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16. Abstract
This literature review relates changes in performance or safety outcome measures for older drivers to their medical conditions or medication use, and associated functional impairments. It was carried out as an initial task in the project, *The Effects of Medical Conditions on Driving Performance*. Researchers conducted a search of peer-reviewed journals, technical reports, and government reports that bear on medical fitness to drive, published between 2000 through 2011. Results were integrated with knowledge gained through a prior, exhaustive literature review carried out under the NHTSA project, *Taxonomy of Older Driver Behaviors and Crash Risk*, to produce a synthesis that considered the prevalence within the U.S. population, effects on the functional abilities needed for safe driving, effects on driving performance, and relationships with motor vehicle crash and violation risk. Researchers prioritized *diabetes, dementia, glaucoma, hepatic encephalopathy, macular degeneration, obstructive sleep apnea, Parkinson's disease,* and *stroke* in terms of the potential for impaired performance and crash risk among older drivers.

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List of Acronyms and Abbreviations

AAMVA ..... American Association of Motor Vehicle Administrators
AD ..... Alzheimer's disease
ADRDA ..... Alzheimer's Disease and Related Disorders Association
ADHD ..... attention deficit hyperactivity disorder
AHI ..... apnea/hypopnea index
AMD ..... age-related macular degeneration
CDC ..... Centers for Disease Control and Prevention
CDR ..... clinical dementia rating
CDRS ..... certified driver rehabilitation specialist
CNS ..... central nervous system
CPAP ..... continuous positive airway pressure
CODES ..... Crash Outcome Data Evaluation System
DMV ..... Department of Motor Vehicles
DPI ..... driver performance index
ESS ..... Epworth Sleepiness Scale
FAA ..... Federal Aviation Administration
FMCSA ..... Federal Motor Carrier Safety Administration
FRA ..... Federal Railroad Administration
FTD ..... frontotemporal dementia
HE ..... hepatic encephalopathy
ICT ..... inhibitory control test
IOP ..... intraocular pressure
ISI ..... insomnia severity index
ITRD ..... International Transport Research Documentation
MAP ..... multivariable apnea prediction
MCI ..... mild cognitive impairment
MHE ..... minimal hepatic encephalopathy
MS ..... multiple sclerosis
MWT ..... Maintenance of Wakefulness Test
NBRS ..... Neurobehavioral Rating Scale
NCHS ..... National Center for Health Statistics
NHANES ..... National Health and Nutrition Examination Survey
NDT ..... Neurocognitive Driving Test
NINCDS ..... National Institute of Neurological and Communicative Disorders and Stroke
NSF ..... National Sleep Foundation
NTIS ..... National Technical Information Services
NTSB ..... National Transportation Safety Board
OAG ..... open-angle glaucoma
OECD ..... Organization of Economic Cooperative and Development
OHE ..... overt hepatic encephalopathy
OR ..... odds ratio
OSA ..... obstructive sleep apnea
OSAH ..... obstructive sleep apnea hypopnea
PD ..... Parkinson's disease
PDI ..... potentially driver impairing

RA ..... rheumatoid arthritis
RDI ..... respiratory disturbance index
RR ..... relative risk
RT ..... reaction time
SACS ..... sleep apnea clinical score
SDLP ..... standard deviation of lane positioning
SNRI ..... serotonin and noradrenalin reuptake inhibitor
SPI ..... simulator performance index
SSRI ..... selective serotonin reuptake inhibitor
TBI ..... traumatic brain injury
TIA ..... transient ischemic attack
TRB ..... Transportation Research Board
TRID ..... Transport Research International Documentation
TRIS ..... Transportation Research Information Services
TTC ..... time to collision
UFOV ..... useful field of view
UPDR ..... Unified Parkinson Disease Rating Scale
WURT ..... Washington University Road Test

Introduction

One factor that distinguishes older drivers from their younger and middle-aged counterparts is a higher prevalence of medical conditions, and the medications used to treat them. Often, the medical conditions that are more prevalent among older people lead to impairments in visual, cognitive, or psychomotor functions needed to drive safely (Carr, Schwartzberg, Manning & Sempek, 2010). Similarly, while some medications restore function and improve mobility for those who would otherwise be unable to drive, an array of potentially driver impairing (PDI) prescriptions and over-the-counter medications have been associated with a statistically significant increase in crash risk (LeRoy & Morse, 2008).

The current understanding of how medical conditions can affect driving is based on the opinions of medical (including rehabilitation) professionals or traffic safety experts, or has been derived from simulation research. Other studies have compared the driving records of drivers whose licenses were restricted as a result of reported medical conditions to those of matched controls with the same conditions who had full driving privilege (Vernon et al., 2002). However, there is a dearth of empirical data about the relationships between medical conditions common among older adults and either performance or safety outcomes of drivers under realistic driving situations. Further, few studies have explored how people with such conditions may limit their driving exposure.

This synthesis of the state-of-the-knowledge in 2011 regarding the effects of medical conditions on driving performance integrates the results of two literature reviews: (1) an exhaustive literature review carried out under the NHTSA project, *Taxonomy of Older Driver Behaviors and Crash Risk* (Staplin, Lococo, Martel & Stutts, 2012) and (2) a search for more recent literature conducted under the NHTSA project, *The Effects of Medical Conditions on Driving Performance* (Staplin, Mastromatto, Lococo, Gish, & Brooks, 2017). Staplin et al. (2012) reviewed literature for research on the effects of arthritis, cataracts, dementia, diabetes, glaucoma, age-related macular degeneration, sleep apnea, and stroke on driving-related functional abilities or driving performance. The current literature search added studies describing the effects of additional medical conditions: multiple sclerosis, hemianopia and quadrantanopia, vestibular disease, Parkinson's disease, hepatic encephalopathy, and traumatic brain injury on driving performance or crash risk.

The present search included peer-reviewed journals, technical reports, and government reports relevant to medical fitness to drive, published from 2000 to 2011. The government reports focused on reviews, analyses, meta-analyses, and guidelines documents produced by U.S. DOT agencies that addressed vehicle operator characteristics. The search included both domestic publications and English-language reports published by other countries.

The present search sought literature relating changes in performance or safety outcome measures for older drivers to their medical conditions or medication use, and associated functional impairments. The search parameters included:

Search Years: 2000 to 2011				
Medical Condition* OR Disease* OR Medication* OR Medicine OR Prescription	AND	Driv* Performance OR Operator Performance OR Crash* OR Driv* Impairment	NOT	Alcohol OR Illicit

The research team conducted additional searches using the same strategy, but entering specific medical conditions as the first key word (using truncation to catch all forms of the condition) as follows: Alzheimer*, Dementia, Diabet*, Peripheral Neuropathy, Seizure*, Epilep*, Narcolepsy, Sleep Apn*, Arthritis, Multiple Sclerosis, Stroke, Cerebral Vascular Accident, Transient Ischemic Attack, Parkinson*, Traumatic Brain Injury, Spinal Cord Injury, Cancer, Cardiovascular, Depression, Hemianopia, Macular Degeneration, Cataract, Glaucoma. These conditions were selected on the basis of literature reviewed in Staplin et al. (2012), and from entries in the AAMVA/NHTSA *Driver Fitness Medical Guidelines* (National Highway Traffic Safety Administration, 2009)

The primary database for this search was TRID, an integrated information source combining the National and international records from TRB's Transportation Research Information Services (TRIS) database and the Organization of Economic Cooperative and Development (OECD)'s Joint Transport Research Center's International Transport Research Documentation (ITRD) database. TRID provides access to over 900,000 records of transportation research worldwide. Additional transportation and science databases were also searched, including NTIS (National Technical Information Services), ScienceDirect, PsycINFO, AgeLine and MedLine, with a crosscheck using Google Scholar. The Federal Motor Carrier Safety Administration (FMCSA), Federal Aviation Administration (FAA), and Federal Railroad Administration (FRA) websites were accessed for any relevant internal reports.

Researchers obtained the following number of hits from each database: TRID (3,179), AgeLine (28), MedLine (258), ScienceDirect (15), PsycINFO (53), and Google Scholar (2). Researchers reviewed all abstracts, and selected those studies that specifically focused on observed driver performance as a function of a medical condition (either on-road or in driving simulators), or analyzed crash and citation data for drivers with medical conditions. Studies limited to self-report data were excluded, as were those conducted to determine the ability of test batteries to predict pass-fail driving performance or crashes. Ultimately, the research team retrieved full text articles for 63 potentially relevant studies.

This document is organized according to three broad domains of medical conditions: *endocrine and metabolic disorders*; *physical and neurological disorders*; and *visual and other sensory disorders*. The medical conditions within these domains are as follows:

- Endocrine and Metabolic Disorders
    - Diabetes
    - Hepatic Encephalopathy

- Neurological and Physical Disorders
    - Arthritis
    - Dementia
    - Multiple Sclerosis
    - Obstructive Sleep Apnea
    - Parkinson's Disease
    - Stroke
    - Traumatic Brain Injury

- Visual and Other Sensory Disorders
    - Age-Related Macular Degeneration
    - Cataracts
    - Glaucoma
    - Hemianopia and Quadrantanopia
    - Vestibular Disorders

In the literature review for each medical condition are sections that describe its prevalence in the U.S. population, effects on the functional abilities needed for safe driving, effects on driving performance, and relationships with motor vehicle crash and violation risk. A section describing medication effects on driving performance or crashes is included only when such discussions were presented in the reports retrieved for this review. No separate search for specific medication effects on driving performance was conducted.

With the exception of diabetes and obstructive sleep apnea, findings are reported only for operators of passenger vehicles. In the diabetes section, one study presents findings for commercial pilots. The obstructive sleep apnea section includes several studies conducted with commercial motor vehicle drivers.

A synthesis at the conclusion of this document identifies a subset of conditions the research team regarded as being of particular concern due to their potential for driving impairment.

Disorders of the Endocrine and Metabolic Systems

Diabetes

Prevalence in U.S. population. Data for 2005 to 2008 indicates that 11% of the U.S. population 20 and older had been diagnosed with diabetes, with prevalence estimates increasing with increases in age (National Center for Health Statistics, 2011). Prevalence estimates by age group were: 3.7% for those 20-44 years, 13.7% for ages 45 to 64, and 26.9% for those 65 and older.

In a toxicology analysis of 1,335 pilots killed in civil aviation crashes, hyperglycemia was found in 3.2% of the pilots (Botch, Chaturvedi, Canfield, & Forster, 2008). Hyperglycemia was defined as concentrations of glucose greater than 100 mg/dL in urine or greater than 125 mg/dL in vitreous fluid. Only 13 of the 43 hyperglycemic pilots (30%) had a known aeromedical history of diabetes; elevated urine glucose and glycated hemoglobin test (HbA1c) findings indicated that their disease was not under control through combinations of diet, hypoglycemic drugs, and insulin. The remaining 70% of the hyperglycemic fatally injured pilots were undiagnosed and/or unreported.

Effects of diabetes on functional abilities needed for safe driving. Chronic complications of diabetes that may affect safe driving performance include visual retinopathy with associated impairments in visual acuity, loss of peripheral vision and dark adaptation; and lower limb peripheral neuropathy that may affect pedal control. Acute events related to hypo- or hyperglycemia may result in transient cognitive dysfunction and loss of consciousness (Kagan, Hashemi, & Korner-Bitensky, 2010). As noted by Sommerfield, Deary, and Frier (2004), because the brain is dependent on a continuous supply of glucose as its primary source of energy, changes in blood glucose concentration rapidly affect cerebral function.

Hypoglycemia, a condition occurring when blood glucose is too low, is a common side effect of treatment with insulin and some antidiabetic medications. Driver impairing symptoms include double or blurry vision, shakiness or trembling, tingling or numbness of the skin, tiredness or weakness, unclear thinking, fainting, and seizures. Adverse effects of hypoglycemia on cognitive functions include deterioration in simple and choice reaction times, speed of mathematical calculation, verbal fluency, attention, memory, and psychomotor function, when concentrations decline below 3.0 mmol/l (54 mg/dL). Acute hypoglycemia (blood glucose concentrations of 2.5 mmol/l [45 mg/dL]) in adults with Type 1 diabetes has also been associated with a statistically significant decline in information processing speed and in spatial abilities enabling interpretation of the surrounding environment, with a clear relevance to safe driving performance (Wright, Frier, & Deary, 2009). The National Institute of Diabetes and Digestive and Kidney Diseases Information Clearing House (2008) provides the following information about hypoglycemia when driving: *Hypoglycemia is particularly dangerous if it happens to someone who is driving. People with hypoglycemia may have trouble concentrating or seeing clearly behind the wheel and may not be able to react quickly to road hazards or to the actions of other drivers. To prevent problems, people at risk for hypoglycemia should check their blood glucose level before driving. During longer trips, they should check their blood glucose level frequently and eat snacks as needed to keep the level at 70 mg/dL (3.9 mmol/l) or above. If necessary, they should stop for treatment and then make sure their blood glucose level is 70 mg/dL or above before starting to drive again.*

Hyperglycemia, or high blood glucose, results when the body has too little insulin or can't use insulin properly. Chronic hyperglycemia is a major cause of complications with diabetes, such as retinopathy and peripheral neuropathy (American Diabetes Association, 2011). Acute hyperglycemia with blood glucose levels raised to 16.5 mmol/l (297 mg/dL) over a period of 20 minutes was associated with impairments in speed of information processing, choice reaction time, working memory, and attention; and increased agitation, anxiety, tiredness, and lethargy in adults with Type II diabetes (Sommerfieldet al., 2004). In tests requiring a speeded response, accuracy was preserved at the expense of speed, particularly for tests of attention that made demands on working memory. Working memory and processing speed are fundamental aspects of cognition in the driving task, and are negatively impacted by acute hyperglycemia.

Effects of diabetes on driving performance.

Martens, Janssen, and Stork (2001) conducted a driving simulator study to determine whether there were differences in performance between non-diabetic drivers and drivers with diabetes under the following conditions: when their blood sugar was normal and when they were hypoglycemic. Participants included 24 non-diabetics, 24 Type I (insulin-dependent) diabetics who were aware of their low-blood sugar symptoms (hypoglycemic aware), 21 Type I diabetics who were unaware of hypoglycemia symptoms, and 24 subjects with Type II (non-insulin dependent) diabetics. The study was conducted in the TNO driving simulator in the Netherlands. There were three simulator environments: a motorway, a rural road, and a city road. All diabetic subjects completed two drives in each environment, once under normal blood sugar conditions (5.0 mmol/l, [90 mg/dl]) and once under experimenter-induced low blood sugar (2.7 mmol/l, [48.6 mg/dl]). Non-diabetic subjects also completed two drives in each environment, but only under normal blood sugar levels. During all drives, both diabetic and non-diabetic subjects had an intra-venal tube to control blood sugar level, but blood sugar level was only manipulated for diabetic patients; diabetic subjects were not advised when this would occur. Each environment contained normal driving conditions and critical event conditions. Critical events included a lead vehicle braking, a package falling from a lead truck, sharp curves, and pedestrians crossing the road. A secondary task involved the detection of a red dot in the periphery; reaction time and misses were recorded. Driving performance measures included speed, standard deviation of lane position (SDLP), the percentage of time a driver was less than 1 s from a lane line, the percentage of time lane lines were crossed, and steering behavior.

Martens et al. (2001) first analyzed whether there were differences in performance between non-diabetics and diabetics under normal blood sugar level. Under all driving environments and conditions, diabetics with Type I diabetes who were *hypoglycemic aware* drove at least as well as non-diabetic drivers. In fact, their performance exceeded that of non-diabetic drivers in several situations in all three simulator environments (e. g., they drove over the centerline less often; showed lower steering deviations when overtaking a vehicle on a rural road; stayed away from the lane lines more often, and had a slower SDLP in curves). Their performance on the secondary task did not differ from the controls except during city driving scenarios (in both normal and critical scenarios), indicating increased effort attending to the driving task when compared to controls. There was also no decrement in the driving performance of Type I diabetics who were *hypoglycemic unaware* compared to the performance of non-diabetic drivers. Like the Type I hypoglycemic aware drivers, the performance of the Type I hypoglycemic unaware drivers exceeded that of the controls in several circumstances, in rural

and city environments (they exceeded the centerline less often and had lower SDLP in curves, and drove slower when approaching a crossing pedestrian). Type I hypoglycemic unaware diabetics showed poorer performance on the secondary task compared to controls in rural and city critical scenarios and in normal city scenarios, indicating increased effort spent on the driving task.

The driving performance of the Type II diabetics with normal blood sugar level was poorer than the non-diabetic drivers under normal driving conditions on the motorway and the rural road scenarios and in critical scenarios on the motorway. Their secondary task performance was poorer than that of the controls in all conditions. On the motorway, they swerved more within their lane and crossed the right lane marking more frequently during critical encounters and were closer to the lane lines more often during normal encounters compared to controls. On the rural road, they drove over the centerline when negotiating curves more often than the non-diabetic drivers.

Martens and colleagues (2001) then analyzed whether differences in performance existed within the diabetes group when their blood sugar was lowered, taking into account any differences observed in the control group from the first drive to the second drive. For both hypoglycemic aware and unaware people with Type I diabetes, there was no adverse effect of low blood sugar on driving performance. For both groups, increased workload was evident in the rural road scenarios under normal driving conditions when their blood sugar was low, compared to when they drove under normal blood sugar level. Drivers with Type II diabetes demonstrated poorer driving performance under low blood sugar conditions on the rural and city roads under normal driving conditions compared to when they drove under normal blood sugar levels. On the rural road, these drivers swerved more in their lane when negotiating a wide curve; on a straight road, they drove more slowly when overtaking a lead vehicle, and exceeded the centerline more often in wide curves and the right edgeline more often on straight roads than when their blood sugar was normal. On city roads, they exceeded the centerline in wide curves more often than when driving under normal blood sugar conditions. They showed poorer secondary task performance during hypoglycemic driving than when driving under normal blood sugar levels in normal and critical scenarios on the rural and city roads and under normal driving on the motorway, indicating increased workload when driving under hypoglycemic conditions. The authors concluded that the driving performance of people with Type I diabetes (both hypoglycemic aware and unaware; and under normal and low blood sugar levels) was at least as good as that of drivers without the condition, however, the driving task was more effortful for these drivers than controls. For people with Type II diabetes, performance was slightly degraded under normal blood sugar levels and more so during hypoglycemic conditions, as compared to controls. This underscores the importance that, people with Type II diabetes should not drive under hypoglycemic conditions.

Cox, Kovatchev, Anderson, Clarke, and Gonder-Frederick (2010) compared the simulated driving performance of 16 people with Type I diabetes with a positive history of hypoglycemia-related driving mishaps over the prior 12-month period (e. g., 2 or more crashes, citations, experiences of driving between two points without any recollection of the trip, or someone else took over control of the car due to hypoglycemia) with 22 drivers with Type I diabetes and a negative history of such mishaps, both under normal blood glucose levels and under hypoglycemic conditions. The two groups did not differ with respect to age, sex,

educational level, diabetes duration, number of insulin units per day, hypoglycemia awareness, driving experience, or miles driven per year. The average age of the subjects was 42, and the average disease duration was 21 years. Groups differed on the number of severe hypoglycemic episodes within the prior 12 months (1.6 for the positive history group versus 0.5 for the negative history group) and the number of driving mishaps in the prior 12 months (2.8 for the positive history group versus none for the negative history group).

Subjects completed driving performance testing on an interactive, fixed platform, virtual reality simulator (Atari Research Driving Simulator). On each day, subjects were tested first under normal blood glucose levels (5.5 mmol/l, [99 mg/dl]), and then under progressive hypoglycemic levels (3.9 to 2.5 mmol/l, [70.2 mg/dl to 45 mg/dl]). The design was randomized and conducted in a crossover manner so that Day 1, half the subjects watched a video of someone driving and rated four autonomic symptoms (sweating, pounding heart, jittery tension, and trembling) and five neuroglycemic symptoms (uncoordination, visual difficulty, lightheadedness, and confusion) on a 0 (not at all scale) to 6 (extremely scale), and then drove the simulator, while the other half drove the simulator first and then watched the video. The order of presentation on Day 2 was reversed. Normal glucose testing always preceded hypoglycemic testing. Driving performance measures included SDLP, driving off road, veering across the midline, inappropriate braking while on open road, missed stop signals, collisions, driving over the speed limit, speed standard deviation, decision time at a stop sign to turn left, and time to execute a left turn. The authors calculated a composite impaired driving score, rating driving as average, better than average, or worse than average. Subjects were instructed to self treat if they felt hypoglycemic by drinking an orange soda (a sugar-free placebo).

Under normal blood glucose conditions, there was no difference in driving performance between positive and negative history groups. Under hypoglycemic conditions, driving performance was not degraded for the negative history subjects, but was 2.5 SD worse for the positive history subjects as compared to their performance under normal glucose levels. The experimental design did not allow for a determination of glucose level at which driving impairment was first manifested. Positive history subjects reported more symptoms during normal glucose testing than during hypoglycemic testing, and more symptoms during normal glucose testing than negative history drivers. This suggests that they experienced more "symptom noise" under normal blood sugar conditions that made it harder to detect hypoglycemia. Negative history drivers reported an increase in symptoms with increasing hypoglycemia. Self-treatment was low for both groups and not significantly different, suggesting that drivers are willing to drive under low glucose conditions. Cox et al. (2010) provided the following clinical recommendations for people with Type I diabetes with a history of driving mishaps (high-risk drivers): (1) more robust carbohydrate dosing to prevent or treat hypoglycemia; (2) counseling to not begin driving at a particular blood glucose threshold (5 mmol/l, [90 mg/dl]); (3) counseling to stop driving immediately if blood glucose falls to less than 4 mmol/l (72 mg/dl), and to treat themselves with fast-acting carbohydrates, and not to resume driving until blood glucose is greater than 5 mmol/l (90 mg/dl).

