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Driving under the influence of substances and motor vehicle fatalities among older adults in the United States

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ABSTRACT

Objective: This study examines contribution of substance use (including alcohol, cannabinoids, stimulants, narcotics, depressants, and hallucinogens) on the probability of drivers being at-fault for a crash on U.S. public roads, with specific emphasis on older adult drivers.

Methods: Data from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS) for the years 2010–2018 were employed for 87,060 drivers (43,530 two-vehicle crash pairs) involved in two moving vehicle crashes. The quasi-induced exposure (QIE) method was used to compute the relative crash involvement ratios (CIRs) for each relevant substance and illicit drug. Mixed-effect generalized linear regression models were fit to examine the effect of substance use on the probability of a driver being at-fault for a crash.

Results: There were 75.51% males and 73.88% Non-Hispanic Whites in our sample. The CIR for those aged 70–79 years was 1.17, and more than double (2.56) for the $\geq$80 years old drivers, while being relatively low among drivers of ages 20 to 69. Substance use, in general, disproportionately increased the probability of being at-fault during a crash, regardless of driver's age. Though older drivers are less likely than other age groups to report substance use, presence of substances among older drivers increased the probability of their being at-fault two to four times during a crash across almost all substances. The regression models, after adjusting for driver's sex, road grade, weather, light conditions, distraction, and speeding at time of crash, revealed that older drug-impaired drivers were twice as likely to be at fault in a fatal crash (aOR = 1.947; 95% CI = 1.821, 2.082; $<$0.0001) compared to their middle-aged counterparts. Similarly, most substance use categories were responsible for the probabilities of higher CIRs among the drivers.

Conclusion: These findings necessitate continued efforts to bring awareness to the deadly consequences of "drugged driving," especially among older adult drivers.

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KEYWORDS
Older adults; motor vehicle fatality; substance use; alcohol-impaired driving; drug-impaired driving

Introduction

Life expectancy in the United States (U.S.) is projected to increase to 85.6 years in 2060, up from 79.7 years in 2017 (Vespa et al. 2018). The number of adults aged 65 years and older is estimated to reach 95 million by 2060, a figure that equates to nearly 25% of the projected U.S. population (Vespa et al. 2018). Recent evidence suggests that most older adults in the U.S. desire to maintain their independence as they age, with approximately 75% stating their preference to age in place within their own communities. These older adults also report that they would not consider alternative living conditions like home-sharing or assisted-living facilities as long as they do not need help with everyday activities, such as transportation or household chores (Binette and Vasold 2018).

For many older adults, operating a vehicle is a marker of their continued autonomy and independence. As of 2018, more than 45 million licensed drivers were aged 65 years and older in the U.S., a 60% increase since 2000 (Federal Highway Administration 2019). The ability to drive promotes social participation, access to resources/services, and is, for some, an important component of their personal identity (Babulal et al. 2019). Older adults who reduce or stop driving often report negative outcomes, such as declines in their general health as well as physical, social, or cognitive functioning (Qin et al. 2020).

Driving poses specific age-related risks for older drivers. Evidence suggests that older adults are at greater risk for adverse outcomes from road traffic crashes—i.e., bodily

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injuries and mortality—than their younger counterparts, most likely resulting from an increased vulnerability to injury in a crash. In 2019, there were 7,214 motor vehicle crash fatalities among people aged 65 and older, accounting for approximately 20% of all motor vehicle fatalities (National Center for Statistics and Analysis 2021). Further, more than 250,000 older adults were treated in emergency rooms for injuries sustained during crashes (Centers for Disease Control and Prevention 2020). The high rates of motor vehicle-related injuries and fatalities among older adults are primarily attributed to physiological changes associated with age, multiple comorbid conditions, and medication use (including polypharmacy) that may result in impairments to visual, cognitive, or psychomotor functions (Lococo et al. 2018).

Perhaps the most concerning issue, in terms of older adults' safety while driving, is the upward trend in the use and misuse of substances such as depressants (e.g., alcohol, benzodiazepines), opioids, stimulants, and cannabinoids. According to the latest National Survey on Drug Use and Health (NSDUH), binge alcohol use among adults 65 years or older rose 30.5% between 2008 and 2018; the NSDUH also reports that illicit drug use in this age group increased from 1.4% to 5.7% (more than 300%) in the same ten-year period (Substance Abuse and Mental Health Services Administration 2019). Research has demonstrated a steep upward trajectory in marijuana use among older adults, in addition to increases in prescription opioid misuse and heroin use (Perlman 2019). Between 2003 and 2014, the prevalence of marijuana use increased significantly from 0.15% to 2.04% (Han and Palamar 2020). The number of U.S. adults aged 55 years and older entering substance use treatment for the first time to address heroin use doubled—from 2,725 in 2012 to 5,636 in 2015 (Perlman 2019).

