

**CRASH PREDICTION MODELS FOR OLDER DRIVERS:
A Panel Data Analysis Approach**

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ABSTRACT

The graying of America is resulting in a larger proportion of older individuals in the population. Recent transportation surveys show that an increasing number of older individuals are licensed to drive and that they drive more than their same age cohort a decade ago. These trends necessitate increased study of their potential highway safety problems.

Considerable progress has been made on understanding older drivers' safety issues. Nonetheless, research has been rather limited and the findings inconclusive. One of the methodological limitations is the lack of considering temporal order between events (i.e., the time between onset of medical condition, symptom, and crash). Without time-series data, researchers have often linked a "snap-shot" of medical conditions and driving patterns to more than one year of crash data, hoping to accumulate enough data on crashes. The interpretation of the results from these studies is difficult in that one cannot explicitly attribute the increase in highway crash rates to medical conditions and/or physical limitations.

This paper uses a panel data analysis approach to identify factors that place older drivers at greater crash risk. Our results show that factors that place female drivers at greater crash risk are different from those influencing male drivers. More risk factors were found to be significant in affecting older men's involvement in crashes than older women. When the analysis controlled for the amount of driving, women who live alone or who experience back pain were found to have a higher crash risk. Similarly, men who are employed, score low on word-recall tests, have a history of glaucoma, or use antidepressant drugs were found to have a higher crash risk. The most influential risk factors in men were the amount of miles driven, and use of antidepressants.

KEYWORDS:

Older Drivers
Highway Safety
Crash Prediction Model
Crash Risk Factors

1. BACKGROUND AND INTRODUCTION

American society is undergoing a major demographic transformation with a larger proportion of older individuals in the population. Data from recent surveys suggest important trends. In the future, more older individuals will be licensed to drive, and they will drive more than their same age cohort a decade before (Hu, Young and Gray, 1993). These trends are a potentially serious highway safety issue.

Safety concerns over driving performance are not unique to the elderly. In fact, older drivers are considerably safer than some age groups, teenage drivers in particular. Concerns about older drivers' safety, however, arise from the fact that the elderly are more likely to have cognitive, motor and sensory deficits. They are also more likely to be afflicted with chronic illness and to use medication that might detrimentally affect their driving performance. Furthermore, concerns about older drivers stem from their frailty. An 80-year-old driver is four times more likely to die in crashes of similar intensity than a 20-year-old driver (Eberhard, 1996).

In 1988, the Transportation Research Board (TRB) of the National Research Council published a report on problems that may inhibit the safety and mobility of older drivers, and identified means of addressing these problems (Transportation Research Board, 1988). Research needed on the safety and mobility of older drivers calls for a re-evaluation of licensing, screening, and testing practices to better identify older drivers who have physiological and psychological functional impairments that may affect their ability to drive safely (Transportation Research Board, 1992).

Considerable progress has been made in the past few years on examining older drivers' driving behavior, age-related physiological and psychological changes, crash patterns, and the drivers' rate of involvement in traffic crashes. Nonetheless, research has been rather limited and the findings on the factors that place older drivers at greater crash risk have been inconclusive. Waller attributed these limitations to several methodological and administrative issues (Waller, 1992). These issues include: diagnostic inaccuracy, small sample size, selection bias, inconsistent definition of criteria for excessive crash risk, the lack of research on the effect of comorbid conditions, and the subtle nature of the interaction between driver and the environment.

This study presents two additional methodological limitations in previous research. First, the combined effects of multiple risk factors have not been fully addressed. This point is similar to Waller's criticism (1992) of the lack of research on the interaction between driver and environment and on the impact of comorbid conditions. Only in the past few years have multivariate analysis techniques been used to quantify the joint impacts of various risk factors on vehicle crash patterns among elderly drivers (Stewart, Moore, Marks, May and Hale, 1993) (Foley, Wallace and Eberhard, 1995) (Ray, Fought and Decker, 1992) (Leveille, Buchner, Koelsell, McClosky, Wolfe and Wagner, 1994) (Koepsell et al., 1994) (McCloskey, Koepsell, Wolf and Buchner, 1994). The advantage of multivariate analysis over uni- or bi-variate analysis is that multivariate analysis examines the impact of a specific risk factor on crashes by statistically holding the remaining risk factors constant. A second additional limitation of previous research is that the chronological (or temporal) order (or correlation) between events (i.e., the date of onset of the medical condition and symptom, and the time of crash) has never been properly addressed. The absence of considering this temporal correlation makes the interpretation of the results in these previous studies somewhat difficult.

The objective of this paper is to illustrate an approach that overcomes the two aforementioned limitations, in identifying factors that place older drivers at greater crash risk. The risk factors examined in our analysis include socio-demographic factors, functional and mental limitations, medical conditions, and medication use (on a limited basis). Excluded from our analysis were vehicular attributes and characteristics of the driving environment.

The next section summarizes a review of the literature that examines the impacts of various simultaneous risk factors on vehicle crash patterns among elderly drivers. This is followed by a discussion in Section 3 of the

merits of considering temporal correlation in the development of a crash prediction model. Section 4 describes the data that we used and Section 5 specifies our model development and framework. Finally, results are reported in Section 6, and discussions and recommendations for future research are presented in Section 7.