Cox et al. (2009) conducted a study using self-reported data over a 12-month period to identify the factors associated with hypoglycemic-related driving mishaps among 452 drivers with Type I diabetes. The mean age of the sample was 42.4 (s. d.12.5), the mean disease duration was 25.9 years, and the average estimated A1C was 7.8%.

Over the 12-month study period, 52% of the subjects reported at least one hypoglycemia-related driving mishap, 32% reported two or more, and 5% reported six or more (Cox et al., 2009). The drivers reported that they had self-monitored blood glucose within 30 minutes of initiating driving for 35% of the mishaps. When blood glucose was self-monitored, and a driver had a subsequent mishap, blood glucose was $\leq$ 90 mg/dl on 78% of the occasions, and < 70 mg/dl on 48% of the occasions. Regression analyses were used to estimate the relative risk of the occurrence of such mishaps, corrected for self-reported annual mileage. Future driving mishaps (within the next 12 months) were statistically significantly associated with using insulin pump therapy (a 35% increase over those using insulin injections), having an episode of severe hypoglycemia in the past year (a 6% increase in risk), a collision in the prior 2-year period, regardless of the cause (a 20% increase in risk), a hypoglycemic-related driving mishap in the prior 2-year period (a 6% increase), and mild symptomatic hypoglycemia while driving in the past 6 months (a 3% increase in risk). The risk increased exponentially with additional reported episodes, (e. g., a 40% increase for 2 collisions in the prior 2-year period). Factors *not* associated with future hypoglycemic-related driving mishaps were age, sex, disease duration, total number of insulin units per day, estimated A1C levels, awareness of low blood glucose by symptoms, blood glucose threshold for treatment, blood glucose threshold for not driving, or whether carbohydrates were available in the car.

Relationship of diabetes with motor vehicle crash and violation risk. An analysis of Crash Outcome Data Evaluation System (CODES) data suggested an elevated crash risk for diabetics (Vernon, Diller, Cook, Reading, & Dean, 2001). The effect size was modest, however – an odds ratio between 1.2 to 1.6 – and disappeared among drivers with higher levels of impairment (and greater restrictions on driving). Thus, a diagnosis for diabetes, in and of itself, may have little value in explaining safety outcomes.

Staplin and colleagues (2012) asserted that the medications used to treat diabetes, rather than the condition itself, may be of greatest concern. Lee, Kwok, Leung, and Woo (2006) found that anti-diabetic medications were related to recurrent falls, but having diabetes was not.

In addition to insulin, there are five classes of oral diabetes medications that help in lowering blood glucose levels by different mechanisms. Blood sugar control can be achieved with the use of a single agent, or a combination, with or without insulin. Of the hypoglycemics, insulin (e. g., Lantus, Humalog, Novolin) was associated with the highest OR (OR=1.80) for a motor vehicle crash in a case-control study by LeRoy and Morse (2008). The other hypoglycemic agents studied had ORs ranging from 1.35 to 1.50. Common side effects associated with hypoglycemics are gastrointestinal upset, bloating, diarrhea and loss of appetite, none of which would predict a direct relationship with impaired driving. Uncommon side effects include shortness of breath, dizziness, and blurred vision, which would fall into the PDI category.

Within this class of medication, compliance may have more to do with PDI effects than metabolic effects of the drug. Taking too much insulin or delaying or missing a scheduled meal or snack can cause low blood sugar (hypoglycemia), and can result in shakiness, dizziness, confusion, difficulty concentrating, drowsiness, weakness, clumsy or jerky movements, and seizures. These symptoms are driver impairing. Low blood sugar, left untreated, can lead to unconsciousness. High blood sugar (hyperglycemia) results from too little insulin, and also has

symptoms that may impair driving, such as weakness, blurred vision, and decreased consciousness. These symptoms may result from skipping an insulin dose or from overeating.

Kagan and colleagues (2010) performed a systematic review of the literature for studies from 1965 to 2010 examining crash and violation risk for drivers with diabetes, with a special emphasis on older drivers. The authors identified 22 studies during this period; only five of these controlled for driving exposure. Of the 22 studies, 9 showed statistically significant increases in crash risk for those with diabetes across all ages. Two of the 9 studies controlled for mileage and reported ratios of 1.97 and 2.60. With respect to drivers 65 and older, 9 studies investigated crash risk for drivers with diabetes, and 2 of these found ORs statistically significantly greater than 1.0. One of these controlled for mileage and reported one of the highest risk levels (OR=2.6).

Of seven studies examining violation risk for drivers with diabetes across all ages , only two reported statistically significant results (relative risks of 1.07 and 1.82), and neither of these controlled for mileage. Two studies focused on older drivers, but neither reported a statistically significant result. The authors note that this may have been the result of a small sample size (n=27).

Only 4 of the 22 studies examined diabetes type and crash and violation risk. Two of the four studies of Type 1 diabetes across all ages found crash risk ratios significantly greater than 1.0 (RR=2.38 and 1.20); one of these controlled for mileage (RR=2.38). The only study that examined violation risk for Type 1 diabetes reported non-statistically significant findings. A study examining Type 2 diabetes and crashes across age groups that controlled for mileage found non-statistically significant results.

Redelmeier, Kenshole, and Ray (2009) investigated the crash risk of 795 people with diabetes referred to the Ontario Ministry of Transportation Medical Advisory Board, as a function of their HbA1c level, during a 2-year period. They hypothesized that drivers with better control (lower HbA1c) would have a lower crash risk. During the study period, 57 drivers were involved in crashes and 738 were not. The authors found that lower HbA1c levels were associated with an *increase* in crash risk (a 26% increase in relative risk for each 1% reduction in HbA1c). This risk persisted even after controlling for potentially confounding factors such as time since diagnosis, treatment type, age, age when diagnosed, insulin use, and age when insulin started. The mean HbA1c for the crash-involved drivers (cases) was 7.4%, which was significantly lower than the 7.9% for the non-crash-involved drivers (p=0.019). Two patient characteristics were independent risk factors for a motor vehicle crash: a history of severe hypoglycemia requiring outside help was associated with a 4-fold increase in crash risk, and older age for the diagnosis of diabetes was associated with a 26% increase per decade. The authors postulated that those whose diabetes was tightly controlled may have driven in more dangerous settings or that intensive treatment regimens may have led to HbA1c levels low enough to result in severe hypoglycemia. Redelmeier, Kenshole, and Ray (2009) concluded that a driver's HbA1c level was neither necessary nor sufficient for determining fitness to drive.

Weaknesses of this study included lack of a driving exposure measure, basing crash outcome on referral source report rather than on driver records. Crash outcome assignment (as reported by the study authors) based on the source of the referral, rather than through examination of driver records in the licensing database, which may have misclassified controls.

Relationship of diabetes with crash risk for other modes of transportation. In the toxicology analysis of 43 fatally injured hyperglycemic aviation pilots, the NTSB established that the pilot's elevated glucose level (1,175 mg/dL) was a factor in one crash, and that the second pilot had been incapacitated due to multiple medical conditions including hyperglycemia (1,548 mg/dL), hypertension, and ulcer (Botchet al., 2008). The urine glucose levels of 13 fatally injured pilots with known diabetic conditions ranged from 189 to 8,815 mg/dL. Further analysis of HbA1c levels obtained for five of these pilots indicated that four had levels greater than 6% (ranging from 7.1 to 12.4%).

Hepatic Encephalopathy

In later stages of liver disease, some blood cannot enter the diseased liver via the portal vein and is re-routed throughout the body before being de-toxified (portal shunting). This blood contains toxins such as ammonia, manganese, and mercepatans that interfere with brain functions. Elevated levels of these toxins in the brain result in psychiatric, cognitive, and motor dysfunction, a condition known as hepatic encephalopathy (HE). HE does not lead to statistically significant loss of neurons, but does cause changes in astrocytes, star-shaped glial cells in the brain and spinal cord, resulting in Alzheimer type II astrocytosis. As there is no single clinical or laboratory test to definitively diagnose HE, clinicians use a common cluster of characteristics and symptoms for diagnosis (Butterworth, 2003).

HE is divided into two subtypes: overt (OHE) and minimal (MHE). OHE may be diagnosed symptomatically in the presence of a clinical confirmation of liver disease, while diagnosing MHE requires the use of specialized neuropsychological testing (Ferenci et al.,, 2002). While those with MHE experience milder symptoms, they are still often significant enough to interfere with daily activities of living. MHE is often a precursor to OHE.

Prevalence in the U.S. population. Estimates of prevalence vary. A review of HE literature by Poordad (2007) found that 20 to 60% of patients with liver disease developed MHE, while 30 to 40% developed OHE; the report estimated 5.5 million cases of chronic liver disease and cirrhosis in the United States.

Medication used to treat hepatic encephalopathy. Lactulose and the antibiotic rifaximin were considered efficacious in treating HE. A clinical trial has shown that use of rifaximin improved driving simulator performance in a group of patients with minimal HE (Bajaj et al., 2011).

Effects of HE on functional abilities needed for safe driving. Those with OHE have been shown to experience cognitive dysfunction, psychomotor slowing, and fatigue. Motor conditions may also arise, including flapping tremor of the hands (asterixis) (Butterworth, 2003). Even those with MHE have exhibited cognitive dysfunction (especially in the domain of attention) as well as difficulty in encoding memory (Weissenbornet al., 2005).

Effects of HE on driving performance. A study examining the on-road performance by a driving instructor found that drivers with MHE performed significantly worse than healthy controls on response to road signs, attending to bicyclists and pedestrians, checking the rearview mirror and the blind spot before changing lanes, tracking, signaling to turn in a timely fashion, and following traffic rules. The driving instructor was 10 times more likely to intervene to avoid

a crash while driving with participants with MHE (Wein, Koch, Popp, Oehler, & Schauder, 2004).

A simulator study of the effects of fatigue on driving in patients with HE found that patients with OHE and MHE were statistically significantly impaired compared to cirrhotic patients without HE in collision avoidance, center lane crossings, and road-edge excursions (i.e., driving off the side of the road). In the second half of the simulator run, patients with MHE performed worse on measures of speeding, center lane crossings, and collisions, indicating the deleterious effects of fatigue, likely exacerbated by the attentional deficits in MHE patients, on their performance (Bajaj, Hafeezullah, et al., 2009).

Relationship of HE with motor vehicle crash and violation risk. In a study of driving histories (both self-and DOT-reported), people with cirrhosis underwent a series of neurocognitive tests including the inhibitory control test (ICT) to diagnose MHE. A diagnosis of MHE based on the ICT score was the only variable statistically significantly associated with DOT-reported motor vehicle crashes (OR, 5.72; 95% CI, 1.22-26.76, $P = .0009$). The relative risk of a DOT-reported crash for those with MHE was 5.77 (95% CI, 2.01-16.6). *All* participants with a self-reported crash had MHE as diagnosed by ICT. A follow-up after one year of driving found a significantly higher rate of driving offenses in those with MHE than those without (15 of 66, 22%, as compared to 3 of 43, 7%, $P = .03$). A multivariate logistic regression, using future offenses as the outcome, found that MHE, as diagnosed by ICT, was statistically associated as a risk factor (OR, 4.51; 95% CI, 1.12-19.39) (Bajaj, Saeian, et al., 2009).

Neurological and Physical Disorders

Arthritis

Arthritis is a term used to describe more than 100 different conditions that affect joints as well as other parts of the body. Arthritis is one of the most prevalent chronic health problems and one of the nation's most common causes of disability (Centers for Disease Control and Prevention, 2010b).

Prevalence in U.S. population. The prevalence of arthritis in the United States is pronounced, with 50 million people affected (22.2% of the population 18 and older), and over 21 million of whom report limited activity as a result of the disease (Centers for Disease Control and Prevention, 2010b). This estimate is based on National Health Interview Survey data from 2007 to 2009, in response to the question, "Have you ever been told by a doctor or other health professional that you have some form of arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia?" The prevalence increases with age, and is higher among women. The CDC reported prevalence by age group as follows: 7.6% among those ages 18 to 44, 29.8% among those 45 to 64, and 50% among those65 and older. Across age, the prevalence in women is 25.9% and for men 18.3%. By 2030 an estimated 67 million Americans 18 or older (25% of the adult population) are projected to have doctor-diagnosed arthritis (Hootman & Helmick, 2006).

The most common form is osteoarthritis, a degenerative joint disease characterized by the destruction of cartilage resulting in bone-on-bone friction, pain, deformities, and restrictions in mobility. The weight bearing joints (hips, knees, lower back) are most affected, but symptoms in the neck, hands, and feet are not uncommon. An estimated 27 million adults had osteoarthritis in 2005 (Lawrence et al., 2008). Obesity and advanced age, as well as family history, are the strongest risk factors for the disease (Carr, 2007).

Other common rheumatic conditions include gout, fibromyalgia, rheumatoid arthritis, and lupus (Lawrence et al., 2008). Gout causes sudden, severe attacks of pain and tenderness, redness, warmth, and swelling in some joints. Gout usually affects one joint at a time, often the big toe. Gout affects men more than women. An estimated 3 million adults had gout in 2005 (Lawrence et al., 2008). Fibromyalgia, an arthritis-related condition that is characterized by generalized muscular pain and fatigue affected approximately 5 million people in 2005; it occurs more commonly in women than in men (Lawrence et al., 2008). Rheumatoid arthritis (RA) is a systemic disease that affects the entire body and is characterized by the inflammation of the membrane lining the joint, which causes pain, stiffness, warmth, redness and swelling. There are 2.5 times as many women as men with RA; it affected approximately 1.5 million adults in 2007 (Myasoedova, Crowson, Kremers, Therneau, & Gabriel, 2010). Lupus is a chronic inflammatory disease that can affect various parts of the body, especially the skin, joints, blood, and kidneys. It affects as many as 322,000 Americans and affects women 8 to 10 times more often than men (Helmick et al., 2008).

Effects of arthritis on functional abilities needed for safe driving. Arthritis can result in several anatomical changes, including: cervical rotation; weak or painful wrist; painful proximal and distal interphalangeal joint (lower and upper finger area) or first carpalmetacarpal; pain or decreased range in knees or hips; ankle rigidity; pain in metatarsophalangeal joints; and single inflamed digits, either acute or subacute, in the hand or foot (Roberts & Roberts, 1993).

Arthritic conditions can affect entering and exiting the vehicle, as well as positioning and comfort in the vehicle. The following control tasks are affected by arthritis: turning the wheel, gripping the wheel, and difficulty stepping on brake. These difficulties may impair backing, parking, and turning maneuvers.

Driving difficulties reported by people with musculoskeletal disease include difficulty using a seat belt, manipulating a car key, adjusting the mirrors and seats, transferring in and out of the car, steering (especially when backing), and using the foot pedal (Jones, McCann, & Lassere, 1991). While no diagnoses were reported, two areas of functional loss associated with arthritis that significantly predict the risk of at-fault crashes among older drivers are head-neck mobility, and lower limb strength and flexibility (Staplin, Gish, & Wagner, 2003; Ball et al., 2006).

Effects of arthritis on driving performance. Staplin et al. (2012) reported findings by Zhang et al. (2007). In that study, older drivers (67 to 80 and older) who reported three or more complaints of pain in the feet, hips, legs, or current treatment for arthritis had significantly slower brake reaction speeds—both in terms of initial reaction speed and physical response speed—than drivers with no complaints of pain in these areas. The brake reaction test measured simple reaction time to move the foot from the accelerator to the brake when a green "traffic light" stimulus changed to red. Initial reaction time was measured from the time the signal turned red until a motor response (foot moving off the accelerator pedal). Physical reaction time was the time between the foot starting to move from the accelerator until the time the brake pedal was fully depressed.

Relationship of arthritis with motor vehicle crash and violation risk. As reported by Staplin and colleagues (2012), a diagnosis of arthritis and the use of non-steroidal anti-inflammatory drugs (NSAIDs) were statistically significantly associated with at-fault crash risk (McGwin, Sims, Pulley, & Roseman, 2000). Analyses of the Utah CODES data showed a higher crash rate for drivers with musculoskeletal disorders (Vernon et al., 2002). However, Koepsell, Wolf, and McCloskey (1994) found that drivers with a diagnosis of osteoarthritis were at no higher risk than a control group.

No new studies were identified in the present review linking arthritis to increased crash or violation risk.

Dementia

The four most common types of dementia are Alzheimer's disease (AD), vascular dementia, frontotemporal dementia, and dementia with Lewy bodies (Snellgrove, 2005).

Prevalence in the U.S. population. The most troubling of the dementias is AD. AD is the most common cause of dementia, accounting for 60 to 80% of cases. Its prevalence is estimated at 13% for Americans 65 and older (Alzheimer's Association, 2011). The prevalence increases with increasing age, although a small percentage of people younger than 65 are affected by early-onset AD. In 2011 about 6% of Americans age 65-74 had Alzheimer's, compared with 45% of those 75 to 84, and 45% of those85 and older. With the increase in the number of baby boomers turning 60 (a rate of approximately 330 every hour), the number of Americans 65 and older with

AD could increase from the present 5.2 million to 7.7 million in 2030 (a 50% increase), tripling to 16 million by 2050 (Alzheimer's Association, 2011).

AD and other dementias are more prevalent in women than men (16% of women over age 71, compared to 11% of men), which is primarily explained by women's extended longevity (Alzheimer's Association, 2011). Studies of age-specific incidence by sex have shown no differences, indicating that women are not at higher risk than men to develop dementia at a given age.

As reported by the Alzheimer's Association (2011), one of the established risk factors for AD is mild cognitive impairment (MCI). MCI is characterized by problems with memory, language or another essential cognitive ability that are severe enough to be noticeable to others and show up on cognitive tests, but not severe enough to interfere with daily life. Estimates are that 10 to 20% of people aged 65 and older have MCI, and that 15% of these progress from MCI to dementia each year, with nearly half of all people who have visited a physician about MCI symptoms developing dementia in three or four years.

de Simone, Kaplan, Patronas, Wassermann, and Grafman (2007) cite research by others that frontotemporal dementia (FTD) is the second most common cause of primary dementia in the period preceding old age (Neary, 1999; Snowden & Neary, 1999).

Effects of dementia on functional abilities needed for safe driving. The essential feature of a dementia is the development of multiple cognitive deficits that include memory impairment and at least one of the following cognitive disturbances: aphasia, apraxia, agnosia, or a disturbance in executive functioning. Memory impairment is required to make the diagnosis of a dementia and is a prominent early symptom. People with dementia become impaired in their ability to learn new material, or they forget previously learned material. Most people with dementia have both forms of memory impairment. Within the context of driving, memory impairment has ramifications in particular when there are changes in familiar environments, such as detour or speed limit signs. It may also affect the ability of a person to retain information from a complex sign.

Aphasia is a deterioration of language function, and may be manifested by difficulty producing the names of people and objects. Comprehension of spoken and written language and repetition of language may be compromised. When one loses the ability to understand language, then signs with words may become meaningless. Aphasia will impair a driver's ability to comply with regulatory traffic sign messages and make appropriate responses to warning and guide signs.

Apraxia is impairment in the ability to execute motor activities despite intact motor abilities, sensory function, and comprehension of the required task. Within the driving context, the greatest concern may be impairment in the use of vehicle controls (e. g., pedal confusion and signaling errors).

Agnosia is a failure to recognize or identify objects despite intact sensory function. For example, someone may have normal visual acuity but lose the ability to recognize objects such as chairs or pencils. When one loses the ability to see the environment in a structured way, then

the relationships between the streets, the cars and the signals may become distorted and driving is likely to become extremely dangerous.

Executive functioning involves the ability to think abstractly and to plan, initiate, sequence, monitor, and stop complex behavior. Impairment in abstract thinking may be manifested by difficulty coping with novel tasks and avoiding situations that require the processing of new and complex information. Executive dysfunction is also evident in a reduced ability to shift mental sets, to generate novel verbal or nonverbal information, and to execute serial motor activities. Impaired abstract thinking may impair a driver's ability to understand how symbols such as picture signs relate to actual driving behavior. Difficulty switching from one task to another will result in increased crash risk for drivers dealing with complex traffic situations (e. g., intersections).

Associated features common in dementia include spatial disorientation and difficulty with spatial tasks, poor judgment, and poor insight. Impaired judgment refers to the inability to make correct decisions, such as when it is safe to turn across the intersection. Although this function is difficult to measure in the clinical setting, it may be one of the most relevant of disturbances to driving safety. Some people exhibit little or no awareness of memory loss or other cognitive abnormalities. They may make unrealistic assessments of their abilities and make plans that are not congruent with their deficits and prognosis. They may underestimate the risks involved in activities, such as driving. Impulsivity can lead to dangerous behaviors, such as prematurely pulling out into traffic or running a red light.

Effects of dementia on driving performance. As described in Staplin et al. (2012), driving problems may be an early sign of dementia, because of the great demands for selective attention, judgment, and visual interpretation. Drivers with dementia may become lost in familiar areas; they may become confused by detours or heavy traffic; they may misinterpret signs and signals; or they may accelerate when they intend to brake (Kaszniak, Keyl, & Albert, 1991). Multiple studies have found that drivers with dementia also have difficulty recognizing traffic signs (Brashear et al., 1998; Carr, Madden, & Cohen, 1991; Hunt, Morris, Edwards, & Wilson, 1993; Carr, LaBarge, Dunnigan, & Storandt, 1998).