Although specific evidence pertaining to the influence of substance use/misuse on motor vehicle crashes and their associated injuries and deaths among older adults is limited, previous studies indicate relationships among these factors within the general population. People of all ages who drive under the influence of alcohol are at higher risk of motor vehicle crashes and related problems than those who do not drink (Bunn et al. 2019). However, as noted previously, older drivers tend to be more seriously hurt in crashes than younger drivers; alcohol further increases these age-related risks (National Center for Statistics and Analysis 2021). In the U.S., an average of one alcohol-impaired driving fatality is reported every 52 minutes, which is approximately 28 deaths each day (National Center for Statistics and Analysis 2019). In 2019, there were 10,142 deaths related to crashes involving drivers under the influence of alcohol (National Center for Statistics and Analysis 2019). The proportion of alcohol-impaired drivers aged 65 years and older rose to 16% in 2019, an increase of 4% compared to 2010 (National Center for Statistics and Analysis 2019). Several studies have linked substance use with fatal crashes based on data from the comprehensive US Fatality Analysis Reporting System (FARS) database. For instance, there is an increased risk of fatal crash involvement among drivers testing positive for alcohol, marijuana, narcotics, stimulants, and/or depressants (Bunn et al. 2019). The use of prescription opioids among drivers has been associated with an increased incidence of two-vehicle crashes, independent of alcohol use (Chihuri and Li 2019); in other studies, positive synergistic effect of fatal crash risk has been reported among people concurrently using prescription opioids or marijuana with alcohol (Li and Chihuri 2019).

Psychoactive prescription medications (e.g., benzodiazepines), pain medications, and medications for sleep are some of the common drugs used by older adults (Blow and Barry 2012). The use of benzodiazepines in older adults has been associated with a 60% (in case-control studies) to 80% (in cohort studies) increase in the risk of motor vehicle crashes, while the co-ingestion of benzodiazepines and alcohol resulted in over a seven-fold increase in the risk for a crash (Dassanayake et al. 2011). Evidence also shows that the use of tricyclic antidepressants was associated with a higher risk of crashes for drivers aged 65 years or older (Dassanayake et al. 2011). The prevalence of prescription opioids detected in drivers in fatal crashes increased significantly from 2.0% in 1993 to 7.1% in 2016, with opioid-influenced drivers above age 65 being twice as likely to have initiated the crash than their middle aged counterparts (Chihuri and Li 2019). The same study found that, among drivers of all ages who tested positive for opioids, about 30% had higher blood alcohol concentrations and almost 67% tested positive for other substances such as depressants, stimulants, and marijuana (Chihuri and Li 2017). Other, small-scale, state-level studies indicate a 65% likelihood of testing positive for alcohol, and about 27% for polysubstance use ($\geq$2 substances) among drivers involved in a crash between 2010 and 2016 (Faryar et al. 2018). Thus, combined with the effects of aging, substance use by older drivers presents a potentially significant increase in the risk of motor vehicle injuries and fatalities.

While the literature has explored the risks posed by older drivers in operating motor vehicles and the increased likelihood of collision associated with substance use, the impact of substance use among older drivers has not been extensively investigated. In this study, we examine contributions of substance use and illicit drugs (including alcohol, cannabinoids, stimulants, narcotics, depressants, and hallucinogens) on the probability of drivers being at fault for a crash, with specific emphasis on older adult drivers. Using the quasi-induced exposure (QIE) method, the study results will advance the understanding of contributing factors to motor vehicle fatalities among older adults, including the role of substance use on motor vehicle fatalities among this subgroup, and help inform potential preventative measures.

