizure in the epileptic population of driving age—81% of the patients in the Gastaut and Zifkin study had CPS. In most instances of CPS, the patient has a brief loss of contact with “reality” and a similarly brief period of mental confusion after the attack is over, but posture and balance are maintained throughout.

Among the 82 driver-patients studied intensively, 74% had a seizure at least yearly, 46% at least monthly, and 23% at least weekly. All of them—that is, all those with seizures at least yearly—were ineligible to drive in France. However, France did not require physicians to report seizure cases to the licensing agency, and many patients with epilepsy had failed to report themselves. Males between the ages of 19 and 30 in higher socioeconomic classes formed the majority of patients continuing to drive without adequate seizure control, and Gastaut and Zifkin recommended that occupational and social pressures on these patients to drive be mitigated. A driver license should be granted to epilepsy patients, they said, only if they have remained seizure-free at least a year.

In the 1980s Maryland, like Wisconsin, changed its laws regarding epilepsy to require a 3-month seizure-free period for driving; previously the period had been 1 year. Fisher and Krumholz (1988) noted, following this change, that generally speaking there has been a progression from great strictness to relative leniency in regulating the driving of patients with seizure disorders. They supported the change, noting that it would probably increase compliance in reporting the condition and in reporting property-damage-only accidents. They admitted that fatal accidents can unquestionably occur during epileptic seizures, and noted that certain studies (e.g., that of Gastaut and Zifkin) of patients attending epilepsy clinics have uncovered strong relationships between their seizures—especially complex partial seizures—and motor vehicle accidents. However, they wrote, these self-selected patients are not representative of the general population of drivers with epilepsy.

Fisher and Krumholz pointed out that although accidents directly caused by a seizure appear to be rare overall, it has been estimated that the average accident rate of the group of drivers with epilepsy is approximately twice that of the population as a whole (Crancer and McMurray, 1968). (This figure agrees roughly with California findings, as shown in Figures 1 and 3, for the P&M Lapses category—composed for the most part of drivers with seizure disorders.) They recognized the problems of nonreport of minor accidents and medication toxicity, but warned that harsh legal restrictions on driving by individuals with seizures might not reduce accident risk, noting that countries with very strict limitations on driving with epilepsy tend to report particularly frequent and severe traffic accidents related to epilepsy. Since extremely strict regulations encourage noncompliance, Fisher and Krumholz argued, sensible but less severe restrictions actually might reduce the risk of traffic accidents.

Concerning seizure prediction, these authors stated that the best predictor appears to be seizure frequency over a period of time. In general, they noted, 3 months is a relatively good predictor of a 1-year seizure-free period; 85% of a sample of 73 patients in a seizure clinic who were seizure-free for 3 months remained seizure-free the subsequent year. With longer time periods prediction improves, but only marginally. In using a 3-month interval, Fisher and Krumholz noted, an attempt was made to strike a reasonable balance between the risk of a new seizure's occurring while driving and causing an accident, and the probable benefits of greater reporting compliance and uninterrupted work, with an improved quality of life for the patient.

Mernoff (1999) identified the issue of allowing driving with epilepsy as one of determining which subsets of these drivers are at particularly high risk. He noted that risk factors for crashes or moving violations among drivers with epilepsy include being young, male, unmarried, and having a history of multiple seizures, a lack of anti-epileptic treatment, and a history of alcohol abuse. He cited a finding of Gastaut and Zifkin (1987) that the presence of an aura and lack of change in mental activity during the seizure (i.e., a simple as opposed to a complex partial seizure) reduced the likelihood that a given seizure would cause a crash.

A recent study of risk factors for crashes directly caused by a seizure was conducted by Krauss, Krumholz, Carter, Li, and Kaplan (1999). Their investigation was a “case-control study” which looked at the prior driving records of 50 “cases,” who had experienced a crash caused by a seizure, and 50 matched “controls,” who had not. All of the subjects had epilepsy, and on the average controls drove the same amount as cases. Factors the authors identified as statistically significantly reducing the odds of a seizure-caused crash—or, in other words, reducing the odds of being in the case group rather than the control group—were long seizure-free intervals, auras that consistently warned of a seizure before it occurred and persisted long enough for the driver to get off the road, few prior crashes of any type, and having had their anti-epileptic drugs reduced or switched. This last finding surprised the authors. To explain it they suggested that recent interactions with their physicians caused patients to take their medications more regularly, though it is also a possibility that reduction in seizure frequency could lead directly to a reduction in medication. Also a recent contact with a physician concerning epilepsy medication is an indicator that the subjects were receiving medical treatment for their condition; see Mernoff’s finding (above) that lack of epilepsy treatment is a risk factor. Nevertheless, since several patients did in fact crash during the period when they were switching or tapering medications, Krauss et al. recommended that patients not drive during this period.

Treatment of a medical condition can itself increase crash risk. For example, Manji and Plant (2000) discussed the effects of surgical resection of a part of the temporal lobe to reduce or eliminate seizures of temporal lobe epilepsy. This, the authors wrote, is now an important therapeutic option for patients with medically intractable seizures which would otherwise prevent them from driving. However, one complication of temporal lobectomy is visual field deficit, which in itself can make driving hazardous and can lead to disqualification for driving by some licensing agencies. In the Manji and Plant study, a small number (24) of patients who had undergone temporal lobe surgery for epilepsy were assessed to determine whether they had developed a visual field defect and whether it would disqualify them for driving according to the UK driving criterion of, in part, “at least 120 degrees width on the horizontal.” Using standard perimeter tests, a field defect was found in between 46% and 54% of the patients; between 25% and 42% would have failed to meet the UK visual field requirement.

Like surgical treatment, the anticonvulsant medications taken by epilepsy patients may themselves impair driving. (Medication effects are discussed further in a later section of this report.) Trimble and Thompson (1983) reported a series of studies comparing the effects of three anticonvulsant drugs—sodium valproate, phenytoin, and carbamazepine—on perceptual and cognitive performance. Investigating performance on tests of attention, perceptual speed, decision making, visuomotor response, and



motor speed during a 2-week drug period, and comparing this with performance on the same tests during a 2-week placebo period, they found that phenytoin caused the most impairment. This drug statistically significantly impaired ability "across all aspects of higher cognitive function" (page 20), although it did not affect the visuomotor response as measured by a simple reaction time task. Degree of impairment was significantly correlated with serum levels of phenytoin; in other words, there was a statistically significant dose-response relationship. The other two drugs, while having some impairing effect, were not as deleterious as phenytoin.

Trimble and Thompson noted that these results are in general agreement with others reported in the literature. Phenytoin has generally unfavorable effects on many aspects of cognitive function. Newer anticonvulsants such as sodium valproate and carbamazepine are less toxic in this respect, and it has been reported (Jeavons and Clark, 1974) that a change to sodium valproate therapy improved school performance and attention in children. With respect to driving, Trimble and Thompson speculated that the adverse effects of phenytoin may be less important in routine driving than in a situation, like an impending crash, where rapid and immediate action is called for. They also made the interesting point that anticonvulsants are not prescribed only for epilepsy, but also for a wide range of disorders including chronic pain, heart disease, anxiety, and manic-depressive illness. Therefore they cautioned that the growing use of these drugs emphasizes the need for further studies of their effects on behavior and cognitive function, and raises questions about the kind of warnings and advice that physicians prescribing such drugs should routinely give their patients.

### **Diabetes mellitus**

As stated in a DMV "Fast Facts" publication on diabetes mellitus, in this disease blood sugar levels are too high—a condition called hyperglycemia. This can impair safe driving by causing drowsiness, confusion, nausea, impaired vision and, if the hyperglycemia is very severe, impaired consciousness. (At this point the patient would not usually be driving.) On the other side of the coin, treating the condition—especially by means of insulin—can overcorrect the glycemic level and cause overly low levels of blood sugar, called hypoglycemia. This can also degrade driving, and probably does so much more commonly than the opposite condition. Hypoglycemia can cause sudden impairment of judgment, loss of coordination, disorientation, dizziness, seizure, and loss of awareness or consciousness. The occurrence of a lapse or loss of consciousness which might recur would make a case reportable under California Health and Safety Code Section 103900.

The risk for treated diabetics of hypoglycemia while driving has led to the common precautionary measure of keeping something in the car to eat and thereby raise the blood sugar level, and to the strongly recommended precaution of always checking blood sugar level before driving, and driving only if it is not too low. Education of the diabetes patient regarding precautionary measures has been so successful that hypoglycemic reactions are rarely implicated in crashes. However, insulin-dependent diabetes is not common, particularly among elderly people. For these, Hansotia (1993) wrote, the problem is to identify long-term complications of the condition that contribute to reduced driving function—such as blood vessel disease, nervous system involvement, early-appearing cataracts, and the fatigue, lethargy, and sluggishness that accompany poor diabetic control.

There are two kinds of diabetes—type I, in which the pancreas does not produce enough insulin to maintain normal blood sugar levels, and type II, in which insulin is produced but the body develops resistance to its effects (Berkow, Beers, & Fletcher, 1997). Among diabetics, about 10% are type I and the remaining 90% type II. All cases of type I (also called insulin-dependent, formerly known as juvenile-onset) diabetes, and type II patients taking insulin—or even some oral medications—to control their condition are reportable under California's lapse law if they experience hypoglycemic reactions causing a loss or lapse of consciousness. Long-term complications like those noted above are not in themselves required to be reported.

Several studies of diabetic drivers were done in the 1960s and 1970s. With the exception of a Swedish study by Ysander (1970) which found no association between the disease and increased crash risk, these showed an inflated accident rate for diabetes patients as a group, the inflation ranging from a 4% to a 78% increase. (The largest figure, which was mileage-adjusted and therefore not truly comparable to the others, came from Waller's "Review of the California Experience" in 1965.) These figures do not indicate dramatically elevated risk, though they do make a case for some increase in risk, which may be caused by relatively subtle deficits. Papers by Lasche' (1985) and Pramming, Thorsteinsson, Theilgaard, Pinner and Binder (1986) on impairment of cognitive function caused by hypoglycemia pointed out that, well before the "lapse of consciousness" point is reached, one's performance on everyday tasks that require planning and control suffers—even at a blood glucose concentration not generally considered to be hypoglycemic. Ratner and Whitehouse (1989) stressed that glycemic (blood sugar) control should not be too strict for very physically active patients, or for patients whose risks from hypoglycemia due to diabetes-control efforts outweigh the risks of hyperglycemia caused by the disease. Examples they named were individuals with unstable angina or a seizure disorder. Similarly, Waller (1992) warned that the changing treatment technology which seeks to avoid late-stage renal, cardiac, or visual (diabetic retinopathy) complications of diabetes by keeping a tight control on blood glucose level has disquieting implications for driving. Hypoglycemic episodes are much more common under overly tight control and, even at modest levels of hypoglycemia, cognitive changes may occur that have the potential for making a driver unsafe without his or her being aware of the condition.

The Hansotia and Broste (1991) report, discussed above in connection with epilepsy, contained information on diabetic drivers as well. Of drivers living in the seven ZIP-code areas in Wisconsin as described above, 1,819 had diabetes. From these drivers, 484 were sampled to form a study group. More than one-third of group members were being treated with insulin, despite the fact that only 10% had type I diabetes. Acute hypoglycemia is the most common side effect of insulin therapy and, during the 4-year prior period studied by the authors, 10% of the diabetic group had a reportedly severe hypoglycemic reaction. Calculating age-standardized SMRs for moving violations and accidents during the study period, as they had done for drivers with epilepsy, Hansotia and Broste found that only the ratio for injury accidents, 1.57, was statistically significantly larger for driver-patients when they were compared with drivers lacking a computerized diagnostic code suggestive of diabetes. The lack of an effect for property-damage-only accidents suggested, as it had for drivers with epilepsy, a possible failure of diabetes patients to report these less serious accidents. As in the case

of epilepsy patients, the authors considered the increased risk of drivers with diabetes not sufficient to warrant further restrictions on their driving privilege.

Cox, Gonder-Frederick, and Clarke (1993) investigated performance decrements in a driving simulator during and after hypoglycemia, as well as the subjects' awareness of their decrements. They studied a volunteer sample of 25 adult type I diabetes patients who had responded to newspaper advertisements soliciting their participation. These volunteers had had the condition for a considerable period (15 years on average) and were experienced drivers (19 years on average). They operated Atari Games Corporation's interactive driving simulator on two consecutive days, which were randomly assigned for each patient to be "control" and "treatment" days. Intravenous insulin was administered as required to obtain specific blood sugar levels. On the control day, which might come either first or second, there were four 4-minute driving tests at euglycemia (a "good" blood glucose level). On the experimental day the four driving tests were given at euglycemia, mild hypoglycemia, moderate hypoglycemia, and again at euglycemia. Patients were unaware of their blood sugar levels. Simulated driving performance was not disrupted at mild hypoglycemia. However, moderate hypoglycemia disrupted steering, causing more swerving, erratic yawing, driving over the midline, and driving off the road. Subjects' recognition of their own impairment was not reliable; after driving (poorly), 25% were still willing to drive.

Cox, Gonder-Frederick, Kovatchev, Julian, and Clarke (2000) refined and extended the earlier study, using a more sophisticated driving simulator and an induction of hypoglycemia through gradual insulin infusion that was better representative of reality. Thirty-seven drivers with type I diabetes drove the simulator for 30 minutes during euglycemia and progressive hypoglycemia. Driving performance, brain waves, and corrective behaviors (swallowing a glucose drink to counteract the hypoglycemia, or stopping the test) were continually monitored. Driving skills were impaired even during mild hypoglycemia though, in all ranges of blood glucose tested, fewer than one-quarter of the drivers were aware that their ability to drive was impaired. Subjects showing substantial impairment were more likely than others to take corrective action, but 6 of the 14 subjects who were seriously impaired during hypoglycemia (43%) did not take any corrective action. Observed driving abnormalities included (sometimes simultaneously) inappropriate braking in the road and driving too fast, in addition to going across the midline and off the road as seen in the earlier study. Some subjects failed to stop at stop signs and many were involved in simulated crashes.

According to Frier (2000), describing the Cox et al. (2000) study, the most alarming observation in the study was that only a minority of the drivers treated their hypoglycemia and/or stopped driving, and in most cases not until their blood glucose had declined to a low level. This reluctance to stop or self-treat, Frier wrote, has been noted previously in medical reports, with some drivers describing a compulsion in real-world driving to keep on despite experiencing symptoms of hypoglycemia. Whether this impaired judgment and loss of rational decision-making can progress to a form of automatism while driving has yet to be determined, Frier stated. He advised diabetic drivers to test their blood glucose before driving and, as Cox et al. (2000) recommended, to ingest carbohydrates if blood glucose is less than a recommended value. "In effect," Frier wrote, "the approach to driving should be similar to that for

premeditated strenuous exercise . . . . While hypoglycemia is responsible for only a very small percentage of road traffic accidents, it can undoubtedly affect driving performance adversely and must be avoided by all diabetic drivers when they are behind the wheel” (p. 149).

McGwin, Sims, Pulley, and Roseman (2000) conducted a population-based case-control study of the relationship between chronic medical conditions, medications, and crashes in the elderly. All subjects were aged 65 or more. According to official records, “cases” had been at fault in at least one crash during 1996. One group of study controls had been involved in a crash during 1996 but were not judged at fault, and another control group had not been crash-involved during that year. The study purpose was to determine whether cases differed from controls in being more likely to have specific diseases or take specific medications, which would allow an inference that certain disease conditions or medications were associated with enhanced crash risk. Aside from the crash fault information, all data were obtained by means of telephone interviews, so disease conditions and medications as well as some personal data were determined through self-report. At this point only the results on diabetes will be mentioned; other relevant results are mentioned at appropriate spots below. Even after statistical adjustments had been made for age, gender, race, and annual mileage, McGwin et al. reported, subjects reporting diabetes, diabetic retinopathy, or diabetic neuropathy (nervous system involvement) were not found to have statistically significantly increased odds of being in the at-fault crash group as opposed to either of the two control groups. Thus, in this study there was no association between diabetes and at-fault crash involvement.

### **Sleep disorders**

Sleep disorders (e.g., narcolepsy, essential hypersomnolence, obstructive sleep apnea) are another reportable cause of possible lapse of consciousness at the wheel. Patients with one of these disorders can fall asleep with little or no warning while driving (Parkes, 1983), and common sense suggests that this can easily cause traffic crashes. Even when the driver does not actually fall asleep at the wheel, some sleep disorders cause a general lethargy which, research indicates, leads to an inflated crash rate. Parkes noted that patients with essential hypersomnolence are persistently not quite awake—though, on the contrary, narcoleptics are alert between attacks. Heavy meals, bodily fatigue, sedatives and alcohol increase the tendency to fall asleep in patients with sleep disorders (as they do in people without them).

Automatic behavior and “sleep drunkenness” can occur in all disorders of excessive sleep, but are most common in hypersomnolence, according to Parkes. During periods of automatic behavior, driving (and accidents) may occur but there is amnesia for the period of the attack. Sleep drunkenness, which occurs most commonly after waking from a deep sleep, causes incoordination and can seriously impair driving ability.