Hunt's (1994) description of other errors made by drivers with dementia and the situations in which they occurred were also reported in Staplin and colleagues (2012), including:

- stopping in the middle of traffic when driving in situations that demand complex or rapid cognitive processing and problem solving, when to an observer, there is no reason to stop;
- failing to yield the right of way or inappropriately attempting to proceed on a green light when turning left at an intersection when the sign reads, "left turn on arrow only;"
- incorrectly interpreting verbal commands or suggestions from a passenger (e. g., directions, reminders to check traffic before making a lane change) or not interpreting them in time for the proper action to occur;
- failing to check their blind spots;
- coasting to near stop in moving traffic; drifting into other lanes;
- driving while pressing the brake and accelerator simultaneously;

- and failing to realize why other drivers honked at them.

A finding from a study by Hunt et al. (1997) was that driving performance in people with dementia of the Alzheimer's type may vary from day to day, as a result of fluctuations in cognitive performance because of stress or fatigue ("good day" versus "bad day"), as well as from differences in the availability of environmental cues.

In the longitudinal study conducted by Duchek et al. (2003), two driving behaviors—lane change and using signals—were impaired with increasing dementia (AD) severity. They studied the driving performance of three groups of older drivers: 58 healthy older controls (CDR=0), 21 with very mild dementia (CDR = 0.5), and 29 with mild dementia (CDR = 1). Driving performance was measured at 6-month intervals for a 2-year period using the Washington University Road Test in a standard car with dual brakes. At the time of the first test session, 41% of older subjects with mild dementia failed the in-traffic road test, compared to 14% of older subjects with very mild dementia, and 3% of the healthy older subjects. A global rating of "safe" (driving behavior unlikely to produce any risk of a crash) was assigned to 78% of the healthy older controls, 62% of those with very mild dementia, and 41% of those with mild dementia. A global rating of "marginal" (driving behavior posed a small to moderate risk of crashing such as driving too slowly) was assigned to 19% of the health older controls, 24% of those with very mild dementia, and 17% of those with mild dementia. Analysis of driving performance over time indicated that subjects *without* AD took statistically significantly longer to receive a rating of "not safe" (driving behavior posed a substantial risk of a crash such as ignoring a traffic signal/sign or stopping for no reason) than subjects with mild dementia. The survival function for the subjects with very mild dementia fell somewhere between the healthy and mild dementia groups. Some with very mild dementia and a few with mild dementia retained safe driving skills after repeated times of testing over the 2-year period. This reinforces the importance of individualized, standardized evaluation of driving skills early in the disease process for drivers diagnosed with dementia, and reevaluation every 6 months to determine when driving performance is no longer safe.

Also documented in Staplin et al. (2012) were simulator study findings that drivers with AD were more likely to crash at intersections and were also more likely to have rear-end collisions than older drivers without dementia (Rizzo, McGehee, Dawson, & Anderson, 2001; Rizzo, Reinach, McGehee, & Dawson, 1997). Behaviors within the 5 seconds preceding the crash included looking without seeing and failing to respond at all, as well as failing to react in time to avoid a collision. Uc, Rizzo, Anderson, Shi, and Dawson (2004) reported that drivers with AD committed more at-fault safety errors (erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behavior) than healthy age-matched controls.

Finally, Staplin and colleagues (2012) included a study conducted by Snellgrove (2005) describing the predictive ability of the Maze test in discriminating passing versus failing an on-road drive test. More detail about that study is provided here, focusing on the on-road assessment findings. Snellgrove studied two groups of older drivers; 23 diagnosed with MCI and 92 diagnosed with early dementia. Sixty percent of the early dementia sample was diagnosed with AD. The mean age of the MCI sample was 76.4 and the mean age of the early dementia sample

was 77.09. The 45-minute driving assessment was conducted in traffic along a pre-determined route and scored according to licensing authority (South Australia [SA]) criteria, by a SA license examiner with expertise in the assessment of fitness to drive in applicants with medical conditions, including dementia. Failure was set as a score of 69% or below (as opposed to the licensing criteria of below 85%), to avoid failing drivers for committing errors considered "bad habits" of experienced, competent drivers such as failure to signal for 5 sec prior to changing lanes or turning. The study failure criteria thus implied that a driver was not fit to drive.

In the Snellgrove (2005) study, a statistically significantly smaller percentage of drivers with early dementia passed the test (23.9%) compared to drivers with MCI (52.2%). The mean percent of driving faults across the 115 drivers was: right turns (44.3%), left turns (38.5%), general driving faults (39%). The mean overall test score was 55%, and most participants (95%) broke at least one road law. Forty-three percent of the participants required at least one physical intervention during the assessment. Verbal feedback provided by the assessor indicated that driving faults were related to poor scanning and observation of other vehicles on the road or parked on the curb, poor scanning and observation of road signs and signals, an inability to monitor and control vehicle speed (both high and low), poor positioning of the car on the road and when parked, confusion with pedals and with gear selection (both manual and automatic), and lack of anticipatory or defensive driving. Faults occurred with higher frequency when driving tasks became more complex and when traffic was heavier. Participants lacked awareness of their faults. Driving performance was not described by diagnosis in this study, as the focus was on the predictive ability of a cognitive screening test.

Nine new studies on dementia and driving performance were uncovered in the present literature review, and are summarized below.

Ott et al. (2008) conducted a three-year longitudinal study of drivers with AD using the methodology described by Duchek et al. (2003), and the Washington University Road Test (WURT) adapted for comparable streets in Rhode Island. Subjects included 52 drivers with very mild dementia (CDR = 0.5) with an average age of 76, 32 drivers with mild dementia (CDR = 1) and an average age of 75, and 44 healthy older controls (CDR = 0) with an average age of 73.5. All subjects were evaluated at baseline; subjects with AD were evaluated every 6 months up to 3 years, while controls were re-evaluated only at 18 months. At 18 months, patients were more likely to fail the road test than controls (15% versus 5%), and CDR 1 patients were more likely to fail than CDR 0.5 patients (43% versus 5%). A survival analysis was conducted across the 3-year study period that combined safe and marginal groups to contrast them against subjects who were not able to continue (either because they were judged unsafe due to road-test failure, at at-fault crash during the study period, or dementia progression to the point that caregivers would no longer allow them to drive). Patients in the CDR 0.5 group had a median time to failure of 605 days; a time period that was statistically significantly longer than 324 days for patients in the CDR 1 group. After adjusting for differences in age, sex, educational level, and years of driving experience, the hazard of failure in the CDR 1 group was 3.5 times higher than in the CDR 0.5 group. Patient age and educational level were also statistically significant predictors of failure: a 6% increase for every year subject age exceeded the average age of the patient group and a 10% increase for every year the subject's educational level lagged behind the average level of the patient group. The study authors conclude that patients with very mild AD (CDR 0.5) can continue to drive safely for an extended period of time, in contrast to those with mild AD (CDR

1), and that because driving ability declines rapidly among patients with dementia, 6-month follow-up driving assessments are reasonable for this group.

In another study using the WURT adapted for similar roadways in Rhode Island, Grace and colleagues (2005) compared the driving performance of 21 patients with probable (mild) AD and 21 healthy older controls. The diagnosis of probable AD was made according to NINCDS-ADRDA criteria. All the control participants were judged safe to drive by the driving instructor compared to 45% of the AD patients. AD patients frequently committed driving errors categorized as operational, tactical, and strategic, with the greatest prevalence in the tactical category. Healthy older controls, in comparison, made few errors in any category, the majority of their errors were in the tactical category (e. g., observing the legal right-turn on red and signaling when pulling over to the curb; 33% of control participants each). The specific maneuvers involving errors by the AD group, and percent of group committing errors on each maneuver are as follows. In the operational category: appropriate reaction to merging traffic (40%); awareness of how driving is affecting others (40%); lane change— problem solves for immediate left turn (35%); merging from right – awareness of traffic environment (25%); and left turn at four-way stop—hesitates without reason (25%). In the strategic category: reasoning about making a left-hand turn onto a one-way street (45%); ability to follow a lengthy command (45%); overall judgment (40%), and lapses of concentration (35%). In the tactical area: merging from right—scanned for lane change (75%); lane change—checks blind spot (70%); lane change—smoothness of change (65%); left turn—turns in appropriate lane (55%); pulls over to curb—signaling (55%); lane changes—signals (45%); checks mirrors (40%); right turn—observed legal right on red (35%); right at four-way stop—complete stop (25%); right turn—signals (25%); parking—checks traffic backing out of space (20%); and drives within 5 mph of speed limit (15%).

Wadley et al. (2009) compared the on-road driving performance of 46 patients with MCI to 59 cognitively normal controls. Unlike prior research that defined mild cognitive impairment as a CDR rating of 0.5, Wadley et al. used Petersen/Mayo criteria[1] which uses multifaceted criteria for MCI case designation. This is because a CDR 0.5 rating may not capture all cases of MCI; a subset of MCI cases may receive CDR scores of 0 a subset of AD patients may receive scores of 0.5. Petersen (2004) describes MCI as a transitional period between normal aging and the diagnosis of clinically probable very early AD; it is a pathological condition, not a manifestation of normal aging. Diagnoses of normal and MCI were determined by consensus conferences of memory clinic staff, including neurologists, neuropsychologists, and nursing staff. Within the MCI group, 43 drivers were diagnosed with amnestic and 3 with nonamnestic MCI. Driving performance ratings ranging from 5 (optimal) to 1 (evaluator took control of car) were given by a CDRS for the following driving skills: right turns, left turns, lane control, gap judgments, steering steadiness, maintaining speed, and a global rating of driving performance.

Wadley et al. (2009) found that participants with MCI were significantly more likely than controls to receive less-than-optimal ratings on left-hand turns (59% of MCI group versus 37% of controls), lane control (39% of MCI group versus 13.6% of controls), and for the global driving score (43.5% of MCI group versus 18.6% of controls). MCI subjects also received less-

[1] The criteria include: (1) memory complaint, preferable corroborated by an informant; (2) objective memory impairment for age; (3) relatively preserved general cognition for age; (4) essentially intact activities of daily living; and (5) not demented.

than-optimal ratings on maintaining proper speed and gap judgment than controls, although these differences only approached significance. Logistic regression models found statistically significant ORs only for lane control and global rating. For lane control, MCI patients were 3.69 times more likely than controls to receive a less-than-optimal rating. For global ratings, MCI patients were 4.23 times more likely than controls to receive less-than-optimal ratings. The lower-than-optimal ratings for left turns were accounted for by age and sex.

Wadley et al. (2009) concluded that although participants with MCI were more likely to demonstrate decrements in driving performance than controls, the impairments were not "frank impairments"—that is, impairments at the level described as "unsatisfactory, "unsafe," or "evaluator took control." Examples of behavior coded as "not optimal" were driving too fast or too slow (5 mph over or under the speed limit), or driving too close to the center of a two-lane road. Thus, changes in driving skills associated with MCI may not warrant driving restriction or cessation, but do warrant monitoring. They note that neither MCI nor "normal" cognitive aging are static conditions, and that driver interventions may be more effective when problems are identified early.

Dawson, Anderson, Uc, Dastrup, and Rizzo (2009) found that older drivers with probable AD made significantly more errors on a standardized road test than control drivers without AD (an average of 5.9 more, after controlling for age and sex). These authors sorted errors into categories of "less serious" and "more serious" and found that drivers with AD made an average of 2.3 more serious errors than controls, after adjusting for age and sex, and this difference was statistically significant. The most common type of serious errors committed significantly more frequently by AD subjects were straddling the center line and failing to proceed through an intersection once a traffic light turned green. Errors were sorted into 15 general categories: starting and pulling away from the curb; traffic signals; stop signs; other signs; turns; lane observance; lane changes; overtaking; speed control; backing; parallel parking; head-in parking; curves; railroad crossings; and miscellaneous errors. Only in the category of lane observance, did AD subjects commit significantly more errors than control drivers (an average of 17 per drive for AD patients compared to an average of 10.8 for controls). The subjects included in this study were 40 drivers with probable AD (mean age = 75.1 years; 83% male) and 115 older drivers without neurological disease (mean age = 69.4 years; 52% male).

In an on-road study conducted by Uc, Rizzo, Anderson, Shi, and Dawson (2005), older drivers with probable AD identified significantly fewer highly salient landmarks and traffic signs than older drivers without dementia. AD patients identified on average 51% of the highly salient signs, whereas controls identified an average of 79% of these signs. The difference persisted after correcting for familiarity with the neighborhood, age, sex, and far and near visual acuity. The AD patients also committed more at-fault safety errors during the landmark task (average of 1.8 errors) than normal controls (an average of 0.4). At-fault safety errors included erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behavior. Even during portions of the drive where there was no secondary landmark task, drivers with AD committed more at-fault safety errors than controls (5.6 errors versus 1.7). Seventy-six percent of the AD patients made one or more at-fault safety errors compared to 30% of the normal controls. There were no differences between groups in basic vehicle control performance (standard deviation of steering wheel position, number of large changes in steering wheel position, or standard deviation of mean speed) on a straight roadway

segment of the road test that included no secondary task. Subjects included 33 older drivers (mean age = 76 years, 85% male) with probable AD of mild severity, and 137 neurologically normal older adults (mean age = 64. l3 years, 50% male).

Frittelli et al. (2008) compared the (simulated) driving performance of 20 patients with probable AD of mild severity (CDR=1), 20 subjects with MCI (CDR = 0.5), and19 age-matched, neurologically normal controls (CDR = 0). The average duration of symptoms for the AD group was 8 months. Overall, impaired driving performance was detected in AD patients, compared to healthy and MCI subjects. Drivers with AD performed significantly worse than MCI subjects and control drivers on three driving behaviors, length of run (432.5 s versus 389.5 s and 372.5 s, respectively), mean time to collision to a preceding vehicle (0.5 s versus 1.7 s and 2.7 s, respectively), and number of off-road events (2.9 versus 1.2 and 0.8, respectively). No statistically significant differences were detected on the number of infractions and stops at traffic lights. A statistically significant difference in driving capabilities was detected in MCI patients compared to healthy controls only on the mean time to collision measure (1.7 s versus 2.7 s). Simple visual reaction times were significantly longer in patients with AD, compared to MCI and healthy controls (511 ms versus 384 ms and 390 ms, respectively). AD patients also showed a greater number of omitted or wrong answers to a simple reaction time test compared to the other groups. No differences were found in reaction time latencies between the MCI and control group.

The findings of Frittelli et al. (2008) replicate those reported by other researchers; that drivers with AD with a level of severity of CDR 1 exhibit unsafe performance compared to healthy age-matched controls. Specific errors include slower driving (longer time to complete the drive); shorter following distances (shorter times to collision to a preceding vehicle) coupled with longer reaction times and missed RT trials, and more lane exceedances (off-road events). These unsafe driving behaviors were evident following an average duration of dementia symptoms of 8 months. Drivers with MCI also showed impairment in safe driving performance compared to healthy controls, described by their shorter time to collision to a preceding vehicle.

Eby et al. (2009) conducted a naturalistic study that objectively measured the driving behaviors and exposure of people with early-stage dementia using in-vehicle technology to instrument the drivers' own vehicles over a two-month period, and compared their driving performance to healthy older adults. Participants included 10 drivers (mean age 71.6, range 63 to 87) with early-stage dementia who completed a driving assessment and were cleared to drive and 26 older drivers without dementia (mean age 64.5, range 61 to 70). Their findings largely corroborated the findings of other researchers with respect to self-restricted driving space: drivers with early-stage dementia drove significantly fewer miles per day (15.3 versus 35.7 for controls), traveled less often on the freeway (21% versus 33% for controls), drove to about half as many unique destinations per week (6.4 versus 12.8 for controls), and stayed significantly closer to home (64.1% of miles driven within 5 miles of home and 81.3% of miles driven within 10 miles of home versus 43% and 60.3%, respectively for controls) . They also drove less at night (11% during nighttime for early-dementia subjects versus 15% for controls, although this difference was not statistically significant).

Safety-related findings were mixed. The early-stage dementia group was about twice as likely to travel at least 10 mph slower than surrounding traffic (4.79% of miles driven versus

1.8% for controls) and they were less likely to use a seat belt (96.5% of miles belted versus 99% for controls), although this difference only approached significance (p=.07). They were also more likely to get lost (0.2 trips on average versus none for the control group). However, unlike the findings reported by Frittelli et al. (2008) in their simulator study, the naturalistic study found that the early-stage dementia group was *half as likely* to follow too closely (3.1% of miles driven versus 6.1% for controls). None of the drivers in either group drove through stop signs, made an inappropriate left turn, or had gear error events. Certain measures were collected only for the early-dementia subjects: they traveled alone slightly less than half of the time, never used an electronic navigation device, and rarely ran red lights (less than 0.5% of trips). None exhibited pedal errors.

One weakness of the Eby et al. study (2009) was that no objective measure of dementia severity was collected for the early dementia group; early-stage dementia was defined as "concerns expressed by a healthcare professional about memory loss or early-stage dementia." Another weakness was that control subjects were not screened for early stage dementia. However, the study was the first to document the driving performance of older people with early-stage dementia objectively under naturalistic driving conditions, and the authors provided recommendations for future studies that would allow for more definitive conclusions to be made about the driving behavior of people with early-stage dementia.

One study shed light on the driving performance deficits manifested by frontotemporal dementia (de Simone et al., 2007). Their interest in FTD as it relates to driving performance are the neuropsychiatric symptoms that may result in behavior and personality changes without associated changes in cognitive functioning. These include agitation, irritability, disinhibition, lack of insight, and inflexibility. Subjects included 15 patients with FTD with an average age of 56 and an average disease duration of 4 years (ranging from 2 to 8). Ten of the 15 patients were still current drivers; the five who ceased driving did so approximately 2 years post-diagnosis. The distribution of apathy was predominantly frontotemporal in six patients, bifrontal in three, and bilateral anterior in two. Fifteen subjects served as controls, matched on age, sex, and educational level. This study used the low-cost driving simulator from STI. Between-group comparisons of speed, speed variation, speeding tickets (driving 10+ miles over the speed limit), pedestrian hits, traffic light tickets, and number of billboards recalled were performed.

de Simone et al. (2007) reported that several FTD patients randomly stopped driving for variable lengths of time throughout the simulation. Average velocity while moving was therefore calculated, and was significantly higher in the patient group than the control group. There was also a statistically significant group difference in speed variability. Patients received significantly more speeding tickets compared to controls. While they drove faster at times than controls and received tickets for traveling 10 or more miles over the speed limit, there were also instances where they drove very slowly for no apparent reason. Driving too fast is a finding that contrasts with the findings of researchers studying drivers with AD who drive *slower* than controls (Frittelli et al., 2008; Eby et al., 2009), although patients with FTD and AD both appear to stop in traffic for no apparent reason. de Simone et al., (2007) found no differences between groups on traffic light tickets or pedestrian hits. Patients recalled and recognized significantly fewer billboards than controls. Speed variability and number of billboards recalled correctly classified 90% of the subjects. None of the controls had a collision or ran a stop sign, and only one had an off-road crash. In comparison, 60% of FTD patients had collisions, 47% had off-road crashes,

and 33% ran stop signs. Statistically significant correlations were found between the Neurobehavioral Rating Scale (NBRS) total score and speeding and NBRS total score and number of stop signs ignored. The agitation factor of the NBRS was positively correlated with number of collisions and score on free recall of billboard messages . No relationship was found for dementia severity score and any of the driving performance measures, nor for frontotemporal or temporal atrophy and any of the driving performance measures. Severity of frontal apathy was positively correlated with total NBRS score. The study authors indicate that the unpredictable driving behavior and disregard for social norms and laws within this population may be explained by the breakdown in social behavior characterizing FTD, and suggest that fitness to drive always be questioned in FTD patients. Of particular concern, 10 of the 15 patients were active drivers at the time they participated in this study.

Vaux, Ni, Rizzo, Uc, and Andersen (2010) found that subjects with probable AD had impaired ability to detect impending collisions, compared to a sample of normal older adults. The sample size in this study was very small (6 drivers with probable AD, diagnosed according to NINCDS-ADRDA criteria and 18 controls). They also used a low-fidelity driving simulation task, consisting of a desktop computer displaying a textured 3D roadway scene and bright red spheres simulating impending collision targets. Trials consisted of both collision and non-collision targets; on half of the trials one target approached the subject and on the other half, six targets approached. There were two time to collision TTC conditions: 1 s TTC with 8 s of approaching motion and 3 s TTC with 6 s of motion. AD patients performed significantly worse than controls on all test conditions (1 versus 6 objects, and 3s versus 1 s TTC). The condition with the longest TTC and the largest number of objects resulted in the largest declines in performance for the AD group.

Relationship of dementia with motor vehicle crash and violation risk. Staplin and colleagues (2012) cited findings from the following studies of dementia and crash risk:

- a twofold increase in crash rate for drivers with dementia as compared to controls (Carr, 1997).
- during the first three years following dementia onset the crash rate for Alzheimer's patients was only slightly higher than that for drivers of all ages in the United States, and remained well below that of young adults. Although the course of AD may vary considerably, these findings suggest that the increase in crash risk develops toward the end of the third year, and more than doubles in the fourth year (Drachman & Swearer, 1993).

A study uncovered in the present literature review by Ott et al. (2008) reported that a significantly higher percentage of normal controls experienced a crash as compared to the AD patients at the 18-month evaluation (11% of controls versus 1% of the AD group). However, this difference was not statistically significant after correcting for miles driven. The crash rate per driver per year was 0.01 for the dementia group and 0.06 for controls during the 3-year study period (based on self- and State-reports), compared to 0.06 for the dementia group and 0.04 for controls at baseline. In this study, subjects with AD with a recent history of at-fault motor vehicle crashes during the period of their illness were excluded from participation, but crashes were not an exclusionary criterion for control subjects. Also, the long-term performance for the AD group reflects the performance of the group's best drivers who remained in the study after

many others were terminated for safety reasons. During the 3-year period prior to the study and the 3-year study period the AD patients experienced 5 rear-end crashes, 5 intersection crashes, one parking crash, and 8 "other crashes." During the same 6-year period, the controls experienced 2 parking crashes, 1 intersection crash, 1 rear-end crash, and 6 "other crashes." Traffic violations were similar for the AD and control groups. The authors suggested that a regular driving assessment program could reduce crash frequency in drivers with AD by increasing awareness and self-monitoring.