Methods

Data and sampling

We used the Fatality Analysis Reporting System (FARS) nationwide database that archives data on fatal injuries sustained in motor vehicle crashes on U.S. public roads. FARS data have been collected by the National Highway Safety Administration since the early 1970s. Each motor vehicle

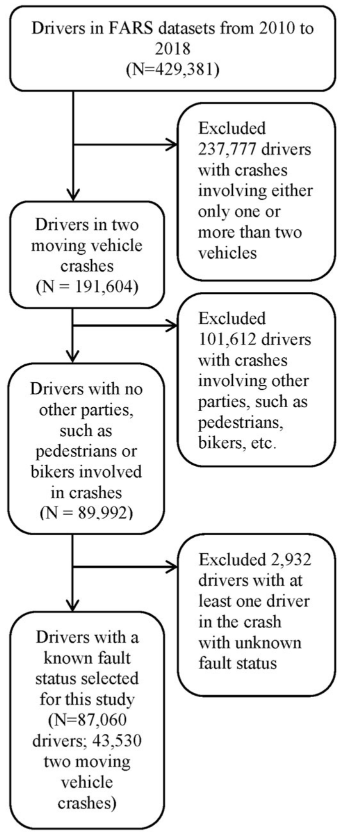

Figure 1. A flow chart depicting the study sample selection process.

crash recorded in the FARS must have occurred on a public road and resulted in the death of at least one person (either the occupant of a vehicle or a non-motorist) within 30 days. FARS data are publicly available and can be accessed on the United States Department of Transportation website (i.e., www.nhtsa.gov). For the current study, we downloaded and compiled FARS data from 2010 to 2018, consisting of 429,381 records for drivers. Our sample included 87,060 drivers involved in two moving vehicles crashes with their drivers at the scene of the crash. Figure 1 depicts a flowchart of our inclusion/exclusion criteria.

Variables

Primary independent variables of interest were the tested presence of alcohol and other drugs in the drivers involved in the crashes. These variables were based on confirmatory results of lab evaluations and other drug tests; all these drug categories, except for alcohol, were treated as binary variables, "yes" or "no." A measure of alcohol was developed based on blood alcohol concentration (BAC) in grams per deciliter (g/dl) and categorized as "0.00," "$>$0.00 to $<$0.08," "$\geq$0.08 to $<$0.10," and "$\geq$0.10." For the next five drug categories (cannabinoids, stimulants, narcotics, depressants, and hallucinogens), a positive test was assigned as "yes," and a negative was labeled "no." Finally, from the dataset, other drugs were grouped and dichotomized as "Other drugs" into "yes" or "no."

Several demographic and explanatory variables were included in the analysis and can be viewed in Tables A1 and A2 in the Supplementary Material. We incorporated self-reported sex as a binary variable, i.e., "male" or "female;" race and ethnicity categorizations were as follows: "non-Hispanic White, "non-Hispanic Black," "Hispanic," and "All others." Age was reported in years and categorized in the interval of 10 years starting with $<$ 20 years and proceeding to $\geq$80 years. The location of the crash was categorized as "urban" or "rural" (see Table A1 in Supplementary Material). For the linear regression analysis, we stratified the drivers' ages into three categories: "$\leq$ 29 years (young)", "30 to $\leq$ 69 years (middle-aged)", and "$\geq$ 70 years (older)".

Other explanatory variables included environmental factors and driver-related factors. They comprised road grade: "no grade" or "some grade" (including unknown slope either up or down-hill, hillcrest, or sag bottom); weather conditions during the crash: "clear" or "not clear" (including rain, sleet or hail, snow, fog, smog, smoke, severe crosswinds, blowing sand or other debris, cloudy, blowing snow, or freezing precipitation); light condition: "daylight" or "not daylight" (including lighted dark, not lighted dawn, dusk, and dark); whether the driver was distracted: "no distraction" or "some distraction" (including looked but did not see, distracted by other occupant or a moving object in vehicle, and adjusting audio or climate controls); and whether the driver was speeding before the crash: "not speeding" or "speeding" (see Table A1 in Supplementary Material). We included these as model co-variates, as they are verified risk factors of fatal traffic crashes associated with alcohol or drug impairment (Valen et al. 2019; Talwar et al. 2020).