2. LITERATURE REVIEW

Stewart, Moore, Marks, May and Hale (1993) examined a group of 1,431 ambulatory elderly individuals who participated in the eighth follow-up of the Florida Geriatric Research Program (Hale, Marks and Stewart, 1980). The control group consisted of 1,289 individuals who were not involved in any crashes during the five year period prior to the eighth visit. The cases were the 142 individuals who were in crashes. Based on the results from their logistic regression model, Stewart et al. found that neither age nor gender was associated with vehicle crashes. They also found that neither the most commonly used drug ingredients nor memory loss contributed to higher vehicle crash rates. The three most important symptoms associated with an increased likelihood of older drivers being involved in vehicle crashes were: feeling cold in the feet and legs, having a high level of protein in the urine, and having an irregular heart beat (Stewart, Moore, Marks, May and Hale, 1993). Stewart, Moore, Marks, May and Hale (1993) also identified bursitis (inflammation of the bursa) to be the only chronic disease that contributes to a higher risk of crashing. In their analysis, the authors related physical and functional characteristics, drug use, and other behavioral factors collected in the eighth visit (that ended in 1987) to traffic crashes that occurred during the five year period prior to the eighth visit. By relating the occurrence of events (in this case, crashes) to a set of risk factors, that are observed after the events occur, the study introduces temporal ambiguity that hinders the proper interpretation of the study's results.

A group of 1,854 individuals aged 68 and older, who were still driving as of 1988, were the basis of a study on vehicle crashes by Foley, Wallace and Eberhard (1995). These drivers were participants in the third follow-up (in 1985) of the Iowa 65⁺ Rural Health Study, one of the four Established Populations for Epidemiologic Studies of the Elderly (EPESE) (Cornoni-Huntley, Brock, Ostfeld, Taylor and Wallace, 1980). Foley, Wallace and Eberhard (1995) used a Cox proportional hazards regression model to calculate the age- and gender-adjusted odds ratio for each of the selected risk factors (Foley, Wallace and Eberhard, 1995). The authors found that gender was a more important risk factor than age. Men were 60 percent more likely to be involved in crashes than women. However, after controlling for this gender effect, the authors no longer found age to be a significant crash risk factor. They concluded that drivers who scored low on the memory test (in the lowest one-third), or had a recent history of back pain had a higher risk of crashing. None of the chronic diseases (such as having had a heart attack, or stroke, diabetes, and arthritis) was significantly correlated with being involved in vehicle crashes (Foley, Wallace and Eberhard, 1995).

Of the prescription and over-the-counter medications taken by the drivers during a two-week period prior to the 1995 interview, Foley, Wallace and Eberhard (1995) found that drivers who reported taking nonsteroidal anti-inflammatory agents were 80 percent more likely to be involved in crashes than those who did not. No association was found between the total number of medications used and the risk of crashes. This finding may not be surprising. The medications used during a two-week period prior to the 1985 interview may well not have any significant impacts on the risk of crashing four to five years later. Recognizing the limitations of their study, Foley, Wallace and Eberhard (1995) considered their findings on medication use to be preliminary.

In their retrospective cohort study, Ray, Fought and Decker (1992) analyzed data collected from 16,262 enrollees in the Tennessee Medicaid program during the period 1984–1988. The study accumulated annual observations for these individuals during the study period. A total of 38,701 person-years of data were accumulated. The focus of the study was on the impacts of four groups of psychoactive drugs on driving. The four drug groups were: benzodiazepines, cyclic antidepressants, oral opioid analgesics, and antihistamines. Ray, Fought and Decker (1992) controlled for demographic characteristics (i.e., age, gender, race, residence) and the use of medical care (as a proxy for health status) in their Poisson regression models. They found that

current users of benzodiazepines and antidepressants have a higher risk of injurious crash involvement than non-users. For these two groups of drugs, the relative risk of crash involvement increases with dose but not with duration of usage. The relative risk for current users of antihistamines or opioid analgesics was not significant (Ray, Fought and Decker, 1992). Since the impact of psychotropic drug use is likely to be confounded by the psychiatric illness for which the drugs are given, the drug's contribution to crash risk becomes somewhat unclear.

Leveille, Buchner, Koepsell, McClosky, Wolf and Wagner (1994) examined similar questions about the effects of medication on driving. They conducted a population-based matched case-control study of older drivers. These drivers were members of a large Seattle-based health maintenance organization (HMO). Unlike the study by Ray, Fought and Decker (1992), estimated relative risks adjusted for the amount of annual driving (as well as for confounding variables such as race, marital status, education level, and use of insulin). The 234 cases who were involved in injurious crashes during 1987 and 1988 were matched (by age, gender, and place of residence) to 447 controls who had not been involved in injurious crashes. Results from their logistic regression analysis indicated that current use of antidepressants and opioid analgesics places older drivers at increased risk of injurious crashes (Leveille, Buchner, Koepsell, McClosky, Wolf and Wagner, 1994). No association was found between increased risk and dosage level. Benzodiazepines and sedating antihistamines had little effect on risk. These findings are somewhat contrary to those by Ray, Fought and Decker (1992). Leveille, Buchner, Koepsell, McClosky, Wolf and Wagner (1994) attributed these discrepancies to the difference between the study populations (i.e., Medicaid enrollees versus HMO enrollees) and to the drugs that the two studies included [e.g., cough medication containing codeine is included in Leveille, Buchner, Koepsell, McClosky, Wolf and Wagner (1994), but not in Ray, Fought and Decker (1992)].