Multiple Sclerosis

Multiple sclerosis (MS) is an autoimmune disease of the brain and spinal cord, characterized by the appearance of lesions and inflammatory processes in the central nervous system (CNS). T-cells, produced by the immune system, leak through the blood-brain barrier and attack the body's own nervous system as though it were an infectious agent. The immune response, unleashed by the T-cells, leads to the characteristic inflammation and lesions throughout the CNS. Over time, the myelin, an insulating layer of fats and protein necessary for conducting action potentials throughout the body, is irreparably damaged, and the brain's own neuroplasticity and repair (remyelination) is not enough to counteract the damage. In addition to the demylineation, inflammation also results in a number of damaging effects, contributing to the disease progression (Compston & Coles, 2002). The disease is more common in women; the peak ages of onset are the mid-20s through early 40s (Liguori et al., 2000).

As MS may affect any location within the nervous system, aspects of the motor, sensory, visual, and autonomic system may be compromised during the course of the disease. The most common symptoms include sensory disturbance (commonly numbness) and dysfunction of the limbs (including ataxia, tremor, and spasticity), partial or complete visual loss or double vision, and gait dysfunction (Stüve & Oksenberg, 2006).

As noted by Ben-Zacharia (2011) in an overview of MS symptom management, approximately half of MS patients will develop cognitive dysfunction. Other common symptoms include fatigue, pain, bladder/bowel dysfunction, sexual dysfunction, and depression.

For MS patients with the most common subtype, these symptoms suddenly flare up in acute attacks, followed by periods of remission. These attacks are both rare (generally less than two a year) and unpredictable, although possible triggers (stress, viral infection, and hot weather) have been identified (Compston & Coles, 2002).

The National Multiple Sclerosis Society has standardized four subtypes which categorize the progress of the disease. They are as follows:

- Relapse-remitting – This subtype describes 80% of MS cases. It is characterized by clinical attacks, followed by periods of remission. Eventually, many of those with relapse-remitting MS will enter the secondary progressive disease phase.
- Primary progressive – The primary progressive manifestation (10 to 20%) involves steady disease progression, with no defined clinical attacks or periods of remission.

- Secondary progressive – Secondary progressive MS occurs in about 65% of patients who initially have relapse remitting MS. This phase of the disease is marked by a steady decline, without any periods of remission.
- Progressive-relapsing – This least common subtype is characterized by a steady decline, *in addition* to defined clinical attacks.

The etiology of MS is as of yet unknown. Some combination of genetic, environmental, and infectious factors is thought to trigger the disease. Those who have relatives with MS are more at risk than the general population, and specific genes have been shown to increase risk. The disease is also more common in regions populated by northern Europeans, with a trend of increasing prevalence with increasing latitude. Several diseases have also been proposed as possible agents for triggering MS: Epstein-Barr, measles, mumps, and rubella (Compston & Coles, 2002).

The Expanded Disability Status Scale, which ranges from 0.0 to 10.0, incremented by 0.5, is used to rate impairment in MS patients. A score of 0.0 represents a normal neurological exam. Scores under 5.0 refer to those who are fully ambulatory without aid up to 300 meters. A score of 9.0 refers to a "helpless bed patient," and 10.0 represents "death due to MS" (Kurtzke, 1983).

Prevalence in U.S. population. Data collected by the National Health Interview Survey for 1989 to 1994 estimated an overall prevalence in the United States of 85 cases per 100,000 population (approximately 211,000 people) (Noonan, Kathman, & White, 2002). A study of three American communities (Lorain County, Ohio; the cities of Sugar Creek and Independence, Missouri; and 19 counties surrounding Lubbock, Texas) found MS prevalence to be lowest in Texas (47.2 per 100,000 population), followed by Missouri (86.3) and the highest in Ohio (109.5) – demonstrating an increasing prevalence with increasing latitude. Prevalence was highest among those 40 to 59 years old (Noonan et al., 2010).

Medications used to treat multiple sclerosis. During clinical attacks, intravenous corticosteroids are used to quickly alleviate symptoms, although such treatment does not appear to have a lasting impact on disease progression (Brusaferri & Candelise, 2000). Medications used to treat the disease aspects of MS aim to decrease inflammation in the CNS. These include interferon beta, glatiramer acetate, mitoxantrone, and natalizumab. Outside of corticosteroids administered during acute attacks, other medications may be used to treat the various symptoms of MS (pain, muscle spasms, fatigue, depression, etc.), although they do not affect disease progression,

Stimulants have been used to treat fatigue in MS patients. Centrally-acting sympathomimetics such as methylphenidate (Ritalin) have been shown to improve driving ability in patients with ADHD (Barkley, Murphy, O'Connell, & Connor, 2005). Eugeroics like modafinil have also been used to alleviate fatigue. In a study of sleep-deprived drivers, modafinil was shown to improve some measures of driving performance in addition to improving self-assessment of driving performance, possibly leading to overconfidence in one's driving ability (Gurtman, Broadbear, & Redman, 2008).

Medications used to treat spasticity, such as bachlofen and gabapentin, often result in drowsiness and may interfere with driving ability. Benzodiazepines, such as diazepam (Valium) and clonazepam (Klonopin), are sometimes used as second- and third-line therapies (Ben-

Zacharia, 2011). Evidence from on-road studies has shown that benzodiazepines statistically significantly impair driving performance (Verster, Veldhuijzen, &Volkerts, 2004).

Tricyclic antidepressants, often used to alleviate pain associated with MS, have been shown to increase the risk of motor vehicle collisions in older drivers (Leveille, Buchner, Koepsell, McCloskey, Wolf, & Wagner, 1994; Ray, Fought, & Decker, 1992).

Selective serotonin reuptake inhibitors (SSRIs) include medications such as fluoxetine (Prozac), sertraline (Zoloft), and paroxetine (Paxil). SSRIs are often used to manage depression in MS patients. A study of motor vehicle crashes in the Netherlands found a statistically statistically significant association between SSRI use and motor vehicle crash risk (Ravera, van Rein, de Gier, & de Jong-van den Berg, 2011), although an earlier (2006) study by Wingen, Ramaekers, and Schmitt suggested that impaired driving in patients on long-term SSRI or serotonin and noradrenalin reuptake inhibitor (SNRI) treatment for depression could most likely be attributed to residual depressive symptoms, as opposed to the medication.

Effects of multiple sclerosis on functional abilities needed for safe driving. The studies obtained through the literature search mainly concentrated on the effects of *cognitive impairment* on driving, with only one study (Marcotte et al., 2008) examining the impact of physical symptoms (spasticity) on driving performance. Because of this, these studies excluded those suffering from more severe physical impairments due to MS, often imposing a cut-off based on their physical limitations.

In a study of cognitively-impaired MS subjects, those with cognitive impairment were slower on measures of timed responses on the NDT (Neurocognitive Driving Test) than MS subjects without cognitive impairment and controls. On the Useful Field of View, a test of visual attention, MS subjects with cognitive impairment performed worse than both the non-cognitively impaired MS subjects and neurologically normal controls on two (central vision and processing speed and divided attention) out of three of the subtests (Schultheis, Garay, & DeLuca, 2001).

Studies of cognitive deficits in patients with relapse-remitting MS have found large deficits in visual information processing speed and attention (Edgar et al., 2011). Information processing speed, as measured by the Symbol Digit Modalities Test, was found to be a marginally statistically significant predictor of driving performance in a scored, behind-the-wheel driving assessment of MS subjects (Schultheis et al., 2010). In the same study, the SPART 24/7 test, a measure of *visuospatial learning and recall*, was a marginally statistically significant predictor of *functional* driving ability, as measured by a driving history that divided MS subjects into two groups: those with driving violations and those without.

Effects of multiple sclerosis on driving performance. As mentioned above, the studies included in this literature review focused on the cognitive effects of MS on functional abilities/driving performance. In one such study (Schultheis et al., 2001), MS subjects were divided into cognitively impaired, MS(+), and non-cognitively impaired, MS(-), groups. As mentioned above, MS patients with cognitive impairment were found to perform worse on measures of *driving performance* (the Useful Field of View [UFOV] test and the NDT that includes simulated driving scenarios) than MS patients without cognitive impairment and controls. During the driving-related tasks of the NDT, the MS(+) group averaged 3.4 errors, while the MS(-) and the controls averaged 3.1 and 2.3 errors, respectively. Additionally, when using UFOV scores to derive an overall rating of driving risk, 100% of controls were classified as very low to low risk drivers, while 86% of the MS(-) group, and 64% of the MS(+) group, were given the same designation. This difference between the MS(+) group and the controls was statistically significant. While the differences between MS patients without cognitive impairment and controls were not statistically significant, the MS patients in this study had no or only mild physical impairment.

A study of people with MS of the relapse-remitting type found that, as compared to neurologically normal controls, those with MS had more crashes (5.3±3.8 as compared to 1.3±1.5, $p < .001$) during a sixty-minute simulator drive. Drivers with MS also had more concentration faults, such as tracking errors, ignoring the right of way or speed limit, and driving without headlights (21.1±15.5 as compared to 7.1±2.6, $p < .01$), (Kotterba, Orth, Fangerau, & Sindern, 2003).

A 2010 study, which incorporated a behind-the-wheel driving assessment and then dichotomized the scores given by a CDRS into pass and no-pass, found that 52 (81.3%) of 66 MS subjects received a passing score (Schultheis et al., 2010).

A 2008 simulator study by Marcotte et al. examined the effects of cognition and spasticity on driving performance in people with MS. The study included two separate tasks: a lane-tracking task (including a divided attention task requiring subjects to respond to pictures displayed on the simulator monitor) and a car-following task, in which subjects had to follow a lead car which continually changed speed. Those with MS exhibited greater variability in lane position and speed maintenance than controls during the lane-tracking task. The MS group also performed worse on a car-following task than controls, with poorer performance in tracking the movements of the lead car. Cognitive function in those with MS was most predictive of variations in lane position and in delay responding to changes in speed of the lead car, while those with spasticity exhibited poor performance in tasks requiring manipulating pedals (e. g., changing and maintaining speed in response to lead car changes).

Relationship of multiple sclerosis with motor vehicle crash and violation risk. Schultheis, Garay, Millis, and DeLuca (2002) divided participants with MS into two groups, those with and without cognitive impairment. They found that those in the cognitively impaired group had a statistically significantly greater incidence of crashes than either controls or MS patients without cognitive impairment, but there was no statistically significant group difference in the incidence of motor vehicle violations. However, motor vehicle crashes and violations are an imperfect measure of driving performance, as driving errors do not always result in violations or crashes, not every violation and crash is recorded, and crashes and violations remain relatively rare events.

Obstructive Sleep Apnea

Obstructive sleep apnea (OSA) is a periodic cessation of breathing during sleep clinically defined as a cessation for intervals of 10 seconds or longer. OSA is a common though often undiagnosed (and under-treated) condition with potentially serious consequences for driving safety. Some people with OSA experience a related condition, hypopnea, characterized by repeated episodes in which airflow is reduced during sleep. Five or more such episodes per hour are considered abnormal and may result in impaired cognitive function. An apnea/hypopnea index (AHI) of fewer than 5 episodes per hour is considered normal (no sleep apnea), 5 to 15 episodes per hour as mild sleep apnea, 15 to 30 per hour as moderate sleep apnea, and 30 or more as severe sleep apnea (American Academy of Sleep Medicine Task Force, 1999).

Prevalence in U.S. population. Estimates of the prevalence of OSA in the United States vary due to the evolving diagnostic criteria (Hiestand, Britz, Goldman, & Phillips, 2006). For example, the Wisconsin Sleep Cohort Study (Young et al.,1993) reported that 4% of men and 2% of women met "minimal diagnostic criteria" for OSA, which was defined as an AHI of *more than 5* events per hour that was associated with daytime hypersomnolence. However, in that same study, 9% of women and 24% of men had an AHI of *five or more* events per hour. As noted by Hiestand et al. (2006), since 1993 the U.S. population has aged and become more obese; the risk of statistically significant sleep-disordered breathing rises with body mass index (BMI) and age. The authors used data from the Berlin questionnaire obtained from 1,506 adults who participated in the National Sleep Foundation (NSF) annual telephone poll. This questionnaire is used to classify those who are at high and low risk for OSA by identifying snoring behavior, daytime sleepiness, obesity, and hypertension, and has been validated in a primary care population. Overall, 31% of men and 21% of women were in the high-risk group. The risk increased linearly with age: 19% for people 18 to 29, 25% for those 30 to 49, and 33% for those 50 to 64. The risk declined after age 65 to 21%. In all but the 18 to 29 age group (where there were no sex differences), the risk was higher for men than for women. One weakness of the NSF poll was that it did not include a representative sampling of ethnic groups present in the United States Only 16% of the sample was nonwhite.

In a study of OSA incidence, 285 people without statistically significant OSA at baseline demonstrated that the incidence of the development of sleep-disordered breathing (AHI greater or equal to 5 events per hour) was about 7% per year, and the incidence of the development of an AHI of more than 15 events per hour was 2% per year (Tishler, Larkin, Schuchter, & Redline, 2003).

Effects of sleep apnea on functional abilities needed for safe driving. People with OSA have fragmented sleep periods associated with snoring and intermittent airway obstruction. This sleep fragmentation leads to chronic sleep deprivation and excessive daytime sleepiness, and is likely to cause cognitive functional deficits reported in this population (Boyle, Tippin, Paul, & Rizzo, 2008). Daytime functional impairments of apnea-hypopnea include drowsiness/sleepiness, memory loss, impaired concentration and coordination, anxiety and depression. During microsleep episodes, attention lapses can impair the ability to detect and respond to critical stimuli and events. As noted by Boyle and colleagues (2008), some people with OSA are unaware of the degree of their sleepiness and cognitive impairment.

Effects of sleep apnea on driving performance.

Sleepiness at the wheel resulting from OSA was correlated with inappropriate lane line crossings during an on-road driving session (Phillip et al., 2008). Subjects included 38 people with untreated OSA (OSA group) (mean age 51) and 14 normal controls (control group) (mean age 46). The mean AHI for the OSA group was 41 (SD, 25) and ranged from 11 to 96. All subjects completed the *Epworth Sleepiness Scale (ESS),* a subjective questionnaire that assesses chronic daytime sleepiness, which rates the tendency to fall asleep in eight different situations in daily life, with scores ranging from 0 (no chance of dozing) to 4 (high chance of dozing). Candidate OSA subjects with ESS scores of 10 or below were excluded from the study. Subjects completed three experimental sessions, each preceded by a regular sleep-wake schedule: polysomnography (OSA group only), a *Maintenance of Wakefulness Test* (MWT) session, and driving session. The MWT is a validated objective measure of the ability to stay awake for a defined period. It requires fighting against sleepiness in a sleep-conducive environment, reflects the ability to stay awake, and is not falsifiable. Members of the OSA group were classified into three groups based on their MWT score: "very sleepy (0-19 minutes), "sleepy" (20-33 minutes), and "alert" (34-40 minutes). Based on MWT scores, 21% of subjects were classified as "very sleepy" (mean MWT score 12 $\pm$ 3 minutes); 39.5% were "sleepy" (mean MWT score 26 $\pm$ 4 minutes); and 39.5% were "alert" (mean MWT score 39 $\pm$ 2 minutes). During the driving session, subjects were instructed to maintain a constant legal speed (80 mph), drive in the center of the lane, and not to cross the painted lane lines except to pass a slower vehicle. The drive covered 125 miles on a straight highway during daytime in light traffic conditions. Halfway into the driving session, subjects completed a *Karolinska Sleepiness Scale* (a 9-point scale, ranging from "very alert" to "very sleepy"). At the end of the drive, subjects completed the *Visual Analog Scale* ranking their self-perceived sleepiness during the drive from 0 (fully alert) to 100 (fighting severely against sleepiness at the wheel).

Phillip et al. (2008) found that the number of inappropriate lane crossings (ILCs) correlated with MWT scores for all subjects. ILCs were defined as crossing the lane lines except when passing another vehicle. There was a statistically significant difference in the number of ILCs between the four driver groups (very sleepy, sleepy, alert, and controls). The "very sleepy" and "sleepy" group had more ILCs than the control group (mean ILCs 1.5 versus 1.53 versus 0.36). The "very sleepy" and "sleepy" groups had more ILCs than the "alert group" (1.5 versus 1.53 versus 0.33). There was no difference in ILCs between the "alert" group and the control group. In addition, the number of ILCs correlated with ESS scores in all subjects. There was a statistically significant effect of ESS group ($\geq$ 16, 10-16, 0-9) on ILCs. The "very sleepy" group (ESS $\geq$ 16) had statistically significantly more ILCs than the non-sleepy group (ESS <10) or the "sleepy group" (ESS 10-16). The mean ILCs for the three groups were: very sleepy (2.11), sleepy (0.82), and non-sleepy (0.38). The number of ILCs corresponded with the *Karolinska Sleepiness Scale* scores and the *Visual Analog Scale* of self-perceived sleepiness at the wheel in both patients and controls. The number of ILCs correlated with BMI, but not with age in both patients and controls.

Phillip et al. (2008) concluded that because sleepiness at the wheel is a reliable predictor of driving risk, and because it is correlated with ILC, self-reported sleepiness should be assessed before making decisions regarding aptitude. Because drivers may not always be honest with their

physicians when their driving privileges are at risk, the MWT may be a helpful supplement to self-reported sleepiness for physicians evaluating the driving risks of sleepy patients.

Using a high-fidelity driving simulator, Paul, Boyle, Tippin, and Rizzo (2005) found that drivers diagnosed with OSA showed significantly greater lane variability, steering variability, and shorter times to lane crossing during periods of "microsleep" compared to the 3-second intervals before or after the microsleep. A microsleep was defined as a 3 to14-second episode during which 4-to-7 Hz (theta) activity replaced the waking 8-to-13 Hz (alpha) background rhythms interpreted from EEG recordings. Microsleeps indicate excessive daytime sleepiness. This study used the SIREN high-fidelity driving simulator with a 60-minute driving scenario consisting of two-lane highways with interactive traffic, and straight and curvy road segments. The simulated drives were purposefully uneventful (minimal traffic, few intersections, no lead vehicles, and no external distractions) to induce drowsiness. Lane positioning variability was higher and time to lane crossing shorter on curved segments than on straight segments, during the microsleep periods. The authors concluded that reductions in steering control and low time to lane crossings in drowsy drivers with sleep apnea could lead to steering errors and lane encroachment, which could result in a crash with an oncoming vehicle or an object on the side of the road.

Using the same subjects and methodology, Paul, Boyle, Boer, Tippin, and Rizzo (2005) found that steering entropy was significantly higher during and after microsleeps than during the pre-microsleep period, when driving on curved sections (but not when driving on straight sections). Steering entropy is a measure of randomness in a driver's steering control, and is higher when drivers make larger erratic steering movements, indicating possibly unsafe behavior. Higher steering entropy on curves indicated that drivers with OSA made large steering corrections post microsleep, which may not have been sufficient to recover control of a vehicle in order to avoid a lane deviation error or a crash.

A third study conducted using the SIREN driving simulator and the 60-minute scenario described earlier, found statistically significant differences in driver control related to the occurrence and duration of microsleeps (Boyle et al., 2008). The 22 subjects OSA subjects in this study had an AHI index of 5 or more (based on polysomnography), with apneas and hypopneas of at least 10 s duration. The mean ESS score was 11 (SD 5.0); a score greater than 10 is generally accepted as an indicator of excessive subjective sleepiness. OSA drivers exhibited over 150 microsleeps episodes in the analysis. Microsleeps in this study were categorized as those with short duration (3s to less than 4.74 s), medium duration (4.74 s to less than 7 s), and long duration (7s or longer). Significantly lower speeds were observed during periods of microsleep compared to non-microsleep periods, but no differences were observed as a function of microsleep duration or roadway type (straight or curved). Lower speeds during microsleeps indicated that sleepy drivers exerted less control over the accelerator pedal during microsleeps by failing to continue to depress it as needed to maintain speed. Subjects also showed greater variability in lane position during microsleeps compared to non-microsleep periods. Standard deviation of lane position was significantly higher on curves (mean = 0.20) than straight roads (mean = 0.16) and increased with longer microsleep durations. Standard deviation of steering wheel angle increased sharply on curved roads when the microsleep durations increased from medium (mean 2.33) to long (mean = 4.61). Minimum time to lane crossing was significantly lower on curves (mean = 0.59 s) than on straight roads (mean = 2.85s), but there were no

statistically significant differences as a function of microsleep period, or microsleep duration. Steering entropy increased during microsleeps, and with each drive segment, indicating that sleepy drivers with microsleep episodes showed worse vehicle control the longer they drove.

In a driving simulator study using a long monotonous drive, Vakulin et al. (2011) found that steering performance was impaired in untreated subjects with severe OSA as compared to healthy controls. Furthermore, while simulator steering performance improved marginally following three months of continuous positive airway pressure (CPAP) treatment, driving ability remained significantly impaired compared with age and sex-matched healthy controls. The OSA subjects were optimally treated based on laboratory CPAP titration polysomnography to establish the therapeutic CPAP setting; compliance over the 3-month period averaged 6.0 hours/night. Steering deviation was measured from the average deviation (cm) from the driver's median lane position sampled at 30 hz. Baseline mean steering deviation for untreated OSA participants was significantly higher than for controls (49.9 cm versus 34.9 cm). At the 3-month follow-up simulator evaluation CPAP-treated OSA subjects demonstrated a small but statistically significant improvement in steering deviation (mean decrease 3.1 cm over full drive), while no statistically significant change was observed for controls. Steering deviation remained significantly higher in treated OSA subjects compared to controls (46.7 cm versus 36.1 cm). OSA subjects had two simulator crashes before treatment and two after treatment, compared to none of the control drivers crashing; the number of events was too small for statistical analyses to be conducted. The authors concluded that driving impairment during long drives persisted in severe OSA patients optimally treated with CPAP.