Statistical analysis

We employed the quasi-induced exposure (QIE) method in this study (Stamatiadis and Deacon 1997; Jiang et al. 2014). QIE analysis is a powerful and popular technique that has been widely implemented by traffic safety researchers in a variety of settings to obtain traffic exposure information and to measure the relative exposures of groups of drivers/vehicles to crash risks and estimate their relative crash propensities (Stamatiadis and Deacon 1997; Jiang et al. 2014; Zhao et al. 2019). When seeking to identify factors that contribute to a crash, it is paramount to examine crash exposure risks (Sagar et al. 2020). The QIE method provides great potential in safety analysis due to its simplistic data requirements and its capacity to derive the disaggregated exposure estimates directly from the crash data (Stamatiadis and Deacon 1997; Jiang et al. 2014). The crash-rate exposure in QIE analysis is measured in terms of the relative crash involvement ratio (CIR); this ratio is computed by measuring the ratio of the percentage of the at-fault drivers to the percentage of the not-at-fault drivers in the same subgroup (cohort) of drivers, assuming that not-at-fault drivers representing the total population under investigation (Jiang et al. 2014; Zhao et al. 2019). A ratio of $>$1 indicates that a driving group results in disproportionately more crashes on the road while a ratio $<$1 represents otherwise (Jiang et al. 2014).

One major underlying assumption of the QIE approach is that the not-at-fault drivers are a fair representation of the general driving population at the location and time of the crash on the road (Curry et al. 2016). This means they act as a random sample of the non-responsible crash-involved drivers on the road at the time and location of crash occurrence, hence, a metric of exposure (Zhao et al. 2019). This assumption has been verified and validated in various settings, populations, locations, and in crashes involving two or more vehicles (Curry et al. 2016; Shen et al. 2019; Zhao et al. 2019). All studies conclude that QIE is a promising technique for estimating exposure in safety analysis. In addition, some of the prominent applications of QIE in traffic safety research include measuring crash risks of specific drivers grouped by age and gender (Mueller et al. 2007; Jiang and Lyles 2011; Zhao et al. 2019), investigating crash risk for drivers under the influence of alcohol (Hours et al. 2008), studying fatal crash risks for drivers with infant and child passengers (Maasalo et al. 2019), evaluating socio-economic and demographic attributes to crash risks (Stamatiadis et al. 2020), assessing the effectiveness of graduated driver licensing programs (Jiang and Lyles 2011), and the crash propensity of various driver/vehicle characteristics (Stamatiadis and Deacon 1997).

Following Stutts et al. (2009), we used driver-related factors and violation charges to create a new variable that establishes each driver's responsibility for the crash—i.e., being "at-fault" and "not-at-fault." Driver-related factors included careless driving, aggressive driving/road rage, being mentally challenged, and other factors. Violations charges included manslaughter or homicide, willful reckless driving, driving to endanger, negligent driving, unsafe reckless driving, fleeing or eluding police, serious violation resulting in death, and other violations. We dichotomized these variables; those who had no violation charges and no driver related factors were categorized as "not-at-fault" while those who either had any violation charge or a driver related factor were categorized as "at-fault" [see Appendix B of Stutts' (2009) study for details]. We then excluded records of two-vehicle crashes that had missing values for the fault variable, resulting in a final study sample of 87,060 drivers (43,530 two-vehicle crash pairs) with known "fault" information (see Figure 1).

In this study, we first analyzed frequencies and percentages for each variable of interest stratified by the drivers' age (see Table A1 in Supplementary Material). Then, we computed the crash involvement ratio (CIR) for each of these measures (see Table A2 in Supplementary Material). The CIR compared the ratios of "at-fault" to "not-at-fault" drivers within a specified group. This number directly indicated the degree of involvement of drivers' fault and crash responsibility with respect to a particular risk factor. We also illustrated the CIR for the key variables in graphic format (see Figures 2–8). We conducted additional analysis to examine dose-response relationship between BAC and CIR (see Table 1). Following the strategy adopted by Zhang et al. (2019), we then used mixed effect generalized linear regression modeling to study the association of age categories and substance use with the binary outcome: crash responsibility (Zhang et al. 2019). In addition to the fixed effects, the mixed effect model also includes a random effect (i.e., CrashID) to account for the unobserved elements of

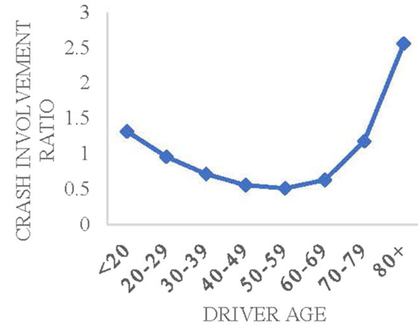

Figure 2. Crash involvement ratio by age (baseline).