Based on the same group of participants as Leveille, Buchner, Koepsell, McClosky, Wolf and Wagner (1994), Koepsell et al. (1994) examined several neurological conditions that commonly impair sensation, cognition, or the motor function of older individuals. The conditions include cerebrovascular diseases (i.e., stroke, transient ischemic attacks or both), syncope, dizziness, seizures, head injury, dementia, and subdural hematoma. The authors did not find many of the conditions to be associated with significantly large crash risk. However, Koepsell et al. (1994) did find that older diabetic drivers who were treated with insulin were at a six-fold higher crash risk, and those treated with oral hypoglycemics were at a three-fold increased risk, while there were no indications of elevated risk among those only treated with diet. Drivers with a longer history of diabetes were at higher risk than those with more recently diagnosed diabetes. Furthermore, drivers with both diabetes and coronary heart disease were eight times more likely to be in vehicle crashes than those without (Koepsell et al. 1994). The authors attribute their somewhat contradictory findings to Washington State's mandatory medication evaluations for drivers with chronic or progressive diseases and to self-regulated driving behavior among their study population.

McCloskey, Koepsell, Wolf and Buchner (1994) studied the same group of participants as Leveille, Buchner, Koepsell, McClosky, Wolf and Wagner (1994) and Koepsell et al. (1994) and found no clear evidence that ocular disease (such as glaucoma, cataracts, and other retinal disorders) or static visual acuity impairment increased older drivers' risk of a motor vehicle collision. They concluded that the types of vision tests generally administered during routine optometry examinations, or at the time of licence renewal, are unable to identify high-risk older drivers. Although no statistically significant association was found between impaired hearing and increased crash risk, the authors found that individuals who used hearing aids while driving had about twice the risk of others. The authors attributed their generally negative findings to several reasons. First, most individuals with severe visual acuity impairment (20/70 or greater) likely were no longer driving, either due to licence testing or to voluntary cessation of driving. Second, drivers with impaired vision may drive with greater caution, and are therefore less likely to be involved in vehicle crashes. Third, persons with the same ocular diagnosis or the same level of full-illumination static visual acuity may be different in their functional visual capability. As a result, the authors recommended future research focusing on the feasibility and the usefulness of using more sophisticated vision tests (such as low-illumination static visual

acuity, visual field restriction, dynamic visual acuity, and useful field of view) to identify high-risk elderly drivers.

3. LACK OF CONTEMPORANEOUS CORRELATION

Much of the previous research has not fully addressed the contemporaneous relationship among events. That is, the potential risk factors and crash data are not for the same points in time. Without time-series data, researchers often link a "snap-shot" of medical conditions and driving patterns to several years of crash data, hoping to accumulate enough data on crashes. The interpretation of results from this type of study is somewhat difficult, however, in that one cannot attribute concurrent highway crash rates to medical conditions or other risk factors. For example, assume that the group of cases, at reference time t , experiences a higher (or lower) crash rate than the control group; and that the crash rate is observed during the period from $t-3$ to t (to accumulate enough crash data). This finding would not, however, allow one to conclude unequivocally that this difference in crash rate is attributable to a specific medical condition that is observed in period t . This is because there may be cases in which the onset of disease took place between $t-3$ and t , but after the time of the crash. There is a need to pinpoint the onset of a medical condition, changes in functional ability, and historical information on the type and quantity of medication used.

A contemporaneous (or temporal) profile is crucial to establishing a relationship between vehicle crashes and medical conditions and/or individuals' functional limitations. Temporal information allows one to identify whether crashes take place before or after the onset of a medical condition. This information removes confounding effects of having individuals involved in crashes before the onset of their medical condition. Without this temporal information, it is unclear whether medical conditions and functional limitations contribute to a higher probability of highway crashes.

The "snap-shot" approach typically "matches" a period of vehicle crashes to a set of explanatory variables. Causality relationships are obscured. By only analyzing a "snap-shot" of longitudinal data, one overlooks the contemporaneous correlation between crashes and their contributing factors, and disregards much of the benefit of having longitudinal data. Thus, to capture the contemporaneous correlation between the outcome of interest (in this case, vehicle crashes) and the contributing factors, we constructed a panel data set.

The idea of a panel data set is that there is an annual "observation" for each subject for each year in which he/she participates in the study. Each annual "observation" contains a participant's current status in terms of physical and mental conditions, diagnosis of diseases, medication use, functional and physical limitations, driving behavior, institutionalization, vehicle crash(es), etc. Ideally, there should be one observation for every participant for every year during the study period. However, data missing for a year or more are not uncommon in a longitudinal study of older individuals, primarily due to death, institutionalization, refusal to continue participation in the study, moving out of state, etc.

4. DATA SOURCE

We constructed our panel data set based on data from the Iowa 65+ Rural Health Study, part of the Established Population for Epidemiological Studies of Elderly (EPESE) program (Cornoni-Huntley, Brock, Ostfeld, Taylor and Wallace, 1980). The reasons for using data from this study were that: (a) it covers a considerably long time period (1981–1993) and (b) it contains a wealth of information relative to other data sources. All noninstitutionalized individuals 65 years or older residing in two Iowa counties (Iowa and Washington) were sought to participate in the baseline survey in 1981 and 1982. The participation rate was 80 percent (3,673 persons) in 1982. An in-home interview was conducted every three years (1982, 1985, 1988); and a telephone

interview was used in the intervening years. The survey and the subsequent follow-ups collected information on demographic attributes, onset of medical condition, symptoms and ailments, functional status, physical functioning, physical activities, vision, drug use (both prescribed and over-the-counter drugs), and cognitive abilities. One driving-related question was added in the third and the fifth follow-ups. Not until the seventh follow-up were more detailed driving-related questions administered.