Tippin, Sparks, and Rizzo (2009) also found slightly impaired driving simulator steering performance in a group of subjects with OSA with the majority comprised of those with mild to moderate severity, compared to a group of age and sex-matched controls. There were no statistically significant differences between groups in number of lane deviations or speed errors, but there was a trend toward greater standard deviation of lane positioning (SDLP) in OSA drivers (0.37 versus 0.329, p=.07). Drivers with OSA were also sleepier than comparison subjects at the end of the drive, but there were no differences in sleepiness between groups before the drive (as measured with the Stanford Sleepiness Scale [SSS]). SSS scores *after* the drive were the strongest predictor of lane deviations. "Sleepy" subjects (scores of 5-7) had an estimated 2.61 times the mean number of lane deviations as the "awake" subjects (scores 1-2), and an estimated 1.62 times the mean number of lane deviations as the "marginally sleepy" subjects (scores 3-4). The most important finding in this study was that drivers with OSA showed reduced vigilance on a target detection task (lower target identification rate) than the control drivers (80.7% versus 86.7% hit rate) across all targets presented centrally and peripherally on the horizon of the driving scene. Performance differences were magnified for peripherally presented targets (those presented 50° and 62.5° left and right of center). The hit rate for the peripheral targets was 72.3% for the OSA group versus 81.4% for the control group. Hit rate was not correlated with AHI severity when divided into three categories of events/hour: 5-to-15, 16-to-30, and 31 or more, but target hit rate was correlated with minimum oxygen saturation. Tippin et al., (2009) concluded that OSA drivers have a shrinking of their functional field of view or a decrease in the efficiency with which they are able to extract information from a cluttered scene, and that nocturnal hypoxemia may be a factor in causing vigilance defects in OSA patients.

Contradictory findings on lane and steering position variability were provided by researchers using a high fidelity driving simulator and driving scenarios with medium-density traffic and roadway conditions requiring a higher degree of attention than that required to drive on a monotonous stretch of highway. The scenarios used in the study by Tassi et al. (2008) included curves and straight sections, and uphill and downhill sections, presented under daytime conditions. A continuous flow of vehicles traveled in the left and right adjacent lanes. Roadwork signs and flashing arrows announced restrictions to one lane. Subjects were instructed to drive at their own pace, obeying traffic rules and speed limitations. Subjects with OSA (mean AHI 58.55, SD 11.33) showed difficulty with speed adjustments (more frequent and variable speed adjustments), allowed more space between their vehicle and others (indicating cautious behavior), and released the accelerator pedal earlier in response to the work zone signs (also indicating cautious behavior) compared to controls. There was no difference between OSA subjects and controls in lane position or steering position variability. OSA subjects had a higher sleepiness score on the ESS on the morning before the first drive than controls and waking EEG suggested that OSA subjects were sleepier than controls, but there were no differences between groups before or after any driving sessions for subjective fatigue, somnolence, or attentional concentration. OSA subjects showed increased beta activity reflecting a larger effort to stay awake (due to chronic sleep disturbances and to sustained wakefulness). The authors concluded that the relative good driving performance in OSA subjects did not mean that their driving ability was unaffected by OSA, but that the OSA group members were more effortful than controls in maintaining satisfactory performance. This was effective except when the drive was so long or monotonous that they could not maintain such efforts.

Relationship of sleep apnea with motor vehicle crash and violation risk. As indicated in Staplin et al. (2012), studies have linked crash risk to the amount of sleep that was previously obtained (Garharino, Nohili, Beelke, De Carli, & Ferrillo, 2001). Anecdotal reports have indicated that drowsy driving as a crash contributing factor easily exceed 100,000 per year. OSA has been associated with a two to seven-fold increase in crash risk, depending on the study population (Teran-Santos, Jimenez-Gomez, & Cordero-Guevara, 1999).

Barr, Boyle, and Maislin (2004) reviewed 19 studies on OSA and crash risk, including those judged by a critical review to have at least a moderately robust design (Connor, Whitlock, Norton, & Jackson, 2001) and reported that nearly all found that those with OSA had from 3 to 7 times greater risk of crashes than drivers without OSA. Barr and colleagues provided detail on the sex-related findings of Young, Blustein, Finn, and Palta (1997): men with sleep-disordered breathing (SDB) were three to four times more likely to be involved in crashes than men without SDB, but no crash risk association was found for women with SDB. However, Young, Blustein, Finn, and Palta found that the ORs for SDB and multiple crashes were positive for both men and women; drivers with an AHI greater than 5 were 4.6 times more likely than drivers without SDB to have *multiple crashes* in a 5-year period. Barr et al. also uncovered findings indicating that an increased crash risk of motor vehicle crashes was found only in patients with the most severe OSA (AHI > 40) (George & Smiley,1999).

In a large retrospective study using an insurance database in British Columbia to analyze crash rates, Mulgrew et al. (2007) found increased rates of motor vehicle crashes for drivers with OSA compared to age- and sex-matched controls, with increased risk for injury crashes over those for property damage alone. The presence of OSA/hypopnea (OSAH) increased the rate

ratio for crashes causing personal injury to 3.67, after controlling for confounding variables. In this study, any degree of OSAH was associated with a significantly increased crash rate compared to control drivers without OSAH. For crashes involving personal injury the relative risks compared to controls, by OSAH severity were as follows: RR = 4.8 for mild OSAH; RR = 3.0 for moderate OSAH, and RR = 4.3 for severe OSAH. Patients without OSAH (AHI 0-5) had an RR of 0.6, which was not significantly different than controls. Within the patient group, the authors found a dose-response relationship between OSAH severity and rate of injurious motor vehicle crashes. Crashes with injury accounted for 9% of all crashes for patients with an AHI of 0-5 (normal), compared to 37% of the crashes in patients with an AHI >30 (severe OSAH). Compared with patients with an AHI index of 0-5, the relative risk of injurious crashes in patients with severe OSAH was 6.1. Patients with mild OSAH (AHI of 6-15) had a 4.9-fold increased risk of injurious crashes compared to those with an AHI of 0-5.

Mulgrew et al. (2007) also found a statistically significant association for male sex in all crashes involving the control drivers, but not for the patient group of drivers, indicating that OSAH has an equalizing effect between the sexes in terms of driving risk. Body mass index and driving exposure also significantly predicted crashes of all types in the patient group. There was no statistically significant relationship between scores on a subjective sleepiness scale (the ESS) and motor vehicle crash rate.

Findley, Smith, Hooper, Dineen, and Suratt (2000) found that drivers with OSA who were treated with nasal continuous positive airway pressure (CPAP) had a decreased crash rate during treatment compared to their pre-treatment rate and compared to drivers with OSA who did not undergo CPAP treatment. The sample of 50 patients with OSA (mean age = 56 years, and mean AHI = 37) included 36 patients who reported regular use of their CPAP in the 2-year period following diagnosis (they self-reported daily use for an average of 7.2 hours/night) and 14 patients who chose not to use CPAP to treat their condition. None of the patients had surgery or treatment other than the CPAP during the study. There were no statistically significant differences in age, sex, weight, or initial AHI for the CPAP and non-CPAP group. The number of State-reported, at-fault crashes in the group of 50 patients was seven crashes in the 2 years prior to treatment (a crash rate of .07 crashes per driver per year). This was significantly higher than the crash rate of the population of drivers in the State (0.01 crashes/driver/year), even after adjusting to match the age and sex of the patients. The before-treatment crash rate was .07 for both the CPAP and non-CPAP groups. During the 2-year treatment period, none of the CPAP users crashed (crash rate = 0), but 2 of the 14 non-CPAP users crashed (crash rate of 0.07 crashes per driver per year, the same as the pre-diagnosis crash rate for this group). The reduction in crash rate for the CPAP group was not due to a decrease in mileage; the self-reported pre-treatment mileage was 13.6 thousand miles/year and estimate during treatment was 12.9 thousand miles/year (not a statistically significant difference). The authors found that this group of 50 OSA patients under-reported their crash experience on a questionnaire and during a telephone interview. Only three of the nine State-reported crashes were self-reported; four crashes were denied and two patients failed to answer questions about crashes. This underscores that self-reporting of automobile crashes by patients to their physicians may not be reliable.

In another study of the effectiveness of CPAP treatment on crash reduction in drivers with OSA, researchers reported a reduction in the percentage of crash-involved drivers from 43.4% to 5.7% (Yoshino et al., 2006). However, crashes were self-reported and the pre-treatment

and post-treatment time periods were not equal, so no direct comparison can be made. The independent risk factors for crashes before treatment were higher body mass index, excessive daytime sleepiness (ESS scores > 10), frequent driving (more than four days per week), and long-distance driving (more than 10,000 km/yr). Following an average of 18 months of CPAP therapy, the independent risk factors for crashing were higher age, presence of residual excessive daytime sleepiness (excessive daytime sleeping following CPAP treatment), and higher body mass index. OSA severity was not a statistically significant predictor of crashes before or after CPAP treatment. Although significantly more drivers with poor treatment compliance were in the crash-involved group, this factor and CPAP treatment duration only marginally approached significance in the multivariate analysis. The authors recommended that obese drivers with OSA and excessive daytime sleepiness undergo early treatment to reduce crash risk, especially those who are frequent or long-distance drivers. In addition, OSAS patients should be monitored for residual sleepiness and be strongly advised to lose weight. Patients with OSAS, especially older drivers should be alerted to the risk factors.

In only one of the reviewed studies did researchers find a lack of association between sleep disturbances and adverse driving events (Vaz Fragoso, Araujo, Van Ness, & Marottoli, 2010). These researchers used two sleep questionnaires (the *Insomnia Severity Index* [ISI] and the *Epworth Sleepiness Scale* [ESS]) and a clinical assessment (the *Sleep Apnea Clinical Score* [SACS]) to identify drivers with sleep disturbances in a sample of 430 community living, active older drivers. The average age of the sample was 78.5 years, and 85% were male. Subjects reported driving an average of 17 miles per day. The ESS has been described earlier. The ISI is a seven-item questionnaire that assesses current sleeping habits and problems related to sleep. Items are rated on a scale from 0 to 4, with a total score ranging from 0 to 28, with higher scores indicating more severe symptoms. Scores of 8 or above are consistent with a diagnosis of insomnia. The SACS assesses clinical risk for OSA based on neck circumference and the presence of hypertension, habitual snoring, and partner-reported apneas. A SACS higher than 15 indicates a higher risk of OSA. Adverse driving events were defined as self-reported and DMV records of crashes, violations, near crashes, and getting lost in the following two years.

The authors found that the median scores on the sleep measures were 3.0 for the ISI, 6.0 for the ESS, and 8.0 for the SACS, which all were substantially lower than the published diagnostic thresholds of 8, 10, and 15. Scores for 26% of the sample were consistent with insomnia, 19.3% with daytime drowsiness, and 20% with a high OSA risk, based on the sleep measures. Twenty-five percent of the drivers had a crash or violation in the subsequent 2-year period, and 51% had either a crash, near crash, violation, or reported getting lost. The lack of association between sleep disorders and adverse driving may have resulted from the sample having only mild sleep disturbances, coupled with their short driving distances. Also, no polysomnography was performed in the study to confirm the presence of OSA/hypopnea; aging is associated with poorer symptom awareness. The researchers note that chronic sleep loss is more prevalent in younger than older people and because older people self-regulate, older people with severe sleep disturbances may be more likely to cease driving.

Three studies on OSA and crash risk for commercial motor vehicle operators uncovered in the literature review are summarized below.

Pack, Dinges, and Maislin (2002) studied the prevalence of OSA among a sample of commercial truck drivers living within a 50-mile radius of the University of Pennsylvania. The

Pennsylvania DMV provided the researchers with a random sample of 4,826 commercial driver license (CDL) holders living within 50 miles of the University of Pennsylvania; these drivers were mailed a multivariable apnea prediction questionnaire. The study included the 1,391 participants who responded to the questionnaire. These subjects were further assessed in a laboratory using the following measures: Epworth Sleepiness Scale, Karolinska Sleepiness Scale, Stanford Sleepiness Scale, Functional Outcome of Sleep Questionnaire, Multiple Sleep Latency Test, Psychomotor Vigilance Test, Divided Attention Driving Task, and the Digit Symbol Substitution Test. Study findings indicated that 17.6% of CDL holders had mild OSA, 5.8% had moderate OSA, and 4.7% had severe OSA. The authors found that the prevalence of OSA increased with increasing age and BMI. In addition, short sleep duration (six hours or less per night) resulted in an increase in the prevalence of OSA. Drivers with the most severe form (AHI $\geq$ 30 episodes per hour) showed degraded performance on the psychomotor vigilance reaction time test and the divided attention driving test—both tests are sensitive to the effects of sleep loss. No association was found between the measures of self-reported sleepiness and the presence and severity of OSA, indicating that self reports of sleepiness are not a reliable source for identifying drivers likely to have OSA.

Barr and colleagues (2004) selected a subsample of 406 participants from the Pack et al., (2002) study to determine crash risk as a function of the presence as well as the severity of OSA (e. g., none, mild, moderate, and severe). The 406 subjects participated in an overnight sleep-testing study using polysomnography to confirm the presence of OSA, measured by the apnea/hypopnea index. Males accounted for 94.6% of the sample. The mean age of the sample was 46.7 years (SD = 11.4). Nearly two-thirds of the drivers (64.6%) were exclusively local/short-distance drivers whose work trips were 100 miles or less from their homes, compared to 8.6% long-haul-only drivers, and 28.7% who indicated they operated both local and over-the-road routes. The outcome of sleep study was that 86 of 406 (21.2%) were diagnosed with mild OSA, 32 of the 406 (7.9%) had moderate OSA, 28 of the 406 participants (6.9%) had severe OSA, and 260 of 406 (64%) had none. Severity was defined using the American Academy of Sleep Medicine Task Force (1999) definition. An ANOVA found statistically significant differences in average age and weight for participants with OSA (48.7 years, 237 pounds) compared to those without OSA (45.5 years, 203 pounds).

Crash histories for these 406 drivers were obtained from the State crash database for the 7-year period prior to the diagnosis of OSA in this study (1989-1996), and from the Motor Carrier Management Information System Crash database for the 7-year period following the diagnosis of OSA in this study (1996-2003). Prior to diagnosis in the overnight studies, 101 of the 406 participants were involved in 135 CMV crashes; after diagnosis, 50 participants were involved in 56 crashes. Ninety percent of those who crashed were involved in one crash. Of the 151 drivers who were crash involved, 64% did not have OSA, compared to 20% with mild OSA, 9% with moderate OSA, and 7% with severe OSA. A logistic regression analysis found no association between OSA and commercial vehicle crash rates; drivers with OSA had no greater probability of crashing than those without OSA, either before or after their diagnosis. Across the 14-year study period, 30.12% of the drivers with OSA crashed, compared to 32.7% of those without OSA.

No link was found between OSA severity and crash rate, however a link was found between *severe* OSA and *severe* crashes. Drivers with severe OSA were 4.6 times more likely

than drivers without OSA to be involved in a *severe crash* (a tow-away crash with multiple injuries). Drivers with severe OSA were no more likely than those without OSA to be involved in less severe crashes, and there were no associations between mild or moderate OSA and crash severity.

Crash rates were normalized by number of (self-reported) miles driven annually for each driver. The only study variables related to crash rate per mile driven were age and use of antihistamines/decongestants; neither OSA presence nor severity were related to mileage-adjusted crash rates. Older drivers and drivers using antihistamines or decongestants were *less likely* to be crash involved.

The findings of Barr et al., (2004) contradict the findings of researchers that OSA has a strong positive relationship to crash risk. Study limitations included incomplete or inaccurate crash records for every subject (MCMIS limitation), use of self-reported data for several variables (e. g., mileage estimates), as well as the type of driving done by the majority of the drivers. The authors noted that the majority of their participants were short-haul drivers who operated local routes, generally driving in dense urban environments that require a higher level of alertness than long-haul operators who drive long stretches on interstate highways under monotonous driving conditions and would be more susceptible to fatigue and day-time sleepiness. No information was collected to determine whether those diagnosed with OSA during the study were treated for this condition, and whether the treatment was effective.

Howard et al. (2004) found that the prevalence of at least mild sleep-disordered breathing was 54 percent in a sample of 2,342 randomly selected commercial vehicle drivers based on their responses to a Multivariable Apnea Prediction questionnaire and 59.6 percent in a randomly selected group of 161 commercial drivers who underwent polysomnography (respiratory disturbance index of 5 or more events per hour). Sixteen percent of the drivers in the polysomnography group had "sleep apnea syndrome" defined as RDI > 5 and an Epworth Sleepiness Scale score greater than 10. These data indicated a very high prevalence of sleep-disordered breathing and OSA in the commercial driver population as compared to the population of working males in the general community in Australia (24% and 4%, respectively). The prevalence of obesity in this population may account for the high percentage of sleep disordered breathing among commercial drivers (42% of the drivers were obese, compared to 16% of adult Australian males). Howard et al. (2004) found a two-fold increased crash risk (self-reported) among the sleepiest 5 percent of drivers, using the Epworth Sleepiness Scale and the Functional Outcomes of Sleep questionnaire. The relationship was slightly stronger for multiple crashes. The Multivariable Apnea Prediction Score was weakly related to increased risk of single-vehicle crashes (OR = 1.14), but not to all crashes. Drivers with a MAP score of 0.50 or higher and a score on the ESS of 11 or more (symptoms of obstructive sleep apnea syndrome) had an increased risk of any crash (OR = 1.30) and of a single vehicle crash (OR = 1.63). The authors note that sleepiness-related crashes were more likely to be single-vehicle crashes, and this may explain the relations found between sleepiness and crash type in their study. In addition to excessive sleepiness, other statistically significant crash contributing factors were use of narcotic analgesics (OR = 2.40) or antihistamines (OR = 3.22). Four percent of the sample reported using either medication.

Parkinson's Disease

Parkinson's disease (PD), a progressive neurological disorder, is the most common form of parkinsonism[2], a neurological syndrome characterized by motor dysfunction. PD results from a loss of dopaminergic neurons in the *substantia nigra*, a component of the basal ganglia. The underlying cause of this neuron death is currently unknown. While a small number of Parkinson's cases are due to known genetic factors, idiopathic Parkinson's accounts for the majority of cases. A diagnosis of Parkinson's disease is based on clinical symptoms observed in a neurological exam: tremor, muscle rigidity, and slowed movement, or bradykinesa (Jankovic, 2008).

As described in a review of the literature by Mindham and Huges (2000), a substantial percentage of people with PD also experience some form of cognitive impairment. While the cognitive impairment in PD patients is usually not as severe as that found in those with Alzheimer's, it can affect many domains, from memory to abstracting reasoning to information processing speed. One study of PD's progression found that, in the later stages of the disease, 48% of patients met the criteria for dementia (Hely, Morris, Reid, & Trafficante, 2005).

Generally, the initial symptoms of PD are mild, and the disease's progression is usually slow. The median age of onset is 60 years, while the mean time from initial diagnosis to death is 15 years (Lees, Hardy, & Revesz, 2009).

There are a variety of assessment scales used to quantify the severity of Parkinson's disease. The following, as identified by the Neurosurgical Service at Massachusetts General Hospital, are used in studies cited in the present review.

- Hoehn and Yahr Staging, which is scored on a scale of 1 to 5; ratings are based on severity of physical symptoms.
- Unified Parkinson Disease Rating Scale (UPDR) is a more comprehensive system, and is divided into three domains: 1) Mentation, Behavior, and Mood 2) Activities of Daily Living and 3) Motor.
- Schwab and England Activities of Daily Living, a simple 0 to 100 (percentage) scale of functionality (with 0% indicating impairment of even vegetative functions and 100% indicating complete independence, with no impairment).

Prevalence in U.S. population. PD is the second most common neurodegenerative disease after Alzheimer's (Bertram & Tanzi, 2005)). Estimates of the prevalence of PD in the United States vary. A study published in *Neurology* in 2007 estimated that there were 340,000 cases of PD in the United States among those 55 and older (Dorsey et al., 2007); estimates for the entire American population place the number of PD cases at over 1 million (Torpy, Lynm, & Glass, 2004). A study of a state registry in Nebraska found that, as of January 2000, the prevalence of PD statewide was 329.3 per 100,000 population (Strickland & Bertoni, 2004). However, this number should not be regarded as representative of the United States as a whole; in a 2010 study of PD among Medicare beneficiaries (those 65 and older) Willis, Evanoff, Lian, Criswell, and Racette (2010) found that prevalence was highest in the Midwest and Northeast.

[2] Other causes of Parkinsonism can include prolonged toxin exposure, metabolic conditions, repeated traumatic injury, and drug-induced parkinsonism

The *overall incidence* of PD in the American population was 13.4 per 100,000 population (Van Den Eeden et al., 2003) and, like many other neurodegenerative diseases, incidence increased with age. The Willis study referenced above found that the *prevalence* of Parkinson's among those 65 to 69 was 553.52 per 100,000 Medicare beneficiaries; among those 85 and older, it had risen to 2,948.93 per 100,000. Males were more likely than females to develop Parkinson's, and the incidence among Whites was greater than that among Blacks or Asians.