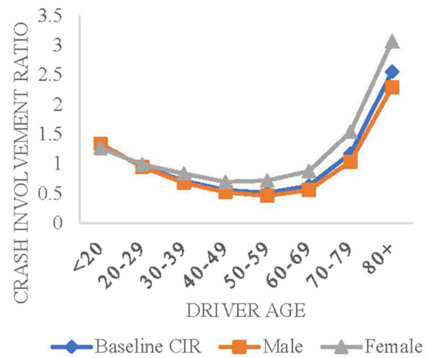

Figure 3. Crash involvement ratio by gender.

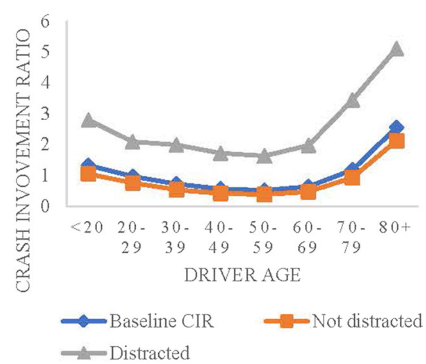

Figure 4. Crash involvement ratio for distraction.

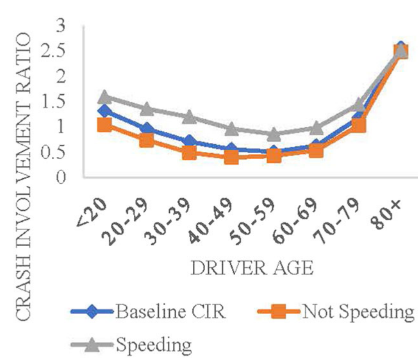

Figure 5. Crash involvement ratio for speeding.

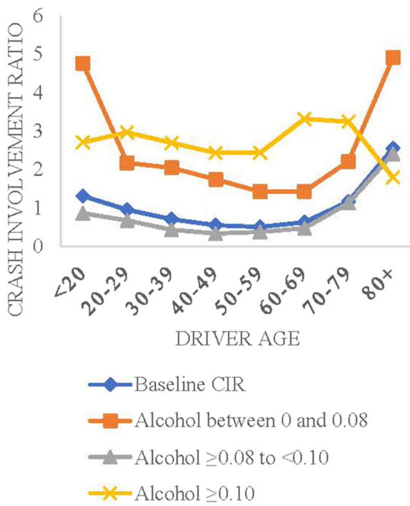

Figure 6. Crash involvement ratio for alcohol (BAC).

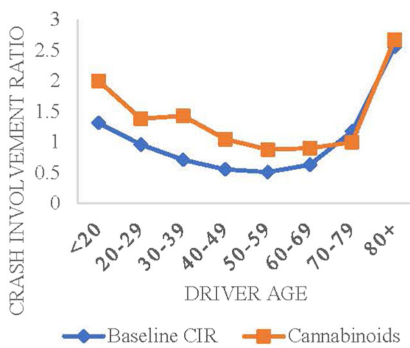

Figure 7. Crash involvement ratio for Cannabinodis.

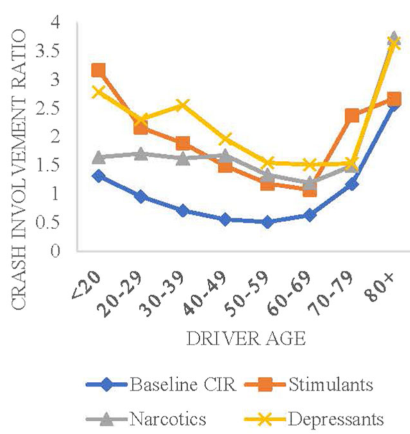

Figure 8. Crash involvement ratio for stimulants, narcotics, depressants.

Table 1. Dose-response relationship between BAC and CIR.

Blood alcohol level (BAC)in g/dl	Frequency	Crash involvement ratios (CIR)
≥0.08 to <0.10	20,786	0.55
≥0.1 to <0.2	1,830	2.45
≥0.2 to <0.3	1,124	3.10
≥0.3 to <0.4	206	3.90

Note: Analysis was not conducted for BAC ≥0.4 due to small *n* values (a total of 39).

substance use. The adopted mixed effect generalized linear model (which includes a random effect) is similar to the conditional logistic regression in terms of computing equivalent estimates. However, the rationale for employing a mixed effect model in this study was due to its computation convenience, given the large sample size. Fitting the data using a random effects model provided a more efficient approach compared to conditional logistic regression model. The analysis was conducted by PROC GEE using SAS 9.4 statistical software (SAS Institute Inc, 2018).