Although questions about the use of medication were asked in every interview, the participants were asked to present the medication containers during the in-person interviews so that the interviewers could record accurately the relevant drug data. The in-person interviews took place in the baseline interview (1982), and in the third (1985) and sixth (1988) follow-ups. Although the tenth follow-up (1992) was also an in-person interview, the processing of the drug use data collected in this follow-up was not completed at the time of the present study, and they were not included in our analysis.

These survey data were linked to the crash files maintained by the Iowa Department of Motor Vehicles (DMV). Since crash records are eliminated from the files after a number of years, our crash analysis is based on crash data from 1985 to 1993. Individuals who were active in terms of not being institutionalized, and not moved out of Iowa; who still drove (self-reported); whose records were found in the Iowa DMV files; and who had not surrendered their driver's licenses (based on information maintained by Iowa DMV) were eligible for this crash analysis.

Several data quality constraints in the Iowa data posed significant challenges in constructing the panel data base (Hu, Trumble and Lu, 1995). Various sets of "rules" had to be developed to impute estimates of the missing data and to rectify data inconsistencies. Our entire panel data set consists of a single observation (or record) for each participant for each year between 1981 (the first year when the first baseline survey began) and 1993 (the last year when the tenth follow-up interview ended). However, since crash data were available only from 1985 onward, our crash analysis was based on data from 1985 to 1993.

In 1985, 926 female drivers and 885 male drivers were eligible for the analysis. By 1993, 507 of the women and 375 of the men remained, resulting in 6,553 female person-years and 5,414 male person-years. The average annual sample attrition rate was 7 percent for females and 10 percent for males. Over the study period, at least 96 percent of the drivers were free from crashes. Male drivers were slightly more likely to be involved in crashes than female drivers. Only one or two drivers in any given year were involved in two crashes.

This Iowa cohort was similar to the general older population at the national scale, in that its prevalence rates of cataract, heart disease and diabetes in the Iowa cohort closely corresponded to those observed in the general older population (National Center for Health Statistics, 1993). However, this Iowa cohort perceived themselves to be in better health than their counterparts from the national survey. While 78 percent of the Iowa participants perceived themselves to be in good to excellent health, 69 percent of the general older population considered themselves in good to excellent health. Furthermore, this Iowa cohort was notably more capable of performing activities of daily living (ADLs) than the national sample. While 4.6 percent of the persons 65 years and over from the national survey needed help to walk across a small room (National Center for Health Statistics, 1993), the corresponding percentage in the Iowa cohort was 3.6 percent. The greatest difference between the national sample and the Iowa cohort was the percentage of individuals who received help in bathing, 6 percent versus 1.5 percent, respectively.

5. MODEL SPECIFICATION AND FRAMEWORK

In theory, the problem of identifying risk factors is equivalent to finding a model that generates the data that we observe. The model selection procedure is generally based on an approach that begins by testing the most general specification, and then, progresses to test a series of more restrictive specifications. This approach

follows classical Neyman-Pearson hypothesis testing. In our case where there are a large number of potential risk factors that contain some degree of redundant information, it is highly probable that more than one model will have approximately the same high likelihood of generating the data that we observe. In such cases, theory as well as modeling objectives, such as policy analysis, should guide model selection decisions.

In this regard, the issue of whether to include information on annual miles driven is an important one. The number of miles driven (VMT) has been widely used in highway safety analysis as a proxy to measure the extent to which one exposes oneself to vehicle crashes. The theory is that the more one drives, the more one exposes oneself to crashes and the more likely one is to be involved in a crash. The opponents of this viewpoint argue that from the policy making perspective, how much one drives is irrelevant since licensing guidelines cannot be based on the amount of driving. We developed two separate models based on two sets of risk factors—one included the average annual miles driven by an average older driver and the other did not. Only results from the model including the average annual miles driven will be presented here. In a separate paper, we examine the consequence of ignoring the impact of the annual miles driven on crashes.

Ideally, the theory that the more one drives the greater the crash exposure should be extended to consider the complexity of driving. That is, the more difficult the driving, the greater the crash exposure. To capture the effect of driving complexity in crash prediction models, one approach is to further categorize VMT by driving environment such as the amount of driving under different weather and lighting conditions, traffic mix, and vehicle speed. Compiling such information demands enormous resources and is seldom available. Nonetheless, it has been recommended in the literature that such information be collected to enhance future highway safety research.

A similar model specification issue is the question of whether less objective variables, such as perceived health, should be included in the model. There was a mixed opinion among the authors to this question. At this point, we do not limit our analysis to only objective measures because the findings from our analysis will be used not only to assist the development of licensing guidelines but also to help older drivers become more aware of different risk factors that affect their probability of being involved in vehicle crashes.

Other model specification issues are less clear cut. For example, the symptoms and treatments of a particular medical condition are usually highly correlated, and may represent the underlying risk factors equally well. In some cases, the choice of variables may have important implications, but the modeling criteria with the available sample cannot clearly discriminate between them. In presenting the modeling results we will discuss these issues in more detail for the particular cases that we encountered.

Although we can analyze crash data using multiple linear regression models, Miaou, Hu, Wright, Davis and Rathi (1993) identified several undesirable statistical properties of these models for the types of analysis in this study: (a) vehicle crashes are discrete events. The use of a continuous distribution, such as a normal distribution, to model vehicle crashes only approximates a discrete process; (b) for some model formulations, multiple linear regression models might predict a negative number of crashes; (c) vehicle crashes are rare events in that the probability of observing no crash is high. The underlying probability distribution is thus significantly skewed to the right, and the normal distribution is clearly inappropriate under this situation.

