# CRASH RISKS OF DRIVERS WITH PHYSICAL AND MENTAL (P&M) CONDITIONS AND CHANGES IN CRASH RATES OVER TIME

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**14. ABSTRACT** This study reviews recent research evaluating traffic safety in individuals diagnosed with epilepsy, syncope, dementia/Alzheimer's Disease, diabetes, and sleep disorders. Additionally, this study evaluates the crash risk of drivers identified as having a physical or mental condition which may affect their ability to drive safely, and compared these findings to previous DMV reports which evaluated crash risk in this population. Research has repeatedly demonstrated that these drivers have a higher crash rate relative to the general population of drivers (Janke, Peck, & Dryer, 1978; Janke, 1993; Mitchell & Gebers, 2001). Crash rates for all drivers referred to DMV for a medical condition in the 2007 calendar year, and were assigned a P&M code (alcohol, drugs, lack of skill, lapses of consciousness, mental condition, or physical conditions) on their driving record were compared to crash rates for the general population of drivers. The mean crash rate for each of the P&M groups was higher than both the general population of drivers (7 per 100 drivers) and males under 25 (10 per 100 drivers). Relative to prior DMV studies, mean crash rates for drivers with a P&M designation of drug addiction, lapses of consciousness, and mental condition had dropped. A logistic regression where age and sex were controlled demonstrated an increased crash risk for each of the P&M conditions ranging from 2.8 to 13.3 times higher than the general population, with individuals with a mental condition having the lowest odds ratio and lack of skill having the highest odds ratio. The odds ratios for all conditions were higher than observed in prior DMV studies. One reason for this increase was an observed decrease in crash rates for the general population of drivers which did not correspond to a drop in crash rates for drivers with a P&M condition. Future research needs to evaluate the specific medical conditions within each P&M designation to better understand the relationship between medical conditions and crash risk in this population of drivers.

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# PREFACE

This report updates information on drivers with physical and mental conditions in a series of earlier California Department of Motor Vehicles (DMV) reports. The primary purpose of these reports has historically been to provide traffic safety administrators and legislators with useful information for formulating policy and law, as well as informing researchers in the field of traffic safety, and the general public. The report was prepared by the Research and Development Branch of the California DMV. The findings, opinions, and conclusions presented in this report are those of the author and not necessarily those of the State of California.

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# EXECUTIVE SUMMARY

## Introduction

Previous research studies conducted by the California Department of Motor Vehicles (DMV) have demonstrated that individuals with medical conditions known to affect driving ability are at higher risk of crashing relative to the general population of California drivers (Janke et al., 1978; Janke, 1993; Mitchell & Gebers, 2001). Drivers with epilepsy, syncope, dementia/Alzheimer's Disease, diabetes, and sleep disorders (e.g., obstructive sleep apnea and narcolepsy) have the highest rate of referrals to the Driver Safety Branch. With the advancement of medical technology and treatments, it is important to periodically reevaluate the relative risk of a crash associated with these conditions.

The purpose of the current study was to evaluate whether drivers identified by the Driver Safety Branch as having a medical condition had higher crash rates prior to their referral to DMV relative to the population of California drivers. In addition, the findings from the current study were compared to the findings in prior DMV studies to examine potential changes over time. This information was intended to help DMV better understand the potential safety risks, and recommend policy or procedural changes, if needed.

## Methods

Crash rates for all drivers referred to DMV for a medical condition in the 2007 calendar year were evaluated. Only those drivers whose hearing resulted in monitoring by Driver Safety were included. These drivers were stratified into groups based on corresponding physical and mental (P&M) designation codes (alcohol, drug addiction, lack of skills, lapses of consciousness, mental condition, and physical condition). A sample of the general population of drivers who were not being monitored by the Driver Safety Branch for a medical condition was used as a comparison group. A second comparison group was comprised of male drivers under the age of 25; this group is known to have a high rate of crashes (Brar & Rickard, 2013).

Variables of interest included the number of crashes in the two years prior to first contact with the Driver Safety Branch for the P&M group. For the comparison groups, a date which corresponded with a date in the P&M group was used. Additionally, the occurrence of a crash (regardless of the number of crashes) was calculated. Given differences in crash rates for age and sex, these variables were also taken into consideration.

## Results

The mean crash rate for the prior two years for each of the six P&M groups (16 to 49 crashes per 100 drivers) was higher than both the general population of drivers (7 crashes per 100 drivers) and the males under 25 group (10 crashes per 100 drivers). However, although still higher than the general population of drivers, there was a drop in the mean crash rates for drivers with a P&M designation of drug addiction, lapses of consciousness, and mental condition relative to what the crash rates for each of the groups were in prior DMV studies. When sex and age were taken into account, the likelihood of a crash occurring in each of the P&M groups increased as compared to prior studies relative to the general population of drivers. One interesting observation was that the number of individuals Driver Safety identified as needing additional monitoring as a result of a medical condition dropped dramatically between 1999 and 2007. Specifically, in 1999, 68% of P&M hearings resulted in additional monitoring, driving restrictions, suspension, or revocation. By 2007, this number had dropped to 24%.

## Conclusions and Recommendations

The current findings are similar to previous DMV studies; crash risk was higher for drivers with a P&M designation relative to the general population of drivers and males under the age of 25. However, drops in crash rates for drug addiction, lapses of consciousness, and mental condition were observed relative to prior DMV studies. In addition, the findings of the current study suggest that age may affect crash risk, particularly for drivers over the age of 70. Sex may also be a contributing factor for some P&M conditions. Based on these data, the reason for the drop in crash rates for the general population of drivers relative to prior research studies is unclear. One possible explanation is that advances in safety technology have reduced the number of fatal and injury crashes, which are more likely to be reported relative to property damage only (PDO) crashes.

The crash rates observed in the current study are likely an overestimation of the relative crash risk for drivers with these P&M conditions, as many referrals to Driver Safety are the result of a crash. In other words, it is likely that some unknown (but potentially large) number of persons with similar conditions have <u>not</u> been referred to the department, even though in many cases such reporting is technically required by law. Previous research has found that crash rates of drivers with epilepsy may not be higher than the general population of drivers (Beghi, Cornaggia, & RESt-1 group, 2002; Lossius, Kinge, & Nakken, 2010; McLachlan, Starreveld, & Lee, 2007), however the current study found that drivers with a lapse of consciousness designation code were almost three times more likely to crash relative to the general population of drivers. This increase may be the result of the inclusion of individuals with syncope, which prior research has shown is associated with an increase in crash rates (Huagui, Weitzel, Easley, Barrington, & Windle, 2000).

P&M designation codes are broad categories which encompass multiple medical conditions, which may also explain the difference in the current findings relative to other research studies (Beghi et al., 2002; Lossius et al., 2010; McLachlan et al., 2007). As such, the effects of a specific medical condition cannot be evaluated using this method. Medical diagnoses categorized under the physical condition designation are diverse, including such disorders as diabetes, cardiovascular disease, and musculoskeletal conditions. Each may be expressed quite differently with respect to their impact on safe driving. Thus, applying conclusions to all medical conditions within a P&M designation code may be inappropriate.

P&M codes are broad designations which do not allow for the evaluation of specific medical conditions. If a specific medical condition is no longer associated with an increase in crash risk, monitoring by Driver Safety may no longer be necessary. Given that each P&M case must be evaluated individually, this could substantially reduce the workload of Driver Safety hearing officers. To address this issue, an evaluation of data contained in Confidential Morbidity Reports (CMR), which identify the specific medical diagnosis, would be necessary.

Additional research is necessary to better understand the effect of medical conditions on traffic safety. The effect on traffic safety of the reduction in the number of individuals whose hearing resulted in a P&M designation code in 2007 relative to 1999 has not been empirically evaluated. It is important to determine the crash risk of drivers whose hearing resulted in no action. If Driver Safety hearing officers are accurately identifying individuals who are safe to drive, the post-hearing crash rates of these drivers should be lower than those who had an action taken against them, or comparable to the general population of drivers. Similarly, it is unknown if restrictions, suspensions, or revocation actions reduce crash rates for drivers with a P&M designation. While the efficacy of Driver Safety procedures is important, evaluation of these procedures has only been conducted once (Janke et al., 1978) and is in need of reevaluation. A clearer understanding of the efficacy of current procedures may lead to more efficient approaches to identifying the appropriate action, potentially improving traffic safety and reducing the workload of Driver Safety hearing officers.

Overall, while the findings from the current study provide an overview of the effect of medical conditions on driving ability, more detailed evaluation is necessary to fully assess these associations. Future research should evaluate the effect of the decreased number of drivers whose hearing resulting in Driver Safety monitoring. The crash rates associated with specific medical condition should also be examined, as well as the efficacy of Driver Safety procedures related to P&M hearings. The findings of these studies may result in recommendations regarding modifications to Driver Safety policies and procedures, and potentially reduce the workload of Driver Safety hearing officers.

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# BACKGROUND

Drivers with medical conditions known to affect the ability to drive safely tend to crash more frequently relative to the general population of drivers. Commonly identified medical conditions include epilepsy, syncope, dementia/Alzheimer's Disease, diabetes, and sleep disorders (Marshall & Man-Son-Hing, 2011). Among these medical conditions, those who have lapses of consciousness (e.g., epilepsy and syncope) have historically had the highest rates of contact with the California Department of Motor Vehicles (DMV) Driver Safety Branch (Mitchell & Gebers, 2001). This is likely, in part, a result of the mandatory reporting law in place since 1939 requiring physicians to report patients who have experienced a lapse in consciousness (California Health and Safety Code [CHSC] §103900). More recently, there has been an increase in the number of drivers who have contact with the DMV Driver Safety Branch due to dementia and Alzheimer's Disease (Janke, 2001). While these conditions have also been required to be reported to DMV since 1988 (CHSC §103900), the increase in referrals is greater than would be expected by population growth alone. One factor that likely contributes to this change is the proportional increase of drivers over age 65, which is expected to continue over the next decade (Camp, 2013). The purpose of the current study is to evaluate the crash risk for drivers with medical conditions which may affect their ability to drive safely. Additionally, crash rates will be compared to previous DMV findings evaluating changes in crash rates over time. Below is a brief review of some common medical conditions that may affect one's ability to drive safely.