Medications used to treat PD. As there is no cure for PD, medication aims to alleviate symptoms. An effective medication regimen can substantially improve the patient's quality of life. Levodopa remains the most commonly prescribed PD medication. It is converted into dopamine, which temporarily reduces the motor symptoms of PD (Lee et al., 2009). Over time, however, levodopa use may result in the development of dyskinesia (Jankovic, 2001). Additionally, use of levodopa medications may exacerbate proprioceptive deficits (O'Suilleabhain, Bullard, & Dewey, 2001). Dopamine agonists, which bind dopamine receptors in the brain, are also used to treat PD. As mentioned above, side-effects of dopamine agonists include excessive daytime sleepiness – another potential hazard for drivers (Ondo et al., 2001). Monoamine oxidase-B inhibitors may also be used to inhibit metabolization of dopamine.

Effects of PD on functional abilities needed for safe driving. As reported by Heikkilä, Turkka, Korpelainen, Kallanranta, and Summala (1998), studies have found that cognitive dysfunction in PD patients extends to attention maintenance of attention, especially in complex tasks (Wright, Burns, Geffen, & Geffen, 1990; Bennett, Waterman, Scarpa, & Castiello, 1995; Cooper & Sagar, 1993). The inability to effectively maintain and shift attention, coupled with other deficits in cognition that result in delayed information processing and decision making, may result in impaired driving ability. Additionally, those with impaired cognition often suffer from deficits in metacognition, rendering them unable to accurately judge their own limitations (Rizzo, Uc, Dawson, Anderson, & Rodnitzky, 2010).

PD patients also experience a variety of visual impairments. Studies have found that PD patients have poorer ocular motility and visual acuity than age-matched controls (Repka, Claro, Loupe, & Reich, 1996). Additionally, those with PD often experience a decline in contrast sensitivity that cannot be accounted for by the normal aging process (Bodis-Wollner, Marx, Mitra, Bobak, Mylin, &Yahr, 1987).

Excessive daytime sleepiness is also reported in those with PD; the use of dopamine agonists to treat the motor symptoms of PD appears to contribute to this (Ondo, Vuong, Khan, Atassi, Kwac, & Jankovic, 2001). Although no association between excessive daytime sleepiness and performance on a driving test was found (Amick, D'Abreu, Moro-de-Casillas, Chou, & Ott, 2007), it should be noted that in one study 22.6% of PD patients indicated that they had fallen asleep while behind the wheel of a car (Ondo et al., 2001).

Effects of PD on driving performance. The motor dysfunction that characterizes PD causes a myriad of problems for drivers. It may impair their ability to initiate movements while driving (Singh, Pentland, Hunter, & Provan, 2006), particularly when braking (Worringham, Wood, Kerr, & Silburn, 2006).

Deficits in visual processing and cognition, especially attention shifting, may impair visual search in drivers with PD. These drivers may be unable to locate and recognize high-

saliency landmarks and signs that are important for both navigation and obeying the rules of the road. Thus, drivers with PD are more likely to make driving errors, especially along dense, urban roadways with many stimuli vying for attention (Uc, Rizzo, Anderson, Sparks, Rodnitzky, & Dawson, 2006). Because of impaired attention shifting, drivers with PD were especially prone to safety errors when driving with distraction or engaged in a concurrent task (Uc, Rizzo, Anderson, Sparks, Rodnitzky, & Dawson, 2006a; Stolwyk et al., 2006). Drivers with PD performed worse than controls on common driving tasks such as following a route with directions given verbally prior to driving. Attempting to follow the route *also* caused drivers with PD to commit more safety errors, possibly as a result of the increased demand on their limited cognitive reserves (Uc, Rizzo, Anderson, Sparks, Rodnitzky, & Dawson, 2007).

The cumulative effects of these impairments on driving performance have been observed in both simulator studies and on-road driving evaluations. Vaux and colleagues (2010) found that drivers with PD performed worse than healthy drivers in a simulated collision detection task. A 2002 study found that drivers with PD had a significantly greater number of driving simulator collisions than age-matched controls; the number of simulator collisions was correlated with Unified Parkinson's Disease Rating Scale-Motor scores ($p < .01$) and was associated with H&Y stage ($p < .01$) (Zesiewicz et al., 2002).

In an on-road evaluation of 25 drivers with PD and 21 healthy controls, those with PD were rated as significantly less safe drivers than controls by both an occupational therapist and a driving instructor. On a scale of 1 to 10, with scores of less than 5 indicating overall poor driving performance, drivers with PD received a mean rating of 4.80, as compared to the controls' mean of 6.56 (Wood, Worringham, Kerr, Mallon, & Silburn, 2005). In another study, on-road driving performance was measured using video tape from an instrumented car. A driving instructor reviewed and scored the video. Results showed that drivers with PD committed a mean of 41.6 safety errors, as compared to a mean of 32.9 for controls (Uc, Rizzo, Johnson, Dastrup, Anderson, & Dawson, 2009).

Relationship of Parkinson's Disease with motor vehicle crash and violation risk. In a survey of 6,620 people with PD in Germany, those who were licensed drivers had been involved in a mean of 0.2 crashes over the past five years; the mean number of crashes in which the driver with PD was at fault was 0.14. Of these, 14.5% had been involved in at least one crash, while 10.8% had *caused* at least one crash (Meindorfner et al., 2005).

A self-report of driving behavior by a small (n=8) group of people with PD showed no statistically significant difference in the mean number of crashes or instances of being pulled over by police over a 2-year period than a control group Drivers with PD reported a higher mean number of miles driven per week than controls (178.13 as compared to 145) and a greater number of weekly trips (6.75 versus 6.11) (Vaux et al., 2010).

Stroke

A stroke is a cerebrovascular accident (CVA) that occurs when the blood supply to the brain is reduced or interrupted. A stroke may be ischemic, producing an infarct (a small, localized area of dead tissue), or it may be hemorrhagic (bleeding).

Prevalence in U.S. population. Stroke statistics presented by the American Heart Association (Roger et al., 2011) indicate that an estimated 7 million Americans20 and older have had a stroke; overall stroke prevalence is estimated at 3%. Prevalence increases with age. Roger et al. (2011) presented prevalence by age and sex, using NCHS/NHANES data from 2005-2008: males 20-39 (0.3%); females 20-39 (0.5%); males 40-59 (1.6%); females 40-59 (2.4%); males 60-79 (7.2%); females 60-79 (8.2%); males 80 and older (14.5%); females 80 and older (14.8%). Each year, approximately 610,000 people in the United States experience a first stroke, and 185,000 a recurrent one. Each year, 55,000 more women than men have a stroke. Data from 2005 indicated that stroke incidence was decreasing for white, but not black people, who continue to have a higher stroke incidence, especially among young adults.

The American Heart Association (Roger et al., 2011) also presented statistics on transient ischemia attacks (TIAs), stroke-like symptoms that last for 1 to 2 hours. A TIA is often considered a risk for a future stroke. A TIA results in a sudden, brief decrease in brain function due to a temporary disturbance of blood supply to an area of the brain, but unlike a stroke, does not cause brain tissue to die (American Heart Association, 2017). The number of TIAs in the United States is estimated to be 200,000 to 500,000 per year, with a population prevalence of 2.3% (approximately 5 million people). The prevalence increases significantly with age.

Effects of stroke on functional abilities needed for safe driving. Stroke is a leading cause of serious, long-term disability in the United States and the length of time to recover from a stroke depends on its severity (Roger et al., 2011). While stroke can result in vision and motor impairments, it is sensory loss (numbness or loss of sensation) and cognitive impairments that are most likely to impair driving. These include memory loss, hemianopia (inattention/neglect to one hemisphere of vision), visual field cuts, impairment of executive function (e.g., decision making) and aphasia (inability to understand or express speech). Stroke can also cause muscle weakness or paralysis (Carr, 2007). Strokes are a major cause of hemianopia. Hemianopic field loss has been reported in 36% of right-brain strokes and 25% of left-brain strokes. Unilateral inattention (visual field neglect) has been detected in 82% of right-brain strokes and 65% of left-brain strokes (Gottlieb & Miesner, 2004).

Effects of stroke on driving performance.

Uc, Rizzo, Anderson, Shi, and Dawson (2005a) found that drivers who had experienced a stroke detected significantly fewer landmark and traffic signs compared to neurologically normal control subjects, and made significantly more at-fault safety errors (e.g., erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behavior) during the sign identification task. A subset of drivers with stroke history performed similarly to controls on all sign identification measures and made no safety errors, suggesting that some people who have had a stroke remain fit drivers.

Subjects included 32 participants who had had a stroke (none with hemianopia, 63% male, mean age 61 years, mean education 14 years) and 147 neurologically normal controls (50% male, mean age 65 years, mean education 15.6 years). All strokes were ischemic; 13 stroke group members had purely right-hemispheric lesions, 14 had purely left–hemispheric lesions, and 5 patients had bilateral lesions or nonhemispheric strokes (in cerebellum or brainstem). Subjects with right hemispheric strokes committed more at-fault safety errors and identified

fewer targets. The authors noted that this was consistent with the predominant role of the right hemisphere in visual perception and visuospatial abilities, which are critical for sign identification performance.

The study protocol involved a battery of cognitive, visual, and motor tasks, followed by assessment on-road in an instrumented vehicle. The on-road test lasted 45 minutes on roadways surrounding Iowa City. Outcome measures included steering wheel position, accelerator and brake pedal position, lateral and longitudinal acceleration, and vehicle speed. Lane tracking and visual scanning activity were recorded by videotape. The experimental drive consisted of on-task (searching for signs and landmarks) and no-task segments. The landmark and traffic sign identification task was conducted as part of the drive along a one-mile commercial segment of a 4-lane divided highway. Drivers were asked to report traffic signs and restaurants. The route included16 road signs (11 with high saliency) and 13 restaurants (all with high saliency) along the route.

For the subset of participants who were unfamiliar with the test area, the stroke group committed significantly more safety errors than the control group. For the familiar drivers, there was no statistically significant difference in number of safety errors between stroke and control drivers. On a straight segment of the drive with no sign task, there was no difference between the groups in basic vehicular control measured by standard deviation of steering wheel position, number of large changes in steering wheel position per minute, and standard deviation of mean speed. Stroke group members with gait impairment (took longer than 12 seconds on the Get Up and Go test) committed significantly more at-fault safety errors during the sign identification task than stroke group members with normal gait. Multiple cognitive measures (verbal and visual memory, visual search, executive functioning, visuoconstructional abilities, visual processing and attention), several visual tests (near and far acuity and CS), and two motor tests (functional reach and peg board) were significantly correlated with percentage of targets identified. Uc et al. (2005a) concluded that drivers who had experienced a stroke showed impairments on a visual search task, which placed demands on visual perception, attention, executive function, and memory likely increased the cognitive load and worsened their driving safety. The finding of no differences in at-fault safety errors between familiar stroke and control drivers suggests that license policies that restrict drivers who have experienced strokes to driving in familiar areas may maintain their mobility and safety.

Relationship of stroke with motor vehicle crash and violation risk. As indicated in Staplin et al. (2012), the evidence of crash risk among people who have had a stroke remains inconclusive. Sims, McGwin, Allman, Ball, and Owsley (2000) reported that a history of stroke or TIA was the only medical condition significantly associated with crashing in a prospective cohort study of 174 older adults in Alabama. An increase in crash risk among those who have had a stroke when compared to controls was reported by Koepsell & colleagues (1994), but not by Salzberg and Moffat (1998).

Traumatic Brain Injury

Traumatic brain injury (TBI) results from sudden physical trauma that damages the brain. Injuries may be classified as primary or secondary. A primary TBI results from the initial physical trauma. Secondary injuries result from cascade of post-injury events such as increases in intracranial pressure due to cerebral edema (Menaker & Scalea, 2009). Motor crashes were the

third leading causes of TBI hospitalizations and deaths, accounting for 17.3% of the total; the top causes were falls (35.2%) and the other/unknown category (21%).

The Glasgow Coma Scale may be used to rate the severity of TBIs. The scale is based on three aspects of neurological functioning: eye opening, verbal functioning, and motor functioning. The scores for each section are added together to obtain an overall score, ranging from 3 to 15. Scores of 13 to 15 indicate mild TBI, scores of 9 to 12 indicate moderate TBI, and scores of 3 to 8 indicate severe TBI (Menaker & Scalea, 2009).

Prevalence in the U.S. population. In the United States, an estimated 1.7 million people experience a TBI every year, and TBI is a contributing factor in nearly a third (30.5%) of all injury-related deaths. TBIs are most common among those 0 to 4, 15 to 19, and 65 and older. TBIs occur in males at a rate 1.4 times that of females (Faul, Xu, Wald, & Coronado, 2010).

A study of the civilian population of the United States conservatively estimated that 3.7 million people (1.1% of the civilian population) were living with long-term disability from a TBI (Zaloshjna, Miller, Langlois, & Selassie, 2008).

Effects of TBI on functional abilities needed for safe driving. In a meta-analysis of previous research on TBI and driving, Brenner, Homaifar, and Schultheis (2008) found that people with TBI experienced cognitive impairments across several domains: attention, executive function, processing speed, and visual spatial and visual memory skills.

A study of central executive function in people who had had a closed-head injury (a subtype of TBI, in which the skull and dura mater, the outermost of the membranes enveloping the brain and spinal cord, remain intact) found that speed of information processing lagged behind that of controls in tests of planning, inhibition, flexibility, and divided attention. The study reported a strong relationship between movement times on a reaction speed test and injury severity as measured by post-traumatic amnesia (Pearson $r = .72$, $p < .001$) (Veltman, Brouwer, van Zomeren, & van Wolffelaar, 1996).

Effects of traumatic brain injury on driving performance. In a simulator study that required people who had experienced TBI to perform a secondary task during driving (detecting a shape-shifting symbol in periphery of the simulated driving screen and indicating its location using their turn signal), reaction time on the secondary task was significantly correlated with crashes in the TBI group ($r = 0.58$, $p = .01$). This correlation could *not* be accounted for by differences in processing speed between those with TBI and controls. Additionally, TBI group members were significantly more likely than age-and education-matched controls to be involved in a crash (Cyr et al., 2009).

A study to assess the ecological validity of driving simulator assessments found that those with moderate to severe TBI performed worse than controls on a driving simulator scored with the Simulator Performance Index (SPI), a composite index of twelve automated performance measures, and with the Driver Performance Index (DPI), an index of overall driving skill. With a failing score defined as a SPI of two standard deviations below the mean of the controls, all controls passed the simulator trial, while 55% of TBI patients failed. The TBI group averaged five times as many errors as controls during the simulated drive (28 as compared to 5.5,

$t = 4.20$, $p = .002$). TBI group members had the most difficulty in speed regulation, steering control, and following traffic regulations (Lew et al., 2005).

Relationship of traumatic brain injury with motor vehicle crash and violation risk. In a retrospective study of 90 people who had experienced a severe brain injury, defined as a score of less than 8 on the Glasgow Coma Scale and a coma lasting for at least 8 hours, 29 subjects (32%) had resumed driving; of these, 11 (38%) had been involved in motor vehicle crashes; 5 of the l1 (45%) had been involved in more than one crash. The relative risk of crashes in drivers who had experienced severe brain injury was 2.3 times greater than that among age-matched drivers in the general Italian population (Formisano et al., 2005). In this study, 80% of the injuries were due to TBI, 7% to ischemic or hemorrhagic stroke, 6% to subarachnoid hemorrhage, and 5% to other causes.

Visual and Other Sensory Disorders

Cataracts

A cataract is a clouding of the lens in the eye that affects vision. A cataract results when protein particles in the lens increase in size to the point of producing statistically significant light scatter; it may develop relatively quickly, over 1 to 5 years.

Prevalence in U.S. population. Cataract is the world's leading cause of blindness and the primary cause of loss of vision in the United States. The Eye Disease Prevalence Research Group (2004a) estimated that 20.5 million Americans over 40 (17.2% of the population) have a cataract in either eye, with the prevalence higher in women than in men, beginning at age 50. Prevalence increases in both sexes with age. The estimated prevalence across sex by age group as reported by this group as follows: 40-49 (2.5%); 50-54 (5.1%); 55-59 (9.1%); 60-64 (15.5%); 65-69 (25%); 70-74 (36.9%); 75-79 (49.9%); and 80 and older (68.3%).

Effects of cataracts on functional abilities needed for safe driving. Cataracts back-reflect light and scatter it within the eye. This impairs acuity, contrast sensitivity, and color discrimination, especially under conditions of dim illumination or strong glare (Kline & Li, 2005). A driver with clouded distance vision may have difficulty reading highway signs on very bright days or at dusk. Cataract may also impair form and depth perception, cause double vision in one eye, and make colors appear faded or changed in hue. Other symptoms include poor night vision, and halos around lights.

Effects of cataracts on driving performance. Cataract-induced visual loss adversely has been shown to impair performance, safety, mobility, comfort, and driving habits of older drivers (Kline & Li, 2005). Owsley, Stalvey, Wells, and Sloane (1999) found that compared to older drivers without cataract those with cataract were approximately twice as likely to report reductions in days driven and number of destinations per week, driving slower than the general traffic, and preferring someone else to drive. Those with cataract were five times more likely to have received advice about limiting their driving and four times more likely to report difficulty with challenging driving situations. Those reporting driving difficulty were two times more likely to reduce their driving exposure.

Wood (2002) reported that contrast sensitivity was a statistically significant predictor of driving performance among drivers with ocular disease. Many drivers in the study's ocular disease groups had cataracts, which can significantly reduce letter contrast sensitivity. Older drivers with moderate to severe ocular disease (e. g., cataracts in both eyes) saw significantly fewer and hit significantly more large, low contrast roadway hazards than did drivers with normal vision. The roadway hazards, 3.2- by 7.2-ft sheets of 31-in thick grey foam rubber, represented large, low contrast objects such as potholes, highway debris, speed bumps, pedestrians, or other vehicles under poor visibility conditions such as rain or fog.

A study by Wood and Carberry (2006) found that improvement in contrast sensitivity after cataract surgery was the best predictor of improved driving performance during an on-road (closed course) test, including the ability to detect and avoid hazards. Prior to the cataract removal, the driving performance of the patients was significantly worse than that of the controls (older subjects with normal vision) in the following areas; road sign recognition, road hazard

recognition, road hazard avoidance, and overall performance. Cataract surgery significantly improved driving performance in all four areas to the levels demonstrated by the controls. The authors reported similar findings in their earlier study, with the addition of the finding that lane keeping performance was impaired in the cataract group prior to surgery, compared to the controls (Wood & Carberry, 2004). Lane keeping performance did not improve significantly following cataract removal.

Carberry, Wood, Watson, and King (2006) found statistically significant driving performance decrements in a group of 33 drivers with cataracts (mean age = 73.9 years) compared to a group of 13 controls with no ocular disease (mean age = 70.8 years). The closed-circuit course represented a rural road environment. Driving performance measures included road sign recognition, road hazard recognition and avoidance, divided attention and reaction times, gap judgment and maneuvering, lane keeping, and speed of completion. An overall measure of driving skill was computed. Impaired visual acuity and contrast sensitivity were significantly associated with worse driving performance in both groups. There was no difference between groups on self-rated driving performance, self-reported crash rate, number of driving days per week, or how often they drove at night or in heavy traffic. Subjects with cataracts rated their vision more poorly than subjects with no eye disease. The cataract group also had lower scores on the activities of daily vision scale, and on the night, distance, glare, and near subscales. The authors concluded that the lack of a relationship between self-rated driving ability and objective measures of driving performance in drivers with cataracts had safety implications; drivers with cataract either lacked insight about the impact of their condition on safe driving performance or overstated their driving skills due to their need to maintain independence through driving, rather than providing a true rating of their ability. Regardless, these drivers did not adopt appropriate compensatory behaviors such as avoiding challenging driving situations. The findings that drivers with cataracts did not self-restrict under challenging driving situations is counter to the findings reported by Owsley et al. (1999).

Relationship of cataracts with motor vehicle crash and violation risk. Owsley's group (1999) found that drivers with cataract were 2.5 times more likely to have a history of at-fault crashes in the prior 5-year period (adjusted for miles driven per week and days driven per week). These associations remained even after adjusting for the confounding effects of age, impaired general health, mental status deficit, and depression. Severe contrast sensitivity impairment due to cataract elevated at-fault crash risk among older drivers. This effect has been reported even when cataract is present in only one eye (Owsley, Stalvey, Wells, Sloane, & McGwin, 2001). This risk was shown to fall after surgery to remove cataracts (Owsley, McGwin, Sloane, Wells, Stalvey, & Gauthreau, 2002). Owsley, Stalvey, Wells, Sloane, and McGwin (2001) concluded that this effect is most likely attributable to improvement in contrast sensitivity. A study by Wood and Carberry (2006) found that improvement in contrast sensitivity after cataract surgery was the best predictor of improved driving performance during a closed course test that measured drivers' ability to detect and avoid hazards.

Glaucoma

Glaucoma refers to a group of eye conditions that damage the optic nerve, which carries visual information from the eye to the brain (National Center for Biotechnology Information,). In many cases this damage results from intraocular pressure (IOP), increased pressure in the eye.

Prevalence in the U.S. population. The Eye Disease Prevalence Research Group (2004c) estimated the prevalence of open-angle glaucoma (OAG) in the United States by age, race, and sex. The estimated prevalence of OAG among people 40 and older was 1.86%, affecting 2.22 million people in the United States. After adjusting for age, the prevalence for Blacks was almost three times that for Whites. The researchers presented prevalence rates by age across race and sex as follows: 40-49 (0.68%); 50-54 (0.91%); 55-59 (1.17%); 60-64 (1.57%); 65-69 (2.09%); 70-74 (2.79%); 75-79 (3.80%); and 80 and older (7.74%).

