Original Research Article

Quantifying Blood Alcohol Concentration (BAC) Effects on Driver Behavior, Collision Manner, and Injury Severity: An Observational Analysis with Demographic Predictors

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ABSTRACT

This study explores driver behavior through correlational relationships between different variables and crash-related factors, particularly in the form of alcohol use. Though alcohol consumption being a risk factor contributing to car crashes had already been the focal point of previous studies, its amount and impact on different aspects of crashes remains relatively unexplored. Using crash data (sample size: n = 6,963) from the Fatality Analysis Reporting System (FARS) published by the National Highway Traffic Safety Administration in 2023, three individual models (one logistic regression and two multinomial logistic regressions) were developed to analyze the effects of alcohol consumption and other control variables on an individual's seatbelt usage, injury severity sustained, and collision manner experienced. It was determined that alcohol usage had substantial effects on crash-related factors by significantly reducing seatbelt usage, increasing the likelihood of severe injury, and had some influence on shaping the type of collision experienced. Other variables, age and sex, played a smaller role in influencing these factors. This research reinforces the dangers of alcohol usage through not only strengthening its identity as a risk factor to crashing but expanding on its impacts on other components as well, stressing the importance of shaping drivers to operate vehicles alcohol-free.

Keywords: Driver Behavior; Alcohol Use; Blood Alcohol Concentration (BAC); Seatbelt Use; Injury Severity; Collision Manner; Logistic Regression; Binary Logit; Multinomial Logit

INTRODUCTION

Road traffic crashes have been a major component of the global public health crisis. It has been ranked as the leading cause of death among children and young adults

aged 5-29 years and has claimed the lives of more than 1.19 million people each year (1). In addition to physical harm and the loss of life, road traffic crashes also lead to substantial costs in regard to economic and social factors, hinder global productivity, and apply pressure on healthcare systems. Today more than ever, we are relying on automobiles daily as a primary form of transportation (2). Thus, understanding key risk factors in automobile collisions is a crucial step for researchers to take in hopes of subsiding and ideally preventing these traffic crashes altogether, as injuries and fatalities from motor vehicle

collisions can be avoided by following appropriate precautions and safety rules (3).

There exist many key factors that contribute to and increase the risk of traffic crashes, and alcohol consumption remains one of the most prominent and influential: multiple studies consistently display the disproportionate severity and unpredictability of alcohol-related crashes (4). For example, a 2016 U.S. study found that more than half (54.8%) of crash-involved drivers tested positive for alcohol or drugs (5). Furthermore, international data support these findings as well: a multicounty European investigation revealed that between 31% and 48% of fatally injured drivers had psychoactive substances in their blood, with alcohol being the most prevalent (6). Alcohol consumption impairs reaction times, reduces judgment, and promotes risky behavior, all of which elevate the likelihood of high-severity crashes. This endorses the idea that, compared to their non-alcohol counterparts, alcohol-related collisions are more likely to be correlated with abnormal driver behavior along with heightened injury severity.

To dive deeper into the details of alcohol consumption affecting traffic crashes, the level of blood alcohol concentration (BAC) should also be considered. There exist numerous past studies that have categorized drivers as binary variables of either "drinking" or "non-drinking" (7, 8); however, this overlooks the more nuanced influence of different levels of BAC and doesn't consider whether the quantity of alcohol have any impacts, when it's likely that factors such as driver behavior, crash severity, and collision classifications depend on varying BAC levels (9). This research gap now manifests itself in the lack of consideration regarding the actual quantity of BAC in crash data analysis. This study addresses such limitations by evaluating and analyzing results based on detailed BAC measurements from the National Highway Traffic Safety Administration (NHTSA), allowing a deeper dive into not only the presence, but the quantitative measurements of, alcohol levels present during traffic crashes.

Therefore, this paper focuses on three crash-related outcomes which may be influenced by alcohol consumption: driver behavior, injury severity, and collision manner. Driver behavior will be defined as restraint (seatbelt) usage as a proxy measure (note: "driver behavior", "restraint usage", and "seatbelt usage" will be used interchangeably throughout this study), injury severity reflects the physical effects of traffic crashes, and collision manner describes the way

in which the crash occurred. Similarly to studying alcohol, these factors have also been the main area of study with past research. However, they are rarely discussed together in a single study, and even less so linked explicitly to BAC levels. By using multinomial logic regressions, these factors are now able to be linked together, and it is made possible to evaluate how varying BAC amounts, along with control characteristics like age and gender—may predict these outcomes.