Results

In the final study sample, 75.51% were males and 24.49% females. Non-Hispanic Whites made up the majority (73.88%), followed by the non-Hispanic Black population (11.61%). Hispanic people made up 10.47% of the sample, with all other racial and ethnic sub-groups accounting for 4.04%. Only 21.37% of the total sample tested negative for any alcohol or drug at all, and 53.65% had no alcohol involvement (negative alcohol test). At least some alcohol was detected in 46.35% of the study sample. Nearly 15% of the study sample reportedly had no alcohol but some drug involvement. In terms of drug categories, 4.70% tested positive for cannabinoids, 3.30% for stimulants, 3.01% for narcotics, 2.72% for depressants, only 0.16% for hallucinogens, and 4.16% for "other drugs."

A variety of driving-related factors were also measured, including situations both outside and inside the vehicle. For example, approximately one-fourth (24.29%) of the drivers were on graded roads (on slopes, hillcrest, sag, uphill, downhill, etc.). While the majority of drivers (73.74%) were involved in crashes during clear weather, 26.26% occurred in "not clear" conditions, which may include rain, sleet or hail, snow, fog, smog, smoke, severe crosswinds, blowing sand, soil, dirt, cloudy, blowing snow, or freezing rain. Most crashes occurred during daylight (62.31%) and 37.69% were at night or in other low-light conditions such as dawn or dusk. Other driver-related factors taken into consideration included distracted driving (e.g., looked but did not see, distracted by other occupant or movement within the vehicle, or adjusting audio/climate control) and vehicular speed. About 19% of the crashes involved some distraction and 21.85% involved speeding (See Table A1 in Supplementary Material).

The CIR among drivers under 20 years of age was higher (1.31) compared to those in age categories between 20 and 69 years (ranging from 0.51 to 0.96), but CIR rose again to 1.17 for 70–79 years and more than doubled to 2.56 for the ≥80 subgroup (See Table A2 in Supplementary Material and Figure 2). Although youth of both genders pose a similar crash risk, the risk potential attributed to older men exceeds that of young drivers, and the CIR for older women is far greater than that of older men. Men's CIR increases nearly one full point, from 1.34 when they are <20, to 2.29 at ≥80 years old, while women's CIR more than doubles from age <20 (1.27) to age ≥80 (3.07) (see Table A2 in Supplementary Material and Figure 3). Overall, non-Hispanic Whites had higher CIR (1.14) in comparison to all other races and ethnicities. The CIR of non-Hispanic White people increased from 1.72 when they were <20, to 2.83 at ≥80 years old while Hispanic CIR increased from 1.79 when they were <20, to 2.77 at ≥80 years old. The non-Hispanic Black group had a lower CIR (0.95) than the non-Hispanic White population

(1.14) throughout the age spectrum other than for <20 years (see Table A2 in Supplementary Material). Environmental factors such as road grade, weather, and light conditions did not affect CIR; however, distracted driving (2.08) and speeding (1.18) led to higher CIR in the study sample (See Table A2 in Supplementary Material and Figures 4 & 5).

Results revealed an overall gradient effect of higher than BAC ≥0.08 leading to higher CIR, indicating a dose-response relationship between BAC and CIR (see Table 1). Moreover, "BAC >0.00 and <0.08" subgroup and BAC ≥0.10 had twice (1.91) and almost three times (2.73) CIR, respectively, compared to no BAC subgroup (0.86) (See Table A2 in Supplementary Material). However, there was an increasing probability of higher CIR for drivers above the age of 70 years, and even more so for those ≥80 years of age (See Table A2 in Supplementary Material and Figure 6). The CIR for drivers ≥80 years under the influence of cannabinoids or "other drugs" (2.67 and 2.88) was higher than those <20 years of age (2.00 and 1.93) (See Table A2 in Supplementary Material and Figure 7). Similarly, for drivers ≥80 years of age and under the influence of narcotics or depressants, CIR was higher (3.72 and 3.63) compared to drivers <20 years (1.64 or 2.78) (See Table A2 in Supplementary Material and Figure 8). However, the CIR for older drivers with stimulants in their systems was lower (2.67 for those ≥80 years subgroup) than younger drivers (3.17 in the <20 years subgroup) (See Table A2 in Supplementary Material and Figure 8).