Untreated narcolepsy, while uncommon, appears to be a cause of some traffic accidents, but much of the substantiation in this area is anecdotal. Parkes reported a survey of 64 narcoleptic patients in which 48% admitted falling asleep while driving, and 25% a resultant crash. Only 4% had stopped driving because of their narcolepsy, however. The average number of attacks in this sample was four to five per day. Treatment of narcolepsy with stimulant drugs like amphetamine and methylphenidate increases

alertness and reduces the frequency of daytime sleep attacks according to Parkes, though attacks are totally abolished in only a minority of cases. Up to one-third of patients become tolerant to amphetamine over the first 3 months of treatment, lessening its effectiveness. Drug treatment of essential hypersomnolence and sleep apnea is usually not very effective.

Parkes recommended that patients with any of these conditions refrain from driving, with the exception of those with well-controlled narcolepsy whose attacks are not sudden. However, effective treatments have recently been developed for obstructive sleep apnea, a relatively common disorder, so the prognosis for driving with that condition may have improved. In sleep apnea the patient's airway repetitively closes during sleep; the resulting lack of oxygen wakes the person, interrupting his (less commonly, her) sleep repeatedly. According to Dement and Mitler (1993), the National Commission on Sleep Disorders Research, which was charged with a 1988 Congressional mandate to evaluate the general societal effects of sleep deprivation, found that 95% of the 5 to 10 million Americans with severe sleep apnea are unaware of their condition and consequently may face cardiovascular complications that may even cause sudden death. Before these extremes occur, patients are more likely to fall asleep during daily activities like driving because of their interrupted sleep at night.

Findley, Levinson, and Bonnie (1992) discussed studies demonstrating the high traffic accident rates of drivers with severe sleep apnea. One of these, by George, Nickerson, Hanly, Millar, and Kryger (1987), found that the accident rate of a group of 27 apneic patients was twice that of a control group of 270 non-apneic subjects. An earlier study by Findley, Unverzagt, and Suratt (1988) found that the crash rate of 29 patients with obstructive sleep apnea was 2.6 times the average rate for all licensed drivers in the state of Virginia. Supporting evidence that sleepiness contributed to this increased accident rate came from the admission by 24% of the apneic patients that they fell asleep at least once a week while driving.

Sleep apnea patients, Findley et al. (1992) noted, tend to have delayed reaction times and difficulty maintaining concentration. A simulator study by Findley, Fabrizio, Knight, Norcross, and LaForte (1989) was cited, in which six untreated patients with obstructive sleep apnea were compared to an age- and sex-matched control group of seven subjects. Performing on a Doron driving simulator, patients (despite the very small size of the groups, which made finding statistical significance more difficult) were significantly worse than controls in reacting to highway, city, and rural driving films.

Attempting to use more readily available testing equipment, Findley et al. studied performance on "Steer Clear," a relatively inexpensive 30-minute test of obstacle avoidance administered on a personal computer. Twelve patients with severe obstructive sleep apnea and 12 age- and sex-matched controls performed on Steer Clear. Patients hit more obstacles than controls did (averages of 44 and 9, respectively), and this result was statistically significant. Treatment for 3 to 5 months with nasal continuous positive airway pressure (nCPAP) improved patients' performance to the extent that, though directionally worse, they were no longer significantly worse than controls.

Steer Clear had earlier been found by Findley et al. (1988) to correlate statistically significantly with crashes per driver over a 5-year period, in a sample of 68 patients with either sleep apnea or narcolepsy. Patients who performed normally on the test had a reported crash rate of 5 per 100 drivers; those performing poorly had a rate of 20 per 100, and those whose performance was extremely poor had a rate of 38 per 100, 7.6 times as many as the 5 for normal performers.

Haraldsson, Carenfelt, Persson, Sachs, and Tornros (1991) investigated long-term driving performance before and after uvulopalatopharyngoplasty (UPP) surgery for obstructive sleep apnea. Fifteen apneic patients were run in an "advanced" driving simulator before and after surgery. Their performance was compared to that of 10 age-matched non-apneic controls. All subjects "drove" for 90 minutes on a monotonous course simulating a rural trip at twilight, while brake reaction time, lateral position deviation, and running-off-road episodes were measured. Before their UPP operation, patients were statistically significantly worse than controls on measures of brake reaction time and lateral position deviation; moreover, eight patients drove off the road, compared to one of the controls. Following surgical treatment, performance improved for most (though not all) patients, while no improvement (which might have come from practice) was noted for retested controls. Only the changes in brake reaction time were statistically significant, however. After surgery 12 of the 15 patients reported marked reduction of sleepiness while actually driving on the road.

A review paper by Mernoff (1999) has been cited above in connection with epilepsy, but it was not limited to epilepsy. The paper concerned paroxysmal disorders and driving, and sleep disorders were some of the conditions discussed. Mernoff stated that analyses have shown a two- to three-fold increased crash risk for persons with sleep apnea. He cited a study by Teran-Santos, Jimenez-Gomez, and Cordero-Guevara (1999) that controlled for many potentially confounding variables and still revealed a strong association between sleep apnea and crash risk. He also noted that Haraldsson, Carenfelt, Lysdahl, and Tornros (1995), in a more recent study than the one cited above, had shown that UPP surgery improved attention and driving performance in patients for at least 3 to 4 years.

Mernoff also cited Horne and Reyber (1995), who wrote that, apart from sleep disorders, other risk factors for having a sleep-related vehicle accident include being male, being less than 30 years old, having limited sleep just before driving, driving long distances, and driving on the job. The peak incidence of these sleep-deprivation accidents was reported to be in the late afternoon and early morning.

More recently, a simulator study of patients with obstructive sleep apnea was conducted by Juniper, Hack, George, Davies, and Stradling (2000). The authors pointed out that there are two distinct visual tasks involved in steering accurately along a road. The first involves processing the view of the road close to the vehicle, which enables the driver to maintain exact position in the lane. The second involves processing the view of the road ahead, which allows the driver to predict the required positioning of the car as the road curves. Other simulator studies, they wrote, while showing that performance is impaired by obstructive sleep apnea (and improves with nCPAP, see above), have not included a realistic perspective view of a road curving ahead and therefore have not measured the second visual task involved in accurate steering.

Juniper et al. compared the performance of 12 patients with moderately severe obstructive sleep apnea with that of 12 healthy matched-control subjects. Controls had been matched to patients on age, sex, and driving experience. Subjects performed three 30-minute drives—one with the road ahead completely visible, another with only that part close to the driver visible, and the third with only that part far from the driver visible. A divided-attention task was added in which subjects were to identify target numbers, shown at the four corners of the screen, as quickly as possible while they were driving. Statistically, apneic patients performed significantly worse than controls in terms of steering error, slower detection of target numbers, and running off the road. They were especially impaired relative to controls on the two drives where only part of the road was visible. The authors suggested that apneic driver-patients may thus be more disadvantaged than normals when the view of the road ahead is obscured, as in fog.

The conditions discussed thus far have largely been paroxysmal; that is, symptoms come as a sudden attack and are not continually present. Certainly lapse or loss of consciousness cannot be continually present in a driver, almost by definition. For this reason DMV does not generally assess drivers with epilepsy or sleep disorders on a road test—a seizure or an episode of sleep would be extremely unlikely to occur during such a test. In the case of diabetes, a chronic disease that can affect many organ systems, a road test can be used for assessment of the patient's general fitness for driving, but the most extreme hazard—lapse of consciousness from hypoglycemia—would again not be expected to occur on the test.

For lapses of consciousness in general, but seizure disorders particularly, DMV has recognized a need for standardized guidelines to assess driver-patients for their liability to lapses while driving. Various risk factors (e.g., a high frequency of seizures before treatment, substantial abnormalities on neurologic examination [Fountain, Lewis, & Heck, 1983]) are related to seizure recurrence, but the relationships are not strong enough to allow prediction in the individual case—even under the assumption that licensing agency staff have sufficient expertise to weigh all of the medical evidence. Therefore the primary criterion used in California (and, generally speaking, in other states) to determine when driving may be resumed is the length of time since the last seizure, called the seizure-free period. (The concept of “seizure-free period” can also be applied to other types of recurrent lapse episodes, like syncope.) In making a licensing decision for an individual driver, it is also necessary to consider other factors—for instance, his or her prior driving record. Some are mitigating factors, like demonstrated reliability and compliance with a medical regimen; others are exacerbating factors, like alcohol consumption. The last is important, considering the findings of Hansotia and Broste (1991) concerning DUI offenses of patients with epilepsy, and that of Ng et al. (1988) concerning the relationship between alcohol consumption and seizures.

According to a DMV survey made shortly before the following guidelines were developed, there was no overall policy on the length of required seizure-free period among Driver Safety office managers. The periods used ranged from 3 to 12 months, with no formalized guides as to when to use any particular length. To improve standardization of procedures and comply with 1991 legislation, guidelines were

formulated with the help of California's Medical Advisory Board and an associated "lapses of consciousness" panel including neurologists, other physicians, patient advocates, and DMV staff. The following guidelines were developed and approved by departmental management.

Departmental Guidelines for Lapses of Consciousness	
1.	No seizure-free period is required for drivers with isolated episodes of lapse of consciousness (e.g., fainting due to strong emotion).
2.	No seizure-free period is required if only nocturnal seizures have been experienced. However, these drivers should be monitored through medical probation. If seizures become diurnal, a reexamination is appropriate to further evaluate driver condition or, if necessary, take an immediate suspension.
3.	When physician-directed medication change leads to a seizure, no seizure-free period is required if drivers resume taking their previous medications.
4.	A 3-month seizure-free period is required if physician-directed medication change or withdrawal leads to a seizure and there is no resumption of previous medications.
5.	A 3-month seizure-free period is required for considering medical probation type II, in which the driver's physician submits regular health status reports to the department.
6.	A 3-month seizure-free period is required if an individual experiences a single seizure after a 6- to 12-month seizure-free period. Probation type II is imposed.
7.	A 6-month seizure-free period is required before placing a driver on medical probation type III, in which the driver rather than the physician submits health status reports to the department. Here the condition has been well controlled for 6 months, but probation is maintained because of some contributing factor that might cause instability.
8.	If the condition is stable and has been controlled for at least 6 months, and there are no coexisting medical or other factors that would exacerbate it, no action is taken.
9.	If seizures (more than one) recur following a 6- to 12-month seizure-free period, a 12-month seizure-free period will be required before the patient is allowed to resume driving.

Before adoption of these guidelines, probation was rarely used in lapse-of-consciousness cases. The types of probation in use were type I, in which the driver promised to see a physician regularly and report to the department any change in his or her condition, and type II, which required medical reports from the driver's physician. The new guides substitute probation type III (which requires regular health reports from the patient) for probation type I, to better comply with legislation (Health



and Safety Code Section 103900 [e]) calling for DMV, in consultation with professional medical organizations, to "develop guidelines designed to enhance the monitoring of patients affected with disorders specified in this section in order to assist with the patients' compliance with restrictions imposed by the Department of Motor Vehicles on the patients' licenses to operate a motor vehicle."

### **Dementia**

Most research evidence indicates that drivers with dementia are at increased crash risk and, moreover, may drive for an extended period of time after disease onset and even after crash occurrence (e.g., Gilley, Wilson, Bennett, Stebbins, Bernard, Whalen, and Fox, 1991). Alzheimer's disease is the most common type of dementia, and Dubinsky, Williamson, Gray, and Glatt (1993) found that although, relative to control subjects, Alzheimer patients reported driving less, avoiding rush hour and highway traffic to a greater extent, and driving more slowly, they still had a greater self-reported accident rate per year—twice as great as their own average rate prior to disease onset (a statistically significant difference). Their rate was also about twice as great as the study control group's rate. This difference was not significant, but it became so when accident rates were adjusted for the patients' lesser mileage.

For this reason dementia has been a matter of concern in traffic safety, and is one of the conditions the law requires to be reported. Even though it does not technically involve a lapse of consciousness, Alzheimer's-type dementia is reportable under the "Reporting Disorders Characterized by Lapses of Consciousness" law, California Health and Safety Code Section 103900. However, as mentioned, it is placed by DMV in the Mental P&M category rather than the Lapses category. While there are more than 60 recognized forms of dementia, as noted above the most prevalent is Alzheimer's disease (AD), typically a steadily progressive condition. In the 15% of Americans over age 65 who have some form of dementia to some degree, more than half (50-60%) of the cases are attributable to AD (Barclay et al., 1988). An additional 20-35% of cases are attributable to multiple infarct dementia (MID), hypoxic brain damage, or small vessel disease of the brain—Barclay and associates suggested that these last three be collectively called the "circulatory dementias" and more recently they have been called "vascular dementias." Vascular dementias result from impaired blood circulation in the brain that causes malfunctioning or death of nerve cells.

AD causes death of nerve cells in the brain as well, but through a different mechanism which has not been entirely clarified. The prevalence of AD increases in an accelerated manner with increasing age; the condition was found, in a study cited by Cummings and Benson (1983), in 2% of 65- to 70-year-olds, 4% of 70- to 80-year-olds, and 22% of those beyond age 80. The average annual incidence for people aged 65 and above was 1.4%, with an overall prevalence rate of 6.2%. Very high prevalence percentages have been claimed for people over age 85; according to Kuhn (1999), 47% of these very aged people have been found to show symptoms of AD (though this does not necessarily imply actual AD; there may have been other reasons for their cognitive impairment).

There have been many studies of dementia and driving, several fairly recent. Gilley et al. (1991) surveyed the primary caregivers of 522 patients from a dementia clinic, a relatively large sample for a dementia study. Of these patients, 333 were licensed to drive at the onset of their disease and their median duration of driving after onset was

approximately 29 months. Patients with AD (two-thirds of the group) drove longer after onset than did those having other dementing conditions, with a median duration of 34 as compared to 24 months. Of the 93 patients still driving at the time of the survey, 23% were reported to have had at least one crash in the preceding 6 months—and 33% to have had a crash, a traffic violation (cited or not), or a near miss. The accident data are certainly suggestive of an inflated rate, although there was no control group. (Had there been one, it is doubtful that near misses and uncited violations could have been recorded in an equivalent manner for that group.) Patients who were taking sedative medications for agitation associated with their dementia had statistically significantly more reported crashes than those who were not.

The finding of Gilley et al. that drivers with dementia are at increased crash risk and may drive for an extended period after disease onset—and even after crash occurrence—support similar findings of Friedland, Koss, Kumar, Gaine, Metzler, Haxby, Moore, and Rapoport (1988), those of a survey study of Alzheimer's patients by Dubinsky et al. (1993), and conclusions drawn from an extensive review of the literature on dementia by Kaszniak, Keyl, and Albert (1991). Friedland et al. reported that the odds of a crash since recognized disease onset in the AD group were 7.9 times greater than odds of a crash during the past 5 years for an age-matched comparison group. The finding of Dubinsky et al. has been described above.

Hunt, Edwards, and Morris (1990) described a study at Washington University in St. Louis in which 1-hour road tests were administered to 27 dementia patients and 13 healthy controls matched on age, sex, driving experience, and educational level. Of the patients, 13 had possible AD and 14 mild AD. Ratings of driving competence made by a driving instructor ignorant of the subjects' medical condition showed that all controls and all questionable AD cases were judged capable of driving; 6 or 43% of drivers with mild AD were also judged to be capable. Unlike the conclusion of some earlier studies (e.g., Friedland et al., 1988; Lucas-Blaustein, Filipp, Dungan, and Tune, 1988) that a diagnosis of AD should preclude driving, Hunt et al. recommended that public policy in this area incorporate measures of dementia severity rather than diagnosis alone, since some patients with mild AD still demonstrate fitness to drive.

Results of a study by Beattie, Tallman, Tuokko, and Weir (1991) support the position that driving-related performance, rather than diagnosis *per se* or even severity of the condition, should be used to determine dementia patients' fitness to drive. Analyzing accident records of 165 clinic patients considered to have dementia at the time of assessment, some of whom were no longer driving, they found that the proportion of patients who had been involved in an accident while they were driving (again, by the time of assessment some had given it up) was statistically significantly greater than the corresponding figure for a control sample randomly selected and matched on age, sex, and area of residence. However, among "survivors" who were still driving, the dementia sample did not contain a statistically significantly greater proportion of crash-involved drivers than the control sample. There was also no significant difference in dementia severity between patients who had stopped driving and those who continued to drive—or, in patients still driving, between those accident-involved and those accident-free.

In another study conducted by the same research group, Beattie, Tuokko, and Tallman (1993) found that their dementia sample had, over a 3-year period, a crash rate about 2.5 times the rate for control subjects individually matched with patients on age, sex, and area of residence in British Columbia. Crash data came from official records. The control sample used by Beattie et al. came from a stratified random sample of the driving population, so it was more representative of drivers in the general population than the volunteers who have been used as controls in some other studies. There were no mileage data available, but it was found that the majority of the dementia group continued driving after symptom onset—for up to 3 years—even after being involved in accidents "for which they were almost always responsible." More than one-third of the crash-involved dementia patients had at least one more crash before they finally stopped driving (Cooper, Tallman, Tuokko, & Beattie, 1993).