## Epilepsy

Epilepsy is defined as having two or more seizures (abnormal neuronal electrical discharges) that affects normal brain functioning (National Institute of Neurological Diseases and Stroke [NINDS], 2015). It is estimated that 48 in 100,000 have epilepsy (NINDS, 2015). Seizures manifest themselves in several ways depending on the region of the brain affected. While some seizures impair consciousness, others do not. Seizures may lead to strange sensations, emotions, or changes in behavior. Seizures are identified in two broad categories: partial seizures (which only occur in a localized region of the brain) or generalized seizures (which occur throughout the entire brain). While some individuals may experience an aura, an abnormal sensation prior to the onset of the seizure, many do not and may lose consciousness without warning. This is the most concerning aspect of the disorder as it relates to safe driving. However, it is not the only symptom that can affect driving ability. After a seizure has ended, individuals may experience extreme fatigue or disorientation for several hours. Side effects of anti-seizure medications, such as sedation, may also affect the ability to drive safely. However, the focus of this document will be on the disorder, as the effects of medications on driving ability are complex and fall outside the scope of this project.

Research has found that individuals with epilepsy have higher crash rates than the general population of drivers (Classen, Crizzle, Winter, Silver & Eisenchenk, 2012; Janke, 1993; Mitchell & Gebers, 2001). Based on data from DMV records, individuals with lapses of consciousness are about twice as likely to crash relative to the population of California drivers (Janke, 1993). Hansotia and Broste (1991) conducted a retrospective population based study including over 30,000 individuals and found that individuals diagnosed with epilepsy had a slightly elevated risk of a motor vehicle crash. However, they did not believe that the rates were sufficient to warrant driving restrictions. One possible explanation for the differences observed in DMV studies (Janke, 1993; Mitchell & Gebers, 2001) relative to Hansotia and Broste (1991) is that DMV studies include multiple medical conditions which may result in a lapse in consciousness, whereas Hansotia and Broste only included individuals with epilepsy. Individuals diagnosed with syncope, which also result in a lapse of consciousness designation, have higher crash rates relative to individuals with epilepsy (Hansotia & Broste, 1991).

## Syncope

Syncope is a clinical manifestation of a loss of consciousness and postural body tone, and is sometimes colloquially referred to as fainting. After the event, individuals typically make a complete recovery without any long term effects (Sorajja et al., 2009). The most common type of syncope is neurally mediated syncope, which results from a drop in blood pressure leading to a reduction of oxygen transported to the brain. Many individuals experience prodromal symptoms, including lightheadedness, dizziness, and a warm sensation (American Heart Association, 2015). Syncope may also occur as a result of cardiac arrhythmia, heat exhaustion, dehydration, pain, and sudden changes in body position. Sorajja and colleagues (2009) found that 12% of patients experienced a second syncopal episode within six months.

Given the sudden lapse of consciousness associated with syncope and the potential risk of a second episode, driving safety is an important concern. MacMahon, O’Neill, & Kenny (1996) found that this is not always addressed by attending physicians. Individuals who had been referred to a syncope clinic were interviewed after their appointment. Of those individuals who were driving, only 13% were asked or informed by their physician about potential driving risks. Twelve percent had reported experiencing symptoms while driving, some resulting in crashes.

These findings are similar to a study which found that 9% of patients at a syncope clinic had one or more episodes while driving (Huagui et al., 2000). Of these individuals, 30% resulted in a crash. The recurrence of syncope episodes was not different between the drivers and non-drivers at 6 and 12 month follow-ups, suggesting that the decision to drive was not related to the frequency of syncope episodes. Overall, these findings support the notion that individuals diagnosed with syncope are at greater risk of crashes than otherwise healthy individuals, increasing the risk of injury or death to themselves or other road users.

## Dementia/Alzheimer's Disease

Another common referral to the Driver Safety Branch is dementia, including Alzheimer's Disease. Dementia is a neurodegenerative condition resulting in cognitive impairments that progress over time (Man-Son-Hing, Marshall, Molnar, & Wilson, 2007). The most distinctive characteristic is memory loss. Other symptoms of dementia include language difficulty, time disorientation, poor judgment, and difficulty thinking abstractly. As the condition progresses, individuals may have difficulty completing daily activities, and experience avolition and changes in mood and personality. Alzheimer's Disease is the most common form of dementia, and is characterized by the development of beta-amyloid plaque and neurofibrillary tangles (Hardy & Higgins, 1992). Beta-amyloid plaque is a protein that the body normally produces and breaks down; individuals with Alzheimer's Disease are unable to break down the plaque, resulting in a build-up between neuronal cells. Neurofibrillary tangles are comprised of a protein known as Tau, which develops within the neuron and ultimately leads to neuronal death. Both of these factors contribute to brain atrophy observed in patients with Alzheimer's Disease.

Man-Son-Hing and colleagues (2007) conducted a systematic review of 23 separate studies evaluating crash risk for drivers diagnosed with dementia and found elevated levels of crash risk relative to the general population of drivers. Individuals with mild cognitive impairments, a precursor to dementia, demonstrated non-detrimental errors in their driving, but their overall ability to drive remained intact (Wadley et al., 2009). Given the decline in cognitive skills and corresponding decline in driving ability, researchers have attempted to identify standardized cognitive measures related to driving ability in this population (Fitten, et al. 1995; Manning, Davis, Papandonatos, & Orr, 2014; Molnar, Patel, Marshall, Man-Son-Hing, & Wilson, 2006; Rapoport et al., 2013). The findings from these studies are mixed, in part due to the type of cognitive task employed. Correlations between performance on standardized cognitive measures and driving skills do not show robust relationships (Molnar et al., 2006). Overall, while increased crash rates are consistently observed in drivers with dementia, standardized measures of cognitive abilities are of limited use in helping licensing agencies and medical personnel determine the driving ability of an individual diagnosed with dementia.

## Diabetes

Diabetes is a common medical condition; approximately 9.3% of people in the United States have been diagnosed with diabetes (Centers for Disease Control and Prevention [CDC], n.d.) It is related to abnormally high blood glucose levels (CDC, n.d.). Glucose is the primary source of the body's energy and is transported to cells for use via insulin (National Institute of Diabetes and Digestive and Kidney Diseases [NIDDKD], 2013). When there is insufficient insulin, or it does not function properly, glucose is not transported to the cells for use, leading to increased glucose in the blood. Over time, this can lead to additional health problems, including problems with the heart, kidneys, eyes, hands, and feet. Individuals may also develop hypoglycemia, which is a significant decrease in blood glucose levels. This occurs as a result of not eating for an extended period of time or eating an improper diet. Individuals who control their diabetes with insulin injections or medications alone have greater difficulty with stabilizing their glucose levels after a meal relative to those who also include a healthy diet and exercise regimen as part of their treatment.

Two forms of diabetes are type 1 and type 2. Type 1 diabetes typically develops as a result of the immune system attacking the cells which produce insulin. It is most commonly diagnosed in younger individuals. The most common form of treatment for type 1 diabetes is insulin injections. Type 2 diabetes can occur at any age but it is most commonly diagnosed in individuals who are middle-age and older, overweight, and maintain a sedentary lifestyle. With type 2 diabetes, insulin does not properly carry glucose to the cells, leading to an increase in blood glucose levels. The most common form of treatment for these individuals is oral medication, but insulin can also be used as a form of treatment.

Four symptoms associated with diabetes which may impair driving include hyper- or hypoglycemia, diabetic retinopathy, and peripheral neuropathy (Stork, Van Haeften, & Veneman, 2006). Both hyper- and hypoglycemia can lead to cognitive impairments and lapses of consciousness during an episode. Cognitive impairments can include decreased attention, memory impairments, slowing of information processing, motor speed, and decision making (Kodl & Seaquist, 2008). However, these impairments are more pronounced during a hypoglycemic event relative to a hyperglycemic event (Ryan, 1997). Type 1 diabetic drivers report more crashes and hypoglycemic episodes relative to drivers with type 2 diabetes (Cox et al., 2003), although the difference is not related to treatment. Cox and colleagues (2003) found that when individuals with type 2 diabetes receive insulin as their primary treatment their crash rates are comparable to the general population of drivers. Diabetic retinopathy is caused by damage to the blood vessels in the retina (American Optometric Association, 2015) which can lead to changes in vision. Symptoms of diabetic retinopathy include blurred vision, seeing spots or having a dark spot in one's field of vision, and impaired night vision. In the long term, this damage can lead to loss of photoreceptors in the retina, resulting in blindness. The symptoms of peripheral neuropathy can include burning pain, numbness, sensory loss, and decrease or loss of ankle reflexes (Boulton, 2005). When the neuropathy occurs in the right foot, this may lead to difficulty using the brake and gas pedals.

## Sleep Disorders

Individuals with sleep disorders are at increased risk of an automobile crash relative to the general population of drivers (Inoue & Komada, 2014). Sleep disorders can result in sleep deprivation, daytime sleepiness, and fatigue, all of which impair attention and reaction time. Two common sleep disorders known to affect safe driving are obstructive sleep apnea and narcolepsy.

Obstructive sleep apnea is the repeated cessation of breathing during sleep, which may lead to hypoxemia. Rates of sleep apnea vary greatly based on age and sex, ranging from 3% to 17% of the population of individuals over the age of 30 (National Heart, Lung, and Blood Institute [NHLBI], 2011). In some cases, individuals may experience hundreds of episodes per night. Frequently, individuals will wake up when they stop breathing. The result of the repeated disruption of sleep includes daytime sleepiness and attention problems. Obstructive sleep apnea is the most common form of sleep apnea and occurs as a result of the airway collapsing. The most frequent treatment for obstructive sleep apnea is the use of Continuous Positive Airway Pressure (CPAP). A CPAP works by providing continuous airflow into a mask that covers the individual's mouth and nose (NHLBI, 2011). The mild pressure of the air flow prevents the airway from collapsing.

Research has consistently documented increased crash rates in individuals diagnosed with sleep apnea (Ellen et al., 2006; Tregear, Reston, Schoelles, & Phillps, 2010). Ellen and colleagues (2006) completed a meta-analysis evaluating the relationship between sleep apnea and safe driving. In studies which only included noncommercial drivers, 85% found increased crash rates for individuals diagnosed with narcolepsy (OR ranging from 1.3 – 7.2). In addition, findings suggest that the use of a CPAP reduced crash rates and improved driver performance as early as the second day after use (Tregear et al., 2010), and driving performance on a simulator was equivalent to controls after seven days of use. These findings suggest that while sleep apnea can increase crash risk, consistent adherence to treatment can reduce that risk to levels comparable to the general population of drivers.