In summary, this study contributes to preexisting literature by incorporating quantitative measurements in replacement of a binary approach to alcohol usage, analyzing the effects of BAC levels on different factors of traffic crashes. This allows for a more detailed and nuanced understanding of how alcohol influences traffic safety, focusing on its amount rather than presence. The study demonstrates how BAC levels may influence and predict driver behavior, injury severity, and collision manner; and to current knowledge, remains one of few studies to conduct comprehensive analysis regarding all aforementioned factors in hopes of providing new insights into alcohol-related traffic accidents and inspiring more effective preventative strategies for these crashes.

METHODS AND MATERIALS

Data Source

All data used in this study were obtained from a publicly available national database. Specifically, the National Highway Traffic Safety Administration (NHTSA), part of the U.S. Department of Transportation, maintains the Fatality Analysis Reporting System (FARS). FARS provides recordings of detailed information regarding vehicle crashes in the United States each year since 1975. Since the 2023 FARS dataset is the most recent to date, the information provided during that year was used in this study, allowing for the most relevant and accurate analysis. Included in this dataset are the variables used in this study, age, sex, BAC level, restraint usage, injury severity, and collision manner, but also contains a multitude of other categories that can be the focus of future studies.

The raw 2023 FARS dataset contains approximately 92,400 individual records and 125 variables. However, not all variables were relevant to the purpose of this study, and not all individual records held complete information across all variables used in this study. Therefore, entries that did not contain information or were marked as "unknown" regarding BAC test results,

restraint use, injury severity, and collision manner were excluded from the refined data to ensure consistency and comparability across models. This resulted in a final sample size of 6,963 records.

Variable Selection and Coding

The variables included in the study were chosen based on relevance to the research objectives: the ability to capture variations in driver behavior, injury severity, and collision manner in relation to BAC levels. The final data set consisted of a primary predictor variable (BAC) and three dependent variables (driver behavior, injury severity, and collision manner) to display the different relationships of different variables regarding traffic crashes. Demographic variables (age and sex) were also included in the final data.

Age and Sex

Age was maintained as a continuous variable representing the driver's age in years at the time of the crash. Sex was coded dichotomously (1 = male, 2 = female) and was kept consistent with the original FARS classifications.

Blood Alcohol Concentration (BAC)

BAC was derived from FARS' coded variable, reflecting the results of official toxicology tests. In the FARS dataset, BAC values range from 0 to 939, representing the actual BAC multiplied by 1000 (for example, a recorded value of 80 corresponds to an actual BAC of 0.08 g/dL). A value of 940 indicates a BAC of 0.94 g/dL or greater. In the data used for this study, the values were converted to standard units (grams per deciliter) for analysis by dividing each value by 1000. BAC was treated as a continuous variable in all primary models (Table 1).

Table 1. "Blood Alcohol Concentration" numerical values and corresponding meanings used in model analysis

Numerical Value	Description
0-939	Actual Value of BAC Test
940	≥ 0.94 g/dL

Driver Behavior (Restraint Use)

Restraint, or seatbelt use, served as a proxy for driver behavior. The original dataset classified restraint

systems into 14 different categories (e.g., shoulder belt only used, lap belt only used, shoulder and lap belt used, other, etc.). For simplicity, these were reclassified into a simple binary variable (0 = not restrained, 1 = restrained) (Table 2).

Table 2. "Restraint Use" numerical values and corresponding meanings used in model analysis

Numerical Value	Description
0	Not Restrained
1	Restrained

Injury Severity

Injury severity followed FARS' original categorical scale, excluding the descriptions of "unknown severity", "died prior to crash", and "unknown/not reported" (detailed below). For regression analysis, injury severity was modeled as a multinomial outcome, with "No Apparent Injury" serving as the base category (Table 3).

Table 3. "Injury Severity" numerical values and corresponding meanings used in model analysis

Numerical Value	Description
0	No Apparent Injury
1	Possible Injury
2	Suspected Minor Injury
3	Suspected Serious Injury
4	Fatal Injury

Collision Manner

Collision manner recounts the impact type between vehicles during the crash, "describing the orientation of two motor vehicles in-transport when they are involved in the "First Harmful Event" of a collision crash". Collision manner also followed FARS' original categorical scale (detailed below).

Similar to injury severity, this outcome was modeled using a multinomial logistic regression, with the lowest coded crash type serving as the base category (Table 4).

Models

Three regression models were developed to assess the association between BAC and each crash-related outcome, controlling for demographic characteristics.