Odenheimer (1993) pointed out, in a review based in part on her own work with associates administering driving tests to the elderly (Odenheimer, Beaudet, & Grande, 1991; Odenheimer, Beaudet, Grande, & Minaker, 1994), that drivers with dementia tend to make typical errors while driving. Their distractibility contributes to errors at intersections and sites where traffic merges. Deficits in judging distance and spatial relationships may interfere with the driver's ability to maintain lane position and estimate a safe gap in oncoming traffic. Isolated memory loss, Odenheimer wrote, may be relevant only where there is a change in routine, such as a detour from the familiar route. Similarly, isolated language impairment should not greatly affect driving in familiar settings, though in unfamiliar settings it would be expected to affect the interpretation of road signs. In agreement with other authors, Odenheimer stated that deficits in simple reaction time would be unlikely to play a role in driving safety. Thus, the major factors making for unsafety in dementing drivers appear to be declines in attention and visuospatial skills. Odenheimer was careful to point out, however, that most often the deficits seen in dementing disorders are not isolated, but occur in variable combinations of deficits in memory, language, visuospatial abilities, selective attention, and "executive functions" like planning.

A study conducted at the Sepulveda Veterans Administration Medical Center in California (Fitten, Perryman, Wilkinson, Little, Burns, Pachana, Mervis, Malmgren, Siembida, & Ganzell, 1995) involved, in addition to automated neuropsychological tests, an especially innovative driving test now called the "Sepulveda Road Test." This was administered on the Medical Center grounds to samples of early AD patients, non-stroke diabetics, early multiple-infarct dementia (MID, a circulatory dementia) patients, and healthy elderly drivers. Tests were given on Saturday mornings when there was light traffic, and were supposed to be roughly the equivalent of a drive in the suburbs. The course was about 2.5 miles long, and on it the investigators set up several areas to specifically test information-processing skills. For example, one intersection displayed several signs to which the driver had to selectively attend—STOP, NO LEFT TURN, and (in the path straight ahead) DO NOT ENTER. The only permissible alternative was to turn right. Dementia patients found it notably difficult to interpret the signage and arrive at the correct conclusion. Some stopped in the intersection, unable to proceed.

A plot of driving scores by group showed only slight overlap between the dementia and non-dementia groups. Dementia patients (AD and MID) were statistically significantly worse than diabetes patients, who were slightly but not significantly worse

than normals. The AD group was the worst of the four. Controlling for cognitive test performance, Fitten and his associates also compared driving performance scores for a subgroup consisting of non-stroke diabetics and AD patients matched by score on a widely used test of mental status measuring basic cognitive functions. Because of the matching, these groups were equivalent in cognitive status as tested, so the AD patients were presumably only very mildly impaired. But there was no overlap in the driving scores of these AD and diabetes patients; the diabetes group was superior. Even though the mental status test was found to be a good predictor of driving performance for the total sample, this finding suggests that the particular cognitive skills it measures (including orientation to time and place, immediate and delayed verbal recall, naming objects, following a three-stage command, etc.) are not those most relevant to driving.

The research evidence consistently points to increased crash risk for drivers with dementia, as a group. Evidence for actual brain features characteristic of Alzheimer's disease in fatally injured drivers comes from Johansson, Bogdanovic, Kalimo, Laaksonen, Berkowicz, Druid, Eriksson, Krantz, Sandler, Thiblin, Lannfelt, Winblad, and Viitanen (1997). An examination of cortical frontal and parietal association areas was performed at autopsy on 98 drivers, ranging in age from 65 to 90, who had died in an automobile crash. The investigators remarked that "senile" plaques and neurofibrillary tangles are the neuropathological hallmarks of AD, though it is possible to have AD without having the latter. With respect to plaques, degree of certainty of an AD diagnosis depends upon whether they are sparse, moderate, or frequent. In one-third of the cases studied by Johansson et al. the age-related plaque score indicated AD, and in an additional 20% the number was high enough to suggest AD. Moreover, genetic analysis showed that dead drivers over age 75, statistically significantly more often than age- and sex-matched controls, had the particular form (allele e4) of the apolipoprotein E gene found to increase the risk of late-onset AD. The authors concluded that many older drivers killed in traffic accidents may have impaired cognitive function, which could have caused their accidents, due to undiagnosed AD.

The study of Hunt, Edwards, and Morris (1990) was cited above. It concluded, among other things, that persons with mild AD may still be competent to drive. According to the dementia guidelines for California DMV (see below), drivers whose dementia is characterized as "mild" by their physician may be licensed following tests that include a road test, if other conditions are favorable. That is, the diagnosis in itself does not preclude driving, though monitoring of such drivers is necessary to detect worsening of their condition. Corroboration of the Hunt et al. findings and support for this DMV policy comes from a later study also performed by the group at Washington University in St. Louis, Carr, Duchek, and Morris (2000). The purpose of this study was to determine whether there was a difference in crash rates and crash characteristics between 63 drivers with AD and 58 nondemented control drivers of approximately the same age. For this purpose the 5 prior years of state-recorded crash data were analyzed and study participants took a road test, after which some were advised not to drive. (The period of 5 years was chosen because subjects with dementia had, on average, about 4 years of cognitive decline, as reported by a collateral source (e.g., a relative), before the first diagnosis of AD, and it seemed to the investigators that the collateral source, usually a relative, often underestimated the duration of pre-diagnosis cognitive decline. A prior period of 3 years was also used and there were no changes in

the general findings.) In addition to driving records, a daily driving diary was completed by each subject or their collateral, and used to estimate their annual mileage.

All subjects with AD were in the “very mild” or “mild” stages of the disease, as staged by a standardized clinical rating scale. Judging from the driving diaries, drivers with mild AD drove less than those with very mild AD, and drivers with AD drove less as a group than control drivers. Crashes were infrequent for both the AD subjects and the controls, and there were no statistically significant differences between the groups. Before adjustment for mileage, drivers with AD showed a total accident rate that was directionally lower than that for controls, although they also showed nonsignificant trends toward more at-fault accidents, more injury accidents, and more crashes in which they were cited for failing to yield. Those in the “mild AD” group (more impaired) showed a directionally lower total accident rate than drivers in the “very mild AD” group, again probably a function of lower mileage. Despite study limitations which they discussed, the authors concluded that their findings represent further evidence that driving privileges should not be suspended based on diagnosis alone.

California DMV guidelines for drivers with dementia follow. They were developed in the early 1990s as the result of meetings of a “dementia panel” consisting of Medical Advisory Board members, specialist physicians not on the MAB, a patient advocate, and DMV staff. The physician panel members included specialists in neurology and geriatrics, among other disciplines. These guidelines represented the first systematized rules the department had adopted for dealing with drivers with dementia; they are stated here only in broad terms.

Departmental Guidelines for Dementia
<p>One intent of the guidelines is to disqualify from driving any patient having a firm diagnosis of moderate or severe dementia. However, if the medical report indicates that the dementia is mild (this is asked specifically of the physician), further evaluation ensues.</p> <p>The driver is scheduled for a reexamination, the first stage of which is a test of knowledge of traffic laws and rules of the road. A driver who fails is disqualified, though with the right to request a hearing. A driver who passes is interviewed by DMV Driver Safety staff. Evidence developed from interviewing the driver may indicate that he or she is not safe to drive. In that case the license is revoked, again with the right to a hearing.</p> <p>If there is a possibility that the person may be capable of safe driving, a lengthy special road test is scheduled, along with the usual vision test. Failure of the road test leads to revocation with the right to a hearing. Success in both tests allows continuation of the driving privilege, although the driver will be scheduled for departmental reexaminations at regular intervals (“calendar reexaminations”). Also, applicable driving restrictions (for example, to a specific familiar area) will be imposed.</p>

As a conclusion to that part of the present paper which deals with reportable conditions, and as an introduction to the following topic, vision disorders, it is important to

mention the existence of a growing body of research that is revealing changes in visual functions associated with Alzheimer's disease (Cormack, Tovee, & Ballard, 2000). In fact, these authors cited work ranging back to 1983 which gives evidence for vision changes in AD, and characterized the visual impairment as low-level (here meaning sensory as opposed to cognitive impairment) and focusing specifically on contrast sensitivity and visual acuity.

The acuity decrement apparently shows itself only under conditions of low light, and therefore would not be detectable in ordinary Snellen-chart acuity testing like that given for licensure. The contrast sensitivity decrement appears to be more pervasive in AD patients. Cormack et al. stated that the ability to detect changes in contrast is the foundation upon which vision is based, and they cited research showing that AD patients generally exhibit reduced contrast sensitivity at all spatial frequencies tested. Thus, they would have difficulty differentiating an object (vehicle, pedestrian, letter on a sign, etc.) from its background if the contrast between object and background was not great. This clearly would affect driving and, in fact, performance on all sorts of tasks that require vision. For instance, in a study of glaucoma patients (see glaucoma below), contrast sensitivity loss was the best predictor of impairment in carrying out visually guided tasks, particularly navigation outdoors (Rose, Bron, & Clarke, 1984).

## **Other Medical Conditions**

### **Vision disorders**

Vision is an indispensable function for driving. The vision disorders most harmful to safe driving appear to be those that severely limit central vision, as macular degeneration can; those that severely impair contrast sensitivity, as glaucoma and untreated cataracts can; and those that severely restrict peripheral vision, as retinitis pigmentosa can. These conditions and others are discussed below.

**Cataract.** Many causes of vision impairment are age-related (perhaps more accurately, aging-related); they are more apt to occur in older people, though this does not mean that they occur only in older people. One which is dramatically age-related is cataract, clouding of the lens. However, unlike the case for many other conditions, a very effective treatment is available for cataract. Intraocular lens implantation—replacement of the clouded lens by a synthetic lens implanted within the eye—brings about a functional cure. Therefore it is untreated cataract that increases crash risk.

According to Klein, Klein, and Linton (1992) as cited in Owsley and McGwin (1999), almost half of older adults have early cataract by age 75, and approximately one quarter have late cataract. Before reducing visual acuity the condition typically impairs contrast sensitivity. Drivers with even early cataract that does not notably affect their high-contrast visual acuity can be expected to have driving difficulties—particularly with glare, as in strong sunlight when contrast differences can wash out in a bright haze, and at night or in fog, when low luminance reduces the contrast between objects and their backgrounds. In fact, most visual system pathologies reduce contrast sensitivity, but glaucoma and cataracts produce the most marked reduction (National Research Council, 1987). In addition to impaired contrast sensitivity, Johnson and Keltner (1983), doing automated visual field screening of 10,000 volunteer driver's license applicants in California, found that cataract was one of the most common causes of visual field loss. (Others were retinal disorders and glaucoma.)

At the time of writing, in early 2001, vision screening for licensure at DMV consists only of a test of high-contrast visual acuity using black letters against a white background. If this is passed at the 20/40 level, absent other indications the license applicant will not be referred to a vision specialist for examination of additional visual functions. This is relevant to cataract because impairment of central visual acuity by cataract may be a very slow process. Some cataract patients who are believed by their ophthalmologists to have marked glare disability or contrast sensitivity loss (as might be tested, for example, by using light gray stimuli against a white background or dark gray stimuli against a black one) show little decrease in their visual acuity. For example, Adamsons, Rubin, Vitale, Taylor, and Stark (1992), wishing to determine the effect of cataracts on glare disability and contrast sensitivity, tested 83 subjects with varying types and amounts of lens opacities and 27 comparison subjects without opacities. Their data confirmed that although individuals with mild to moderate lens opacities have diminished contrast sensitivity and increased glare disability, decreased visual acuity accounts for little of this disability. This is consistent, Adamsons et al. wrote, with previous reports showing that glare disability and contrast sensitivity are unrelated to visual acuity.

Owsley, Stalvey, Wells, and Sloane (1990) examined crash risk in older drivers with cataract. Almost all (97%) of their cataract group had clouded lenses in both eyes, with at least one eye having a best-corrected visual acuity of 20/40 or worse. (20/40 is the DMV vision screening standard; a score worse than this entails referral to a vision specialist for examination and possible correction.) The comparison group was composed of drivers of similar age without cataract or other eye diseases. Compared to this group, cataract patients were 2.5 times as likely to have had a crash during the prior 5 years, after adjusting statistically for mileage, age, coexisting medical conditions, and level of cognitive functioning as shown by a standard test, among other factors. The adjustment process ensured that the result could most plausibly be attributed to cataract or the lack of it, rather than to mileage or one of the other factors.

**Glaucoma.** A common cause of blindness worldwide, glaucoma damages the optic nerve; this damage is usually, though not always, associated with increased pressure within the eyeball. Patients typically show visual field loss. This is an important limitation for driving; for instance, Johnson and Keltner (1983) found that, over the 3 years prior to vision testing, drivers with binocular field loss had traffic accident and conviction rates (adjusted for mileage) twice as high as those with normal visual fields. (There was no difference from controls for subjects with only monocular field loss, suggesting that these drivers compensated adequately by turning their heads.) Contrast sensitivity loss is also a feature of all forms of glaucoma, and in the most prevalent form of the disease is affected even before field loss is noticeable (Saraux & Nordmann, 1990). Patients may also show visual acuity loss, poor night vision, and poor depth perception.

Drugs can control intraocular pressure in glaucoma; there are topical as well as systemic medications for the condition, though it has been reported that the use of topical medications for glaucoma increases the risk of falling in elderly persons (Glynn, Seddon, Krug, et al., 1991). Also, laser or conventional surgery can open aqueous outflow paths to reduce pressure, though existing optic nerve damage cannot be

reversed. Retinal vascular complications that occur in one form of the disease can be contained to some degree by laser photocoagulation treatment, but the most serious complications affecting the macula (the area of the retina, lying slightly lateral to its center, that includes the region of maximum visual acuity) cannot be treated in this way because the treatment might destroy normal retinal tissue.

Owsley and McGwin (1999), in a review of vision impairment and driving, cited several studies of crash risk in older drivers with glaucoma. One of these, conducted in Washington state by McCloskey, Koepsell, Wolf, and Buchner (1994), indicated that older drivers involved in an injury collision were 50% more likely to have glaucoma than were those not involved in any crash. (Owsley and McGwin pointed out, however, that in this study other factors which could have confounded the result, such as coexisting medical conditions—comorbidity—and mileage, were not controlled.) Foley, Wallace, and Eberhard (1995) also found an increased crash rate (unadjusted for mileage) for older drivers with glaucoma. Hu, Trumble, and Lu (1997), studying a cohort of elderly people from 1981 to 1993, found that male drivers with a self-reported history of glaucoma were 1.7 times more likely than those not reporting glaucoma to be involved in a crash. No relationship was found for women. Finally, Owsley, McGwin, and Ball (1998) found that older drivers involved in injury crashes during the prior 5 years were 3.6 times more likely than those who were crash-free to have glaucoma.

**Diabetic retinopathy.** This is a vascular complication of both type I and type II diabetes, discussed above. In diabetic retinopathy, deterioration of the blood vessels of the retina can lead to ischemia (a lack of adequate blood supply) and from there to pathological growth of new blood vessels (proliferative retinopathy) with possible hemorrhage and blindness. Contrast sensitivity loss is an early symptom (Saraux & Nordmann, 1990). Reuben, Silliman, and Traines (1988) noted that among persons aged 65 or more, those with longstanding diabetes (at least 15 years) are about twice as likely as those with a disease duration of 5 years or less to have retinopathy. Among diabetic drivers, they wrote, 8% have proliferative retinopathy, 5% are blind in one eye, and 2.4% have a severe bilateral decrease in visual acuity. The hyperglycemia which is the defining symptom of untreated diabetes mellitus is also associated with blurred vision even in the absence of retinal disease, due to changes in the hydration of the lens.

In a Wisconsin epidemiological study of diabetic retinopathy, 3.6% of younger-onset patients (under 30 at onset) and 1.6% of older-onset patients (30 or more at onset) were legally blind (Aiello, Gardner, and King, 1998). In the first group, 86% of blindness was attributable to diabetic retinopathy; the figure was 33% for the second group. Overall, according to Owsley and McGwin (1999), diabetic retinopathy is estimated to be the most frequent cause of new cases of blindness among adults aged 20 to 74 years. No studies have shown an association between diabetic retinopathy and increased crash risk, though the 57% higher rate of injury accidents found for diabetic drivers by Hansotia and Broste (1991) may in part have been due to retinal changes associated with the disease. It should be mentioned that diabetes is associated with non-retinal ocular changes as well (Swann, 1999). Some of those listed by Swann were refractive changes, changes in the cornea, cataract, neuropathies of cranial nerves (which may cause, for instance, double vision), and glaucoma.