A second sleep disorder known to affect driving is narcolepsy. Narcolepsy affects approximately 1 in 3,000 people in the United States (National Institute of Neurological Diseases and Stroke [NINDS], 2016) and is characterized by recurrent changes in brain wave activity, specifically the emergence of REM sleep during daily routines (Inoue & Komada, 2014). REM sleep may be triggered by stress, intense emotions, or there may be no apparent trigger. Common symptoms associated with narcolepsy include daytime sleepiness, fatigue, and episodes of REM sleep. Individuals may also experience cataplexy (sudden loss of muscle tone or muscle weakness), sleep paralysis (paralysis that occurs when a person is entering REM sleep but the individual is fully conscious), and hypnogogic hallucinations (hallucinations that occur at the onset of sleep). A common treatment for narcolepsy is stimulants, such as Methylphenidate and Methylamphetamine, which is usually prescribed to treat Attention Deficit Disorder. This medication does not treat the condition, but helps to alleviate symptoms.

Daytime sleepiness is frequently reported in individuals diagnosed with narcolepsy, and tends to be more pronounced relative to individuals diagnosed with sleep apnea. Research has distinguished a difference between daytime sleepiness and fatigue (Droogleever-Fortuyn et al., 2012). Daytime sleepiness was defined as the inability to stay awake and alert during daily activities, whereas fatigue is a feeling of exhaustion which is not relieved by sleep. Individuals who were prescribed stimulants were more likely to report fatigue relative to daytime sleepiness. They also found fatigue was associated with greater functional impairments relative to daytime sleepiness.

Driver sleepiness accounts for 1% - 3% of all automobile crashes, (Lyznicki, Doege, Davis, & Williams, 1998), and individuals with narcolepsy are at an even greater risk. Previous research found that 55% of individuals with narcolepsy reported experiencing an automobile crash or a near miss in the past five years (Ozakiet et al., 2008). Phillip et al. (2013) evaluated driving performance in individuals diagnosed with narcolepsy while taking modafinil (a drug which reduces daytime sleepiness), a placebo, and a control group with no sleep disorders. In a double blind study, participants' driving score was based on the number of times that the car crossed the lane lines. While individuals in the control group made fewer driving errors relative to individuals diagnosed with narcolepsy, individuals treated with modafinial made fewer driving errors relative to the placebo group. Other research has found that individuals with narcolepsy taking a stimulant (e.g., methamphetamine) during a simulated driving task performed equivalent to control participants who had not been diagnosed with narcolepsy (Mitler, Hajdukovic, & Erman, 1993). Like individuals with obstructive sleep apnea, effective treatment of the symptoms appears to significantly reduce crash risk in this population.

## Current Study

As the demographics of California's driving population continue to change and advancements are made in treatments for medical conditions, it is important to periodically re-assess the crash risks of drivers who have medical conditions that can affect their ability to drive safely. The most recent evaluation of crash rates for this population was conducted over a decade ago (Mitchell & Gebers, 2001). During this time there have been significant advancements in the treatment of medical conditions, including pharmaceutical treatments. For example, since 2001, new drugs such as Rivastigmine and Memantine have been approved by the Food and Drug Administration (FDA) to reduce the cognitive and behavioral symptoms associated with Alzheimer's Disease. These newer medications may minimize symptoms better than older drugs, have fewer side effects, and reduce potential driving impairments. These treatments may also increase the length of time that an individual is able to continue driving safely.

Along a similar vein, there has been an increase in the number of drivers reaching retirement age during the past decade which corresponds to an increase in the number of drivers with age-related medical conditions. In the past 10 years, the average life span in the United States has increased 2.1 years for men and 1.8 years for women (Arias, 2015) leading to an increase in the number of senior drivers. Given this, the risk models developed by Mitchell & Gebers (2001) are in need of updating.

While medical treatments are effective overall, one must be cognizant that there may be variability in the effectiveness of these treatments, as well as potential side effects, at the individual level. As such, it may be necessary for DMV to continue to track individuals with medical conditions that may affect their ability to drive safely. This information is intended to help DMV better understand the potential safety risks, and recommend policy or procedural changes if needed.

## Goals and Benefits

The goal of the current study was to evaluate the crash risks of drivers referred to California DMV for Physical and Mental conditions (as identified by P&M codes on the Driver Record Master) that may affect their ability to drive safely. Additionally, these data were compared to the findings of previous studies conducted by DMV's Research and Development Branch to evaluate potential changes in crash rates over time. This investigation was important because it allows DMV to evaluate how trends in population demographics and treatment options over the past decade may have affected crash risks among drivers with different P&M codes.

## Research Questions

1. For individuals identified as having a physical or medical condition (P&M code), what are the crash rates for two years prior to their first contact with Driver Safety, relative to the general driving population?

2. Have these rates changed over time compared to findings from previous DMV studies?

# METHOD

## Data Source

All individuals identified in the Driver Safety Branch database as having contact with the department for a physical or medical condition between January 1, 2006 and December 31, 2010 were initially included in the analysis (n = 384,037). Driver record data for two years prior to their first contact with Driver Safety (reference date) was extracted from the Driver Record Master file. In addition, hearing data from the Driver Safety database was also obtained.

All X records were excluded from the analysis (n = 18,428, or 4.8% of the sample). Additionally, anyone under the age of 20 at the date of first contact with Driver Safety was excluded to minimize any potential effects of restrictions imposed by the Graduated Driver's License requirement. Individuals over the age of 99 were also excluded from the sample as they were likely not representative of the driving population. These age requirements resulted in a reduction of 5,376 individuals, or 1.4% of the sample. Finally, some of the driver license numbers obtained by Driver Safety did not correspond with the information in the Driver Record Master (DRM) file; these data were also excluded (n = 1,509, or 0.39% of the sample). This reduced the total sample by 25,313 (6.6% of the sample) for a total sample size of 358,724.

To maintain consistency with previous studies, only one year of data for the P&M group was included in these analyses: the 2007 calendar year. To compare crash rates for drivers with P&M codes relative to the general population of drivers, only drivers from the sample who were currently being monitored for a physical or mental condition by Driver Safety at the date of data extraction (February 26, 2015), as indicated by the presence of a P&M code on their driving record, were included in this analysis (n = 30,869).

This sample was stratified based on the broad P&M designations (i.e., alcohol-related, drug addiction, lack of skill, lapses of consciousness, mental conditions, progressive physical conditions, and static physical conditions). There have been some minor changes to the P&M categories since Mitchell and Gebers (2001) completed the previous analysis. Specifically, "lack of knowledge or skill" is now referred to as "lack of skill" and "physical condition" has been divided into "progressive physical condition" and "static physical condition." To maintain consistency with these previous studies, only crash rates for two years prior to their first contact with Driver Safety was evaluated (not including the date of contact). When comparing the data over time, it is important to note that in addition to reflecting changes in population data and treatment options, these changes in crash rates may also represent enforcement differences, statute changes (e.g., in financial responsibility laws), or improvements in automotive technology.

A second sample of 500,000 drivers was randomly selected from a 10% sample of California drivers to serve as a comparison group. Any driver with a P&M code on their record at the date of extraction (September 8, 2015) was removed from the sample (n = 12,727 or 2.5% of the sample). As with the P&M sample, all X records (n = 59,038 or 11.8%) were excluded. Individuals under the age of 20 and over 99 were also excluded from the study (n = 48,638 or 9.7% of the sample). Any individual who was identified as being deceased (n =33,536 or 6.7%) was also removed. This resulted in a total sample size of 346,061 (69.2% of the original sample) of drivers in the comparison group. These drivers were randomly assigned a reference date during the 2007 calendar year to correspond with the reference dates for the P&M group.

Consistent with previous DMV studies (Janke, 1993; Mitchell & Gebers, 2001) a second comparison group was comprised of male drivers under the age of 25 who have a higher crash rate relative to any other group (Brar & Rickard, 2013). A second random sample of 250,000 California drivers was obtained from the 10% sample. All males between the ages of 18 and 24 were extracted from this sample, leaving a total of 11,841 drivers. Any duplicate cases between this sample and the random sample of the general driving population were removed. Additionally, date of licensure was used to ensure that the drivers had been licensed for the two years prior to the reference date. Using the same procedure as the sample of drivers from the general population, cases that did not meet the study criteria were excluded from further analyses. This resulted in the removal of 2,387 cases (20.2%) for a total sample size of 9,454. As with the random sample of the general driving population, drivers in the under-25 age group were randomly assigned a reference date during the 2007 calendar year to correspond with the references dates for the P&M group.

## Analysis Method

This section provides an overview of the statistical analyses that were used in the parameter estimation process. Some details are reserved for the results section as context is necessary to provide a better understanding. All analyses were conducted using SAS version 9.3. For the current study, sex and age were entered into the logistic regression models as covariates, consistent with previous Departmental research (Janke, 1993; Mitchell & Gebers, 2001). This approach is advantageous compared to a standardized or matching procedure in that it allows for the evaluation of these covariates, as well as any potential interaction effects. The following analyses were conducted:

1. Participant demographics for each of the P&M groups and the comparison group.

2. Descriptive driving statistics for each of the P&M groups and the comparison group.

3. Logistic regression of main effects to assess the likelihood of accident involvement based on group, not adjusted for sex or age.

4. Logistic regression of main effects to assess the likelihood of accident involvement based on group with sex and age entered as covariates.

5. Logistic regression of main effects and interactions between group, sex, and age to assess the likelihood of accident involvement based on group.

**Variables**. Variables were obtained from the DRM and Driver Safety database. Primary variables of interest included age which was grouped in ten year intervals, and sex, which was coded dichotomously (male = 1 and female = 2). Current P&M codes were obtained and dummy coded for later analysis. Due to the structure of the driver record, only one P&M code can be present at a given time. The codes include the following categories: Alcohol (A), Drugs (D), Lack of Skill (K), Lapse of Consciousness (L), Mental Condition (M), Progressive Physical Condition (P), and Static Physical Condition (S). For the purposes of comparing present findings to previously published reports, Progressive and Static Physical Conditions were combined. Occurrence of a crash (0 = no crash, 1 = one or more crashes) during the two years prior to first contact with the Driver Safety Branch was the dependent variable.