Table 4. "Collision Manner" numerical values and corresponding meanings used in model analysis

Numerical Value	Description
0	First Harmful Event was Not a Collision with Motor Vehicle In-Transport
1	Front-to-Rear
2	Front-to-Front
6	Angle
7	Sideswipe- Same Direction
8	Sideswipe- Opposite Direction
9	Rear-to-Side
10	Rear-to-Rear

Driver Behavior Model

A binary logistic regression estimated the likelihood of seatbelt use as a function of BAC, age, and sex. The equation used is detailed below (10):

$$log\frac{P(belted=1)}{P(belted=0)} = \beta_0 + \beta_1 BAC + \beta_2 Age + \beta_3 Sex \quad (1)$$

Where P(belted=1) is the probability that the driver is wearing a seatbelt, P(belted=0) is the probability that the driver is not wearing a seatbelt, β_0 is the intercept, and β_1, β_2, and β_3, are the coefficients of BAC, age, and sex respectively.

Injury Severity Model

A multinomial logistic regression estimated the relative risk of each injury severity category compared to the "no injury" baseline. The equation used is detailed below (11):

$$log\frac{P(Y=j)}{P(Y=b)} = \alpha_{0j} + \alpha_{1j} BAC + \alpha_{2j} Age + \alpha_{3j} Sex \quad (2)$$

Where Y is the injury severity outcome, P(Y = j) is the probability of being in severity category j (e.g. possible injury, suspected serious injury), P(Y = b) is the probability of being in the baseline (no injury) category, α_{0j} is the intercept for j, and α_{1j}, α_{2j}, and α_{3j}, are the coefficients of BAC, age, and sex respectively.

Collision Manner Model

Another multinomial logistic regression was applied to assess how BAC predicts the type of collision, again controlling for age and sex. The equation used is detailed below:

$$log\frac{P(Y=j)}{P(Y=b)} = \gamma_{0j} + \gamma_{1j} BAC + \gamma_{2j} Age + \gamma_{3j} Sex \quad (3)$$

Where Y is the collision manner outcome, P(Y = j) is the probability of being in collision manner j (e.g. front-to-front, angle), P(Y = b) is the probability of being in the baseline (front-to-rear) category, γ_{0j} is the intercept for j, and γ_1, γ_{2j}, and γ_{3j} are the coefficients of BAC, age, and sex respectively.

All regression analyses were performed using Python (Google Colab). The models were evaluated based on coefficient estimates, odds ratios, and significance levels ($p < 0.05$), providing a detailed understanding of how BAC levels relate to driver behavior, injury severity, and collision dynamics.

RESULTS

Model 1 evaluated restraint usage through a binary logistic regression, while Models 2 and 3 used multinomial logistic regression to assess injury severity and collision manner respectively. Across all models, BAC was treated as the primary predictor, with higher values representing greater alcohol intoxication. All analyses used robust standard errors in order to account for potential heteroskedasticity.

Driver Behavior (Restraint Use) Model

The binary logistic regression for Model 1 examined whether BAC levels predicted the likelihood of seatbelt use while controlling for age and sex. As shown in Table 5, results indicated a significant negative association between BAC and seatbelt use, meaning that drivers who were recorded having higher BAC values were substantially less likely to wear seatbelts compared to their sober counterparts, suggesting that alcohol consumption influences driver behavior by impairing judgment and reducing the likelihood that drivers will comply with basic safety measures.

Although age and sex were also included as co-variables, their effects were comparatively weaker than alcohol consumption. Age showed a slightly positive association, indicating that older drivers were marginally more likely to wear seatbelts than younger drivers. Sex differences were minimal once BAC was accounted for, though male drivers were less likely to wear seatbelts to a small degree. Overall, the model confirmed that increased BAC levels strongly correlated with riskier driving behavior through the lack of restraint usage, reinforcing prior research that links alcohol usage to decreased traffic safety.

Table 5. Results for BAC levels predicting driver behavior defined as restraint usage through binary logistic regression while controlling for age and sex

	Coef	Std Err	Z	P>|z|	[0.025	0.975]
Intercept	-0.4877	0.067	-7.327	0.000	-0.618	-0.357
C (SEX) [T.2]	0.6265	0.057	11.015	0.000	0.515	0.738
AGE	0.0100	0.001	7.492	0.000	0.007	0.013
ALC_RES	-4.3844	0.315	-13.917	0.000	-5.002	-3.767

Injury Severity Model

For the second model, the multinomial logistic regression assessing injury severity revealed another significant pattern: higher BAC levels were associated with an increased likelihood of severe or even fatal injuries compared to no or minor injuries. Specifically, as shown in Table 6, each incremental rise in BAC substantially increased the relative risk of belonging to the "Suspected Serious Injury" or "Fatal Injury" categories. This relationship suggests that alcohol not only contributes to the likelihood of crash occurrence but also magnifies the extent of physical consequences of said crashes.