**Age-related macular degeneration.** The macula of the retina (or the fovea centralis, which is at its center) provides the greatest visual acuity. It has the highest concentration of cones, the photoreceptor cells essential for sharp vision. There are different kinds of “maculopathies” or macular pathologies; in one kind, called age-related macular degeneration, the nourishment of the cones in this area of the retina is disrupted and they die, resulting in a loss of central visual acuity. There are two types of the disease—wet, which involves leaking blood vessels, and dry, which does not. The wet type is much less common but accounts for 90% of cases of legal blindness. This type is treatable by means of a laser, but treatment only prevents further visual loss; it does not restore vision which has already been lost. The much more common dry type is not treatable, but neither is it as severe in its effects; it usually reduces central vision only to levels of 20/50 to 20/100 (Beers & Berkow, 2000). Owsley and McGwin (1999) noted in their review of the vision literature that very few studies have discussed the condition’s impact on driving, though they cited several indicating that drivers with age-related macular degeneration (AMD) report more difficult driving, more avoidance of challenging driving situations, and less risk-taking behavior than drivers without the condition.

The Washington State study of McCloskey, Koepsell, Wolf, and Buchner (1994) found no association between AMD and crash involvement, but as noted above it did not take driving exposure and some other factors into account. Considering the evidence for AMD drivers’ avoidance of various situations, it seems likely that self-restriction counteracted the elevation in crash risk that would have been expected for them. While AMD patients performed worse than age-matched normal drivers in a variety of driving situations on a simulator and on the road, they also had had fewer crashes than the normal drivers, suggesting the effectiveness of their self-restriction.

**Retinitis pigmentosa.** Retinitis pigmentosa, or RP, is a rare inherited disease in which the retina progressively degenerates, eventually causing blindness (Berkow, Beers, & Fletcher, 1997). The rods (the second type of photoreceptor cell, concentrated in the periphery of the retina and to be distinguished from cones), which enable vision in low light, degenerate so that vision becomes poor in the dark and, over time, in the periphery. In late stages of the disease, the patient has a small area of central vision mediated by cones and little peripheral vision remaining (tunnel vision). No treatment can slow the progression of retinal damage, according to Berkow et al.

Fishman, Anderson, Stinson, and Haque (1981) reported that drivers with RP were involved in more crashes during the prior 5 years than disease-free controls, an association due in part to a disproportionate number of female RP patients who were crash-involved. However, severity of patients’ visual impairment was not shown to increase the probability of a crash.

Szlyk, Severing, and Fishman (1991) assessed the driving performance of RP patients on an interactive driving simulator test developed by Atari Games Corporation. All of their subjects showed varying degrees of peripheral visual field loss due to their disease. Performance of the 21 people in the RP group was compared to that of 31 visually normal control subjects. Subjects in both groups were required to have Snellen acuity of at least 20/40, and in fact all drove regularly. The groups were statistically equivalent in age, sex, years of driving experience, and annual mileage. The first

symptoms of RP often begin in early childhood; here the youngest subjects were in their thirties and the oldest in their sixties. After measurement of binocular visual fields, subjects completed the simulation exercise in which, among other tasks, they had to follow road signs, stay in the proper lane, and react to objects in the periphery. Subjects also reported the number of crashes in which they had been involved within the last 5 years, and the investigators obtained their official (Illinois) driving records covering the last 5 years. The latter included only accidents in which police were called to the scene and filed a report.

Subjects with RP reported statistically significantly more accident involvement than control subjects did. This was true both for total accidents and for accidents involving failure to detect information in the visual periphery. In this study, unlike that of Fishman et al. (1981), risk varied directly with severity of visual field loss. However, no statistically significant differences between groups were found for state accident records, which was perhaps not surprising in view of those records' limited nature. RP subjects tended to show a higher rate of simulator crashes than controls did; they traveled statistically significantly greater distances before reacting to peripheral information, strayed out of their lane significantly more often, and showed significantly more lateral eye movements in apparent compensation for their decreased peripheral vision.

**Low vision and use of a bioptic telescopic lens.** Bioptic telescopic lens systems, or BTLs, consist essentially of a telescope mounted before one eye to enable low-vision drivers to resolve fine detail, as in reading street signs. Persons with either congenital or acquired low vision may be allowed to gain licensure in California through the use of BTLs, despite their being unable to meet the 20/40 acuity screening standard without them. (They are no longer allowed to use BTLs to exceed the absolute 20/200 acuity cutoff for licensure, pursuant to Chapter 985, Stats. 2000.) Some special training with BTLs is needed; in driving the device is to be used only for brief "spotting" and for most purposes the driver looks through his or her regular "carrier" lenses, upon one of which the telescope is mounted. This is necessary because, when a person is looking through the telescope, its highly magnified image obscures most of the surrounding visual field. Two studies have been conducted by DMV to see how the traffic safety record of BTL users, as a group, compares to that of the driving population as a whole.

In the more recent of these, Clarke (1996) compared the 2-year accident and citation rates of the 609 drivers in California then using BTLs and over 28,000 drivers randomly selected from the driving population to serve as a comparison group. Rates were statistically adjusted to equate age and sex between the groups, and the adjusted total and casualty accident rates for the BTL group were 1.9 and 1.7 times higher, respectively, than those for the comparison group. An opposite result was found for citations; the adjusted rate for the BTL group was 0.7 of the adjusted rate for the comparison group on this measure. All differences found were statistically significant, and these differences were even greater when only drivers with valid licenses were considered. The inflated crash rates of BTL drivers confirmed results of an earlier DMV study (Janke, 1983) and suggested that these drivers may not sufficiently compensate for their increased risk, although the finding for citations is suggestive of self-limitation of the amount they drove.

**Reported driving difficulty and visual disabilities.** Possession of a vision deficiency (e.g., reduced contrast sensitivity, perhaps caused by glaucoma) does not necessarily lead to increased crashes if the affected driver avoids situations that unduly challenge his or her limited visual abilities. This was confirmed by Hennessy (1995) in a study testing drivers on an assortment of vision tests, collecting questionnaire data from them, and investigating their prior accident records. For example, for drivers aged 26-39 the association of poor contrast sensitivity with crashes depended on subjects' reported level of avoidance of heavy traffic. Those who had poor contrast sensitivity and who never avoided driving in heavy traffic experienced more crashes than did similarly impaired drivers who avoided heavy traffic. Among those who avoided heavy traffic, the number of crashes for drivers who "often" avoided it was smaller than for drivers who "sometimes" did.

A study by McGwin, Chapman, and Owsley (2000) investigated the relationship between visual abilities and reported difficulty in specific driving situations. (Avoidance, as studied by Hennessy, is related to difficulty—people who have difficulty in a specific situation and therefore tend to avoid it probably reduce their crash risk, but if they have difficulty in a situation and do not avoid it, their crash risk may well be increased. Feelings of difficulty can be based on a lack of certain specific abilities, though what they are may not be consciously recognized by the driver.) McGwin et al. asked their subjects, 384 drivers between the ages of 55 and 85 who were selected as either with (75%) or without (25%) cataracts, about difficulty they experienced while driving in various higher-risk situations—e.g., in the rain, at night, in heavy traffic, and in making left turns. They investigated the relationship between these responses and visual acuity, contrast sensitivity, glare tolerance, and "useful field of view" or UFOV—the last being a test that goes well beyond simple visual function into the cognitive arena, measuring perceptual speed, divided attention, and selective attention. Results showed particularly increased difficulty in higher-risk driving situations among those with decreased visual acuity or decreased contrast sensitivity, even after adjusting statistically for age, gender, weekly mileage, cognitive function as measured by a commonly used standardized test, and visual functions other than the one being considered. After adjustment, decreased visual acuity was statistically significantly associated with reported difficulty in making left turns and in driving at night, on high-traffic roads, during rush hour, or alone; decreased contrast sensitivity was significantly associated with difficulty in making left turns and in driving on high-traffic roads.

**Visual effects of multiple sclerosis.** These will be mentioned very briefly; research is relatively lacking in this area. In multiple sclerosis (MS), nerves of the eye, brain, and spinal cord lose patches of myelin (the "insulating" material around the axons of neurons [Berkow, Beers, & Fletcher, 1997]). The course of the disease is varied and unpredictable. In many people it starts with an isolated symptom followed by months or years without further symptoms. In others, symptoms become worse and more generalized within weeks or months. There may be remissions and relapses; as relapses become more frequent, disability worsens and may become permanent. There are promising treatments, some still under investigation, to reduce the frequency of relapses.

Symptoms, which are diverse and depend upon the area(s) affected, generally appear first between the ages of 20 and 40. While demyelination in the nerves serving muscles causes the mobility problems generally thought of as typifying MS, demyelination in pathways carrying sensory information to the brain causes sensory disturbances. Vision disturbances may include double vision, dim or blurred vision, and loss of central vision. Lessened contrast sensitivity may also be a feature; Saraux and Nordmann (1990) reported results of using a contrast sensitivity test as a diagnostic tool to detect “silent” lesions of the visual pathway in MS patients. They stated that, in this disease, bilateral involvement of the visual path was shown in almost all cases.

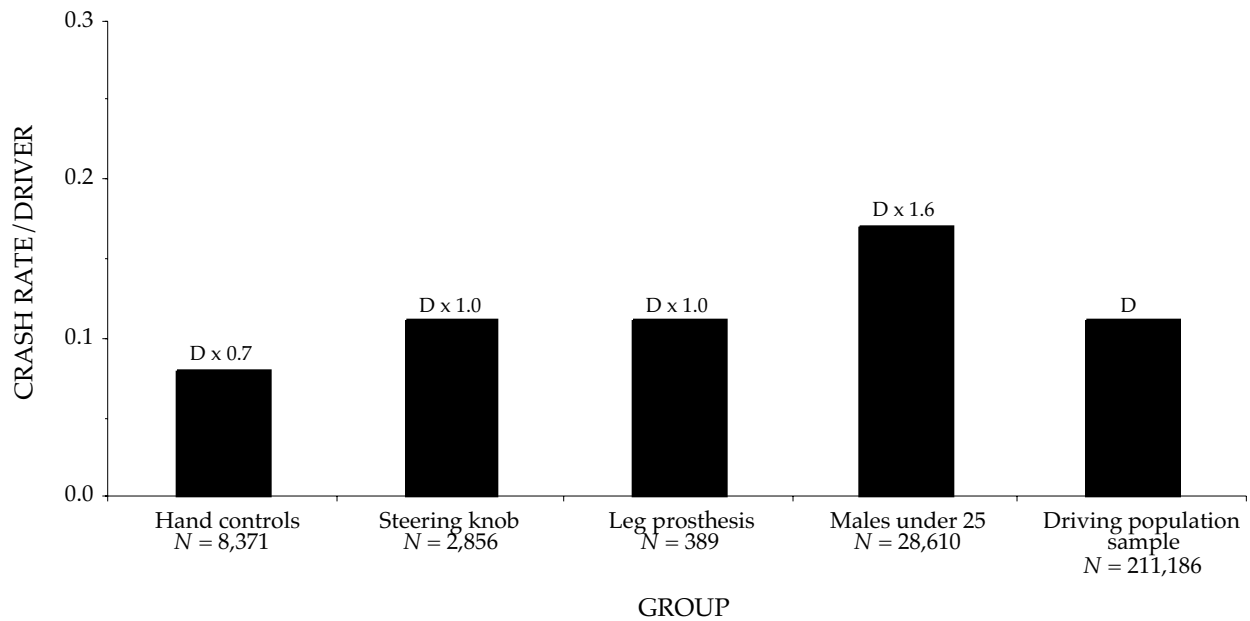
### **Orthopedic disabilities**

Whether congenitally or through disease or trauma, some drivers lack, or lack the use of, one or more of their limbs. Evidence from two DMV studies indicates that these drivers are not at increased crash risk. The earlier study was conducted at the request of California State Assemblyman John Quimby (Dreyer, 1973) to ascertain whether drivers disabled in this way have crash records different from those of population drivers. A systematic 20%, essentially random, sample of the driver license database was drawn, consisting of all drivers whose license numbers ended in 13 through 32. It included 694 disabled drivers, identified by the presence on their license of restrictions to hand controls, a knob on the steering wheel, or a leg prosthesis. These represented a population in California of about 3,500 orthopedically disabled drivers, and they were compared to a random sample of 1,237 population drivers. Disabled drivers’ crash records were reportedly “as good as or better than” those of drivers without such disabilities.

Mitchell and Gebers (2001) replicated Dreyer’s study. They identified, in a pass through the database, all drivers having one of the restrictions used in that study, and applied both a relative rate (times-as-many) analysis and an analysis using odds ratios to their driving-record data. These data were for the 2 years ending 3 months before the file pass in February 2001. (Since no date is associated with assignment of a restriction, the most recent prior period was used—with a 3-month “buffer” added to avoid losing driving incidents that were so recent they did not yet appear on the record.)

The orthopedically disabled groups were restricted to hand controls, a knob attached to the steering wheel, or a leg prosthesis. The comparison group was a random sample from the driving population; Mitchell and Gebers also used for comparison purposes a group randomly chosen from males under 25, as discussed above. Dreyer’s finding was confirmed by both of the analyses they made; the relative crash rates of all orthopedically disabled groups were equal to or less than that of the driving-population sample. The relative crash rate for the young male group was almost 60% greater than that found for any other group. Results of the relative rate or “times-as-many” analysis are shown in Figure 5. Crash rate is on the Y-axis; rates *relative* to that of the driving-population sample, called D, are above the bars corresponding to the groups, and the numbers of drivers in each group (Ns) are below the bars.

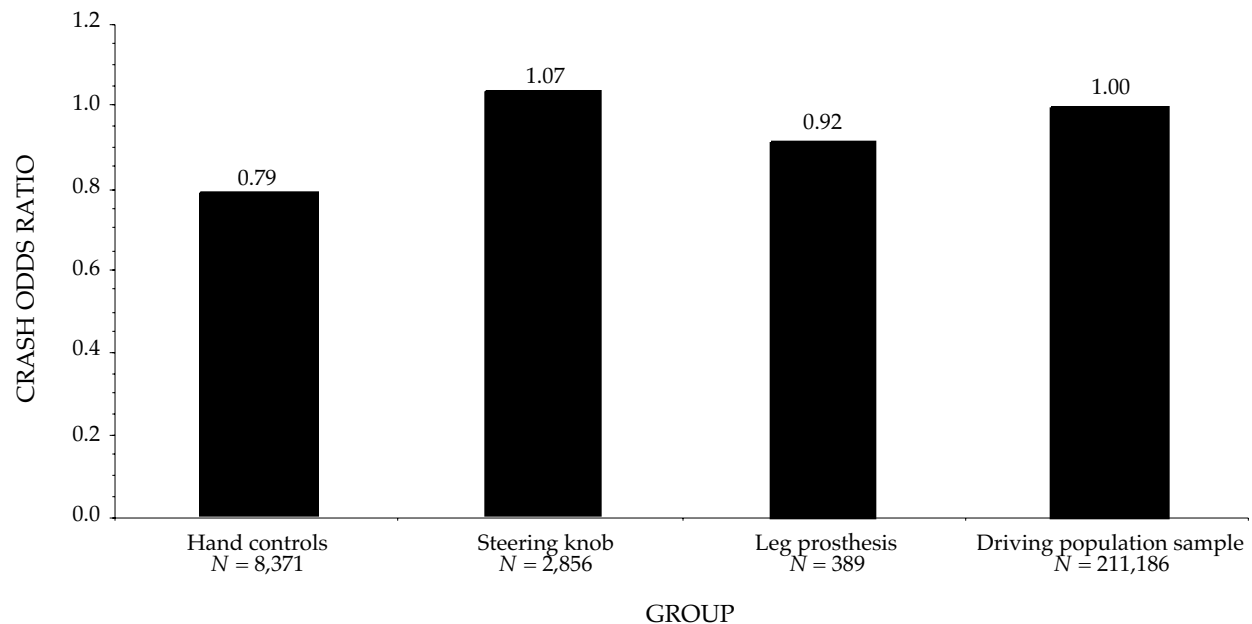
Results of the authors' statistical analysis unadjusted for age and sex will not be shown here, but they are consistent with those shown in Figure 5. This analysis produced odds ratios—which, it will be remembered, are the odds of crash involvement for each orthopedically disabled group relative to those odds for the comparison group. Odds ratios for the three disabled groups ranged from 0.8 to 1.0, again indicating a crash risk that was at worst equal to that of the driving population. Risk for the hand-controls group was less than population risk, a statistically significant difference.



Note. D represents crash rate per driver for a sample randomly selected from the driving population. Entries above bars for the other groups show how many times larger each group's crash rate per driver is than the population rate, D.