# RESULTS

The following analyses were conducted to determine the crash rates of individuals identified as having a medical condition which may affect their ability to drive safely. Additionally, these findings were compared to the findings of prior DMV research studies. It is important to note that comparisons between the current findings and those from previous research studies are limited to the data available in previous reports. Specifically, early studies (Janke, 1993; Janke et al., 1978) used a rudimentary calculation to control for sex and age, whereas Mitchell and Gebers (2001) included these variables as covariates into the regression equation which allowed the specific effects to be evaluated. While all reports provide descriptive statistic on crash rates, demographic information and logistic regression analyses were only reported in Mitchell and Gebers.

## Participant Demographics

Demographic information was examined for each of the P&M conditions and the comparison groups (Table 1). Given the small number of individuals identified as having a static physical condition, they were combined with the progressive physical condition. Prior to combining the two groups, means, standard deviations, and 95% confidence intervals for crash rates were compared to ensure that the groups were similar. Mean age and proportion female in each group were also similar. Given the similarities, the two groups were combined for all analyses.

Table 1

Number of participants, mean age and standard deviation, and the percent female for each P&M group and the random sample of California Drivers in 2007

| Risk Group | *n* | Mean Age | SD | % Female |
|---|---|---|---|---|
| Alcohol | 620 | 48.0 | 15.4 | 16.0 |
| Drugs | 873 | 39.8 | 12.1 | 25.3 |
| Lack of skill | 4,772 | 76.6 | 14.9 | 46.4 |
| Lapses of consciousness | 8,913 | 53.3 | 20.0 | 41.2 |
| Mental condition | 7,876 | 70.8 | 17.8 | 44.3 |
| Physical condition | 7,815 | 67.4 | 16.7 | 37.4 |
| Random driver sample | 346,061 | 45.2 | 16.0 | 49.0 |
| Random sample-males under 25 | 9,454 | 21.1 | 1.7 | 0.0 |

CA DMV studies prior to Mitchell and Gebers (2001) did not include demographic data; as such, the data from the current study can only be compared to data obtained in 2000. Consistent with Mitchell and Gebers (see Table A), there were more males than females in all of the P&M conditions. The pattern of age differences also appeared similar, the average age for drugs was much lower, and the lack of skill, physical and mental condition referrals were older relative to the average age of the comparison group. The random driver sample for this study is slightly older (almost 2 years) relative to the sample in Mitchell and Gebers (2001). However, the average age of the P&M-referred drivers increased between 3.4 to 9.1 years, depending on the category. Given this difference in age shift across categories, the analyses provide age-adjusted crash risk estimates.

One of the largest apparent differences between the current findings (n = 30,869) and Mitchell and Gebers's (2001) results (n = 68,952) is the total number of individuals with a P&M designation. One hypothesis for this difference was the result of a methodological difference relative to actual changes. Specifically, the current study only evaluated crash rates for individuals whose hearing with Driver Safety resulted in a P&M code indicating a need for monitoring, whereas Mitchell and Gebers evaluated crash rates for all individuals who had contact with Driver Safety, regardless of the outcome. Other studies used the same methodology as the current study for data collection (Janke et al., 1978 [n = 20,464]; Janke, 1993 [n = 52,986]), and the data indicate that there appeared to be a linear increase in the number of individuals whose hearing resulted in a P&M code for further monitoring until sometime after 2000. A significant decrease was observed in the current study. A comparison of the number of individuals referred to Driver Safety for a hearing relative to those who which resulted in monitoring by Driver Safety was significantly different between 2000 (Mitchell & Gebers, 2001) and 2007 (reported in the current study). Based on data from the Driver Safety database, in 2000, 68% of drivers referred to Driver Safety received a P&M code, indicating further monitoring was necessary, whereas in 2007, only 24% were determined to need further monitoring.

## Mean Crash Rates

Mean crash rates for each of the P&M conditions and the comparison groups were calculated (Table 2). Of the P&M conditions, those drivers referred for lack of skill had the highest two year crash rate with almost 49 crashes per 100 drivers. These findings are consistent with previous findings (Janke et al., 1978; Mitchell & Gebers, 2001). Mean crash rates for Mitchell and Gebers and Janke et al., can be found in Appendices A and B, respectively. As with prior

CA DMV studies, crash rates for the mental condition were the lowest of all P&M conditions. These crash rates have continued to drop over time when compared to previous DMV studies with approximately 16 crashes per 100 drivers. Comparatively, crash rates in 1975 for these drivers were 26 crashes for every 100 drivers. Other notable changes between 2000 (Mitchell & Gebers, 2001) and the present include an increase in crash rates for individuals referred for an alcohol condition (26 vs. 29 crashes per 100 drivers). Additionally, a drop in crash rates for individuals with lapses of consciousness (22 vs. 19 crashes per 100 drivers) and drug addiction (34 vs. 30 crashes per 100 drivers) was also observed.

The crash rates for both comparison groups were lower than any of the P&M conditions. Relative to Mitchell and Gebers (2001), crash rates for both the random sample of California drivers (10 vs. 7 crashes per 100 drivers) and males under the age of 25 (16 vs. 10 crashes per 100 drivers) have decreased.

Table 2

Prior 2-year total crash rates per 100 drivers for each group

| Risk group | Mean crash rate | SE |
|---|---|---|
| Alcohol | 29 | 2.3 |
| Drugs | 30 | 2.1 |
| Lack of skill | 49 | 1.0 |
| Lapses of consciousness | 19 | 0.5 |
| Mental condition | 16 | 0.5 |
| Physical condition | 23 | 0.6 |
| Males under 25 years | 10 | 0.4 |
| Random sample | 7 | 0.1 |

## Logistic Regression

Logistic regressions were conducted to evaluate crash risk for individuals with P&M conditions relative to a sample of California drivers for the 2007 calendar year. A sample of males under the age of 25 was also compared to the sample of drivers from the general population in the first model where age and sex were not controlled. These data are based on the occurrence of a crash for the two years prior to their first contact with Driver Safety Branch. Group was entered into the model; the regression coefficient reflects the likelihood of a crash occurring relative to the referent group.

Using the Wald Chi-Square statistic, results presented in Table 3 show a statistically significant model relative to the constant-only model when group was the only variable entered into the equation, $\chi^2(7, N = 385{,}583) = 8{,}453.69$, $p < .001$. Odds ratios (see Figure 1) reflect an overall pattern of crash rates among P&M conditions similar to prior DMV studies, with the lack of skill group having the highest crash rates relative to the population and the mental condition group having the lowest crash risk.

Table 3

Logistic regression evaluating crash rates by P&M group who had contact with Driver Safety Branch in 2007, relative to the crash rates of the general population of California drivers

| | | | | | | | 95% CI for odds ratio | |
|---|---|---|---|---|---|---|---|---|
| Predictors | $\beta$ | *SE* | Wald $\chi^2$ | *df* | *p* | Odds | Lower | Upper |
| Intercept | -2.70 | 0.007 | 148,608.58 | 1 | <0.001 | | | |
| Alcohol | 1.56 | 0.090 | 272.89 | 1 | <0.001 | 4.73 | 3.93 | 5.69 |
| Drugs | 1.48 | 0.810 | 332.05 | 1 | <0.001 | 4.37 | 3.73 | 5.13 |
| Lack of skill | 2.27 | 0.030 | 5,551.95 | 1 | <0.001 | 9.66 | 9.10 | 10.25 |
| Lapses of consciousness | 0.99 | 0.030 | 1,087.29 | 1 | <0.001 | 2.70 | 2.55 | 2.87 |
| Mental condition | 0.77 | 0.035 | 495.13 | 1 | <0.001 | 2.16 | 2.02 | 2.31 |
| Physical condition | 1.25 | 0.030 | 1,785.31 | 1 | <0.001 | 3.50 | 3.29 | 3.70 |
| Males under 25 years old | 0.42 | 0.036 | 135.22 | 1 | <0.001 | 1.52 | 1.42 | 1.63 |

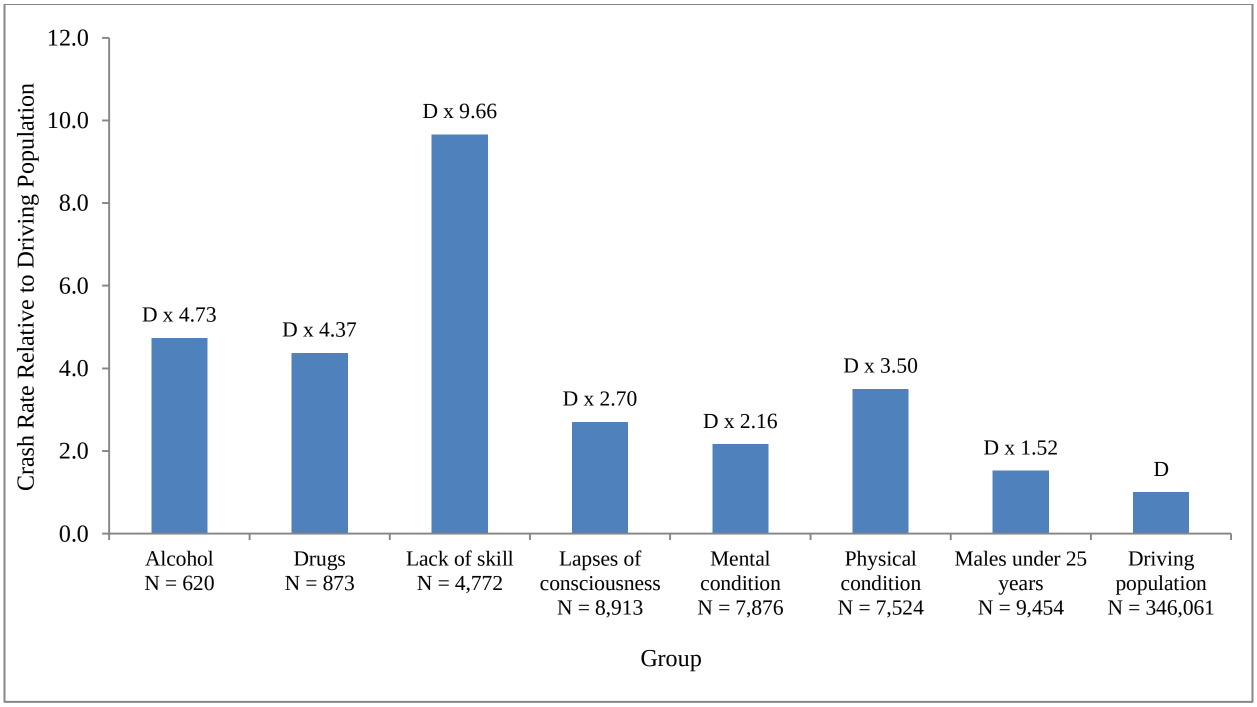


*Figure 1*. Prior 2-year crash rate by group for all drivers with P&M contact in 2007, where D represents the comparison sample for the general population of California drivers.