Table 2 presents the adjusted Odds Ratios (OR) using mixed-effect generalized linear regression models. After adjusting for drivers' sex, road grade, weather, light conditions, distraction, and speeding at the time of the crash, the results revealed that both young (adjusted [a] OR = 1.337; 95% CI: 1.269, 1.408; $p < 0.0001$) and older adult drivers (aOR = 1.947; 95% CI: 1.821, 2.082; $p < 0.0001$) had higher odds of crash responsibility compared to middle-aged drivers (see Table 2). In terms of alcohol, those who had BAC between >0.00 and <0.08 had higher odds of crash responsibility (aOR = 1.759; 95% CI: 1.596, 1.937; $p < 0.0001$), whereas those with BAC ≥0.10 had almost two and a half times (aOR = 2.462; 95% CI: 2.106, 2.884; $p < 0.0001$) probability of crash responsibility. Use of cannabinoids (aOR = 1.232; 95% CI: 1.098, 1.383; $p = 0.0004$); stimulants (aOR = 1.485; 95% CI: 1.296, 1.705; $p < 0.0001$); narcotics (aOR = 1.389; 95% CI: 1.215, 1.588; $p < 0.0001$), and depressants (aOR = 1.654; 95% CI: 1.447, 1.889; $p < 0.0001$) were associated with higher odds of crash responsibility when compared to their counterparts who tested negative for those substances. Again, those with a positive result for "other drugs" had higher crash responsibility by about 38% (aOR = 1.380; 95% CI: 1.247, 1.528; $p < 0.0001$) compared to drivers who tested negative for "other drugs" (see Table 2).

Table 2. The mixed-effect generalized regression modeling, adjusted for drivers' sex, road grade, weather, light conditions, distraction, and speeding at the time of crash.

Characteristics	Adjusted OR	95% CI
Age (Ref: middle-age 30 to ≤ 69 years)		
Young (≤ 29 years)	1.337	(1.269, 1.408)*
Older (≥70 years)	1.947	(1.821, 2.082)*
Alcohol (BAC) (Ref: 0.00 g/dl)		
>0.00 to <0.08	1.759	(1.596, 1.937)*
≥0.08 to <0.10	0.785	(0.745, 0.828)*
≥0.10	2.464	(2.106, 2.884)*
Cannabinoids (Ref: no Cannabinoid)		
Cannabinoids	1.232	(1.098, 1.383)*
Stimulants (Ref: no Stimulants)		
Stimulants	1.485	(1.296, 1.705)*
Narcotics (Ref: no Narcotics)		
Narcotics	1.389	(1.215, 1.588)*
Depressants (Ref: no Depressants)		
Depressants	1.654	(1.447, 1.889)*
Hallucinogens (ref: no Hallucinogens)		
Hallucinogens	0.974	(0.593, 1.601)ns
Other drugs (Ref: no Other drugs)		
Other drugs	1.380	(1.247, 1.528)*

Abbreviations: OR, Odds Ratio; CI, Confidence Interval; Ref, Reference group; BAC, Blood Alcohol Concentration; g/dl, grams per deciliter.
*P-value <.001.
[ns]P-value: Not significant.

Discussion

Millions of drivers aged 70 years and older operate motor vehicles across the U.S. each year (Federal Highway Administration 2019). Accumulated evidence suggests that older drivers are more prone than others to experience adverse health outcomes (i.e., bodily injury or death) as a result of motor vehicle crashes (National Center for Statistics and Analysis 2021). Although few studies have examined the relationship between substance use and motor vehicle crashes, injuries, and fatalities, extant research suggests that these factors may be linked (Adeyemi et al. 2022). Therefore, data indicating increase in binge drinking and illicit drug use among the older U.S. population is concerning (Perlman 2019). This study employed the QIE technique to better understand the relationship between substance use and motor vehicle crash risk among drivers on public roads, with an emphasis on older drivers.