**Figure 5.** Prior 2-year crash rate by group for orthopedically impaired and comparison drivers.

In a second analysis, Mitchell and Gebers adjusted for age and sex. Group odds ratios obtained in this analysis are shown in Figure 6 on the Y-axis, and more precisely above each bar. Allowing for the fact that crash odds ratios rather than crash rates are shown, the conclusion remains the same. Only the steering-knob group had a crash odds ratio over 1.00 (the equal-odds condition), and this difference was not statistically significant—that is, there was a substantial probability that it had occurred by chance. Both the steering-knob and the leg-prosthesis groups were statistically indistinguishable from the driving population, while the hand-controls group again showed itself to be at statistically significantly lower risk.



Note. The number above each bar corresponding to a group is the same as the value shown on the Y-axis—i.e., the odds of a crash for that group compared with the odds of a crash for a group randomly selected from the driving population. The driving population group is compared with itself, so its odds ratio equals 1.00. For other groups, values less than 1.00 indicate less, and values more than 1.00 indicate more, than the population risk.

**Figure 6.** Ratio of restriction group's crash odds to driving population's crash odds for orthopedically impaired drivers, after adjustment for age and sex.

In adjusting for age and sex, Mitchell's and Gebers' analysis necessarily evaluated the independent effects of age and sex, emerging with conclusions consistent with those noted earlier in the report:

- There is a nonlinear relationship between age and the odds of involvement in a traffic accident. Drivers aged 45-59 were taken as a comparison group. Therefore, for each of the other seven age groups used by the authors, an odds ratio above 1.00 would imply greater risk, and an odds ratio below 1.00 lesser risk, than that of middle-aged drivers. An odds ratio of 1.00 would imply equal risk. (As an example, an odds ratio of 1.50 for a given age group would indicate that the group was 50% more likely than drivers aged 45-59 to have been involved in an accident during the criterion period, while an odds ratio of 2.00 would indicate that the group was 100% more likely.) It was found that the crash odds ratio was 1.80 for drivers below 25, the highest value found. The odds ratio decreased to 0.80, its lowest point, for drivers aged 70-74. Thereafter it increased somewhat, but remained below 1.00 even for drivers aged 80 or more, who showed an odds ratio of 0.96. In terms of crash odds ratio, these oldest drivers were statistically indistinguishable from the comparison group of drivers aged 45-59, while all other age groups had crash odds ratios statistically significantly different from 1.00.

- An odds ratio of 1.23 was found for sex. Since women were the comparison or referent group, this indicated that males were 23% more likely than females to have been involved in an accident during the criterion period.

### **Parkinson's disease**

Parkinson's disease (PD) is of special concern for driving because it causes progressive motor dysfunction and possible impairment of cognitive functions. Though experimental evidence for driving-related decrements associated with PD is not definitive, generally because of small sample sizes and noncomparable control groups, it is highly suggestive of increased risk. According to the Merck Manual, Home Edition (Berkow, Beers, & Fletcher, 1997), the disease affects about 1 in every 250 people over age 40 and about 1 in every 100 people over age 65.

In a study by Dubinsky, Gray, Husted, Busenbark, Vetere-Overfield, Wiltfong, Parrish, and Koller (1991), 150 patients were interviewed regarding their driving record and driving habits, and compared with 100 control subjects. Thirty patients had stopped driving on account of their disease. Parkinson's patients reported no more traffic accidents overall, though their crash rate per mile was greater than that of control subjects. There was a statistically significantly higher crash rate per mile for patients with a score indicating cognitive impairment on a commonly used screening test for dementia. In contrast, two widely used measures of general disability in PD showed no correlation with crash rate. The authors concluded that although some PD patients should not drive, 'good' drivers in the study group, 118 of whom were still driving, could not be readily distinguished from 'bad' ones.

Lings and Dupont (1992) reported a laboratory investigation of driving ability in Parkinson's patients. Using a mock car, they compared the performance of 28 patients with a median age of 65—all on supposedly optimal drug regimens and without complicating disorders—with that of 109 healthy younger (median age 49) controls. Most, but not all, subjects in both groups drove or had previously driven. Patients statistically significantly more often than controls showed failure to react to stimuli such as a red light, directional errors, reduced speed and strength of movement, and prolonged reaction times. Results did not change when subjects without a driver license were excluded. This is an example of a noncomparable control group, and it would be expected that controls would perform better because they were younger, if for no other reason. But some observations made by the authors illustrated troubling performance decrements shown by patients. Twenty-one patients could not adhere to the testing schedule because after reacting to a signal they were not ready to continue for some time. In seven cases it was necessary to urge them verbally, and five failed completely to react on at least one occasion. (This never occurred among members of the control group.) Though patients' drug treatment was reportably considered optimal, the authors concluded that this "optimality" was of limited relevance to traffic safety. Berkow et al. (1997) also made some interesting comments on the intricacies of treatment that seem relevant here. They wrote that "after several years, the period of relief following each dose of levodopa-carbidopa [the foundation of treatment for PD] becomes shorter, and periods when initiating a movement is difficult alternate with periods of uncontrollable hyperactivity. Within seconds, a person's condition may change from being fairly mobile to being severely impaired (the on-off effect). Such

abrupt changes affect more than half the people who take levodopa for 5 or more years and are usually controllable by taking lower, more frequent doses” (pp. 345-346).

Lings' and Dupont's findings are basically similar to the findings of a small-scale simulator study (Madeley, Hulley, Wildgust, and Mindham, 1990) in which PD patients with less advanced disease showed longer reaction times and less accurate steering when contrasted with healthy age- and sex-matched controls. Another small-scale investigation of PD patients' driving abilities in a simulator was conducted as a pilot study by Dubinsky, Schnierow and Stein (1992). Sixteen PD patients with a mean disease duration of 6 years, and 16 normal control subjects, were recruited from the Movement Disorders Clinic of the University of Kansas Medical Center. Unfortunately, the control group, with a mean age of 51, was again considerably younger than the patient group, with a mean age of 67. In addition, most control subjects were female while most patients were male. PD severity was determined for patients by means of a rating scale, and all subjects were administered a cognitive status test. During the (interactive) simulator test, driving tasks included curve negotiation, passing and avoiding moving traffic, dividing attention (i.e., responding to signals presented in the upper corner of the monitor during driving), maintaining lane position and velocity, and responding to signal lights. Driver performance variables were measured automatically by the simulator. The findings were that patients took longer to complete the course and had fewer correct responses and longer response times in the divided attention tasks; also, their speeds and lane positioning were more variable. In addition, the PD group had more run-off-road accidents. However, it could not be determined how much, if any, of the difference in driving behavior was due to the age difference between groups. Within the patient group, neither disease severity nor scores on the cognitive test differentiated between good and bad drivers.

Heikkila, Turkka, Korpelainen, Kallanranta, and Summala (1998) investigated the performance of driver-patients with PD on cognitive and psychomotor laboratory tests and a standardized 45-minute on-road driving test. Twenty patients (mean age 59) with mild to moderate disease were compared to 20 age-matched healthy control subjects. All subjects were male and drove regularly; their driving ability was evaluated separately by a neurologist, a psychologist, a vocational rehabilitation counselor, and a driving instructor, each using a standardized 10-point scale. Patients and controls also evaluated their own driving ability. Apart from three traffic accidents in the Parkinson's disease group during the past 2 years compared with none in the control group, there were no differences in the driving histories of members of the two study groups. To avoid on-off effects (see above), the neuropsychological laboratory assessments and the road test were administered when the drivers with Parkinson's disease considered that they were at their optimal level of performance. There was a high correlation between the laboratory tests and the driving test, both in the patient group and the control group, and patients with Parkinson's disease performed worse than controls on both types of test. PD patients committed many more risky driving errors than controls on the road test, notably in making left turns. Their problems manifested themselves mainly under urban conditions, where there are more stimuli that must be taken into account. The authors concluded that driving ability is greatly decreased in patients with even mild to moderate Parkinson's disease.



### **Cardiovascular conditions**

Discussing morbidity and mortality rates, Shephard (1987) noted that, in the general population aged 35 to 64 years, cardiac deaths average about 4.6 per 1,000 man-years and 1.3 per 1,000 woman-years. In moving from the age group of 40 to 44 years to that of 60 to 64 years, there is a 10- to 11-fold increase in the risk of a heart attack, and a 26-fold increase in the risk of a cardiac death. Thus the disorder is serious and accounts for many deaths, but it has not been shown to be a significant risk factor for driving. Reviewing early studies, Janke et al. (1978) concluded that the evidence suggests that the majority of cardiovascular patients do not pose an increased hazard to the public through their driving. They tentatively attributed this to patients' generally reduced driving, which reduces their accident risk. Potvin, Guibert, and Loiselle (1993), in a critical review of more recent studies dealing with the traffic accident risk of cardiovascular patients, similarly concluded that none of the well-controlled studies in the literature have demonstrated a consistent increase in risk associated with heart disease.

As mentioned above, cardiovascular disease that is likely to lead to recurrent lapses of consciousness is reportable in California. It is categorized as Physical in the P&M program. Coronary artery disease, which may lead to a sudden "coronary" (or "heart attack," or myocardial infarction), is the leading cause of death in people aged 65 or more but, according to Wielgoez and Azad (1993) there is a "surprisingly" low incidence of cardiac-related events while driving. In general, they wrote, only 0.9 to 2.1 per 1,000 motor vehicle crashes are caused by sudden incapacitation, with about half of these related to a cardiac cause. Symptoms of cardiovascular disease which may be of more general concern for driving are the pain of angina pectoris, dizziness, or blurred vision. Because of the variety of cardiovascular conditions, some of them will be described briefly before summarizing studies of their effect on driving.

**Coronary artery disease, angina pectoris, myocardial infarction.** Partial or complete blockage of the coronary arteries by fatty plaques is a leading cause of sickness and death in middle-aged and elderly people. According to Scheidt, Bedynek, Bruce, Clark, Fox, Friedman, Kishel, McHenry, and Shephard (1987), it is considered the major potential cause of acute incapacitating illness in heavy-vehicle commercial drivers, aside from substance abuse and fatigue. In about 40% of cases, angina pectoris (which may be felt as pain or pressure, and may be interpreted by the patient as indigestion) is the initial manifestation of coronary artery disease (Orencia, Bailey, Yawn, & Kottke, 1993). The remaining cases may show either myocardial infarction (a "heart attack" due to inadequate blood supply to, and the resulting death of, part of the heart muscle) or unexpected sudden death. Myocardial infarction may occur as a sudden event accompanied by severe, disabling pain. Disability is not necessarily immediate, however, and a driver at the wheel of a vehicle may have time to pull over and stop before becoming incapacitated.

Shephard (1987) amplified on this, writing that studies of middle-aged men undergoing rehabilitation after a coronary suggest that the duration of heart attack symptoms would usually be sufficient to allow the driver to pull over, and in many instances a determined individual could even drive to the hospital. A cardiac crisis, Shephard wrote, is commonly preceded by 6 to 24 hours of discomfort. Thereafter, acute symptoms typically last about 30 minutes, though in 25% of cases the duration is less

than 30 seconds and in 14% less than 5 seconds. He warned that the time involved in getting off the road includes not only the time required to stop the vehicle but also the time required to recognize the illness and make the decision to pull over. That in itself may occupy 5 to 10 seconds.

**Congestive heart failure.** Wielgosz and Azad (1993) wrote that congestive heart failure can result from many different processes, including high blood pressure, inflammatory changes of the heart muscle, longstanding disease of the heart valves, and coronary artery disease. They gave the prevalence as 3% in persons aged 45 to 64, 6% overall in persons 65 or more, and 10% overall in those aged 75 or more. Basically, as stated by Wood (1956), in congestive heart failure the heart fails to maintain a blood circulation adequate for bodily needs. This often develops gradually, with symptoms of fluid retention, shortness of breath, and decreased ability to undergo exertion; both stamina and alertness may be impaired. The circulation may be adequate during rest but inadequate when the patient is stressed by exercise. However, the reserve mechanisms of the heart and circulatory system are frequently sufficient to compensate for months or years, at least partly, in the presence of extensive disease. Scheidt et al. (1987) noted that the presence of adequate reserves and a low potential for disruption of the heart rhythm (evaluated through stress testing) may allow even heavy-vehicle commercial driving. Nevertheless, Wielgosz and Azad warned that although heart disease need not preclude driving, patients should stop for a break after 90 minutes of driving and should not drive for more than 6 hours a day.

**Cardiac arrhythmias.** According to Marshall and Shepherd (1968), cardiac arrhythmias are paroxysms of rapid heart action which, if long and sustained, almost always occur as a complication of heart disease or some other condition directly affecting heart function. Serious arrhythmias prevent the heart from contracting normally and can decrease the supply of blood to the brain sufficiently to cause visual impairment, dizziness, or syncope. However, arrhythmias are treatable; e.g., by means of drug therapy or implantation of a defibrillator.

**Cardiac effects of pulmonary disease.** Marshall and Shepherd (1968) noted that many forms of lung, or pulmonary, disease may eventually affect the function of the heart. The term "cor pulmonale" is often applied to these situations, referring to cardiac enlargement or cardiac failure in association with lung disease. Symptoms relevant to driving are the same as for congestive heart failure, though here the lack of brain oxygenation is exacerbated because of the underlying lung disease. This can cause cognitive impairment which, if severe, can be considered a circulatory dementia.

**Hypertension.** Untreated high blood pressure, or hypertension, usually progresses as a chronic condition without notable symptoms that might alert the patient until irreversible target-organ complications appear (Berkow et al., 1997). These complications include stroke (see below), dementia (see above), myocardial infarction, congestive heart failure, and kidney failure (Toole, 1984). Severe acute bouts of hypertension can cause headache, weakness, mental disturbance, dizziness, and loss of consciousness. The potential for syncope caused by severe hypertension was mentioned as a special hazard to driving by Balkanyi (1972).

Although diagnosed high blood pressure can usually be controlled through medications, several of the most useful drugs have side effects which can impair driving (Leon, Bercu, Dawson, & Lee, 1987). These side effects can include depressed reflexes, drowsiness, syncope, and other central nervous system effects. Therefore starting or changing medication is always a concern in assessing a patient's ability to drive.

**Some studies of cardiovascular conditions and driving.** Crancer and O'Neill (1970), cited in Brainin, Naughton, and Breedlove (1976), randomly selected groups of drivers with arteriosclerosis ("hardening of the arteries"), hypertension, rheumatic heart disease, and other cardiovascular conditions, and compared their prior driving records to those of presumably healthy drivers who were matched with patients on age, sex, and city of residence. Mileage and other aspects of exposure to crash risk were not controlled. The arteriosclerotic and hypertension groups had accident rates statistically significantly higher than those of comparison drivers, while rates for other cardiovascular disease groups were not significantly different from those of the comparison group. Violation rates for all groups were comparable.

Waller and Naughton (1983) examined the crash experience of 725 Vermont drivers with ischemic heart disease who were living in the community. These patients were compared with the total Vermont driving population and with samples matched on demographic variables and community of residence. For study purposes the authors divided the patient sample into four severity levels based on signs and symptoms of ischemic heart disease (again, inadequate circulation of blood to the heart muscle, usually caused by coronary artery disease). They increased the severity rating if the patient had comorbid conditions or was over age 54, and decreased it if a cardiac pacemaker had been implanted or coronary artery bypass surgery had been performed. Comorbid conditions included hypertension (in 41% of patients) and pulmonary disease (in 23%); other diseases coexisting with their heart disease in more than 10% of patients were arthritis, depression, diabetes, alcoholism, and cerebrovascular disease.

The authors examined subjects' driving records, and shortened the attributed period of driving by the length of each term of hospitalization plus a 45-day post-hospitalization recuperation period. Paired control subjects were examined over the same time periods as the patients with whom they were paired. Crash rates for both male and female patients were substantially less than either the comparison group rates or the corresponding gender rates for the Vermont driving population. This is understandable in view of prior evidence (from Waller, 1981) that cardiac patients reduce their mileage considerably, cut down on long-distance driving and driving in bad weather, and tend to avoid driving alone, after dark, and in heavy traffic. All of this reduces exposure to the risk of a crash. However, even after an attempt at adjusting for the probable lesser mileage of study patients by inflating their rates 20%, the patients' rates were still lower than those of matched comparison subjects, though the differences were not statistically significant.

Consistent with Waller's evidence, Potvin, Guibert, Philibert, and Loiselle (1990) reported finding that the crash odds ratio for male drivers aged 45-70 who were known to Quebec's licensing agency as having cardiovascular disease, compared to those not so known, was only 0.81. This value, indicating decreased risk, was statistically

significantly different from 1.00, the equal odds condition. Potvin et al. attributed this apparent protective effect of heart disease to less driving, particularly in harsh climatic conditions, by drivers with the condition. In a later paper reviewing other researchers' investigations of the traffic accident risk of cardiovascular patients, Potvin et al. (1993) concluded, as mentioned above, that none of the well-controlled studies in the literature have demonstrated a consistent increase in risk associated with cardiovascular disease.

It should be noted, though, that McGwin, Sims, Pulley, and Roseman (2000), telephone-surveying older drivers, found that after statistical adjustment for age, gender, race, and annual mileage, the odds of having been at-fault in a crash during 1996, relative to not having been in a crash during the same period, were statistically significantly enhanced for subjects who reported that they had heart disease.