One important consideration when evaluating the crash risk of drivers with physical and mental conditions is the demographic differences between these drivers relative to the general population of drivers. Specifically, the average age and distribution of sex tend to be different. For example, the average age of individuals in the lack of skill group is higher than that of the general population of drivers (age 76.6 vs. age 45.2). In the alcohol group, only 16% of drivers are female relative to 49% of the general population. Given these group differences, a logistic regression was conducted to evaluate crash rates for individuals with P&M conditions relative to the driving population after controlling for sex and age. The procedure for the logistic regression was similar to the first, with a few exceptions. In this analysis, sex and age were entered into the equation as covariates prior to P&M group being entered. Additionally, males under the age of 25 were not included in these analyses.

The Wald Chi Square was significant when compared to the constant-only model, $\chi^2(12, N = 376{,}134) = 9{,}475.12$, $p < .001$ (Table 4). The odds ratios for all groups were generally higher than those found in previous DMV studies (Appendices A and B). Although the parameter estimates for sex and age are not of direct interest for the present analyses, it is worth noting that they are consistent with prior findings: men generally have a higher crash risk than women, the youngest drivers (aged 20-29) have an elevated crash risk relative to those in their 40s, and older drivers (aged 60-69 and 70+) have lower crash risk. These estimates should be interpreted with caution, as they do not take into account differences in exposure.

Table 4

Logistic regression evaluating crash rates by P&M group who had contact with Driver Safety Branch in 2007, relative to the crash rates of the general population of California drivers when controlling for sex and age

| | | | | | | | 95% CI for odds ratio | |
|---|---|---|---|---|---|---|---|---|
| Predictors | β | *SE* | Wald $\chi^2$ test | *df* | *p* | Odds ratio | Lower | Upper |
| Intercept | -2.70 | 0.007 | 148,608.58 | 1 | <0.001 | | | |
| Sex (referent group = M) | -0.17 | 0.013 | 171.14 | 1 | <0.001 | 0.85 | 0.83 | 0.87 |
| Age (referent group = 40-49) | | | 1,030.79 | 5 | <0.001 | | | |
| 20-29 | 0.39 | 0.020 | 400.54 | 1 | <0.001 | 1.48 | 1.43 | 1.54 |
| 30-39 | 0.01 | 0.020 | 0.18 | 1 | 0.675 | 1.01 | 0.97 | 1.05 |
| 50-59 | 0.00 | 0.021 | 0.03 | 1 | 0.873 | 1.00 | 0.96 | 1.04 |
| 60-69 | -0.13 | 0.025 | 25.98 | 1 | <0.001 | 0.88 | 0.84 | 0.92 |
| 70 + | -0.34 | 0.026 | 173.61 | 1 | <0.001 | 0.71 | 0.68 | 0.75 |
| Group | | | 7,766.34 | 6 | <0.001 | | | |
| Alcohol | 1.55 | 0.095 | 269.86 | 1 | <0.001 | 4.72 | 3.92 | 5.68 |
| Drugs | 1.39 | 0.081 | 293.41 | 1 | <0.001 | 4.03 | 3.43 | 4.72 |
| Lack of skill | 2.58 | 0.035 | 5,568.43 | 1 | <0.001 | 13.26 | 12.39 | 14.19 |
| Lapses of consciousness | 1.06 | 0.031 | 1,213.07 | 1 | <0.001 | 2.89 | 2.72 | 3.07 |
| Mental condition | 1.02 | 0.037 | 767.82 | 1 | <0.001 | 2.78 | 2.58 | 2.99 |
| Physical condition | 1.46 | 0.031 | 2,160.31 | 1 | <0.001 | 4.31 | 4.06 | 4.59 |

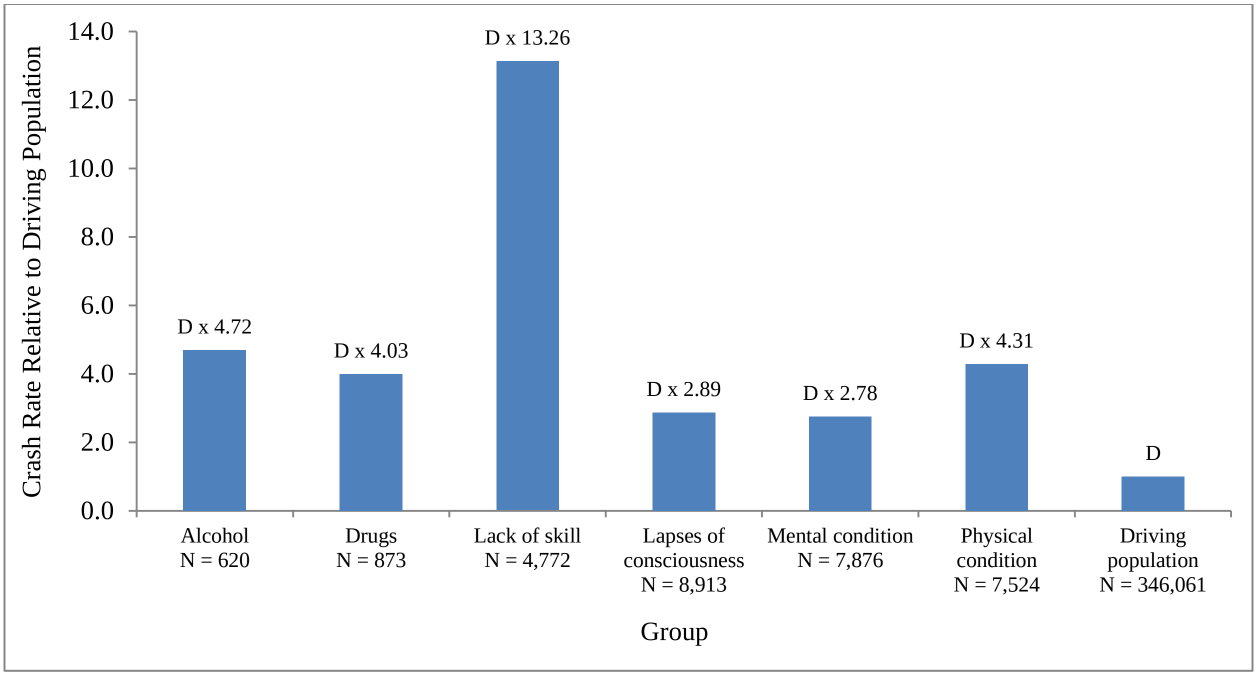


*Figure 2*. Prior 2-year crash rate by group after controlling for sex and age for all drivers with a P&M contact in 2007, where D represents the comparison sample representing the general population of California drivers.

Additional logistic regression analyses were conducted to test specific models developed a priori which included interaction terms. A summary of all models and corresponding significance values are reported in Table 5. Models A and B reflect the models previously reported in Tables 3 and 4. All five models were statistically significant with Model E being the best fitting model based on the Wald Chi-Square value. However, the three-way interaction included in Model E suggests that it did not contribute significantly to the fit of the model. The sex by age interaction in this model is the contributing factor which improved model fit relative to Model D. Given that the goal of the current study was to evaluate driving safety as it related to medical conditions, the model which best addressed this question was Model D; analyses for this model can be found in Table 6. Odds ratios and 95% confidence intervals for the interaction terms are available in Appendix D. For the interested reader, results of the logistic regression analysis for Model C is included in Appendix E. These findings are similar to Mitchell and Gebers (2001) with the exception that the three way interaction (Model E) was not significant in the current study. It is not clear from the present data why this latter difference was found.

Table 5

Summary of logistic regression model findings and Wald Chi-Square values for each model

| | Poisson Regression Models | | | | |
|---|---|---|---|---|---|
| Predictor Variable | A | B | C | D | E |
| Group | p = < .001 | p = < .001 | p = < .001 | p = < .001 | p = < .001 |
| Sex | | p = < .001 | p = < .001 | p = < .001 | p = < .001 |
| Age | | p = < .001 | p = < .001 | p = < .001 | p = < .001 |
| Sex X Group | | | p = < .001 | p = < .001 | p = < .05 |
| Age X Group | | | | p = < .001 | p = < .001 |
| Sex X Age | | | | | p = < .001 |
| Sex X Age X Group | | | | | p = < .291 |
| | $\chi2$ = 8453.69 | $\chi2$ = 9475.12 | $\chi2$ = 9521.12 | $\chi2$ = 9605.64 | $\chi2$ = 9670.26 |
| | df = 7 | df = 12 | df = 18 | df = 48 | df = 83 |
| | p = < .001 | p = < .001 | p = < .001 | p = < .001 | p = < .001 |

Table 6

Logistic regression analysis for Model D

| Predictors | β | *SE* | Wald $\chi^2$ test | *df* | *p* |
|---|---|---|---|---|---|
| Intercept | -2.65 | 0.016 | 26,996.28 | 1 | <0.001 |
| Sex (referent group = M) | -0.17 | 0.014 | 152.50 | 1 | <0.001 |
| Age (referent group = 40-49) | | | 1,150.82 | 5 | <0.001 |
| 20-29 | 0.40 | 0.020 | 391.57 | 1 | <0.001 |
| 30-39 | 0.00 | 0.020 | 0.00 | 1 | =0.977 |
| 50-59 | 0.00 | 0.023 | 0.02 | 1 | =0.903 |
| 60-69 | -0.12 | 0.028 | 18.43 | 1 | <0.001 |
| 70 + | -0.61 | 0.036 | 295.06 | 1 | <0.001 |
| Group | | | 641.65 | 6 | <0.001 |
| Alcohol | 1.60 | 0.178 | 81.12 | 1 | <0.001 |
| Drugs | 1.12 | 0.167 | 44.80 | 1 | <0.001 |
| Lack of skill | 2.00 | 0.173 | 134.08 | 1 | <0.001 |
| Lapses of consciousness | 0.99 | 0.073 | 185.35 | 1 | <0.001 |
| Mental condition | 0.85 | 0.129 | 43.86 | 1 | <0.001 |
| Physical condition | 1.40 | 0.098 | 206.70 | 1 | <0.001 |

Table 6 (cont.)