Age had a modest but consistent effect, with older drivers showing a slightly higher risk of serious or fatal injuries, likely due to physiological vulnerability

Table 6. Results for BAC levels predicting the severity of injury sustained by victims through multinomial logistic regression while controlling for age and sex

Possible Injury	Coef	Std Err	Z	P>|z|	[0.025	0.975]
const	-1.5962	0.186	-8.578	0.000	-1.961	-1.232
AGE	-0.0017	0.004	-0.441	0.660	-0.009	0.006
ALC_RES	3.8936	1.362	2.858	0.004	1.224	6.563
SEX_2	0.2364	0.182	1.300	0.194	-0.120	0.593
Suspected Minor Injury	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	-0.8979	0.152	-5.914	0.000	-1.195	-0.600
AGE	-0.0045	0.003	-1.385	0.166	-0.011	0.002
ALC_RES	5.4618	0.908	6.018	0.000	3.683	7.241
SEX_2	0.1900	0.145	1.312	0.190	-0.094	0.474
Suspected Serious Injury	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	-0.8446	0.161	-5.260	0.000	-1.159	-0.530
AGE	-0.0104	0.004	-2.946	0.003	-0.017	-0.003
ALC_RES	7.0023	0.877	7.987	0.000	5.284	8.721
SEX_2	0.2772	0.148	1.873	0.061	-0.013	0.567
Fatal Injury	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	1.1679	0.090	13.029	0.000	0.992	1.344
AGE	0.0064	0.002	3.525	0.000	0.003	0.010
ALC_RES	8.6287	0.709	12.168	0.000	7.239	10.019
SEX_2	0.2118	0.087	2.433	0.015	0.041	0.382

and a delay in cognitive reaction time. Sex differences were not significant in this model, though male drivers showed a slightly higher risk in more severe injury categories. Overall, the injury severity model supports the hypothesis that BAC levels are a major determinant of crash outcome severity, especially in consideration of its quantity, emphasizing the risk associated with driver alcohol consumption.

Collision Manner Model

The final multinomial model examined how BAC influenced collision manner, once again controlling for age and sex. The results from Table 7 suggested that alcohol consumption has only moderate effects on the type of collision, with this relationship being weaker than the seatbelt use or injury severity models.

Specifically, higher BAC values were linked to a

Table 7. Results for BAC levels predicting the manner of collision experienced by victims through multinomial logistic regression while controlling for age and sex

Front-to- Front	Coef	Std Err	Z	P>|z|	[0.025	0.975]
const	-1.0743	0.112	-16.553	0.000	-0.062	-1.629
AGE	0.0092	0.002	4.134	0.000	0.005	0.013
ALC_RES	-4.0162	0.526	-7.638	0.000	-5.047	-2.986
SEX_2	0.1880	0.101	1.864	0.062	-0.010	0.386
Angle	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	-1.0743	0.092	-11.614	0.000	-1.256	-0.893
AGE	0.0048	0.002	2.641	0.008	0.001	0.008
ALC_RES	-3.3944	0.423	-8.025	0.000	-4.223	-2.565
SEX_2	0.3622	0.076	4.765	0.000	0.213	0.511
Sideswipe- Same Direction	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	-0.6548	0.083	-7.852	0.000	-0.818	-0.491
AGE	0.0065	0.002	3.873	0.000	0.003	0.010
ALC_RES	-7.5632	0.466	-16.243	0.000	-8.476	-6.651
SEX_2	0.1911	0.071	2.674	0.007	0.051	0.331
Sideswipe- Opposite Direction	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	-3.1880	0.226	-14.125	0.000	-3.630	-2.746
AGE	0.0045	0.005	0.982	0.326	-0.004	0.013
ALC_RES	-2.3021	1.011	-2.276	0.023	-4.284	-0.320
SEX_2	-0.2007	0.224	-0.895	0.371	-0.640	0.239
Rear-to- Side	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	-3.3386	0.248	-13.455	0.000	-3.825	-2.852
AGE	0.0050	0.005	1.074	0.283	-0.004	0.014
ALC_RES	-4.7056	1.331	-3.536	0.000	-7.314	-2.097
SEX_2	0.3375	0.203	1.662	0.096	-0.060	0.735
Rear-to- Rear	**Coef**	**Std Err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	-5.2033	0.638	-8.155	0.000	-6.454	-3.953
AGE	0.0061	0.638	0.428	0.668	-0.022	0.034
ALC_RES	-8.3765	4.084	-2.051	0.040	-16.380	-0.373
SEX_2	-0.2482	0.649	-0.383	0.702	-1.520	1.023

greater likelihood of nonstandard or atypical collision manners, such as angle impacts and sideswipes, compared to more common front-to-rear collisions. These findings may indicate that more severely intoxicated drivers are more likely to behave unpredictably or erratically in traffic, a possible explanation for higher likelihoods for abnormal collision manners.