### **Cerebrovascular disease and brain trauma**

According to Brainin, Breedlove, and Naughton (1977), cerebrovascular accident (CVA) or stroke is a term used to describe three general conditions. One is blockage in the flow of blood to part of the brain, frequently caused by a blood clot. Another is pressure imbalance caused by an aneurysm of the wall of a blood vessel. The third is rupture of a brain blood vessel; that is, an intracranial or intracerebral hemorrhage. According to Hansotia (1993), who reviewed many relevant studies, some post-stroke patients can drive safely and others not, but it is very difficult to distinguish between the two groups precisely. He suggested that one course of action would be to adopt a rule similar to that used in the United Kingdom for drivers who have suffered a stroke. There, all persons reported with the condition have their driver licenses suspended for 3 months, with a careful assessment at the end of the suspension period to see whether driving can safely be resumed. The assessment includes tests (presumably administered by a physician or psychologist) for visual field defects, visual inattention, spatial vision defects, motor impairment, memory defects, and general cognitive impairment. A diagnostic road test should also be given.

Hopewell and van Zomeren (1990), citing a paper by Bush (1986), claimed that stroke is the single most debilitating physical disorder affecting the brain's neurological functioning. It accounted in 1986 for an estimated 2.1 million pre-retirement years of disability among the United States population. Also in 1986, it was estimated that there are 500,000 new adult victims of CVAs annually in the United States (Siev, Freishtat, and Zoltan, 1986) and that at any given time there are 2 million stroke survivors. Of those surviving the initial incident, Siev et al. claimed, 75% will be rehabilitated to some degree of independence. While noting a recent "dramatic" decline in stroke mortality, Hansotia (1993) cited Kurtzke (1985) in presenting an estimate that, among Caucasian populations (figures for other ethnic groups were not given), the mortality rate due to stroke is 50 to 100 per 100,000 population, the annual rate of new cases 100 to 200 per 100,000, and the rate of existing cases 500 to 600 per 100,000. Studies show an exponential increase in stroke rates with age.

Incidence rates for transient ischemic attacks (TIAs), which can be an early warning sign of a stroke, range from 0.3 per 1,000 to 1.24 per 1,000 per year, according to Kurtzke. TIAs are temporary disturbances in brain function caused by insufficient blood supply for brief periods. Because the blood supply is restored quickly, brain tissue does not die as it does in a stroke. However, the seriousness of a TIA is underscored by the fact that

in the general Caucasian population of the United States the likelihood of a stroke's occurring in persons 65 to 74 years of age is about 1% per year, but in a matched TIA population the likelihood increases to 5-8% per year. Symptoms of a TIA, though fleeting, may include blindness in one eye, weakness on one side of the body, language deficit, inability to execute voluntary movements, and/or confusion. (If a stroke occurs, the same symptoms may appear but they will not be fleeting.) TIAs, by definition, are supposed to leave no residual effects, but Toole (1984) noted that research in progress in 1984 indicated long-lasting cognitive impairment in some patients.

Residual disabilities following a CVA which are likely to increase crash risk can include musculoskeletal impairment, sensory damage, perceptual and cognitive problems, and emotional problems. Symptoms depend upon the part of the brain affected, as well as the extent of damage. Specifically visual problems in perception and cognition include visual neglect (in which there is reduced awareness or even no awareness of the opposite side of the body from the lesion and external stimuli on that side), impaired visual attention, and impaired oculomotor skills. All have obvious importance for driving. Medications used to prevent additional strokes can also increase crash risk through producing visual impairment, drowsiness, lightheadedness, or impaired attention (Toole, 1984).

There have been a number of studies of driving after a CVA. Wilson and Smith (1983) studied stroke patients who had been cleared by hospitals to resume driving. In a road test these patients showed difficulties in entering and leaving the highway, driving in roundabouts (traffic circles), and performing two tasks at once in a staged emergency. They showed lack of awareness of other vehicles that might interact with theirs, and difficulty in aligning their vehicles with the side of the road. These findings, the authors wrote, call into question the adequacy of ready-for-driving decisions that are made on a medical basis alone, as these presumably were.

Legh-Smith, Wade, and Langton (1986) conducted a survey dealing with driving after a stroke. In all, 492 patients were interviewed. Data were collected from caregivers on patients' pre-stroke driving practices as soon as possible after the CVA occurred, and data on functional disability, cognitive status, depression, and driving were collected 1 year after the stroke. Of those who had been drivers preceding their CVA (39% of the total sample), 42% were driving 1 year post-CVA. This group was younger, less disabled, and had better cognitive functioning than those who had given up driving. Driving cessation did not depend upon the cerebral hemisphere affected (which may be relevant because the right hemisphere has been said to be involved in visuospatial perception). However, it was associated with depression and decreased social activities, even though many patients had access to transportation through drivers within their household or outside it. It was not determined whether the depression noted by Legh-Smith et al. was caused by post-CVA disabilities, by the reduction in social activities, or by their combined effect.

Quigley and De Lisa (1983) reported on a group of 50 post-CVA subjects who underwent driver retraining. Of this group, 31 were relicensed. The authors noted differential licensing rates for patients with lesions in the left as opposed to the right cerebral hemisphere, in that 74% of the patients with left CVAs passed the driving test, as compared to 52% of the patients with right CVAs. As noted above, the right cerebral

hemisphere may be involved in perception of spatial relationships—and in addition, unilateral neglect, or lack of perception of stimuli in one half of the visual field, is usually found in the left visual field, corresponding to a right-hemisphere lesion (Heilman & Watson, 1977). Quigley and De Lisa found that their subjects showing unilateral neglect tended to drift sideways while driving, while some subjects had to be excluded from actual driving practice for such reasons as poor planning, poor judgment, or lack of caution. Other problems which Quigley and De Lisa observed among patients were inability to perceive hazards and inattentiveness to signs, difficulty in sequencing their actions in starting and stopping the vehicle, and confusion at two-stage commands and between left and right.

Commenting on whether brain-damaged subjects show impairment in basic driving skills at the operational level, van Zomeren, Brouwer, and Minderhoud (1987) noted that there is little concern expressed in the driving-related literature about motor deficits like hemiparesis, since it is relatively easy for technical adaptations of the vehicle to compensate for such impairments. Most of the other impairments described in the literature fit into five general categories, the authors stated. These are inadequate visual scanning and other visual problems like double vision and visual field defects, problems in spatial perception and orientation, poor tracking ability (e.g., when trying to drive in a straight line or in following a curve), slowness in acting, and confusion when complex actions have to be carried out. Reported personal communication of the authors with the staff of a Dutch rehabilitation center added two relevant observations. In their training program, rehabilitation staff noted, some patients showed problems resulting from poor coordination of their legs. Patients had difficulty in controlling the brake and accelerator—they were braking too brusquely and were unable to drive very slowly, as required in highly congested traffic. The center's driving instructor also noted that some retrainees were able to judge traffic adequately when riding a bicycle, but not when driving a car. In his view, stimuli came too fast for the drivers in the latter case. According to van Zomeren et al., the greatest operational (as opposed to strategic) problems of brain-injured drivers appear to be in spatial vision and in an inability to deal with complex situations that require rapid sequencing of responses.

Because of the variable nature of brain damage, van Zomeren et al. concluded that while only about half of the population with cerebral lesions can be retrained to an acceptable level of driving skill, those who do resume driving after professional training cannot be described as a high-risk group. In future research, they believed, attention should be paid to the cause of the lesion, the size of the lesion, the site of the lesion (e.g., right as opposed to left hemisphere), the interval since the injury or the beginning of the cerebral disease, and the amount of previous driving experience, since overlearned skills may be less vulnerable to brain damage. Patients with stable brain lesions commonly compensate for consciously recognized deficiencies by adaptively modifying their driving style and limiting their driving. To do this they have to be aware of their deficits, and to that extent their insight and self-critical abilities must be functional. Therefore van Zomeren et al. felt that the most important cause of increased crash risk for brain-injured patients may be negative changes in planning, judgment, and impulse control resulting from lesions in the frontal lobes, in combination with operational shortcomings.

Despite earlier findings implying at least potentially enhanced crash risk for brain-injured individuals, a recent study in Washington state (Haselkorn, Mueller, & Rivara, 1998) was unable to show increased risk of crashes or moving violations for these patients. It should be stressed, though, that the time period studied represented only the first 12 months following hospitalization for the injury, a time during which recovering patients probably did not drive as much as usual. The study used extraordinarily large patient samples—1,910 individuals hospitalized with stroke (CVA), 896 hospitalized with traumatic brain injury (TBI), 4,369 hospitalized with limb fracture but no brain injury, and 2,509 hospitalized with appendicitis. (The latter two groups were included to evaluate the success of linking hospital data to official driving records.) Each group's driving record for the 12 months after hospitalization was compared with that of its own age-matched, gender-matched, and ZIP code-matched nonhospitalized comparison group from the driving population. In addition, 12-month prior (to hospitalization) driving records were obtained for all subjects. Relative rates of occurrence of a crash or a traffic citation during the 12 months after hospitalization were found through obtaining the incident rates of crashes or violations among the hospitalized groups and dividing by the corresponding rates for the matched comparison groups. Age, sex, and prior driving record were controlled statistically.

With the exception of patients in the CVA group, the proportion of subjects with reported crashes or violations in the prior period was greater among hospitalized than among nonhospitalized individuals. For the TBI category this disparity was "quite marked" (suggesting a possible reason for their brain injury). After adjustment for age, sex, and prior record, the risk of a crash occurring within the 12 months after hospitalization was not elevated in either the CVA or the TBI group relative to their respective comparison groups. Of these brain-lesioned subjects, only those with TBI had a "modestly" increased risk of receiving a citation during this period. Patients with fracture also showed an increased risk of citation, suggesting to the authors an inability to control for propensity to take risks (which may have contributed to their fracture). The authors' general conclusion was that their study did not show individuals with CVA or TBI to have an increased risk of crashes. However, they recognized as a substantial limitation of their investigation the fact that exposure—amount and conditions of driving during the criterion period—was not controlled. (As mentioned, driving was probably reduced during recuperation.) Absent exposure data, Haselkorn et al. recommended that individuals who have sustained a TBI or CVA work closely with health care providers to evaluate their fitness to drive, and that states which have rescreening policies for such drivers continue to use them.

McGwin, Sims, Pulley, and Roseman (2000) reported that in their telephone survey of older drivers—244 of them at fault in a crash during 1996, 182 in a crash but not at fault, and 475 not in a crash—those stating that they had had a stroke were statistically significantly more likely to be in the at-fault group. This result was obtained both with and without statistical adjustment for age, sex, race, and annual mileage.

### **Effects of medication**

Medication is a two-edged sword—it can improve driving performance by improving the driver's underlying condition, which may in itself impair driving, but can also degrade driving performance through unwanted side effects. Because of the complexity of the topic, this report will not even attempt to present information on the

possible interactions between different medications as they relate to driving. But it should at least be noted that many people—particularly older people—take several therapeutic drugs, perhaps prescribed by several different physicians, in addition to over-the-counter drugs; some of these can be expected to interact to the detriment of driving. In general, benzodiazepines are the class of drugs for which the clearest evidence of driving hazard exists; this will be discussed below.

A recent simulator study demonstrating the beneficial effect of medication was that of Cox, Merkel, Kovatchev, and Seward (2000). They studied the effect of stimulant medication on the driving performance of young male adults with attention-deficit hyperactivity disorder, or ADHD. Adolescents with ADHD have been found to be more likely to be involved in crashes than matched controls (Weiss, Hechtman, Perlman, Hopkins, & Wener, 1979). Cox et al., using an Atari Games Corporation Research Driving Simulator, sought to show that there is poorer driving performance in those with ADHD, and that stimulant medication (Ritalin) improves their performance. The authors investigated a very small number of subjects, 7 ADHD subjects and 6 non-ADHD subjects, all aged 19 to 25, but used methods designed to counteract sources of possible bias in order to enhance the interpretability of their findings. Subjects' diet and sleep conditions were controlled by admitting them to the research center the evening before the study. They were introduced to the driving simulator and drove the practice course for a minimum of 15 minutes until they felt comfortable with its operation. The next morning they were awakened, given breakfast, and then either a placebo pill (vitamin C) or a Ritalin pill. The study staff responsible for drug administration and testing did not know the group or pill taken for any subject, and subjects did not know which type of pill they received. After ingesting their pill subjects drove one of two equivalent driving scenarios for about 30 minutes, after which they were asked to rate how well they had driven. At noon there was lunch; later in the afternoon a snack and whichever Ritalin or placebo pill they had not yet taken, and the test/self-rating sequence was repeated using the alternative driving scenario.

Compared with control subjects, ADHD subjects reported having 3.4 times more accidents and 1.7 times more citations in their driving careers. They also drove considerably worse on the simulator than controls did under the placebo condition. On Ritalin their simulator performance improved statistically significantly while that of controls tended to become worse, so the groups approached each other and became statistically equivalent. All of the individual ADHD subjects demonstrated better driving on Ritalin, while only one non-ADHD subject did so. The authors noted that theirs is the first study demonstrating the objective benefit of a stimulant medication on driving performance.

Cox et al. noted as study limitations that the subject sample was small and in a restricted age range. And, given their positive finding about Ritalin, they pointed out that a barrier to its effectiveness is its short half-life. If longer-acting medications are equally beneficial in terms of driving improvement, then they might be considered the medication of choice for active drivers with ADHD, the authors wrote.

Many other studies have investigated the undesirable side effects of medications and their effects on driving or driving-related behavior. The following discussion of earlier



studies is taken from a review article by Ray, Thapa, and Shorr (1993). Their paper concentrated on medications and the older driver because older people are the major consumers of medications, though it recognized that impairing medication effects are not limited to older people. Ray et al. discussed both laboratory and epidemiologic studies, finding the clearest evidence for driving impairment in the case of the benzodiazepines. The existence of this relationship, they emphasized, is an unambiguous conclusion emerging from hundreds of studies of these drugs' effects on psychomotor function.

Benzodiazepines, one of which is Valium, are currently the most frequently prescribed medications for managing anxiety and insomnia in the elderly population. Functions impaired by the drug are legion. The authors presented a list of studies showing dose-related benzodiazepine impairment of vision, attention, information processing, memory, motor coordination, tasks involving complex skills, and driving under controlled conditions. In addition, sedation and drowsiness from the medication are more common in elderly than in young patients, and the degree of immediate and residual impairment increases with age.

Studies of open-road driving under controlled conditions in younger adults show, Ray et al. wrote, that the benzodiazepines produce impairment comparable to that from a blood alcohol concentration of 0.10%, a level above California's *per se* limit of 0.08% and one associated with a sixfold increased risk of crash involvement. There are fewer studies of driving incidents as they occur in the "real world," but the findings of such epidemiologic studies are consistent with those of controlled investigations. In one such study (Ray, Fought, & Decker, 1992), a cohort of over 16,000 elderly Medicaid enrollees was followed in terms of crash experience and psychoactive drug use. The analysis was conducted among Medicaid enrollees because computerized claims for prescriptions filled at the pharmacy provided a detailed record of their drug use.

The study period ran from 1984 to 1988, and involved almost 39,000 person-years of follow-up. Each day in the period was classified with respect to probable use of psychoactive drugs, including benzodiazepines, cyclic antidepressants, opioid analgesics, and antihistamines; the overall purpose of the study was to see whether cohort members taking any of these drugs were subsequently overinvolved in accidents, relative to members who did not take the drugs. From police crash reports, 495 injury crashes involving a member of the cohort as a driver were found. Demographic characteristics and indicators of health status were controlled statistically in the data analysis. For nonusers of benzodiazepines or other psychoactive drugs, the rate of involvement in injury accidents was 12 per 1,000 person-years. The rate was 50% higher in current benzodiazepine users (relative risk of 1.5), and their crash risk increased in a positively accelerated manner with benzodiazepine dose. Users of cyclic antidepressants were found to have a more-than-doubled rate (relative risk of 2.2) of injury accidents. Risk again increased with increasing dose; for users of amitriptyline (Elavil), in particular, persons receiving 125 mg or more of the drug had a nearly sixfold higher crash rate. In contrast, there was a slightly but not statistically significantly increased risk of injury crash involvement for users of oral opioid analgesics (to relieve pain); there was similarly no significant increase in risk for antihistamine users.

In this study and others cited in the Ray et al. (1993) review article, benzodiazepines and cyclic antidepressants were the medications (other than insulin for diabetes) most strongly linked to unsafe driving, both in controlled studies of psychomotor function and in epidemiologic studies of adverse outcomes in the “real world.” Benzodiazepines are commonly prescribed for conditions (anxiety, insomnia) that in themselves would not generally lead to crashes; Ray et al. regarded this as another reason for prescribing them very cautiously. Depression, for which cyclic antidepressants are prescribed, may in itself make driving more dangerous, though the research necessary to show this has not been done. However, Ray et al. suggested avoiding use of antidepressant drugs with extensive side effects, like amitriptyline and imipramine.