Logistic regression analysis for Model D

| Predictors | β | SE | Wald χ2 test | df | p |
|---|---|---|---|---|---|
| Group X Sex | | | 37.23 | 1 | <0.001 |
| Alcohol X Sex | 0.03 | 0.270 | 0.01 | 1 | =0.922 |
| Drugs X Sex | 0.65 | 0.179 | 13.03 | 1 | <0.001 |
| Lack of skill X Sex | 0.20 | 0.061 | 10.87 | 1 | <0.001 |
| Lapses of consciousness X Sex | -0.21 | 0.064 | 10.61 | 1 | <0.001 |
| Mental condition X Sex | 0.03 | 0.070 | 0.14 | 1 | =0.711 |
| Physical condition X Sex | 0.08 | 0.062 | 1.67 | 1 | =0.197 |
| Group X Age | | | 237.15 | 30 | <0.001 |
| Alcohol X 20-29 | -0.04 | 0.320 | 0.02 | 1 | =0.898 |
| Alcohol X 30-39 | -0.30 | 0.288 | 1.10 | 1 | =0.294 |
| Alcohol X 50-59 | -0.90 | 0.267 | 0.10 | 1 | =0.747 |
| Alcohol X 60-69 | 0.25 | 0.343 | 0.53 | 1 | =0.465 |
| Alcohol X 70+ | 0.09 | 0.363 | 0.06 | 1 | =0.814 |
| Drugs X 20-29 | 0.20 | 0.220 | 0.00 | 1 | =0.950 |
| Drugs X 30-39 | 0.12 | 0.235 | 0.26 | 1 | =0.611 |
| Drugs X 50-59 | 0.32 | 0.240 | 1.80 | 1 | =0.180 |
| Drugs X 60-69 | 0.04 | 0.450 | 0.01 | 1 | =0.928 |
| Drugs X 70+ | -0.31 | 1.070 | 0.08 | 1 | =0.771 |
| Lack of skill X 20-29 | -0.29 | 0.280 | 1.07 | 1 | =0.302 |
| Lack of skill X 30-39 | -0.29 | 0.278 | 1.07 | 1 | =0.302 |
| Lack of skill X 50-59 | -0.07 | 0.261 | 0.10 | 1 | =0.757 |
| Lack of skill X 60-69 | 0.24 | 0.202 | 1.43 | 1 | =0.232 |
| Lack of skill X 70+ | 0.87 | 0.177 | 24.12 | 1 | <0.001 |
| Lapses of consciousness X 20-29 | -0.17 | 0.105 | 2.71 | 1 | =0.100 |
| Lapses of consciousness X 30-39 | 0.31 | 0.103 | 9.27 | 1 | <0.01 |
| Lapses of consciousness X 50-59 | 0.14 | 0.101 | 1.95 | 1 | =0.163 |
| Lapses of consciousness X 60-69 | 0.20 | 0.115 | 3.17 | 1 | =0.075 |
| Lapses of consciousness X 70+ | 0.58 | 0.099 | 34.12 | 1 | <0.001 |
| Mental condition X 20-29 | -0.84 | 0.236 | 12.83 | 1 | <0.01 |
| Mental condition X 30-39 | -0.19 | 0.210 | 0.86 | 1 | =0.353 |
| Mental condition X 50-59 | -0.12 | 0.178 | 0.45 | 1 | =0.501 |
| Mental condition X 60-69 | -0.02 | 0.170 | 0.01 | 1 | =0.916 |
| Mental condition X 70+ | 0.59 | 0.136 | 18.39 | 1 | <0.001 |
| Physical condition X 20-29 | -0.29 | 0.191 | 2.27 | 1 | =0.132 |
| Physical condition X 30-39 | -0.17 | 0.180 | 0.90 | 1 | =0.343 |
| Physical condition X 50-59 | -0.01 | 0.118 | 0.00 | 1 | =0.953 |
| Physical condition X 60-69 | -0.10 | 0.120 | 0.69 | 1 | =0.407 |
| Physical condition X 70+ | 0.38 | 0.108 | 12.15 | 1 | <0.001 |

# DISCUSSION

The primary goal of the current study was to evaluate crash risks of individuals who have been identified by California DMV as having a physical or mental condition that may affect their ability to drive safely. These findings were compared to findings from previous DMV studies which investigated this population of drivers. These comparisons allowed for the evaluation of trends in crash rates among individuals with a P&M condition over time.

## Mean Crash Rates

The overall pattern of crash rates for P&M conditions were comparable to prior DMV studies; however there were some distinct differences. The reported crash rates for the general population of California drivers, as well as male drivers under the age of 25, were lower relative to previous findings (Mitchell & Gebers, 2001). This decline over time in crash rates is consistent with other recent studies (e.g., Brar & Rickard, 2013). One possible reason is the increase in safety technologies available in newer model cars. These technologies have likely resulted in fewer injury and fatal crashes, leading to fewer police-reported crashes. Property damage only (PDO) crashes are less likely to be reported to the authorities than are fatal/injury crashes. However, this reduction in crash rates was not observed in all of the P&M conditions. A decrease in mean crash rates for individuals with P&M designations of drugs, lapses of consciousness, and mental condition was observed, although not as significant as in either of the comparison groups. However, there was a small increase in the mean crash rates of drivers with alcohol, lack of skill, and physical condition codes. It is unclear why this increase was observed; the current analysis cannot determine causation. Future research should investigate whether these individuals were more likely to have multiple crashes on their record and also the type of crashes (e.g., fatal/injury versus PDO, at-fault versus not-at-fault).

## Relative Crash Risk for P&M Drivers

Odds ratios were calculated to evaluate the relative likelihood of an individual with a P&M condition crashing relative to the general driving population. The relative odds ratios from the current study were higher than those in the two previous departmental studies regardless of P&M designation code (Janke, 1993; Mitchell & Gebers, 2001). The increase in odds ratios may reflect methodological differences, wherein the current study only included individuals whose Driver Safety Hearing resulted in a P&M designation. When comparing these findings to odds ratios in 1973 (Janke et al., 1978), the relative likelihood of a crash occurring in all P&M conditions were lower in the current study, with the exception of the alcohol condition which was similar. It is possible that the increase in odds ratios may also reflect changes in law enforcement procedures. This could also potentially explain the increase in crash rates relative to the general population of drivers. This could be determined by examining the number of those individuals referred to the Driver Safety Branch by law enforcement as a result of a crash, relative to those that were not crash-related, and comparing the ratios to previous years.

Several models developed a priori were compared (see Table 5); it was determined that sex, age, P&M condition, and all interactions except the three-way interaction was the best fitting model (Model D). The sex of the driver appeared related to individuals with drugs, lack of skill, and lapse of consciousness codes. In the case of drugs and lack of skill, females exhibited increased relative crash risk compared to males in these P&M conditions. In the case of lapse of consciousness, males exhibited increased relative crash risk compared to females. No sex interactions were observed in the other P&M conditions. It is important to note that overall, the number of individuals with an alcohol or drug designation was low (alcohol = 620, drug = 873). These numbers are further reduced when they are separated by sex. Ideally, a minimum of 2,000 individuals per group (condition and sex) would be necessary to provide reliable evidence. Given the instability of the regression parameters, any interpretation for the findings for these two groups should be made with caution.

An evaluation of age as it relates to P&M condition revealed that age differences were observed in all P&M conditions, except for alcohol and drugs. In the lack of skill and physical condition categories, relative crash rates were higher for drivers aged 70 and older when compared with the referent group (aged 40-49). For drivers in the mental condition, drivers between the ages of 20 and 29 appeared to have lower relative crash rates, whereas those aged 70 and older had higher relative crash rates. Findings for the lapses of consciousness group were less clear. Drivers in this condition between the ages of 20 and 29 had lower relative crash rates. Whereas all other groups showed an increased relative crash risk, it was only statistically significant for those between the ages of 30 and 39 and those aged 70 years and older.

The interaction between P&M condition and age suggests that age may affect driving performance, particularly in drivers aged 70 and older. Additionally, there exists an interaction between P&M condition and sex, specifically with regards to drugs, lack of skill, and lapses of consciousness.. However, evidence directly relating to the medical condition and the extent to which it may affect driving (e.g., information contained in Confidential Morbidity Reports and the actual driving record) should be the focus of the decision by Driver Safety Hearing Officers. It is important to note that P&M codes provide a limited amount of information, and that specific diagnoses within each condition may vary. For example, it is likely that the majority of individuals aged 70 and older classified as having a mental condition have been diagnosed with dementia, whereas this diagnosis is not likely to be observed in the younger age groups. Younger drivers with a mental condition designation code are more likely to have a psychological disorder that may affect their ability to driver safely. Individuals diagnosed with dementia may be at greater risk of crashing relative to other mental conditions unrelated to age, which could explain why drivers 70 years and older was the only age group to show an increase crash risk relative to the reference group in the mental condition. However, without additional information this conclusion cannot be confirmed. Further research is also needed to explore the reasons behind the lack of a three-way interaction between age, sex, and condition, which was observed in Mitchell and Gebers (2001). Findings from the current study do not provide sufficient information to evaluate this difference.

## Limitations

One concern, particularly in older drivers, is related to comorbidity of medical conditions in drivers who are monitored by Driver Safety. When drivers have multiple medical conditions it is difficult to determine the effect of each medical condition independently, and whether there is an additive effect with multiple conditions. Similarly, side effects of medications may affect driving ability, confounding the effects of the underlying medical condition. These potential interactions are difficult to empirically evaluate, especially given the limited nature of what is available on the driver record, but must be taken into consideration.

A second consideration is that these crash rates are likely overestimates of the risk of persons with these conditions, given that many drivers are referred to Driver Safety by law enforcement as the result of a crash. The number of drivers monitored by Driver Safety is only a proportion of the number of individuals in the state with these medical conditions. Other drivers not being monitored have not come to the attention of DMV because they have not crashed, nor has anyone reported them as being potentially unsafe. In short, P&M referrals may not be "representative" of the population of drivers with these conditions. This affects, in particular, the "times-as-many" estimates–figures 1 and 2–since the comparison group is representative of the general population. That said, the fact that these persons were referred to DMV is *prima facie* evidence of potentially increased crash risk.