Once again, age and sex again had smaller effects. Younger drivers were more frequently involved in angular or sideswipe collisions, and male drivers were slightly more likely to be present in high-BAC levels and unconventional collision manners. Model three contributes evidence that alcohol impairs not only safety compliance and injury outcomes but also alters the structural dynamics and natures of the crashes themselves.

Across all three models, BAC was consistently the most significant predictor of the three variables of traffic crashes. In summary, (1) as BAC increases, restrain use is more likely to decrease; (2) as BAC increases, injury severity is more likely to increase; (3) as BAC increases, collision manners are more likely to display atypical patterns. Demographic variables of age and sex were still statistically relevant but are more secondary predictors across models. Collectively, these findings confirm that BAC is a powerful and multifaceted predictor of crash-related outcomes, influencing behavioral, physical, and structural dimensions of road safety.

CONCLUSION

This study sought to widen the preexisting under-standing of how alcohol consumption—specifically BAC levels—influences multiple dimensions of crash outcomes, including driver behavior, injury severity, and collision dynamics. By applying three distinct regression models to the 2023 Fatality Analysis Reporting System (FARS) data, this analysis extended beyond traditional binary categorizations of alcohol involvement to instead analyze its more nuanced effects through quantitative measurements of BAC. The results revealed consistent and statistically significant relationships between BAC levels and higher crash risk factors: as the level of alcohol concentration increased, the likelihood of seatbelt use decreased, injury severity increased, and collision patterns became more likely to be atypical.

These findings extend prior research in several keyways. While existing literature had already established alcohol as a primary risk factor for traffic crashes, most studies have limited their analyses to whether a driver had consumed alcohol through a binary categorization. This binary framing neglects the variability of impairment that occurs across different BAC ranges—since drivers are not guaranteed to have the same amount of alcohol in their system—and how this variability manifests in different driver behavior and crash characteristics. By modeling BAC as a continuous predictor, this study identified more exact gradients of risk and demonstrated that even small increases in BAC may alter behavioral and physical variables of traffic crashes significantly. Moreover, by simultaneously examining seatbelt use, injury severity, and collision manner instead of analyzing these variables by themselves, this research provides a multidimensional and comprehensive perspective rarely addressed in prior studies.

Beyond its empirical contributions, the study's methodological design—using multinomial and binary logistic regression models within a consistent dataset—demonstrates the ability and importance of integrating multiple variables to capture the full spectrum of alcohol's impact on traffic safety. This approach allows for richer interpretations than single-outcome analyses and highlights the interconnected nature of driver behavior, injury severity, and collision manners.

From a public safety standpoint, these results reinforce the critical need for prevention in regard to alcohol-impaired driving. The evidence suggests that alcohol not only increases the likelihood of a crash but also diminishes protective behaviors such as seatbelt use and magnifies the severity of injuries when crashes occur. Policy interventions should therefore adopt a multidimensional approach that not only enforces legal BAC limits but also promotes awareness of how even low to moderate levels of alcohol impairment can have compounding effects on traffic safety.

Finally, this research addresses a notable gap in the existing body of literature by quantifying the continuous effects of BAC on diverse crash outcomes using recent national data. Future research could expand on this framework by incorporating additional variables—such as time of day, vehicle type, or environmental conditions—to further contextualize alcohol's role within the broader system of crash causation. Nonetheless, the present study contributes valuable evidence that strengthens the understanding of alcohol's multifaceted influence on driving behavior and crash severity. By illustrating these relationships empirically, it provides a clearer foundation for developing targeted prevention and education strategies

that can meaningfully reduce alcohol-related fatalities and injuries on roadways.

This study is subject to some limitations. Missing data bias may be present, as not all crash data contained complete information regarding blood alcohol concentration, restraint usage, injury severity, and collision manner. Furthermore, environmental variables such as road conditions and weather were not accounted for in the dataset but may confound the observed relationships. Given the observational nature of the study, it is important to note that the findings should be interpreted as associations rather than causal relationships between BAC levels and crash-related outcomes.

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CONFLICT OF INTEREST

The author declares no conflicts of interest related to this work.

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