To avoid these problems, the Poisson regression model has been widely used to study count data. The Poisson regression model stipulates that each count y_i is drawn from a Poisson distribution with parameter λ_i , which is related to the regressors, \mathbf{x}_i . The primary equation of the model is

$$Prob(Y_i = y_i) = \frac{e^{-\lambda_i} \lambda_i^{y_i}}{y_i!} \quad (1)$$

where $y_i = 0, 1, 2, \dots$, and λ_i is commonly formulated as being log-linearly dependent on the regressors, x_i ,

$$\ln \lambda_i = \beta' x_i \quad (2)$$

and

$$E[Y_i | x_i] = \lambda_i, \quad \text{Var}[Y_i | x_i] = \lambda_i \quad (3)$$

In principal, the Poisson model is a nonlinear regression model with a log-likelihood function of

$$\ln L = \sum_i [-\lambda_i + y_i \beta' x_i - \ln y_i!]. \quad (4)$$

The parameters β can be estimated by using maximum likelihood techniques.

The Poisson model has been criticized for its implicit assumption that the variance of y_i is equal to its mean. In many cases, count data are found to exhibit greater variation (or overdispersion) relative to a Poisson model. In other words, the variance of the data is frequently greater than that indicated by the Poisson model. Several factors contribute to overdispersion in the data, including omitted variables, uncertainty in explanatory variables, and correlations of dependent variables among sample units (Miaou, Hu, Wright, Davis and Rathi, 1993). If overdispersion is significantly different from zero, the negative binomial (NB) regression model is an alternative to the Poisson model. In essence, the NB model is an extension of the Poisson regression model which allows the variance of the process to differ from the mean. We tested the overdispersion parameter and found it to be not significantly different from zero.

Also, to address the possibility of correlation among the y_i 's, the number of accidents in a year for the i th participant for all years during the study period (from 1985 to 1993), we tested an alternative model of a random effects specification for the Poisson regression model where

$$\ln \lambda_{i,t} = \beta' x_{i,t} + \mu_i, \quad (5)$$

where $i = 1, \dots, N$, $t = 1, \dots, T$, and μ_i has a gamma distribution that varies across participants. Results from the test could not reject the null hypothesis as specified in (2), indicating that the Poisson specification with independent observations is appropriate.

6. RESULTS

The potential factors contributing to older drivers' probability of being involved in a vehicle crash include: demographic attributes, limitations in performing physical activities, chronic conditions, physical features, psychosocial characteristics, symptoms, drug use, and other health-related factors (Hu, Trumble and Lu, 1995). Also included in the crash model are the annual miles driven by individual drivers and the use of medication.

The first stage of our analysis was to develop separate gender-specific models. The results from these models were then used to formulate a single combined-gender model to explain the variation in the crash rates between genders. Results from the first stage of this analysis suggest that there are significant gender differences in a number of the risk factors that determine the probability of an older driver being involved in vehicle crashes.

The results for older female drivers are shown in Table 1. After testing a series of restricted models derived from the most general model that was considered in this study, we developed the final female model (at a significance level of $\alpha=0.05$). The final crash model for older female drivers (Table 1) was then subjected to a number of diagnostic tests for omitted variables. At least 60 variables were subjected to these types of diagnostic tests (Hu, Trumble and Lu, 1995), including use of antidepressants, nonsteroidal anti-inflammatory agents and benzodiazepines; employment status; status on activities of daily living; living arrangements; self-perceived health status; glaucoma; history and surgery of cataract; Parkinson's disease; diabetes; heart attack; stroke; arthritis; osteoporosis; etc. From the diagnostic tests, four factors were identified as being borderline in significance. They were hospital stay, being employed, having experienced one stroke, and having difficulty in seeing a friend across the street. Further tests suggest that these borderline factors should not be included in the final model if the significance level, α , is set at 0.05. All of these borderline factors have a negative coefficient, suggesting that they are augmenting the impacts of the annual miles driven on crash involvement, by adjusting the relative exposure. An important result is that the final model coefficients are reasonably robust with respect to the inclusion of any one of these borderline variables. Thus, even if the difficulty of seeing a friend across the street really should be included in the model, the conclusions (to be discussed) regarding the annual miles driven and having difficulty in extending arms over shoulder level, would not noticeably change.

Table 1. Crash Prediction Models for Older Drivers
[Poisson Regression Model, *with* the Annual VMT]

Variable	Gender-specific				Combined-Gender
	Female		Male		Coefficients
	Coefficients	Average characteristic	Coefficients	Average characteristic	
Constant	-3.97**		-4.14**		-4.17**
Annual miles driven	0.07**	3,230 miles	0.04**	8,320 miles	0.05**
Having difficulty in extending arms	0.85**	2%	-		-
Back pain	-		-		0.23**
Living alone	-		0.42**	17%	0.31**
Employed (male only)	-		0.47**	21%	0.44**
History of Glaucoma (male only)	-		0.54**	7%	0.54**
Low scores on word-recall tests (male only)	-		0.40**	78%	0.33**
Antidepressant (male only)	-		0.72**	3%	0.69**
Log Likelihood (LL)	-616.4		-712.4		-1329.4
Number of Observations	5,288		4,110		9,389
Restricted Likelihood value	-622.6		-726.98		-1359.9

- Nonsignificant.