Thomas (1998) reviewed the scientific literature from several countries on benzodiazepine use and accidents, selecting those studies that were of highest quality according to objective standards. In his view, case-control studies suggest that using benzodiazepines approximately doubles the risk of motor vehicle accidents.

Galski, Williams, and Ehle (2000) pointed out that although many patients take opioid medications on a regular basis to relieve intractable pain, there have been no studies exploring the effects on driving skill of opioid use over an extended period of time. They conducted a pilot study to determine the effects of medically prescribed, stable opioid use on the driving abilities of patients with persistent, non-malignant pain. Sixteen patients on this type of therapy underwent a comprehensive off-road driving evaluation consisting of a “pre-driver” test, a driving simulator evaluation, and behavioral observation during simulator performance. They were compared to a comparison group of 327 “cerebrally compromised” patients who had undergone the same evaluation and then had either passed ( $n = 162$ ) or failed ( $n = 165$ ) an actual road test. Patients taking opioids equaled or exceeded the scores of comparison subjects—whether pass or fail in the road test—on the pre-driver and simulator tests. Behaviorally they were generally superior to comparison subjects also, though they had greater difficulty in following simulator instructions and showed, like the road-test fail comparison group, a tendency toward impulsiveness. But the very small size of the opioid-user sample made it difficult to show statistical significance, so while there was no contradiction of a notion that these medications do not impair driving-related performance, the authors called for a larger research effort into the question. (It will be recalled from the discussion above that Ray et al. (1992) found a slightly but not statistically significantly increased risk of injury accidents for users of opioid analgesics.)

The population-based case-control study of the relationship between chronic medical conditions, medications, and crashes in the elderly, conducted by McGwin, Sims, Pulley, and Roseman (2000), has been cited in various places above. With respect to medications, after statistical adjustment for age, gender, race, and annual mileage the odds of being in the at-fault crash group, as compared to the no-crash group, were statistically significantly increased for drivers taking non-steroidal anti-inflammatory drugs (NSAIDs) like Advil for pain relief. Significant risk enhancement was also found, after adjustment, for angiotensin-converting enzyme (ACE) inhibitors and anticoagulants. The former compounds block a chemical the body produces that raises blood pressure, and the latter reduce blood clotting, according to the PDR (Physicians’ Desk Reference) Family Guide to Prescription Drugs (1999). Anticoagulants might be used, for instance, after a heart attack or in treating deep vein thrombosis.

An interesting finding of McGwin et al. was that, after adjustment, calcium channel blockers statistically significantly *reduced* the odds of being in the at-fault crash group, relative both to drivers not in a crash and to drivers not at fault in a crash. Calcium channel blockers, again according to the PDR Family Guide, are the most widely prescribed drugs in the US today. They dilate the arteries and reduce resistance to the flow of blood, and have proven to be beneficial not only for high blood pressure but also for angina and other problems of a weakened heart.

Parkinson's disease (PD) and the on-off effect of extended levodopa treatment were discussed above. PD is a condition in which there is a loss of dopamine-producing cells deep in the brain. Some medications, while not themselves convertible to dopamine, can nevertheless function like it in stimulating dopamine receptors and thereby allowing transmission within the motor system to enable smoother, better coordinated movement. These medications are called "dopamine agonists," and they may be used either with carbidopa-levodopa or alone in treating the disease. Side effects are known, and one recent study (Frucht, Rogers, Greene, Gordon, and Fahn, 1999) reported evidence for "a new side effect" of two dopamine agonists, pramipexole and ropinirole. According to these authors, eight PD patients taking pramipexole and one taking ropinirole fell asleep while driving, causing accidents. The sleep attacks ceased when the drugs were stopped. Other researchers, Ferreira, Galitzky, Montastruc, and Rascol (2000), reported in a letter to the British journal *Lancet* that in their experience three patients with PD had had sleep attacks at the wheel, each while taking one of three different dopamine agonists. These researchers stated a belief that all dopamine agonists can induce sleep attacks, and it seems that this possible relationship deserves to be explored further.

### **Three-Tier Testing: Toward An Improved Licensing Assessment System**

The above, while lengthy, has only scratched the surface of relationships between driving and some medical conditions and medications. From the evidence it is arguable that the most important aspects of driving a vehicle are visual and cognitive. Severe cognitive impairment, amounting to dementia, is reportable by law. However, undiagnosed dementia is not reportable despite probably contributing to traffic accidents, as Johansson et al. (1997) found. Severe visual impairment is also not reportable by law. But making more conditions reportable might keep some patients from seeking appropriate treatment, so perhaps a more promising approach, or at least a promising supplementary approach, is improved driver assessment by DMV itself.

One way in which this could be accomplished is through adoption of a tiered assessment system like the one for renewal applicants that is now under field study by departmental researchers. "Tiered" implies that most or all of these applicants would take a set of brief screening tests; only if their performance was poor on this first tier would they proceed to the next tier(s) of lengthier, more diagnostic tests. The system now being studied at DMV includes three tiers. The tests on these tiers have all been shown, in federally funded pilot studies that began in 1993 (Janke, 2001), to be related to impairment and/or road test score. Some have also been shown, in a study by Hennessy (1995), to be related to crash involvement.

On the first tier are the usual high-contrast acuity and knowledge tests and, in addition, structured observation of applicants by a technician who will record the presence of certain objectively defined signs of possible impairment, a question examining the applicant's traffic judgment, and a wall-chart test of low-contrast acuity. Low-contrast acuity, or contrast sensitivity, has been discussed above; it is both important for driving in itself and one of the earliest visual functions to be impaired by several eye diseases that can ultimately reduce high-contrast acuity and peripheral vision as well. In operational use of the system, applicants who failed either this test or the Snellen vision screen would be sent to a vision specialist. When they came back after a diagnostic workup and possible correction by the specialist, those still showing questionable vision would be further assessed on more intensive second-tier tests to identify any other sorts of possible impairment that should be checked on the road, as would applicants who had failed the knowledge test decisively (e.g., 8 or more errors out of 18 items) or for whom a sign of substantial impairment had been observed. Applicants who passed all tests on the first tier would be licensed, though perhaps with a restriction—e.g., to corrective lenses.

The second tier would consist of automated tests of perceptual and information-processing speed and accuracy, as well as the ability to make a particular discriminative motor response to a particular stimulus. In operational use, license applicants who performed very well on second-tier tests, and applicants whose performance was so poor that they were judged to be a hazard on the road, would not proceed to the third tier, the road test. The former group would be licensed—though, based on their first-tier performance, the license would probably need to be restricted appropriately. The latter group would lose the driving privilege. A third (and probably the largest) group, those who performed neither very well nor very poorly, would be tested on the road. For these, road-test performance would have primacy in determining whether their licenses would be renewed; if licensed, license restrictions would be based on their total test performance.

Outside of the licensing cycle, drivers reported to DMV by physicians or others for presumed impairment would be required to take as many tests as needed to reliably identify their functional impairments, evaluate their driving safety and, should they be licensable, determine appropriate license restrictions to enable them to drive safely in a limited manner.

An example of how license restrictions could be based on test performance in an operational system might involve an applicant with seriously reduced contrast sensitivity. This would have been detected on the first tier, and the applicant would have been sent to a vision specialist for a thorough vision examination. Then he or she would take the second-tier tests and probably the road test. Consider, for example, an applicant with uncorrected cataract. Assuming acceptable performance on the road test, and absent other risk factors like a poor driving record that would have to be considered, such a driver might be restricted from night driving, strongly advised to avoid driving in heavy traffic, rain, or fog, and told to return for reexamination in a year. In that year, perhaps the condition would have been surgically corrected. In general, performance on all three tiers of the assessment system would be taken into account in assigning restrictions, so that the conditions of driving could be optimally linked to the driver's functional capabilities.

In addition to improving driver assessment and regulation in general, implementing a tiered driver assessment system would be expected to go far toward assisting drivers, perhaps especially older drivers, toward safe mobility. A strength of the system is that, if it were operational, the amount of testing a driver would be required to undergo would be based on his or her individual test performance, rather than on broad demographic characteristics. Assuming that field testing of the system confirms its promise, it would be both an efficient and a functionally relevant way of identifying and regulating drivers at enhanced risk of crashes due to physical or mental impairment.

## REFERENCES

- Adamsons, I., Rubin, G., Vitale, S., Taylor, H., & Stark, W. (1992). The effect of early cataracts on glare and contrast sensitivity: A pilot study. *Arch. Ophthalmol*, 110, 1081-1086.
- Aiello, L., Gardner, T., & King, G. (1998). Diabetic retinopathy. *Diabetes Care*, 21, 143-156.
- Aizenberg, R., & McKenzie, D. (1997). *Teen and senior drivers* (Report No. 168). Sacramento, CA: Department of Motor Vehicles.
- Balkanyi, A. (1972). Various causes of disturbance of consciousness important for traffic medicine. *Praxis*, 60(17), 532-534.
- Barclay, L., Weiss, E., Mattis, S., Bond, O., & Blass, J. (1988). Unrecognized cognitive impairment in cardiac patients. *J. Am. Geriatr. Soc.*, 36, 22-28.
- Beattie, B., Tallman, M., Tuokko, H., & Weir, B. (1991). Retrospective analysis of demented and not demented drivers compared with controls (Abstract). *J. Am. Geriatr. Soc.*, 39, 35.
- Beattie, B., Tuokko, H., & Tallman, K. (1993). Driving performance in the cognitively impaired elderly: Final report. Vancouver, BC: Health and Welfare Canada.
- Beers, M., & Berkow, R., Eds. (2000). *Merck manual of geriatrics*, 3<sup>rd</sup> Edition Whitehouse Station, NJ: Merck Research Laboratories.
- Berkow, R., Beers, M., & Fletcher, A., Eds. (1997). *Merck manual of medical information*, home edition. New York, NY: Simon & Schuster Inc.
- Brainin, P., Breedlove, R., and Naughton, T. (1977). Impact study on driving by special populations: Final report, Volume II. Darien, CT: Dunlap and Associates, Inc.
- Brainin, P., Naughton, T., & Breedlove, R. (1976). *Impact study on driving by special populations: Final report, Volume I*. Darien, CT: Dunlap and Associates, Inc.
- Bush, G. (1986). The history of consumer advocates in the head-injury movement. Paper presented at the meeting of the Postgraduate Course on Rehabilitation of the Brain-Injured Adult and Child. Williamsburg, Virginia.
- Carr, D., Duchek, J., & Morris, J. (2000). Characteristics of motor vehicle crashes of drivers with dementia of the Alzheimer type. *J. Am. Geriatr. Soc.*, 48, 18-22.
- Clarke, N. (1996). An evaluation of the traffic safety risk of bioptic telescopic lens drivers (Report No. 163). Sacramento, CA: Department of Motor Vehicles.
- Cooper, P., Tallman, K., Tuokko, H., & Beattie, B. (1993). Vehicle crash involvement and cognitive deficit in older drivers. *J. of Safety Res.*, 24, 9-17.
- Cormack, F., Tovee, M., & Ballard, C. (2000). Contrast sensitivity and visual acuity in patients with Alzheimer's disease. *Int. J. Geriatr. Psychiatry*, 15, 614-620.

- Cox, D., Gonder-Frederick, L., & Clarke, W. (1993). Driving decrements in type I diabetes during moderate hypoglycemia. *Diabetes*, 42, 239-243.
- Cox, D., Gonder-Frederick, L., Kovatchev, B., Julian, D., & Clarke, W. (2000). Progressive hypoglycemia's impact on driving simulation performance: Occurrence, awareness and correction. *Diabetes Care*, 23, 163-170.
- Cox, D., Merkel, R., Kovatchev, B., & Seward, R. (2000). Effect of stimulant medication on driving performance of young adults with attention-deficit hyperactivity disorder: A preliminary double-blind placebo controlled trial. *J. Nerv. Ment. Dis.*, 188, 230-234.
- Crancer, A., & McMurray, L. (1968). Accident and violation rates of Washington's restricted drivers. *Journal of the American Medical Association*, 205, 272-276.
- Crancer, A., & O'Neill, P. (1970). A record analysis of Washington drivers with license restrictions for heart disease. *Northwest Medicine*, 69, 409-416.
- Cummings, J., & Benson, D. (1983). *Dementia: A clinical approach*. Stoneham, MA: Butterworth Publishers.
- Dement, W., & Mitler, M. (1993). It's time to wake up to the importance of sleep disorders. *J. Am. Med. Assoc.*, 269, 1548-1549.
- Dreyer, D. (1973). *Physically handicapped drivers: A comparative study of driver records* (Report No. 42). Sacramento, CA: Department of Motor Vehicles.
- Dubinsky, R., Gray, C., Husted, D., Busenbark, K., Vetere-Overfield, B., Wiltfong, D., Parrish, D., & Koller, W. (1991). Driving in Parkinson's disease. *Neurology*, 41, 517-520.
- Dubinsky, R., Schnierow, B., & Stein, A. (1992). *Driving performance in Parkinson's disease: Preliminary report*. Paper presented at October 1992 meeting of the American Neurological Association.
- Dubinsky, R., Williamson, A., Gray, C., & Glatt, S. (1993). Driving in Alzheimer's disease. *J. Am. Geriatr. Soc.*, 40, 1112-1116.
- Ferreira, J., Galitzky, M., Montastruc, J., & Rascol, O. (2000). Sleep attacks and Parkinson's disease treatment. *Lancet*, 355, 1333-1334.
- Findley, L., Fabrizio, M., Knight, H., Norcross, B., & LaForte, A. (1989). Driving simulator performance in patients with sleep apnea. *Am. Rev. Respir. Disease*, 140, 529-530.
- Findley, L., Levinson, M., & Bonnie, R. (1992). Driving performance and automobile accidents in patients with sleep apnea. *Clinics in Chest Medicine*, 13, 427-435.
- Findley, L., Unverzagt, M., & Suratt, P. (1988). Automobile accidents in patients with obstructive sleep apnea. *Am. Rev. of Respir. Disease*, 138, 337-340.
- Fisher, R., & Krumholz, A. (1988). Driving and epilepsy. *Maryland Med. J.*, 37, 795-798.
- Fishman, G., Anderson, R., Stinson, L., & Haque, A. (1981). Driving performance of retinitis pigmentosa patients. *Br. J. Ophthalmol*, 65, 122-126.
- Fitten, L., Perryman, K., Wilkinson, C., Little, R., Burns, M., Pachana, N., Mervis, J., Malmgren, R., Siembida, D., & Ganzell, S. (1995). Alzheimer and vascular dementias and driving: A prospective road and laboratory study. *J. Am. Med. Assoc.*, 273, 1360-1365.
- Foley, D., Wallace, R., & Eberhard, J. (1995). Risk factors for motor vehicle crashes among older drivers in a rural community. *J. Am. Geriatr. Soc.*, 43, 776-781.
- Fountain, A., Lewis, J., & Heck, A. (1983). Driving with epilepsy: A contemporary perspective. *Southern Med. J.*, 76, 481-484.