Effects of glaucoma on functional abilities needed for safe driving. Glaucoma eventually results in destruction of optic nerve fibers and is the second leading cause of blindness in older adults. The condition gradually constricts the peripheral visual field, and can result in a total loss of vision. This process is painless and people are often unaware of any visual field deficits (Klein, 1991). Visual field loss in one eye can be masked by the other eye; people are unlikely to notice any loss of overall visual function until the later stages of the disease. Half of those diagnosed with glaucoma in one study of over 5,000 participants were previously unaware of the condition (Tielsch et al., 1991). Drivers with OAG and peripheral visual field loss may have difficulty seeing cars or pedestrians approaching from the side, and may show reduced contrast sensitivity (Klein, 1991).

Effects of glaucoma on driving performance. Szlyk, Taglia, Paliga, Edward, and Wilensky (2002) used an interactive driving simulator to compare the performance of 25 drivers with glaucoma (and no other eye disease) to 29 age-equivalent normally sighted drivers. Driving performance measures included: (1) braking response time to a stop sign; (2) number of lane boundary crossings; (3) horizontal eye movement; (4) slope of the brake response curve; (5) near crashes; (6) number of failures to stop at a stop sign or red traffic signal; (7) mean speed; and (8) number of crashes. The groups differed significantly only in braking response time to a stop sign. The glaucoma group showed *shorter* response times as compared to controls. The authors postulated this was the result of hypervigilance in the glaucoma group. Among only the glaucoma members, analyses showed a statistically significant relationship between better contrast sensitivity and shorter braking response times. The glaucoma group had significantly worse contrast sensitivity than controls (mean in the better eye 1.58 versus 1.75), but their acuity was not significantly different. The authors found that poorer *contrast sensitivity* in the better eye among glaucoma group members was correlated with slower speeds, more lane boundary crossings, and longer braking response times. The authors concluded that because contrast sensitivity is the first visual function affected by glaucoma, it may be an important component in driver license screening, particularly for people with glaucoma. Additionally, because study inclusion criteria included regular daily driving with an unrestricted license, those with moderate or severe glaucoma who ceased or self-limited driving were excluded, resulting in an underestimation of the effects of glaucoma on driving performance.

In an on-road, in-traffic study comparing the driving performance of 20 drivers with glaucoma (mean age 68 years, 70% male) and 20 controls without (mean age 67 years, 70% male), Haymes, LeBlanc, Nicolela, Chiasson, and Chauhan (2008) found only one performance difference; drivers with glaucoma were six times more likely than controls to have the front-seat driving instructor apply the dual brake or take over steering control to avoid an unsafe maneuver. The OR reached 10.6 after adjusting for age, sex, number of systemic medications, use of psychotropic medication, and driving exposure. Twelve (60%) glaucoma group members

required intervention compared to 4 (20%) control group members. For 8 of the 12 from the glaucoma group and 1 of the 4 controls, failure to see and yield to a pedestrian triggered the intervention. Other causes were failure to see and stop at a stop sign and failure to yield to an oncoming vehicle. There were no group differences on time to complete the on-road evaluation, number of skills scored as satisfactory, or overall rating of driving performance. Of the three visual measures obtained in the study (distance visual acuity, contrast sensitivity, and visual fields), only worse eye MD[3] was significantly correlated with critical interventions. Those with glaucoma had significantly decreased MD compared with the controls; scores indicated slight to moderate impairment. Better eye mean MD was -1.66 dB (2.19 SD), and worse eye mean MD was -6.53 dB (4.88 SD). Patients with glaucoma with worse eye MD -4 dB or below were more than four times as likely as those with better visual fields to have the driving instructor intervene. The most common cause of the intervention was failure to see and yield to a pedestrian. It is important to note that the glaucoma group was limited to those who met the visual standards for driving in Nova Scotia (having no more than moderate visual field impairment). Haymes et al. (2008) concluded that people with glaucoma who met the visual standard for driving had good general driving skills and performed standard driving maneuvers as well as age-matched normal vision subjects did; however, their ability to detect and respond to peripheral obstacles and hazards and unexpected events was impaired.

Carberry, et al. (2006) found significantly poorer driving performance for a group of 29 drivers with glaucoma (mean age 69.9 years) as compared to 13 controls with no ocular disease (mean age 70.8) in a closed-circuit course study (the course is described in the "Cataracts" section above). Impaired visual acuity and contrast sensitivity were significantly associated with worse driving performance in both groups, as were left and right Hodapp scores (classifying severity of glaucomataous loss as minimal, early, moderate, or severe) for the glaucoma group. There was no difference between groups on self-rated driving performance, self-reported crash rate, number of driving days per week, or how often they drove at night or in heavy traffic. Drivers with glaucoma rated themselves as having good vision; however, 86% had impaired peripheral vision including several with severe field loss. The authors noted that this lack of insight denied the driver the opportunity to adjust their behavior to compensate for the effect of diminished visual abilities on driving, by avoiding more hazardous driving environments (such as nighttime and heavy traffic).

Coeckelbergh, Brouwer, Cornelissen, and Kooijman (2004)[4] showed no effect of diagnosis (e. g., glaucoma, age-related macular degeneration, or retinitis pigmentosa) on the percentage of participants passing an on-road driving test. Instead, a model including visual attention and contrast sensitivity predicted on-road performance. Drivers with a central visual field defect were at greater disadvantage than those with a peripheral visual defect, likely due to compensatory strategies used by the latter group. The authors warned against assessing driving performance based on a diagnosis alone.

Relationship of glaucoma with motor vehicle crash and violation risk. A 5-year retrospective study from Canada compared crash risk in patients from a glaucoma clinic to

[3] The Humphrey Field Analyzer mean deviation (MD) was used as the main global index of visual field impairment.

[4] This study was not critically reviewed because participants did not meet the European visual requirements for driving, due to central or peripheral visual field defects.

controls. Those with glaucoma were at higher risk for police-reported motor vehicle crashes (OR=3.21), including at-fault crashes (OR=7.21) (Haymes, LeBlance, Nicolela, Chiasson, & Chauhan, 2007). A number of studies have also shown an increase in crash risk in patients with glaucoma (Hu, Trumble, Foley, Eberhard, and Wallace, 1998; Owsley, McGwin, & Ball, 1998; Szlyk, Mahler, Seiple, Deepak, & Wilensky, 2005); while some have not (McGwin et al., 2004; McCloskey, Koepsell, Wolf, & Buchner, 1994). Two studies that found an elevated crash risk for people with those with moderate to severe glaucoma, who had statistically significant visual field loss (<100 degrees total horizontal field); or impairment in the central 24-degree radius field in the worse functioning eye (Szlyk et al., 2005; McGwin et al., 2004).

In a review of the literature on vision impairment and driving, Owsley and McGwin (1999) noted that the use of topical eye medications in older patients with glaucoma increased their risk of falling, and postulated that medications used to treat glaucoma may independently contribute to motor vehicle crashes. Haymes et al. (2007) found an increased risk of a fall in the prior 12 years for people with glaucoma as compared to controls (OR=3.71), after adjustment for age, sex, body mass, number of systemic medications, and better eye HFA MD. Forty-seven of the 48 people in the glaucoma group used glaucoma eye drops during the study verses none of the controls.

Homonymous Hemianopia and Quadrantanopia

Hemianopia is visual field loss through the vertical midline. It usually occurs in both eyes (homonymous hemianopia), although it can occur in one eye only. Hemianopia may be complete or incomplete. In complete hemianopia, the entire hemifield is lost. In incomplete hemianopia, the loss of the hemifield is partial – such as in quadrantanopia, in which a quadrant of the affected hemifield is lost.

The causes of hemianopia are varied: the most common include stroke, trauma, tumors, infections, or the results of surgery; some cases are congenital. A 2006 review of 15 years' worth of medical records of patients with homonymous hemianopia found that 37.6% of the cases of homonymous hemianopias were complete, while 62.4% were incomplete, with homonymous quadrantanopia (29%) being the most common type of incomplete homonymous hemianopia. The causes of homonymous hemianopias identified were: stroke (69.6%), trauma (13.6%), tumor (11.3%), brain surgery (2.4%), demyelination (1.4%), and rare causes and unknown etiology (1.6%) (Zhang, Kedar, Lynn, Newman, & Biousse, 2006).

Prevalence in U.S. population. The incidence of visual field loss (of any type) increases with age. According to Prevent Blindness America (2008), 2.8% of the U.S. population ages 40 and older suffer from some form of visual impairment. A 1983 study of 10,000 subjects applying for drivers' licenses found that 3.0% to 3.5% in those ages 16 to 60 had visual field loss. Prevalence increased to 13% for those ages 65 and older, with the most common causes being glaucoma, retinal disorders, and cataracts (Johnson & Keltner, 1983). Stroke risk, the most common cause of homonymous hemianopia, also increases with age: only 0.7% of those ages 18-24 reported having a history of stroke, as compared to 7.9% of those ages 65 and older (Centers for Disease Control and Prevention, 2010a). An Australian study found homonymous field defects in 8.3% of subjects with a history of stroke (Gilhotra, Mitchell, Healey, Cumming, & Currie, 2002).

Medications (assistive devices) used to treat homonymous hemianopia and quadrantanopia. Assistive devices such as visual field expanders have been used to widen patients' field of view (Drasdo & Murray, 1978).

Effects of homonymous hemianopia and quadrantanopia on functional abilities needed for safe driving. Visual field defects prevent drivers from having a complete, unobstructed view of their environment. Even outside of driving, those with hemianopia often bump into objects hidden by their blind hemifield. When driving, they may lack the ability to scan sufficiently fast enough to fully comprehend traffic patterns, signs, and other crucial visual cues (Pambakian & Kennard, 1997).

Effects of homonymous hemianopia and quadrantanopia on driving performance. Drivers with hemianopia were more like likely to receive lower overall ratings than those with normal visual fields in an on-road (interstate and non-interstate) driving assessment of drivers with hemianopia and quadrantanopia, Driving performance measures, scored by an occupational therapist, covered five domains: interaction-communication with other road users and pedestrians, driving style, vehicle control skills, adjustment to traffic speed conditions, reaction to unexpected events, and unusually bad driving maneuvers (e. g., turning the wrong way on a one-way street). Those with hemianopia performed worse than controls in every domain except interaction with other road users. During the drive, the therapist verbally intervened (e. g., "slow down") for half of the drivers with quadrantanopia and almost half (45%) of the drivers with hemianopia, as compared to interventions for only 16.7% of controls. Additionally, the therapist physically intervened for 40.9% of drivers with hemianopia, but for only 1 of the 30 controls (Elgin et al., 2010). However, the same study found that the overall rating of drivers with quadrantanopia was similar to that of drivers with normal visual fields.

A 2011 study by Parker et al. that combined a driver questionnaire and an on-road driving assessment of 17 subjects with hemianopic field loss, and 7 subjects with quadrantanopic loss, and 24 age-matched controls found that drivers with field loss reported significantly greater difficulty in driving situations that relied on peripheral vision and independent mobility (e. g., driving alone/driving long distances or in unfamiliar areas). Field loss group members were also more likely to have had someone suggest that they stop or limit their driving in the past year (29.2%) than drivers with normal visual fields (4.2%). During the on-road assessment, a certified driver rehabilitation specialist rated 3 drivers with visual field as unsafe and 21 as safe; all 24 controls were rated as safe drivers. There were no statistically significant associations between drivers' self-perception of their driving ability and their on-road rating.

In another on-road driving assessment of subjects with visual field defects (22 drivers had homonymous hemianopic field loss and 8 had quadrantanopic field loss) and controls (30 drivers with normal visual fields), Wood et al. (2011) found that those with visual field defects drove more slowly than those with normal visual fields. The field loss group spent almost 90% of the drive at speeds below 50 km/hour and 10% of the time at 50-70 km/hour, while controls spent 82% of the time at 0-50 km/hour and 17% of the drive at 50-70 km/hour.

In a simulator study of lane positioning, drivers with hemianopia took lane positions that compensated for their blind hemifield. Those with right homonymous hemianopia took a more leftward lane position than did drivers with normal visual fields, especially on straight road

segments, to gain a greater margin of safety on their blind side. While those with left homonymous hemianopia took a position to the right of the lane center, so did drivers with normal vision, perhaps due to the perceived threat of oncoming traffic in the left lane (Bowers, Mandel, Goldstein, & Peli, 2010).

Another simulator study, conducted using the National Advance Driving Simulator, found that drivers with visual field loss (in this study, the six subjects with visual field loss had an average visual field of 71.51 degrees; three had homonymous hemianopia as a result of a stroke) performed as well as controls with normal visual fields on a sign identification task. During a simulated intersection incursion, those with visual field loss had a significantly smaller (i.e., less safe) time to collision with the intruding vehicle than those with normal visual fields (Lockhart, Boyle, & Wilkinson, 2009).

Relationship of homonymous hemianopia and quadrantanopia with motor vehicle crash and violation risk. Lockhart et al. (2009) discussed above did not find differences in self-reported crashes between drivers with visual field loss and those with normal visual fields. However, this relied on self-report, and the sample size was very small.

Macular Degeneration (Age-Related)

Macular degeneration affects the central region (macula) of the retina, where the highest density of photoreceptors that provide the ability to resolve fine detail is found. Macular degeneration exists in wet (exudative) and dry forms, and is graded by clinicians as mild, intermediate, or severe. The wet form, though less common, has a poorer prognosis and accounts for the highest proportion of loss of functional vision (Carr, 2007). Because of its increasing prevalence with advancing age, this disease is often labeled age-related macular degeneration (AMD).

Prevalence in the U.S. population. The Eye Diseases Prevalence Group (2004a) estimated that 1.47% percent (1.75 million) of Americans over 40 have AMD in one eye, and over 15% of White women over age 80 are affected by the disease. Aside from family history, the strongest risk factors are being Caucasian and female. Across sex and race, the prevalence of AMD by age group is: 40-49 (0.05%); 50-54 (0.34%); 55-59 (0.39%); 60-64 (0.56%), 65-69 (0.91%); 70-74 (1.66%); 75-79 (3.24%); and 80 and older (11.77%).

Effects of age-related macular degeneration on functional abilities needed for safe driving. AMD is the leading cause of blindness in older adults; more people have glaucoma and cataracts, but fewer with cataracts and glaucoma end up blind (Klein, 1991). Although people with AMD typically do not lose all of their sight, they may become incapable of reading road signs or seeing cars because of loss of central vision (Klein, 1991). Owsley and McGwin (2010) reported that visual acuity in the early stages of AMD typically remained good (20/40 or better), but other visually disabling symptoms can present early. These include visual limitations under reduced illumination, delay in dark adaptation, and deficits in spatial and temporal contrast sensitivity.

Effects of age-related macular degeneration on driving performance. Szlyk et al. (1995) study participants included 10 older drivers (mean age = 75.7) with AMD and average binocular visual acuity of 20/70, ranging from 20/30 to 20/100, and 11 controls (mean age = 71)

with binocular vision better than 20/40. People with glaucoma or more than a mild cataract were excluded from participation. The drivers with AMD demonstrated poorer driving simulator performance compared to controls in terms of lane boundary crossings (14.5 versus 3 for controls, $p<.05$), and simulator crashes (1.5 versus 0.55 for controls, $p<.03$), The AMD group also demonstrated poorer performance on components of an on-road test, with significantly more points deducted for driving too slowly (defined as 5 mph below the speed limit), failing to check blind spots while merging, failing to signal properly when merging, and for drifting outside the lane markings.

Relationship of age-related macular degeneration with motor vehicle crash and violation risk. Increased crash risk has been demonstrated for patients with macular degeneration when driving at night (Szlyk, Fishman, Severing, Alexander, & Viana, 1993; Szlyk et al., 1995), though both of these studies were based on small samples. However, in a larger study, Owsley et al. (1998) also found a statistically significant association between MD and *at-fault* crash risk.

Szlyk et al. (1995) recorded crashes within the prior five-year period, obtained through both self-report and State crash records. The (self-reported) annual mileage for the AMD group (9,400 miles, SD 3,800) and Control group (8,700 miles, SD 6,300) were not significantly different. In this study, the drivers with AMD performed more poorly on the driving simulator and on-road test compared to the Control group, but these differences did not translate to real-world crashes. The authors hypothesized that drivers with AMD compensated for their poorer driving skills by driving more slowly, and by limiting driving in unfamiliar areas

Vertigo (Vestibular Deficiency)

"Dizziness" is used to describe general symptoms of spatial disorientation. It has been divided into four subtypes: vertigo, presyncopal lightheadedness, disequilibrium, and other dizziness (Drachman & Hart, 1972). Vertigo is severe dizziness, and the feeling of moving or spinning, even when standing still. It is often accompanied by nausea. Vertigo accounts for about 25% of all episodes of dizziness (Neuhauser & Lempert, 2009) and may be classified into two subtypes based on its origin: peripheral (the inner ear or vestibular system) or central (balance centers of the brain). The studies examined concern only peripheral vertigo.

The feeling of vertigo may have a variety of etiologies. In a study of 70 vertigo patients in general practitioners' officers, the following three diagnoses predominated (Hanley & O'Dowd, 2002):

- Benign paroxysmal positional vertigo (BBPV) – The suspected cause of this condition, the most common cause of vertigo (Neuhauser & Lempert, 2009), is calcium deposits (known as otoconia) within the labyrinth of the inner ear that become dislodged, causing abnormalities in the distribution of endolymph fluid (Bhattacharyya et al., 2008). The feeling of vertigo may be triggered by actions such as looking up or down, rolling over, or rapid head movement.
- Acute vestibular neuronitis – This condition is marked by a sudden onset of severe vertigo that then lessens in intensity over several days or weeks; tinnitus is absent and hearing is preserved (Cooper, 1993). This condition is believed to be caused by lesions on the vestibular nerve.

- Meniere's disease – A disease of the inner ear, usually marked by episodes of vertigo, and intermittent tinnitus (ringing of the ears), hearing loss, and sensations of aural pressure and fullness (Sajjadi & Paparella, 2008).

Other causes include vestibular schwannoma (acoustic neuroma), a benign intracranial tumor that disrupts vestibular system function (McDonald, 2011), and temporary illnesses and conditions such as viral or bacterial infections that cause vestibular inflammation (labyrinthitis), migraines, motion sickness, and physical trauma.

Prevalence in U.S. population. In a review of several studies (the majority of which took place in western European nations), of the epidemiology of dizziness in both the community and a primary care setting Sloane, Coeytaux, Beck, and Dallara (2001) noted the following: dizziness is common in all adult age groups, it is more prevalent in women than in men, and its prevalence increases with age. A 1993 study by Kroenke and Price of adults ages 18 and over in five representative U.S. communities found that 23% had suffered from dizziness at some point (Kroenke & Price, 1993).

A study of African-American and White community-dwelling residents in Chicago, Illinois ages 65 and older found that the overall prevalence of dizziness in this group was 9.6%, increasing with age from 6.6% in those ages 65-74 to 18.4% in those ages 85 and older (Aggarwal et al., 2000).

Medications used to treat vertigo. Many cases of dizziness/vertigo have a favorable spontaneous course, resolving with little or no intervention (Huppert, Strupp, & Brandt, 2010). Common antivertiginous medications include dimenhydrinate (Dramamine), droperidol (Inapsine), meclizine (Antivert), phenobarbital, prochlorepraxine (Compazine), and promethazine (Phenergan) (Lanska, 2009).

Effects of vertigo on functional abilities needed for safe driving. As those with vertigo often rely on visual clues for help with orientation, they may have troubling navigating confusing environments (overpasses with disorientating spatial clues or ramped parking garages) or during times of reduced visual conditions (at night, in the rain). Spatial navigation skills, which are compromised in people with vertigo, are crucial for tasks such as parking a car or maintaining lane position. Additionally, rapid head/eye movement, which is often problematic for vertigo patients, is necessary for tasks such as scanning or checking mirrors and blind spots.

Effects of vertigo on driving performance. An on-road, instrumented vehicle study found no *functional* difference in head movement between a small group (n=3) of bilateral-vestibular deficient drivers and controls, although there were statistically statistically significant differences in the size and speed of head movements. Additionally, assessment of driving behavior by an occupational therapist and an orthoptist found few differences between the two groups; similarly, there were no differences on a driving task (reading street signs out loud) (MacDougall, Moore, Black, Jolly, & Curthoys, 2009).

The use of the *Driving Habits Questionnaire* to compare self-reported driving habits and skills between patients with dizziness (of various etiologies) and controls found that the dizziness group members reported difficulty navigating in situations that are aided by head movements, such as driving in reduced visibility (at night or in the rain), left turns, high traffic density

(freeways or rush hour), and maneuvers that required good spatial navigation skills (parking, lane maintenance). Analysis of responses by diagnostic group indicated that those with chronic vestibulopathy and those whose dizziness resulted from surgery reported the most difficulty driving. Additionally, those in every diagnostic group reported sometimes needing to pull off the road due to vertigo (Cohen, Wells, Kimball, & Owsley, 2003).

Relationship of vertigo with motor vehicle crash and violation risk. In the 2003 study by Cohen et al., referenced above, drivers with dizziness were significantly less likely to report having been pulled over by the police for moving violations than controls (10% as compared to 26%, $p = .017$) in the past year. Moreover, they were less likely to report having received tickets than controls during the same time period (6% as compared to 16%, $p = .072$). Self-reported crash rates did not differ between patients and controls.

Synthesis of Reviewed Literature

The charts and tables on the following pages facilitate comparisons among all medical conditions included in this review, according to the most salient results in the current literature. The prevalence data summarized in Table 1, together with the OR and relative risk values displayed in the adjacent chart (Figure 1), allow comparisons for 12 of the 14 identified medical conditions. The reviewed studies pertaining to *homonymous hemianopia/quadrantanopia* and *vertigo* were not included in the comparisons because the studies did not report data appropriate to these comparisons or the data were aggregated with data for other conditions under a broader heading (e. g., visual field disorders).