There is ample evidence to suggest that crash rates for individuals diagnosed with epilepsy are overestimated and may not be higher than the general population of drivers (Beghi et al., 2002; Lossius et al., 2010; McLachlan et al., 2007). Hansotia and Broste (1991) even suggested that diagnosis of epilepsy should not warrant driving restrictions. The current study observed an increased relative risk of crashing for individuals being monitored by Driver Safety for a lapse of consciousness. However, this classification includes a broad range of medical conditions, one of which is epilepsy. This broad classification of medical conditions makes it difficult to identify the crash risks of individuals based on their specific medical condition. As previously mentioned, individuals diagnosed with syncope, which also result in a lapse of consciousness designation, have higher crash rates relative to individuals with epilepsy. Thus, the current study is unable to independently determine the crash rates of individuals with epilepsy. Applying these conclusions to all medical conditions within one P&M category may lead to unsubstantiated conclusions. This may be true for all P&M classifications. For example, the physical condition category includes individuals with diabetes, cardiovascular disease, and musculoskeletal conditions which may express themselves quite differently in regards to driving behaviors.

## Recommendations

The effect on traffic safety as a result of the reduction in the number of individuals whose Driver Safety hearing led to a P&M code designation in 2007 relative to 2000 has not been empirically evaluated. While there has been an overall decrease in the number of individuals assigned a P&M code designation, it is unknown if this pattern is consistent across all codes. Additionally, it is important to determine the crash risk of those individuals whose Driver Safety hearing resulted in no action. If Driver Safety officers are accurately identifying individuals who are safe to drive, their post-hearing crash rates should be comparable to the general population of drivers, or at least lower than those drivers flagged for further monitoring. If drivers whose hearing resulted in no action have a higher crash rate relative to the population, then an evaluation of Driver Safety procedures may be necessary to determine what factor(s) is/are associated with incorrect identification of safe drivers by Driver Safety hearing officers.

Similarly, actions taken by Driver Safety for individuals who receive a P&M designation code on their driving record can include a driving restriction, suspension, or revocation of their driving privilege. It is not precisely known if, and to what extent, these actions effectively reduce crash rates for this population of drivers. The effectiveness of licensing actions has been demonstrated for other types (DUI, Negative Operator points) of unsafe drivers. In addition, Mitchell & Gebers (2001) conducted a set of analyses for a certain limited set of restrictions (hand controls, steering knob, and leg prosthesis) that are normally applied to drivers with a Static (S) or Progressive (P) Physical Condition.[1] While the efficacy of Driver Safety procedures for determining the safety of drivers with medical conditions is important, this evaluation has only been conducted in a comprehensive manner once and is in need of reevaluation (Janke et al., 1978). Updated information may result in policy and/or procedural changes that may better identify unsafe drivers and implement appropriate actions. A clearer understanding of the efficacy of current procedures may lead to more efficient approaches in identifying the appropriate action, potentially reducing the workload of Driver Safety Hearing Officers. For example, if crash rates for older drivers with a mental condition designation (which may be the result of a dementia diagnosis) whose hearing resulted in no action are still significantly higher than the general population of drivers, this may suggest a reconsideration of the current policies and procedures applied to this group of drivers.

P&M codes are broad representations of classes of medical conditions, and do not provide much detail about the effect of a specific medical condition on traffic safety. By evaluating crash rates for specific medical conditions, relative to a class of conditions, as is provided by P&M codes, the potential risk of crashing for these populations can be evaluated. If a medical condition is no longer associated with an increase crash risk, monitoring by Driver Safety may no longer be necessary. Given that each case must be evaluated individually, this could substantially reduce the workload of Driver Safety Hearing Officers. For example, epilepsy accounts for a large number of cases referred to Driver Safety due to mandatory reporting. However, if crash rates for this population does not significantly affect traffic safety relative to the general population of drivers as suggested by previous research (Beghi et al., 2002; Lossius et al., 2010; McLachlan et al., 2007), only cases of intractable seizures may require contact with Driver Safety.

One approach to evaluating crash rates associated with specific medical conditions involves the use of Action Reason Codes (ARC). These provide more information about the diagnosis relative to P&M codes (among other information); however, in some cases the specific medical condition is not identified. To evaluate specific medical conditions that frequently result in a Driver Safety referral, a review of Confidential Morbidity Reports (CMR) would be necessary. A CMR is completed by the individual's treating physician and includes diagnosis, severity, treatment, and sometimes associated symptoms. Thus, by reviewing CMRs, the effects of severity, treatment, and/or symptoms could also be assessed. The primary obstacle to reviewing

[1] Broadly speaking, these analyses found that persons with these type of restrictions on the record either had a crash risk no different from that of the general population of drivers, or (for those restricted to the use of hand controls) a significantly lower crash risk.

CMRs relative is that only paper copies are available, which would require more time to obtain the necessary information. ARCs are in electronic format making them more easily accessible on the driver record master file.

## Conclusions

The findings of the current study are comparable to previous findings (Janke et al., 1978, Janke, 1993; Mitchell & Gebers, 2001) with crash rates being higher in each of the P&M conditions relative to the general population. One distinct observation was the drop in mean crash rates for the general population of drivers and males under the age of 25; a corresponding drop was not observed in all P&M conditions. Additional research is necessary to determine why this occurred and how this varies by specific medical condition (e.g., by ARC). If crash rates for specific medical conditions are comparable to the general population of drivers, evaluation and monitoring may no longer be necessary, unless the condition is severe and symptoms are not well controlled. This may reduce the amount of workload of Driver Safety Hearing Officers. While the findings from the current study allowed for the evaluation of changes over time, additional research is necessary to evaluate the effect of specific medical conditions on traffic safety.

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# APPENDICES

# APPENDIX A

Table A

Number of participants, mean age, and the percent of females within each sample for each P&M group and the random sample of California drivers in 2000 (Mitchell & Gebers, 2001)

| Risk group | *N* | Mean Age | % Female |
|---|---|---|---|
| Alcohol | 1,127 | 44.58 | 15.1% |
| Drugs | 2,879 | 35.29 | 26.1% |
| Lack of skill | 12,581 | 70.39 | 46.2% |
| Lapses of consciousness | 25,462 | 45.00 | 45.6% |
| Mental condition | 7,600 | 64.48 | 43.0% |
| Progressive physical | 19,303 | 58.27 | 35.4% |
| Random driver sample | 210,893 | 43.32 | 48.6% |

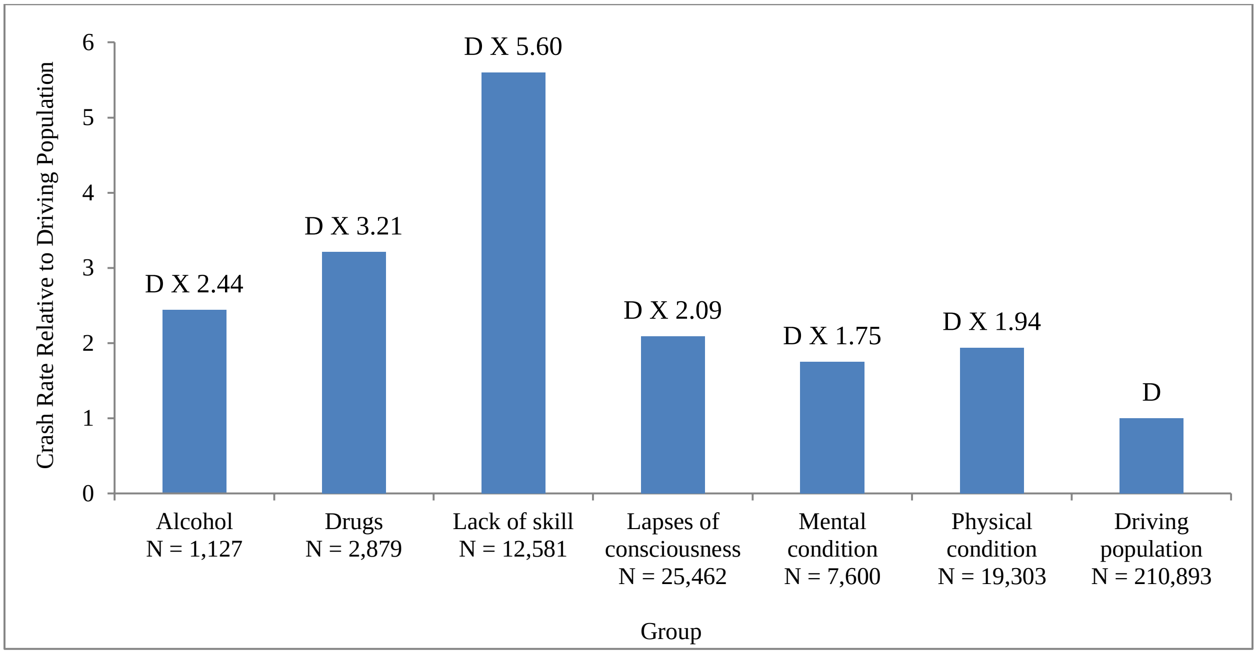
Table B

Prior 2-year total crash rates per 100 drivers for each group in 2000 (Mitchell & Gebers, 2001)

| Risk group | Mean crash rate |
|---|---|
| Alcohol | 26 |
| Drugs | 34 |
| Lack of skill | 47 |
| Lapses of consciousness | 22 |
| Mental condition | 19 |
| Physical condition | 21 |
| Random driver sample | 10 |
| Males under 25 | 16 |

Figure A

Prior 2-year crash rate by group after controlling for sex and age for all drivers with a P&M referral to Driver Safety in 2000 relative to the comparison sample representing the general population of California drivers.  See Mitchell & Gebers (2001).