**Significant at $\alpha = 0.05$.

Having difficulty in extending arms above shoulder-level increases the probability of an older female driver being involved in vehicle crashes. This limitation probably reflects older female drivers' motor capability. The probability of being involved in vehicle crashes and the odds ratio for the final model are presented in Table 2. There are two parts to this table. The first part is the probabilities of an older female driver being involved in vehicle crashes as a function of two risk factors—annual miles driven and a possible motor deficit (as represented by having difficulty in extending her arms over her shoulders.) The second part of the table is the odd ratios. The first row of the odd ratios contains the odds ratio for an older female driver who has no difficulty in extending her arms above her shoulders, and drives 6,000, 9,000 and 12,000 miles in a year, relative to a similar driver driving only 3,000 miles a year. For example, an older female driver who drives an average of 6,000 miles a years is 1.23 times more likely to be involved in vehicle crashes than another female driver who drives 3,000 miles a year, given that both women have no difficulty in extending their arms above their shoulders. Similarly, the second row of this table contains the odds ratio for an older female driver who has difficulty in extending her arms above her shoulders relative to one without this disability, given that both women drive the same number of miles a year. For example, an older female who has difficulty in extending her arms above her shoulders is more than twice as likely to be involved in vehicle crashes than another female driver without this functional limitation, given that both women drive 3,000 miles a year. Regardless of the amount of annual driving, women who have difficulty in extending their arms above their shoulders are at a two-fold elevated crash risk compared to those without this difficulty.

Table 2. Probabilities and Odds Ratios of Crash Risk Factors Older *Female* Drivers

	Annual Miles Driven			
	3,000	6,000	9,000	12,000
<i>Probability</i>				
Annual miles driven	0.023	0.028	0.035	0.042
Having difficulty in extending arms	0.053	0.065	0.079	0.096
<i>Odds Ratio</i>				
Annual miles driven*	1.00	1.23	1.51	1.85
Having difficulty in extending arms†	2.30	2.29	2.28	2.27

* Reference category is older female drivers who drive 3,000 miles a year and who have no difficulty in extending their arms.

† Reference category is older female drivers who drive the same number of miles a year and who have no difficulty in extending their arms.

Estimation results for older male drivers are also summarized in Table 1. The significant risk factors in this model are the annual miles driven, living alone, being employed, having a history of glaucoma, having potential cognition deficit, and using antidepressants. Glaucoma is likely to result in substantial deterioration of peripheral vision which is essential for safe driving. One of the side effects of antidepressants, particularly cyclic antidepressants, is sedation, and susceptibility to these side effects increases with age (Ray, 1992). Moreover, two of the frequently prescribed antidepressants (amitriptyline and trazodone) have been found to have a detrimental effect on cognitive, psychomotor and car-driving tasks (Ray, 1992).

The most notable gender difference is the impact of employment status on crash involvement rate. For example, the crash rate of older male drivers who had jobs was significantly higher than those without jobs.

However, older female drivers who had a job had a significantly lower crash rate than those without a job, but the impact of employment status on older female drivers' involvement in crashes was marginal. One plausible explanation for this result may be that older women who choose to be employed are in better physical condition than those who are unemployed. The estimated mileage coefficient for older male drivers is almost half that estimated for older female drivers, indicating that the influence of mileage on the likelihood of being involved in vehicle crashes is significantly smaller in men than in women. The probabilities of being involved in vehicle crashes and the odds ratios for this model are presented in Table 3. The interpretation of the odd ratios in this table is the same as that in Table 2. These odds ratios suggest that the use of an anti-depression drug, which doubles the probability of being involved in a vehicle crash, is the single most influential risk factor other than the amount of driving.

Table 3. Probabilities and Odds Ratios of Crash Risk Factors Older *Male* Drivers

	Annual Miles Driven			
	3,000	6,000	9,000	12,000
<i>Probability</i>				
Annual miles driven	0.018	0.020	0.023	0.026
Living alone	0.027	0.031	0.035	0.040
Employed (yes)	0.028	0.032	0.037	0.042
History of glaucoma (yes)	0.031	0.035	0.039	0.045
Scored low on word-recall tests	0.027	0.030	0.035	0.039
Antidepressant (yes)	0.037	0.042	0.047	0.054
All above variables	0.208	0.233	0.260	0.290
<i>Odds Ratio</i>				
Annual miles driven*	1.00	1.14	1.29	1.47
Living alone*	1.52	1.51	1.51	1.51
Employed (yes)†	1.59	1.58	1.58	1.58
History of glaucoma (yes)†	1.70	1.70	1.70	1.69
Scored low on word-recall tests †	1.49	1.49	1.49	1.49
Antidepressant (yes)†	2.04	2.04	2.04	2.03
All above variables†	11.56	11.40	11.22	11.02

* Reference category is older male drivers who drive 3,000 miles a year and who have none of the other risk factors.

† Reference category is older male drivers who drive the same number of miles a year and who have none of the other risk factors.

Results from the diagnostic test for omitted variables in the model for older male drivers identified two borderline risk factors: boredom and scoring in the top second to fifth percentile on the overall depression scale. When the boredom variable is included in the model, it is significant at the 0.05 level. However, including this marginal risk factor reduces the magnitude of the coefficient for antidepressant drugs to be insignificant at the 0.05 level. This confirms the relationship between boredom and depression and suggests that the decision to include which one of these two variables in the model is arbitrary. Since it may be more desirable to develop a model based on more objective factors, the use of an antidepressant drug is included in the final model instead of the self assessment of boredom. The estimated coefficients for any particular factor in the final model remain relatively stable regardless of whether the borderline factors are included, indicating that these estimation results are fairly robust.