Our analyses suggest that drivers in all age categories had higher probability for being at-fault for a crash on U.S. public roads when they tested positive for alcohol and/or other drugs. Older drivers (i.e., those 70 years or older), however, had much higher probability of being at-fault for a crash in each substance category (i.e., alcohol, cannabinoids, stimulants, narcotics, depressants, and other drugs). The mixed-effect generalized modeling results, adjusted for drivers' sex, road grade, weather, light conditions, distraction, and speeding at the time of crash showed that in almost all situations, drivers under the influence of alcohol or drugs had higher odds of being at-fault for crash responsibility compared to their counterparts.

Previous studies suggest that older adults tend to underreport substance use behavior compared to younger individuals (Rockett et al. 2006), and the recent National Survey on Drug Use and Health (NSDUH) data indicate that substance use behaviors—including binge drinking, opioid misuse, and illicit drug use—have significantly increased in recent years among older adults (Schepis and McCabe 2021). In addition to the general health risks associated with substance use and misuse among the older population (Schepis and McCabe

2021), our findings indicate that these behaviors, when coupled with the desire to continue driving, may increase the likelihood that older adults will be at-fault for crashes on U.S. public roads. It is also important to understand that the elevated fatal crash risk among older drivers, as compared to younger drivers may be due largely to their increased vulnerability to injury and reduced capacity to recover from crash impact-related injuries, rather than a greater tendency to get into crashes (Cicchino and McCartt 2014). Furthermore, higher use of prescription medications, including using multiple pharmaceuticals with potential drug interactions, as well as slowing of metabolism and drug clearance may result in impaired driving among older drivers (Hill et al. 2020)

There are some limitations to this study. Although we used a large multi-year national dataset, its cross-sectional nature makes it difficult to determine causal relationships between the dependent and independent variables. There were also missing observations in the FARS dataset, which may present a barrier to identifying significant trends or relationships in this study. This database includes only fatal crashes and limits us from analyzing how alcohol and other drug use might affect casualty rates due to non-fatal crashes. The data only provide information about drug presence and do not indicate whether the drug was prescribed or illicit, or if the driver was impaired by a drug. It is usually difficult to evaluate at what level a driver is impaired by different substances (other than alcohol) from the dataset, and it is unknown how polysubstance use might exacerbate impairment. Also, the reported alcohol data for the BAC $\geq$0.08 to $<$0.10 subgroup does not seem consistent with the expected crash responsibility, given the higher BAC in this category. However, it is not possible for us to discern the actual problem associated with available data for this category in the FARS dataset. Furthermore, the drug testing and reporting protocols across states and jurisdictions are not uniform. Only fatally injured drivers are tested in some jurisdictions; others test every driver involved in fatal crashes or perform no test at all. Thus, a jurisdiction that performs more tests is likely to have a higher percentage of drug positive drivers (Berning and Smither 2014). Moreover, a combination of blood alcohol level tests and the subjective assessment of investigating police officers at the scene of crash is used by FARS to ascertain that alcohol or drugs are involved in each crash, thereby limiting our ability to distinguish between different levels of intoxication. As previously noted, the higher odds of CIRs among older drivers need to be assessed carefully considering the generally lower substance use reported by this subpopulation.

Our findings indicate the need for concentrated efforts to prevent both drunk and drugged driving for all age groups, but especially among older adults. Specific to limiting driving while intoxicated (DWI), evidence suggests that the most effective deterrents are strong DWI laws, enforcement of such laws, and the regular use of sobriety checkpoints (Ferguson 2012). These strategies would ideally be accompanied by educational interventions to increase knowledge of such laws. At least one recent study suggests that the majority of U.S. drivers aged 70 years and older are unaware of their state's blood alcohol content (BAC) legal limit, and as noted, "even if they were aware of the limit, it is unlikely that such drivers are aware of their actual BAC before getting behind the wheel" (Talwar et al. 2020). Hence, there is also a need for anti-DWI campaigns tailored to older adults; such campaigns have been shown to moderately reduce fatal crash rates (Niederdeppe et al. 2017). Evidence-based strategies for preventing drugged driving are less clear, as many preliminary interventions have yet to be evaluated, leaving many prevention specialists feeling unprepared to address drugged driving (Stelter et al. 2019). As prevention specialists and other healthcare professionals continue developing best practices for deterring drugged driving, they should ensure that their intervention efforts address the specific needs of older adults.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Disclosure statement

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Data availability statement

The Fatality Analysis Reporting System (FARS) is a nationwide database that archives data on fatal injuries suffered in motor vehicle traffic crashes; it is publicly available on the United States Department of Transportation website: www.nhtsa.gov.

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