**APPENDIX B**

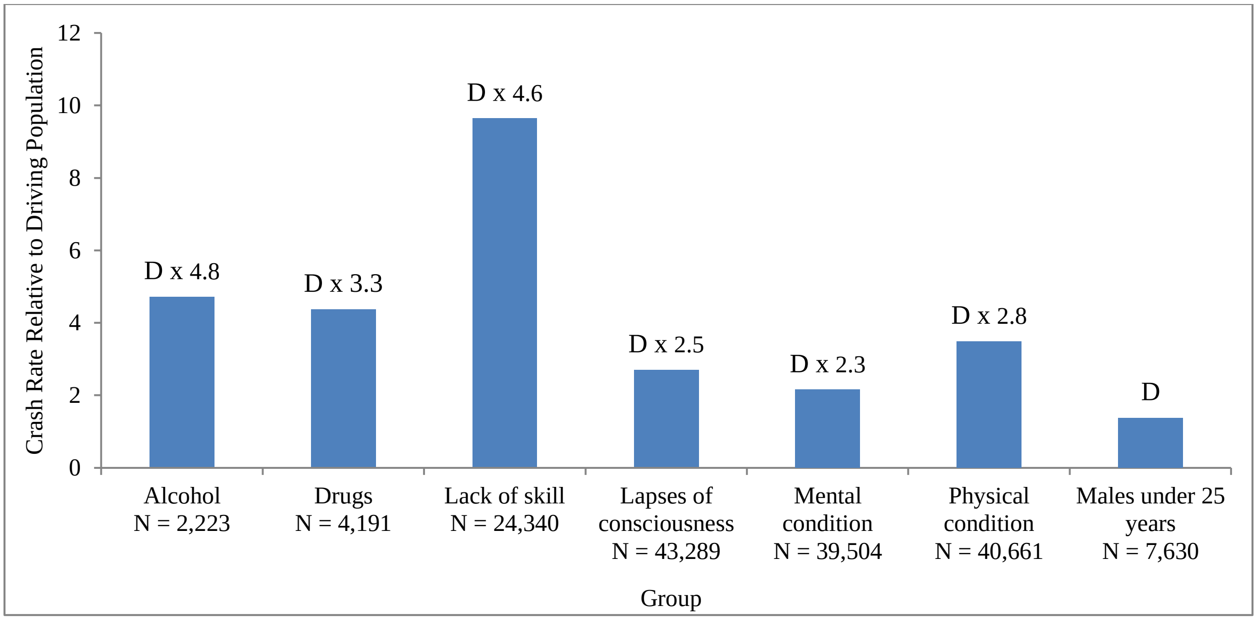
Table C

Prior 2-year total crash rates per 100 drivers for each group in 1975 (Janke, Peck, & Dryer 1978)

| Risk group | Mean crash rate |
|---|---|
| Alcohol | 55 |
| Drugs | 37 |
| Lack of skill | 53 |
| Lapses of consciousness | 29 |
| Mental condition | 26 |
| Progressive physical | 32 |

Figure B

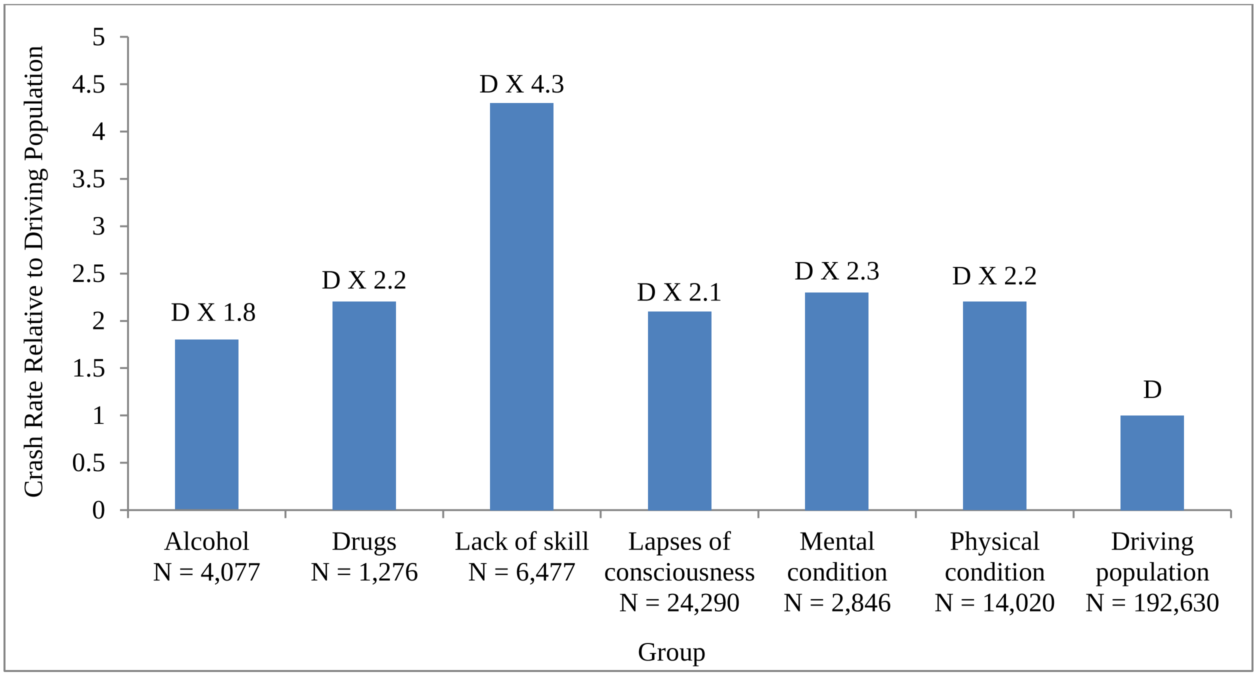
Prior 2-year crash rate by group for all drivers with a P&M referral to Driver Safety in 1974 – 1975 relative to the comparison sample representing the general population of California drivers. Controls for sex and age are not included in these data. See Janke et al. (1978).



# APPENDIX C

Figure C

Prior 2-year crash rate by group after controlling for sex and age for all drivers with a P&M referral to Driver Safety in 1991 relative to the comparison sample representing the general population of California drivers. See Janke (1993).



# APPENDIX D

Table D

Odds ratios and 95% confidence intervals for age by condition interaction terms

| Risk group | Odds ratio | 95% CI Lower | 95% CI Upper |
|---|---|---|---|
| Alcohol X 20-29 | 1.44 | 0.769 | 2.686 |
| Alcohol X 30-39 | 0.74 | 0.421 | 1.297 |
| Alcohol X 50-59 | 1.09 | 0.648 | 1.842 |
| Alcohol X 60-69 | 0.88 | 0.448 | 1.712 |
| Alcohol X 70+ | 1.69 | 0.833 | 3.436 |
| Drugs X 20-29 | 1.52 | 0.985 | 2.346 |
| Drugs X 30-39 | 1.13 | 0.712 | 1.783 |
| Drugs X 50-59 | 0.73 | 0.455 | 1.161 |
| Drugs X 60-69 | 1.08 | 0.448 | 2.606 |
| Drugs X 70+ | 2.52 | 0.309 | 20.449 |
| Lack of skill X 20-29 | 1.12 | 0.646 | 1.941 |
| Lack of skill X 30-39 | 0.75 | 0.435 | 1.292 |
| Lack of skill X 50-59 | 1.07 | 0.704 | 1.634 |
| Lack of skill X 60-69 | 0.88 | 0.598 | 1.308 |
| Lack of skill X 70+ | 0.77 | 0.551 | 1.086 |
| Lapses of consciousness X 20-29 | 1.26 | 1.028 | 1.542 |
| Lapses of consciousness X 30-39 | 1.37 | 1.122 | 1.664 |
| Lapses of consciousness X 50-59 | 0.87 | 0.718 | 1.056 |
| Lapses of consciousness X 60-69 | 0.92 | 0.737 | 1.141 |
| Lapses of consciousness X 70+ | 1.03 | 0.861 | 1.238 |
| Mental condition X 20-29 | 0.64 | 0.407 | 1.020 |
| Mental condition X 30-39 | 0.82 | 0.548 | 1.237 |
| Mental condition X 50-59 | 1.13 | 0.799 | 1.598 |
| Mental condition X 60-69 | 1.15 | 0.825 | 1.591 |
| Mental condition X 70+ | 1.03 | 0.794 | 1.330 |
| Physical condition X 20-29 | 1.12 | 0.774 | 1.629 |
| Physical condition X 30-39 | 0.84 | 0.593 | 1.196 |
| Physical condition X 50-59 | 1.01 | 0.804 | 1.268 |
| Physical condition X 60-69 | 1.24 | 0.988 | 1.564 |
| Physical condition X 70+ | 1.27 | 1.037 | 1.545 |

Table D (cont.)

| Risk group | Odds ratio | 95% CI Lower | 95% CI Upper |
|---|---|---|---|
| Alcohol X sex | 0.86 | 0.509 | 1.463 |
| Drugs X sex | 1.60 | 1.130 | 2.274 |
| Lack of skill X sex | 1.03 | 0.915 | 1.155 |
| Lapses of consciousness X sex | 0.68 | 0.604 | 0.771 |
| Mental condition X sex | 0.86 | 0.754 | 0.987 |
| Physical condition X sex | 0.91 | 0.809 | 1.023 |

# APPENDIX E

Table E

Logistic regression analysis for Model C (factors = sex, age, group, sex X group)

| Predictors | β | *SE* | Wald $\chi^2$ test | *df* | *p* |
|---|---|---|---|---|---|
| Intercept | -2.66 | 0.016 | 29,102.30 | 1 | <0.001 |
| Sex (referent group = F) | -0.18 | 0.01 | 160.12 | 1 | <0.001 |
| Age (referent group = 40-49) | | | 1,028.88 | 5 | <0.001 |
| 20-29 | 0.39 | 0.020 | 402.34 | 1 | <0.001 |
| 30-39 | 0.01 | 0.020 | 0.02 | 1 | =0.651 |
| 50-59 | 0.00 | 0.021 | 0.02 | 1 | =0.881 |
| 60-69 | -0.12 | 0.025 | 25.57 | 1 | <0.001 |
| 70 + | -0.34 | 0.026 | 171.04 | 1 | <0.001 |
| Group (referent group: comparison) | | | 4,829.83 | 6 | <0.001 |
| Alcohol | 1.54 | 0.102 | 227.62 | 1 | <0.001 |
| Drugs | 1.22 | 0.097 | 156.67 | 1 | <0.001 |
| Lack of skill | 2.49 | 0.045 | 3,076.62 | 1 | <0.001 |
| Lapses of consciousness | 1.13 | 0.038 | 889.07 | 1 | <0.001 |
| Mental condition | 0.99 | 0.047 | 443.30 | 1 | <0.001 |
| Physical condition | 1.43 | 0.034 | 1,363.73 | 1 | <0.001 |
| Group X sex | | | 36.83 | 1 | <0.001 |
| Alcohol X sex | 0.04 | 0.267 | 0.02 | 1 | =0.881 |
| Drugs X sex | 0.65 | 0.178 | 13.18 | 1 | <0.001 |
| Lack of skill X sex | 0.21 | 0.061 | 11.59 | 1 | <0.001 |
| Lapses of consciousness X sex | -0.19 | 0.064 | 8.60 | 1 | <0.05 |
| Mental condition X sex | 0.07 | 0.070 | 0.99 | 1 | =0.319 |
| Physical condition X sex | 0.09 | 0.062 | 1.92 | 1 | =0.166 |