- Friedland, R., Koss, E., Kumar, A., Gaine, S., Metzler, D., Haxby, J., Moore, A., & Rapoport, S. (1988). Motor vehicle crashes in dementia of the Alzheimer type. *Annals of Neurology*, 24, 782-786.
- Frier, B. (2000). Hypoglycemia and driving performance. *Diabetes Care*, 23, 148-150.
- Frucht, S., Rogers, J., Greene, P., Gordon, M., & Fahn, S. (1999). Falling asleep at the wheel: Motor vehicle mishaps in persons taking pramipexole and ropinirole. *Neurology*, 52, 1908-1910.
- Galski, T., Williams, J., & Ehle, H. (2000). Effect of opioids on driving ability. *J. Pain Sympt. Manage.*, 19, 200-208.
- Gastaut, H., & Zifkin, B.G. (1987). The risk of automobile accidents with seizures occurring while driving: Relation to seizure type. *Neurology*, 37, 1613-1616.
- Gebers, M. (1999). *Strategies for estimating driver accident risk in relation to California's negligent-operator point system* (Technical Monograph 183). Sacramento, CA: Department of Motor Vehicles.
- Gebers, M., and Peck, R. (1987). *Basic California traffic conviction and accident record facts* (Report No. 114). Sacramento, CA: Department of Motor Vehicles.
- George, C., Nickerson, P., Hanly, P., Millar, T., & Kryger, M. (1987). Sleep apnoea patients have more automobile accidents. *Lancet*, 8556, 447.
- Gilley, D., Wilson, R., Bennett, D., Stebbins, G., Bernard, B., Whalen, M., & Fox, J. (1991). Cessation of driving and unsafe motor vehicle operation by dementia patients. *Arch. Intern. Med.*, 151, 941-945.
- Glynn, R., Seddon, J., Krug, J. Jr., et al. (1991). Falls in elderly patients with glaucoma. *Arch. Ophthalmol.*, 109, 205-210.
- Grubb, B., Wolfe, D., Samoil, D., Madu, E., Temesy-Armos, P., Hahn, H., & Elliot, L. (1992). Recurrent unexplained syncope in the elderly: The use of head-upright tilt table testing in evaluation and management. *J. Am. Geriatr. Soc.*, 40, 1123-28.
- Hansotia, P. (1993). *Seizure disorders, diabetes mellitus, and cerebrovascular disease: Considerations for older drivers*. In S. M. Retchin (Ed.), *Clinics in geriatric medicine: Medical considerations in the older driver* (pp. 323-340). Philadelphia, PA: W.B. Saunders Company.
- Hansotia, P., & Broste, S. (1991). The effect of epilepsy or diabetes mellitus on the risk of automobile accidents. *New Eng. J. Med.*, 324, 22-26.
- Haraldsson, P., Carenfelt, C., Lysdahl, M., & Tornros, J. (1995). Long-term effect of uvulopalatopharyngoplasty on driving performance. *Arch. Otolaryngol. Head Neck Surg.*, 121, 90-94.
- Haraldsson, P., Carenfelt, C., Persson, H., Sachs, C., & Tornros, J. (1991). Simulated long-term driving performance before and after uvulopalato-pharyngoplasty. *J. for Oto-Rhino-Laryngology (ORL)*, 53, 106-110.
- Haselkorn, J., Mueller, B., & Rivara, F. (1998). Characteristics of drivers and driving record after traumatic and nontraumatic brain injury. *Arch. Phys. Med. Rehabil.*, 79, 738-742.
- Heikkila, V-M, Turkka, J., Korpelainen, J., Kallanranta, T., & Summala, H. (1998). Decreased driving ability in people with Parkinson's disease. *J. Neurol. Neurosurg. Psychiatr.*, 64, 325-330.
- Heilman, K., & Watson, R. (1977). Mechanisms underlying unilateral neglect syndrome. *Advances in Neurol.*, 18, 93-106.
- Hennessy, D. (1995). *Vision testing of renewal applicants: Crashes predicted when compensation for impairment is inadequate* (Report No. 152). Sacramento, CA: Department of Motor Vehicles.

- Herner, B., Smedby, D., & Ysander, L. (1966). Sudden illness as a cause of motor vehicle accidents. *Brit. J. Industr. Med.*, 23, 37-41.
- Hopewell, C. A., & van Zomeren, A. (1990). *Neuropsychological aspects of motor vehicle operation*. In D.E. Tupper and K.D. Cicerone (Eds.), *The neuropsychology of everyday life: Assessment and basic competencies* (pp. 307-334). Norwell, MA: Kluwer Academic Publishers.
- Horne, J., & Reyber, L. (1995). Sleep related vehicle accidents. *Brit. Med. J.*, 310, 565-567.
- Hu, P., Trumble, D., & Lu, A. (1997). *Statistical relationships between vehicle crashes, driving cessation, and age-related physical or mental limitations: Final summary report*. Washington, DC: U.S. Department of Transportation.
- Hunt, L., Edwards, D., & Morris, J. (1990). Driving performance in mild senile dementia of the Alzheimer type. *Annals Neurol.*, 28, 228-229.
- Janke, M. (1983). Accident rates of drivers with bioptic telescopic lenses. *J. Safety Res.*, 14, 159-165.
- Janke, M. (1993). Reportable medical conditions and driver risk. *Alcohol, Drugs and Driving*, 9, 167-183.
- Janke, M. (1994). *Age-related disabilities that may impair driving and their assessment* (Report No. 156). Sacramento, CA: Department of Motor Vehicles.
- Janke, M. (2001). Assessing older drivers: Two studies. *J. Safety Res.*, in press.
- Janke, M., Peck, R., & Dreyer, D. (1978). *Medically impaired drivers: An evaluation of California policy. Final report to the California Legislature* (Report No. 67). Sacramento, CA: Department of Motor Vehicles.
- Jeavons, P.M., & Clark, J.E. (1974). Sodium valproate in treatment of epilepsy. *Brit. Med. J.*, 2, 584-586.
- Johansson, K., Bogdanovic, N., Kalimo, H., Laaksonen, H., Berkowicz, A., Druid, H., Eriksson, A., Krantz, P., Sandler, H., Thiblin, I., Lannfelt, L., Winblad, B., & Viitanen, M. (1997). *High incidence of Alzheimer pathology and apolipoprotein E e4-allele found in older drivers who died in automobile accidents*. In Johansson, *Older automobile drivers: Medical aspects*, Addendum V. Stockholm, Sweden: Karolinska Institute.
- Johnson, C., & Keltner, J. (1983). Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. *Arch. Ophthalmol.*, 101, 371-375.
- Juniper, M., Hack, M., George, C., Davies, R., & Stradling, J. (2000). Steering simulation performance in patients with obstructive sleep apnoea and matched control subjects. *Eur. Respir. J.*, 15, 590-595.
- Kaszniak, A., Keyl, P., & Albert, M. (1991). Dementia and the older driver. *Human Factors*, 33, 527-537.
- Klein, B., Klein, R., & Linton, K. (1992). Prevalence of age-related lens opacities in a population. *Ophthalmol.*, 99, 546-552.
- Krauss, G., Krumholz, A., Carter, R., Li, G., & Kaplan, P. (1999). Risk factors for seizure-related motor vehicle crashes in patients with epilepsy. *Neurol.*, 52, 1324-1329.
- Kuhn, D. (1999). *Alzheimer's early stages*. Alameda, CA: Hunter House Publishers.
- Kurtzke, J. (1985). *Epidemiology of cerebrovascular disease*. In F. McDowell & L. R. Kaplan (Eds.), *Cerebrovascular survey report for the National Institutes of Neurological and Communicative Disorders and Stroke* (rev.). Rochester, MN: Whiting Press. Page 1.
- Lasche, E. (1985). The diabetic driver. *Diabetes Care*, 8, 189-191.



- Leon, D., Bercu, B., Dawson, D., & Lee, C. (1987). *Cardiovascular pharmacologic agents*. In S. Fox, Conference on cardiac disorders and commercial drivers (pp. 67-74). Washington, DC: Federal Highway Administration.
- Legh-Smith, J., Wade, D., & Langton, H. (1986). Driving after stroke. *J. Royal Soc. of Med.*, 79, 200-203.
- Lings, S., & Dupont, E. (1992). Driving with Parkinson's disease: A controlled laboratory investigation. *Acta Neurol. Scand.*, 86, 33-39.
- Lucas-Blaustein, M., Filipp, C., Dungan, C., & Tune, L. (1988). Driving in patients with dementia. *J. Am. Geriatr. Soc.*, 36, 1087-1091.
- Madeley, P., Hulley, J., Wildgust, H., & Mindham, R. (1990). Parkinson's disease and driving ability. *J. Neurol. Neurosurg. Psychiatry*, 53, 580-582.
- Manji, H., & Plant, G. (2000). Epilepsy surgery, visual fields, and driving: A study of the visual field criteria for driving in patients after temporal lobe epilepsy surgery with a comparison of Goldmann and Esterman perimetry. *J. Neurol. Neurosurg. Psychiatry*, 68, 80-82.
- Marshall, R., & Shepherd, J. (1968). *Cardiac function in health and disease*. Philadelphia, PA: W.B. Saunders Co.
- McCloskey, L., Koepsell, T., Wolf, M., & Buchner, D. (1994). Motor vehicle collision injuries and sensory impairments of older drivers. *Age Aging*, 23, 267-272.
- McGwin, G. Jr., Chapman, V., & Owsley, C. (2000). Visual risk factors for driving difficulty among older drivers. *Acc. Anal. & Prev.*, 32, 735-744.
- McGwin, G., Jr., Sims, R., Pulley, L., & Roseman, J. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: A population-based case-control study. *Am. J. Epidemiol.*, 152, 424-431.
- Mernoff, S. (1999). Paroxysmal disorders and driving. *Med. and Health/Rhode Island*, 82, 436-438.
- Mitchell, E., & Gebers, M. (2001). *Technical Supplement to "Medical conditions and other factors in driver risk."* (Unpublished report). Sacramento, CA: Department of Motor Vehicles.
- National Research Council. (1987). *Work, aging, and vision: Report of a conference*. Washington, D. C.: Author.
- Ng, S., Hauser, W., & Brust, J. (1988). Alcohol consumption and withdrawal in new-onset seizures. *New Engl. J. Med.*, 319, 666-673.
- Odenheimer, G. (1993). *Dementia and the older driver*. In S. M. Retchin (Ed.), Clinics in geriatric medicine: Medical considerations in the older driver (pp. 349-364). Philadelphia, PA: W.B. Saunders Company.
- Odenheimer, G., Beaudet, M., & Grande, L. (1991). Cognitive performance correlates with driving performance in the elderly. *Gerontologist*, 31, 84.
- Odenheimer, G., Beaudet, M., Grande, L., & Minaker, K. (1994). Performance-based driving evaluation of the elderly driver: Safety, reliability, and validity. *J. Gerontol. Med. Sci.*, 49, M153-M159.
- Orencia, A., Bailey, K., Yawn, B., & Kottke, T. (1993). Effect of gender on long-term outcome of angina pectoris and myocardial infarction/sudden unexpected death. *J. Am. Med. Assoc.*, 269, 2392-2419.
- Owsley, C., & McGwin, G. Jr. (1999). Vision impairment and driving. *Survey Ophthalmol.*, 43, 5335-5350.
- Owsley, C., McGwin, G., Jr., & Ball, K. (1998). Vision impairment, eye disease, and injurious motor vehicle crashes in the elderly. *Ophthalmic Epidemiol.*, 5, 101-113.

- Owsley, C., Stalvey, B., Wells, J., & Sloane, M. (1990). Older drivers and cataract: Driving habits and crash risk. *J. Gerontol. Med. Sci.*, 54A, M203-M211.
- Parkes, J. (1983). The sleepy driver. In *Driving and epilepsy—and other causes of impaired consciousness* (pp. 23-28). Proceedings of a 1992 International Symposium sponsored by Labaz. Nottingham, Great Britain: The Royal Society of Medicine and Academic Press Inc.
- PDR Family Guide to Prescription Drugs, 7<sup>th</sup> Edition. (1999). New York: Three Rivers Press (Medical Economics Co., Inc.)
- Popkin, C., & Waller, P. (1988). Epilepsy and driving in North Carolina: An exploratory study. *Acc. Anal. & Prev.*, 21, 389-393.
- Potvin, L., Guibert, R., & Loiselle, J. (1993). Cardiovascular diseases and traffic accidents: Weighing the evidence. *J. Safety Res.*, 24, 233-241.
- Potvin, L., Guibert, R., Philibert, L., & Loiselle, J. (1990). The relative risk of traffic accidents among drivers with cardiovascular disease (abstract). *Am. J. of Epidem.*, 132, 808.
- Pramming, S., Thorsteinsson, B., Theilgaard, A., Pinner, E., & Binder, C. (1986). Cognitive function during hypoglycaemia in type I diabetes mellitus. *Brit. Med. J.*, 292, 647-650.
- Quigley, F., & De Lisa, J. (1983). Assessing driving potential of cerebral vascular accident patients. *Am. J. Occup. Ther.*, 37, 474-478.
- Ratner, R., & Whitehouse, F. (1989). Motor vehicles, hypoglycemia, and diabetic drivers. *Diabetes Care*, 12, 217-222.
- Ray, W., Fought, R., & Decker, M. (1992). Psychoactive drugs and the risk of injurious motor vehicle crashes in elderly drivers. *Am. J. Epidemiol.*, 136, 873-883.
- Ray, W., Thapa, P., & Shorr, R. (1993). *Medications and the older driver*. In S. M. Retchin (Ed.), *Clinics in geriatric medicine: Medical considerations in the older driver* (pp. 413-438). Philadelphia, PA: W.B. Saunders Company.
- Reuben, D., Silliman, R., & Trainee, M. (1988). The aging driver: Medicine, policy, and ethics. *J. Am. Geriatr. Soc.*, 36, 1135-1142.
- Rose, J., Bron, A., & Clarke, D. (1984). Contrast sensitivity and visual disability in chronic simple glaucoma. *Brit. J. Ophthalmol.*, 104, 113-120.
- Saraux, H., & Nordmann, J. (1990). Value of a study of contrast sensitivity in the evaluation of visual function: Applications to pathology and visual selection. *Bull. Acad. Natl. Med.*, 174, 497-506.
- Scheidt, S., Bedynek, J., Bruce, R., Clark, H., Fox, S., Friedman, G., Kishel, J., McHenry, P., & Shephard, R. (1987). *Ischemic heart disease*. In S. Fox, Conference on cardiac disorders and commercial drivers (pp. 7-26). Washington, DC: Federal Highway Administration.
- Shephard, R. (1987). *The cardiac patient and driving—the Ontario experience*. In S. Fox, Conference on cardiac disorders and commercial drivers. Washington, DC: Federal Highway Administration.
- Siev, E., Freishtat, B., & Zoltan, B. (1986). *Perceptual and cognitive dysfunction in the adult stroke patient*. Thorofare, NJ: SLACK Inc.
- Simpson, H., & Mayhew, D. (1992). *Reducing the risk for new drivers: A graduated licensing system for British Columbia*. Victoria, BC: Motor Vehicle Branch, Ministry of the Attorney General.
- Sjogren, H., Eriksson, A., & Ostrom, M. (1996). Role of disease in initiating the crashes of fatally injured drivers. *Acc. Anal. & Prev.*, 28, 307-314.

- Spudis, E., Penry, J., & Gibson, P. (1986). Driving impairment caused by episodic brain dysfunction: Restrictions for epilepsy and syncope. *Arch. Neurol.*, 43, 558-564.
- Swann, P. (1999). Non-retinal ocular changes in diabetes. *Clin. and Exper. Optom.*, 82, 43-46.
- Szlyk, J., Severing, K., & Fishman, G. (1991). *Peripheral visual field loss and driving performance*. Chicago: University of Illinois Eye Center.
- Teran-Santos, J., Jimenez-Gomez, A., & Cordero-Guevara, J. (1999). The association between sleep apnea and the risk of traffic accidents. *New Engl. J. Med.*, 340, 847-851.
- Thomas, R. (1998). Benzodiazepine use and motor vehicle accidents: Systematic review of reported association. *Can. Fam. Physician*, 44, 799-808.
- Toole, J. (1984). *Cerebrovascular disorders* (3rd edition). New York: Raven Press.
- Trimble, M., & Thompson, P. (1983). *The toxic effects of medical treatment and their effects on driving*. In *Driving and epilepsy—and other causes of impaired consciousness* (pp. 17-22). Proceedings of a 1992 international symposium sponsored by Labaz. Nottingham, Great Britain: The Royal Society of Medicine and Academic Press Inc.
- Van der Lugt, P. (1975). Traffic accidents caused by epilepsy. *Epilepsia*, 16, 747-751.
- Van Zomeren, A., Brouwer, W., & Minderhoud, J. (1987). Acquired brain damage and driving: A review. *Arch. Phys. Med. Rehab.*, 68, 697-705.
- Waller, J. (1965). Chronic medical conditions and traffic safety: Review of the California experience. *New Engl. J. Med.*, 273, 1413-1420.
- Waller, J. (1977). Hunting the evasive solutions to medical impairment and highway crashes. *J. Chron. Dis.*, 30, 393-400.
- Waller, J. (1981). *Transportation patterns of persons with recent hospitalization for heart disease* (Final report). Washington, D.C: AARP Andrus Foundation.
- Waller, J. (1992). Research and other issues concerning effects of medical conditions on elderly drivers. *Hum. Factors*, 34, 3-15.
- Waller, J., & Naughton, T. (1983). *Driving and crash experience and ischemic heart disease - implications for countermeasures*. In 27th Annual Proceedings, American Association for Automotive Medicine, October 3-6, San Antonio, TX. Morton Grove, IL: AAAM.
- Weiss, G., Hechtman, L., Perlman, T., Hopkins, J., & Wener, A. (1979). Hyperactive as young adults: A controlled prospective ten-year follow-up of 75 children. *Arch. Gen. Psychiatry*, 36, 675-681.
- Wielgosz, A., & Azad, N. (1993). *Effects of cardiovascular disease on driving tasks*. In S. M. Retchin (Ed.), *Clinics in geriatric medicine: Medical considerations in the older driver* (pp. 341-348). Philadelphia, PA: W.B. Saunders Company.
- Williams, C., Chang, B., & Graham, J. (1992). Mandatory physician reporting of dementia to the DMV. *The Gerontologist*, 32 (Special Issue 2), 62.
- Wilson, T., & Smith, T. (1983). Driving after stroke. *J. Royal Soc. Med.*, 79, 200-203.
- Wood, P. (1956). *Diseases of the heart and circulation* (2nd ed.). Philadelphia: Lippincott.
- Ysander, L. (1970). Sick and handicapped drivers. *Acta Chirurgica Scandinavica*, 409 (Suppl. 1), 1-82.