The only common risk factor in the two gender-specific models was the annual miles driven (Tables 1). As a first step in developing a single model for both genders, we combined all of the significant factors identified from the gender-specific models and examined the coefficient estimates for both genders separately as well as combined. Experiencing back pain was also included in this examination due to the results from the diagnostic tests for omitted variables (Hu, Trumble and Lu, 1995). Inspection of the coefficient estimates suggests that both genders may have the same values for three of the factors — the annual miles driven, living alone, and experiencing back pain. Hypothesis tests confirm that these three factors influence both male and female drivers' crash probabilities in a similar manner. However, hypothesis tests that both genders share the same coefficient values for the following factors: employed, a history of glaucoma, use of an antidepressant, having difficulty in extending arms over shoulders, and possible impaired cognitive ability (as a proxy for the low scores on word-recall tests), were all rejected at the 0.05 significance level. This implies that these risk factors influence older male drivers' likelihood of being involved in crashes differently than those of older female drivers.

A combined model for both genders was then estimated using these pooled test results. The estimated coefficients for the final model of combined genders are presented in Table 1. Risk factors that are common to both women and men are: the amount of annual driving, living alone, and experiencing back pain. Risk factors that are specific to older male drivers are employment, a history of glaucoma, potential cognition deficit (as partly reflected by the low scores on word-recall tests), and use of antidepressants. The probabilities of being involved in vehicle crashes and the odds ratios for this final combined-gender model are presented in Table 4. These odds ratios show that the most influential risk factor in males other than the amount of annual driving is the use of an antidepressant.

Table 4. Probabilities and Odds Ratios of Crash Risk Factors, Gender Combined

	Annual Miles Driven			
	3,000	6,000	9,000	12,000
<i>Probability</i>				
Annual miles driven	0.018	0.020	0.023	0.027
Living alone	0.024	0.028	0.032	0.037
Back pain (yes)	0.022	0.025	0.029	0.034
Employed (male only)	0.027	0.031	0.036	0.041
History of glaucoma (male only)	0.030	0.034	0.040	0.045
Scored low on word-recall tests (male only)	0.025	0.028	0.032	0.037
Antidepressant (male only)	0.035	0.040	0.046	0.053
All factors for <i>males</i>	0.202	0.229	0.259	0.293
All factors for <i>females</i>	0.030	0.035	0.040	0.046
<i>Odds Ratio</i>				
Annual miles driven*	1.00	1.15	1.32	1.52
Living alone*	1.37	1.36	1.36	1.36
Back pain (yes) †	1.25	1.25	1.54	1.25
Employed (male only)†	1.54	1.54	1.69	1.54
History of glaucoma (male only)†	1.70	1.70	1.69	1.69
Scored low on word-recall tests (male only)†	1.39	1.39	1.39	1.39
Antidepressant (male only)†	1.98	1.98	1.98	1.97
All factors for <i>males</i> †	11.47	11.30	11.10	10.88
All factors for <i>females</i> †	1.71	1.71	1.70	1.70

* Reference category is older drivers who drive 3,000 miles a year and who have none of the other risk factors.

† Reference category is older drivers who drive the same number of miles a year and who have none of the other risk factors.

Diagnostic tests for omitted variables in the combined-gender model showed that boredom, being severely depressed (as represented by being in the top 2–5 percent of the overall depression score), and having difficulty in extending arms over shoulders in female drivers are all significant at the 0.05 level if included individually in the final combined-gender model. The decision to exclude these variables is, therefore, somewhat arbitrary. To have a final model with all factors significant at the 0.05 level would require omitting one or more factors in the final combined-gender model (Table 1) to accommodate the borderline factors identified in the diagnostic tests. The resulting log—likelihood values for the alternative models would be approximately similar to that of the final model (in Table 1). It is interesting to note that including the variable, boredom, has the largest effect on the coefficient of the variable, use of an antidepressant by male drivers. Both variables are surrogates of depression. Similarly, including the variable, having difficulty seeing a friend across the street, appears to have the largest effect on the estimated coefficient of a history of glaucoma in male drivers. The other two borderline factors, scoring in the top 2–5 percent on the overall depression scale and having difficulty in extending their arms over their shoulder in female drivers, appear to have a more diverse effect, yielding a small change in several of the final coefficients.

7. DISCUSSION

The amount of annual driving and motor deficit (as partly reflected by the difficulty in extending arms) were the two most significant risk factors in older women being involved in crashes. When included in the model, the variable that denotes annual driving is the single most influential risk factor in crash involvement. Interestingly, when annual driving is included in the model, gender became insignificant even at the 0.10 level. This result is primarily due to the strength of annual driving in explaining the crash variation between genders.

For male drivers, being employed and cognitively disabled (partly represented by low scores on word-recall tests), having a history of glaucoma, and using antidepressants amplify the likelihood of being involved in vehicle crashes. Use of antidepressants by male drivers is the second most important risk next to the amount of annual driving. The chance of older male drivers who use antidepressant being involved in crashes is double that of identical drivers who do not use anti-depression drugs. After controlling for the amount of annual driving, we found that (a) men who scored low on a word-recall test, perhaps implying possible impaired cognition, are 40 percent more likely to be involved in vehicle crashes than men who did not, holding other risk factors constant; (b) in contrast, cognitive ability (as partially represented by low scores on a word-recall test) is irrelevant in older female drivers being involved in crashes. A possible explanation of this result is that older female drivers may cease driving before their cognition becomes a problem; (c) living alone and experiencing back pain also increase the likelihood of crash involvement.