Among the various medical conditions considered in this review, the research team prioritized eight as being of particular concern in relation to their potential for driving impairment: *diabetes, dementia, glaucoma, hepatic encephalopathy, macular degeneration, OSA, PD,* and *stroke*. These are discussed below.

- **Diabetes**. Prevalence for this condition has been documented in the population as a whole at 11% among people 20 and older, increasing with age to 26.9% for those 65 and older. Risk also increases for people who are overweight, do not exercise regularly, and those with low HDL cholesterol or high triglycerides, and high blood pressure. Americans are aging and getting heavier, so the prevalence of diabetes can be expected to increase in the coming years. Medications to control diabetes can cause hypoglycemia, which can cause driver impairing symptoms including double or blurry vision, shakiness or trembling, tingling or numbness of the skin, tiredness or weakness, unclear thinking, and loss of consciousness. Adverse effects of hypoglycemia on cognitive functions include deterioration in simple and choice reaction times, speed of mathematical calculation, verbal fluency, attention, memory, and psychomotor function when concentrations fall below 3.0 mmol/l (54 mg/dL). Performance effects of hypoglycemia on driving include lane line exceedences and poorer secondary task performance for Type II diabetics and poorer overall driving performance for Type I diabetics who had experienced a diabetes-related driving mishap in the prior 12 months. Studies on the crash risk of people with, as compared to people without diabetes have found ORs ranging from 1.04 and 3.24. With respect to drivers 65 and older, studies have found ORs ranging from 1.06 to 2.88.

- **Dementia**. Prevalence for this condition has been documented in the older population at 13% for Americans 65 and older, increasing with increasing age to 45% of those 75 to 84 and 45% of those 85 and older. Among those 65 and older, 10% to 20% have mild cognitive impairment (MCI), and 15% of these will progress from MCI to dementia each year. Nearly half of all people who have visited a physician about MCI symptoms develop dementia within four years. Dementia is associated with impairments in memory, executive function, spatial orientation, judgment, insight, and impulsivity. While some people with very mild dementia, and a few with mild dementia retain safe driving skills, a study reported that 41% of older subjects with mild dementia failed an in-traffic road test as compared to 14% with very mild dementia.

Table 1. *Prevalence Estimates for Included Medical Conditions*

Condition	General population	Older Adults
Diabetes	11% of the Americans over 18 (National Center for Health Statistics, 2011)	26.9% of Americans 65 and older (National Center for Health Statistics, 2011)
Hepatic encephalopathy	5.5 million cases of liver disease in the United States; 30 to 40% of people with cirrhosis and 10 to 50% of those with transjugular intrahepatic portosystemic shunt will develop overt hepatic encephalopathy; 20 to 60% of those with liver disease develop minimal hepatic encephalopathy (Poordad, 2007).	
Arthritis	20.2% of Americans over 18 (Centers for Disease Control and Prevention, 2010b)	50% of Americans 65 and older (Hootman & Helmick, 2006)
Dementia	1.7% of Americans had Alzheimer's in 2011 (Alzheimer's Association, 2011)	13% of Americans over 65 have Alzheimer's, increasing to 43% in those 85 and older (Alzheimer's Association, 2011).
Multiple sclerosis	0.08% (Noonan, Kathman & White, 2002)	0.05% of those 60 and older (Baum & Rothschild, 1981).
Obstructive Sleep Apnea (OSA)	24% of men and 9% had an AHI of >5 events per hour; 4% of men, 2% of women also had daytime hypersomnolence.31% of men and 21% of women were at high risk for OSA (Hiestand, Britz, Goldman, & Phillips, 2006).	21% of Americans 65 and older were at high risk for OSA (Hiestand, Britz, Goldman, & Phillips, 2006).
Parkinson's disease	0.3% of the population (Torpy, Lymn, & Glass, 2004; U.S. Census Bureau data).	1.6% of Medicare beneficiaries (Willis, Evanoff, Lian, Criswell, & Racettte, 2010).
Stroke	3% of Americans 20 and older (Roger et al., 2011).	7.2 % of males and 8.2% of females 60-79; 14.5% of males and 14.8% of females 80 and older (Roger et al., 2011).
Traumatic brain injury (TBI) (long term disability)	1.1% of American civilians (Zaloshjna, Miller, Langlois, & Selassie, 2008).	Annual incidence among those 65 and older (ER visits, hospitalizations, fatalities): 237,844 (Faul, Xu, Wald, & Coronado, 2010).
Cataracts	17.2% of those over 40 have a cataract in at least one eye (Eye Disease Prevalence Research Group, 2004b).	25% of those 65-69; 36.9% of those 70-74; 49.9% of those 75-79; 68.3% of those 80+ (Eye Disease Prevalence Research Group, 2004b).
Glaucoma	1.9% of those over 40 (Eye Disease Prevalence Research Group, 2004c).	2.1% of those 65-69; 2.8% of those 70-74; 3.8% of those 75-79; 7.7% of those 80+ (Eye Disease Prevalence Research Group, 2004c).
Homonymous hemianopia; quadrantanopia	3.0 to 3.5% of drivers under 60 had visual field defects (Johnson & Keltner, 1983).	13% of drivers 65 and older had visual field defects (Johnson & Keltner, 1983).
Age related macular degeneration (AMD)	1.5% of Americans over 40 (Eye Disease Prevalence Research Group, 2004a).	0.6% of those 60-64; 0.9% of those 65-69; 1.7% of those 70-74; 3.2% of those 75-79; 11.8% of those 80+ (Eye Disease Prevalence Research Group, 2004a).
Vertigo	23.2% of people 18 and older across 5 communities reported problem dizziness at some point (Kroenke & Price, 1993).	9.6% of those 65 and older reported dizziness (Aggarwal et al., 2000).

Key to Figure 1 (below)

a: any crash
b: at-fault crash
c: less-than-optimal rating on road test - lane control
d: less-than-optimal rating on road test - global driving score
e: severe crashes (tow-away with multiple injuries; injurious crashes)
f: multiple crashes
g: single vehicle crash
h: wrong turn on road assessment
i: got lost on road assessment
j: at-fault safety error on road assessment
k: crash involvement, moderate vs minor disease severity
l: crash involvement, advanced vs minor disease severity
m: crash involvement, suddent onset of sleep at the wheel

OR	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0 or higher
RR	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0 or higher
Medical Condition and Severity																																									
DIABETES																																									
History of severe hypoglycemia requiring outside help																															4.07[a]										
Use of insulin									1.8[a]																																
Hypoglycemics other than insulin				1.35[a]		1.5[a]																																			
Severity not specified; older drivers >65 years																			2.88[a]																						
Hx of severe hypoglycemia in past 12 mo OR hypoglycemia-related driving mishap in past 2 yr	1.06[a]																																								
Stabilized with no episodes of ketosis or altered consciousness for 6 mo							1.6[a]																																		
Any diabetes stable on diet or adult onset stable on oral agents				1.3[a]																																					
HEPATIC ENCEPHALOPATHY																																									
Minimal (as diagnosed by the Inhibitory Control Test)																																				4.51[a]					5.72[a] 5.77[a]
ARTHRITIS																																									
Female drivers advised by medical professionals that they had arthritis									1.8[b]																																
Use of NSAIDs								1.7[b]																																	
Unrestricted drivers with musculoskeletal disorders						1.59[a]																														4.51[a]					
Restricted drivers with musculoskeletal disorders									1.84[b]																																11.29[b]
DEMENTIA																																									
Mild Cognitive Impairment																											3.69[c]							4.23[d]								
Severity not specified											2.0[a]																														
MULTIPLE SCLEROSIS																																									
With cognitive impairment																																									9.1[a]
OBSTRUCTIVE SLEEP APNEA																																									
Mild (AHI =5 to 14)																	2.6[a]																						4.8[e]		
Moderate (AHI = 15 to 29)										1.9[a]											3.0[e]																			
Severe (AHI = 30+)											2.0[a]																								4.3[e]		4.6[e]			
Sleepiest 5% of drivers (EpworthSleepiness Scale Score 18-24)										1.91[a]							2.67[f]																							
Sleepiest 5% of drivers (Functional Outcomes of Sleep Q'aire Score 96-100)													2.23[a]	2.39[f]																										
Symptoms of OSA: Ess 11+ and MAP .50+				1.30[a]			1.63[g]																																
AHI (any severity level)																											3.67[e]													6.3[a]
PARKINSON'S DISEASE																																									
Mild-to-moderate (H&Y stage: 2.2, SD: 0.6)																			2.81[h]																			4.7[j]		7.5[j]
Various levels of severity (comparisions are WITHIN PD group, not to neurologically normal drivers)					1.42[k]	1.51[l]															3.16[m]																		
STROKE																																									
Self-reported stroke or TIA																		2.7[a]																						
TRAUMATIC BRAIN INJURY																																									
Severe, Glasgow Coma Scale < 8 and coma lasting 48 hours or more														2.3[a]																											
MACULAR DEGENERATION																																									
Not specified																								3.3[e]																	
CATARACTS																																									
Not specified																2.5[b]																									
Severe CS impairment 1 eye																		2.7[b]																							
Severe impairment both eyes																																									6.0[b]
GLAUCOMA																																									
not specified																											3.6[a] 3.6[e]														5.2[a]
Slight to moderate impairment (HFA MD mean better eye -1.66; mean worse eye -6.53)																																									6.0[j]

Figure 1. Odds Ratios and Relative Risk Ratios for Adverse Driving Events, as Reported in Literature Review of Medical Conditions and Driving Performance.

Research showed that drivers with dementia of the Alzheimer's type were more likely to crash at intersections than older drivers without dementia. Behaviors within the five seconds preceding the crash included looking without seeing, failing to respond, and failing to react in time to avoid a collision. Drivers with AD committed more at-fault safety errors (erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behavior) than healthy age-matched controls. The crash rates for drivers with dementia was twice that of controls.

- **Glaucoma**. High prevalence for this condition has been documented among the oldest cohorts: 2.1% among those 65-69, 2.8% among those 70-74, 3.8% among those 75-79, and 7.7% among those 80 and older. Glaucoma results in a gradual constriction in the peripheral visual field, which can result in a total loss of vision. Because the condition is painless, people are often unaware that of any deficits in their visual field. Drivers with open-angle glaucoma and peripheral visual field loss have exhibited failure to see and yield to cars or pedestrians approaching from the side, and failure to see and stop at stop signs. Multiple studies have shown an increase in crash (including at-fault crashes) and violation risk for people with glaucoma compared to controls.

- **Hepatic Encephalopathy**. While the literature did not document a high prevalence for this condition, some of the factors that trigger HE are common among older adults. These include medications that affect the nervous system (such as tranquilizers or sleep medications), dehydration, and low oxygen levels. Physical and cognitive symptoms of HE include mild confusion, forgetfulness, poor concentration, and poor judgment. Severe symptoms include extrapyramidal movement disorders, extreme anxiety, seizures, severe confusion, sleepiness or fatigue, and slow movement. These may all have important consequences for safe driving. In a research study, drivers with MHE performed significantly worse in on-road driving maneuvers including following road signs, attending to bicyclists and pedestrians, checking the rearview mirror and blind spot before changing lanes, tracking, signaling to turn in a timely fashion, and following traffic rules. The driving instructor was 10 times more likely to intervene to avoid a crash while driving with people with MHE. Those with cirrhosis and MHE as diagnosed by the inhibitory control test had a significantly higher crash rate over the preceding year and on prospective follow-up compared to those without MHE. Physicians and other health care providers may not be aware of the effects of HE on driving performance so may not provide counseling to their patients who have this condition.

- **Macular Degeneration**. AMD has a high prevalence among the oldest cohorts with rates of 0.9% among those 65-69, 1.7% among those 70-74, 3.2% among those 75-79 and 11.8% among those 80 and older. It is the leading cause of blindness in people 65 and older. More people have glaucoma and cataracts, but fewer with cataracts and glaucoma become blind. Drivers with AMD demonstrated poorer driving simulator performance compared to controls as follows, exhibiting delayed braking response times to stop signs, slower speeds, more lane boundary crossings, and more simulator crashes. They also demonstrated poorer performance than controls in on-road tests, with significantly more points deducted for driving too slowly, failure to check blind spots while merging, failure to use turn signals for merging, and failure to maintain proper lane position (drifting

outside the lane markings). Drivers with AMD have shown crash risk as compared to controls (OR = 3.3).

- **Obstructive Sleep Apnea**. This is a common, often undiagnosed (and under-treated) condition with potentially serious consequences for driving safety. Prevalence estimates range from 4-24% for men and 2 to 9% for women across all ages . However, questionnaire findings used to classify people at high and low risk for OSA by identifying snoring behavior, daytime sleepiness, obesity, and hypertension found 31% of men and 21% of women in the sample were at high risk. One study showed the risk increased linearly with age, affecting: 19% of people 18 to 29; 25% of those 30 to 49; and 33% of those 50 to 64. The risk remained high after age 65 (21%). People with OSA have fragmented sleep periods associated with snoring and intermittent airway obstruction. This sleep fragmentation leads to chronic sleep deprivation and excessive daytime sleepiness, a likely cause of cognitive deficits reported in this population. Sleepiness at the wheel resulting from OSA has been correlated with inappropriate lane line crossings during an on-road driving sessions and in simulator studies. OSA has been associated with a 2- to a 7-fold increase in crash risk; people with the condition are also at significantly higher risk of serious injury in crashes. Researchers have found that drivers with OSA who were treated with nasal continuous positive airway pressure (CPAP) had a decreased crash rate during treatment as compared to their pre-treatment rate and compared to drivers with OSA who did not undergo CPAP treatment. However, other researchers found that, while simulator steering performance improved marginally following three months of CPAP treatment, driving performance remained significantly impaired compared with age and sex-matched healthy controls.

- **Parkinson's disease**. PD is the second most common neuro-degenerative disease after Alzheimer's. Prevalence estimates indicate 1.6% of Medicare beneficiaries are affected. Because PD is more common in people 60 years old and older, the incidence of PD is expected to increase with the aging of the baby boomers. Cognitive effects of PD include deficits in memory, attention, abstract reasoning, and information processing speed, coupled with deficits in metacognition, rendering people with PD unable to accurately judge their own limitations. Physical symptoms include muscle rigidity and stiffness, tremors, slowed movements, and difficulty with balance and walking. Medication to treat PD symptoms can cause excessive daytime sleepiness without any forewarnings of being sleepy. The cumulative effects of these impairments on driving performance have been observed in both simulator studies and on-road driving evaluations.

- **Stroke**. Overall stroke prevalence is estimated at 3%, but increases with age, with prevalence higher in females than males. Estimates are 7.2% among males and 8.2% among females 60-79 (7.2%), 14.5% among males and 14.8% among females age 80 and older. Stroke symptoms can include vision and motor impairments, sensory loss (numbness or loss of sensation) and cognitive impairments. These include memory loss, hemianopia (inattention/neglect to one hemisphere of vision) or visual field cuts, impairment of executive functions and aphasia. Additional impairments include muscle weakness or paralysis. Strokes/cerebral vascular accidents are a major cause of hemianopia. As indicated in the review, the evidence of crash involvement among those who have had strokes remains inconclusive. Depending on the driving environment,

some post-stroke drivers perform as well as normal controls while others commit more safety errors. An estimated 30 to 50% of people who have had a stroke return to driving, and many do not undergo any formal evaluation of their driving abilities or receive advice before resuming driving (see Schultheis & Fleksher, 2009).

Many medical conditions anecdotally or logically associated with driving impairment were excluded from this review. Such conditions and the rationale for their exclusion are as follows.

Depression. Much of the literature on depression and driving ability or crashes and violations focused on the effects of medications used to treat depression, with the most common being selective serotonin reuptake inhibitors (SSRI) and serotonin-norepinephrine reuptake inhibitors (SNRI), although studies have also examined the effects of older classes of medications such as tricyclic antidepressants and monoamine oxidase inhibitors (MAOI). It would seem that the symptoms of depression (deficits in attention, insomnia or hypersomnia, lethargy, etc.) would impair driving ability; however, there was a dearth of studies examining the relationship between un-medicated depression and driving performance or crash risk. This review was concerned primarily with the direct effects of the medical condition. Multiple studies have explored the side-effects of both older and newer antidepressants which could potentially impair daily activities (including driving performance).

S*eizure disorders/epilepsy* and *narcolepsy*. People with seizure disorders/epilepsy that severely interferes with activities of daily living are likely to be either screened out of the driving population or appropriately monitored to reduce risk. Narcolepsy, too, is subject to a range of existing licensing safeguards addressing sleep disorders, as its impact on everyday functioning is well understood. Also, the prevalence of this disorder is low – approximately 1 in 2,000 people (Mignot, 2004) – and studies examining the effects of narcolepsy on driving are rare.

For various other conditions, their most common etiologies often included diseases already covered in the literature review (e. g., peripheral neuropathy resulting from diabetes). Likewise, when several conditions were similar (e. g., transient ischemic attack and stroke) the research team focused on the more debilitating, provided that there was sufficient prior research.

Cancer. Few studies examining *cancer* were uncovered during the literature review. The existing studies primarily explored the effects of medication and treatments (e. g., opioids, surgery, radiation therapy in head and neck cancers) on driving safety.

Perhaps the most counterintuitive exclusion from the present review was the broad category of *cardiovascular diseases*. While cardiovascular conditions may precipitate various sudden, incapacitating events (e. g., stroke) there was little evidence on the effects of cardio-vascular disease *per se* on driving safety.

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Appendix A

The following sources explain the origin of the statistics presented in Table 1, as well as any operations performed on them to obtain a percentage:

Diabetes, General population: National Center for Health Statistics, 2011.

Diabetes, Older adults: National Center for Health Statistics, 2011.

Hepatic encephalopathy, General population and Older adults: Figures come from Poordad's 2007 literature review. The true prevalence of hepatic encephalopathy is not fully known.

Arthritis, General population: Centers for Disease Control and Prevention, 2010b

Arthritis, Older adults: Hootman & Helmick, 2006

Dementia, General population: An estimated 5.4 million Americans, of all ages, have Alzheimer's in 2011 (Alzheimer's Association, 2011). A total figure of 312,420,332 was used for the U.S. population (U.S. Census Bureau population clock, as of 10/14/2011) to arrive at the estimated 1.73%.

Dementia, Older adults: Alzheimer's Association, 2011.

Multiple sclerosis, General population: Noonan, Kathman, & White estimated nationwide multiple sclerosis prevalence at 85 per 100,000 population (2002) during the years 1989 through 1994, using the National Health Interview Survey. This was converted into a percentage.

Multiple sclerosis, Older adults: A 1981 study by Baum and Rothschild analyzed the results of the National Multiple Sclerosis survey, conducted under the auspices of the National Institute of Communicative Disorders and Stroke, and found the prevalence of MS among those ages 60 and older to be 52.58 per 100,000 population (based on the years 1970 through 1975). This was converted into a percentage.

Obstructive sleep apnea, General population: Data from the Berlin questionnaire obtained from 1,506 adults who participated in the National Sleep Foundation (NSF) annual telephone poll (Hiestand, Britz, Goldman, & Phillips, 2006).

Obstructive sleep apnea, Older adults: Data from the Berlin questionnaire obtained from 1,506 adults who participated in the National Sleep Foundation (NSF) annual telephone poll (Hiestand, Britz, Goldman, & Phillips, 2006).

Parkinson's disease, General population: An article in the Journal of the American Medical Association estimated the number of Parkinson's cases among the American population as "more than 1 million…". The 0.34% figure in the preceding table comes from taking the number of

Parkinson's cases as 1 million, and then using the U.S. Census Bureau estimates for the American population in 2004 (293,045,739).

Parkinson's disease, Older adults: A 2010 study of Medicare beneficiaries ages 65 and older, with data from 1995 and 2000 through 2005 (Willis, Evanoff, Lian, Criswell, & Racette).

Stroke, General population: An estimated 7 million Americans ages 20 and old have suffered a stroke; overall prevalence is estimated at 3% (2008 data) per Roger et al (2011).

Stroke, Older adults: Data from Roger et al. (2011).

Traumatic brain injury, General population: Data on the percentage of civilian population living with long-term TBI disability comes from Zaloshjna, Miller, Langlois, & Selassie (2008).

Traumatic brain injury, Older adults: For an acute event such as TBI, incidence, as opposed to prevalence, is the proper statistic. Data on TBI in older adults taken from Faul, Xu, Wald, and Coronado (2010) on incidents from 2002 through 2006.

Cataracts, General population: Data taken from the Eye Disease Prevalence Research Group (2004b).

Cataracts, Older adults: Data taken from the Eye Disease Prevalence Research Group (2004b).

Glaucoma, General population: Data taken from the Eye Disease Prevalence Research Group (2004c).

Glaucoma, Older adults: Data taken from the Eye Disease Prevalence Research Group (2004c).

Homonymous hemianopia and quadrantanopia, General population: Data taken from screening of approximately 10,000 volunteers applying for drivers' licenses in California (Johnson & Keltner, 1983).

Homonymous hemianopia and quadrantanopia, Older adults: Data taken from screening of approximately 10,000 volunteers applying for drivers' licenses in California (Johnson & Keltner, 1983).

Macular degeneration (Age-related), General population: Data taken from the Eye Disease Prevalence Research Group (2004a).

Macular degeneration (Age-related), Older adults: Data taken from the Eye Disease Prevalence Research Group (2004a).

Vertigo, General population: As vertigo is a subset of dizziness, the prevalence numbers for dizziness presented like over-estimate the prevalence of vertigo. Dizziness prevalence taken from Kroenke & Price, 1993.

Vertigo, Older adults: As vertigo is a subset of dizziness, the prevalence numbers for dizziness presented likely over-estimate the prevalence of vertigo. Dizziness prevalence taken from Aggarwal et al. (2000).

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