When the amount of annual driving is included in the model, the estimated coefficient for the amount of annual driving remained robust and its significance level high ($p = 0.00001$), regardless of how many and which variables were included in the model. This result suggests that the annual-driving variable is the single most important risk factor in crash involvement. We conducted several tests and concluded that the exclusion of annual driving from the crash model leads to considerable data noise not being explained by the model and that models without this variable are likely to be incorrectly specified.

In sum, we found conclusively that the more one drives the more one is likely to be involved in vehicle crashes. This is true for both men and women. None of the commonly studied medical conditions (e.g., diabetes, heart disease, stroke, Parkinson's disease) are associated with high vehicle crash rates. One plausible explanation of this rather surprising finding is that the mere presence of any disease is not as significant a predictor of crash risk as the functional limitations caused by the disease. The only medical condition that increases crash risk

in older drivers is glaucoma. Even then, the association between glaucoma and highway crashes is only evident among older male drivers.

Another notable conclusion from our analysis is that factors, that place older women at a higher risk of crashing, are different than those for older men. In addition to the amount of annual driving, living arrangement and persistent back pain (factors common to both genders), more factors affect older men's involvement in crashes. For older men, if they are employed or cognitively disabled (partially reflected by low scores on the word-recall tests), have a history of glaucoma, and use antidepressant drugs, then they are more than six times more likely to be involved in vehicle crashes than those who do not have these factors, but live alone and suffer from persistent back pain.

There are several limitations to our study that warrant further research. First, a substantial amount of data had to be imputed due to non-responses, data gaps, and data inconsistencies. Missing data were imputed based on various rules, primarily depending on whether information was available on when a given event (e.g., onset of medical conditions, crashes) took place. Survey variables were first grouped into two categories: one with "date" information available, such as "when did you stop driving?", and one without "date" information. For variables in the first category, missing data were imputed based on the year when the event occurred. For survey variables (or events) where no date information was available, the imputation rules were primarily based on the responses recorded in the interviews both prior and subsequent to the intermittent year(s) with missing information. The rules state, for example, that if the response in the prior interview was "suspected to have" a given disease and the response in the subsequent interview was "definitely have" a given disease, then the status for having that disease in the intermittent year(s) was assumed to be positive.

These assumptions need to be validated in future studies. Validation can be accomplished by using statistical methods that handle an unbalanced panel sample. These methods allow the model's estimates to be computed either with or without the imputed data. Imputation rules can be tested to evaluate which conclusions are sensitive to which imputation rules. Results from this type of sensitivity analysis will provide an indication on the robustness of the estimates with regard to data imputation methods. Despite the extent to which data were imputed, we believe that our panel data analysis, in which risk factors were evaluated immediately prior to the crash, reduces the ambiguity in the data, thereby increasing one's confidence in the estimated models.

The second limitation to our study is that the conclusions on the impact of medication use on crash involvement are preliminary in that only partial medication use data were available at the time of our study. Medication use among older drivers adds an important dimension to the issue of older drivers' safety. The use of psychoactive drugs has been known to produce psychomotor impairment in individuals 65 years of age or older (Ray, 1992). As a result, it may interfere with older drivers' ability to safely operate a motor vehicle. While there is an extensive literature on the impacts of medication on safe driving among the younger population, little is known about how these drugs affect the driving performance and/or the crash involvement of older drivers. Ray (1992) identified three factors that make further research in this area urgent. First, psychoactive drugs are among the most frequently used medications in the older population, and this usage increases with age. Based on the 1988 National Disease and Therapeutic Index, persons 65 years or older constitute 12 percent of the U.S population but receive 29 percent of all prescriptions. Second, older drivers are more susceptible than younger drivers to the effects of many medications on the central nervous system. Finally, many functional capabilities necessary for driving decrease with age and this deterioration may reduce older drivers' capability to compensate for drug-induced impairment. To strengthen the conclusions of our present study, medication use data collected in every follow-up should be considered in future studies.

Another major limitation to this study is that its results might not be generalized readily to other populations in the country. Two factors contribute to this possible limitation. First, the two counties included in the Iowa 65+ Rural Health Study are rural counties. Traffic mix in rural areas is typically different from that in urban

areas. The effects that traffic mix and perhaps even highway geometric design and travel speed have on crash involvement are also unknown. Second, the residents in these two counties are believed not to be representative of the country. The impacts of income and employment status on driving decisions may not have been fully addressed.

We propose that this limitation be addressed by augmenting the results from this study with results from similar analysis using data from other EPESE-like sources, such as the Yale Health and Aging Project (Cornoni-Huntley, Brock, Ostfeld, Taylor and Wallace, 1980), the study of the Health and Functioning in Marin County (Reed, Satariano, Gildengorin, McMahon, Fleshman and Schneider, 1995), and the Study of Physical Performance & Age Related Changes in Sonomans. By comparing results across these studies, one can more conclusively build a consensus on the risks of older drivers being involved in vehicle crashes.

Despite these limitations and despite the probable fact that somewhat different conclusions might be reached once these limitations are appropriately addressed, we believe that a key contribution of this present work is the application of panel data analysis, which has been widely used in economics research for decades (Greene, 1993). By aligning annual status on medical conditions, functional limitations, medication use, driving behavior, and vehicle crashes, this technique takes full advantage of the information observed among individuals over time, thereby rectifying the ambiguity that arises from the absence of contemporaneous correlation in previous studies.

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