A comparison of contributing effects on 2-vehicle alcohol-related crashes between impaired and nonimpaired operators

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ABSTRACT

Objective: Driving under the influence of alcohol is a crime that places the lives of all motorists in danger. Though it is a largely preventable act, impaired driving has accounted for 31 to 38% of fatal crashes across the country over the last decade. When an impaired operator crashes his or her vehicle, there is often a second unit, of which the operator is not impaired, involved in the crash.

Methods: This research looks at approximately 14,000 2-unit crashes involving an impaired operator in the State of Ohio from 2008 through 2012. The research is focused on determining the effects of crash and operator characteristics in 2-unit alcohol-related crashes through the use of 2 mixed logit models.

Results: It is found that several factors have similar effects on the injury severities of both the impaired and nonimpaired operators, including head-on crashes, the use of seat belts, and the deployment of airbags. There are, however, several factors that affect the 2 operators differently. It is found that the impaired operator’s injury severity is based on the type and, more important, the size of the vehicle he or she is driving, the roadway geometry, and the speed of the vehicle driven by the nonimpaired operator. The nonimpaired operator is equally affected by the speed of the impaired vehicle as much as his or her own speed, and the nonimpaired operator’s injury severity is virtually independent of the type of vehicle being driven.

Conclusions: Researchers may disseminate the results to community groups such as Mothers Against Drunk Driving and Safe Communities to increase awareness of the dangers of drunk driving in an effort to reduce the number of alcohol-related crashes.

Introduction

Drinking and driving has been a critical concern within the traffic safety community for decades. Though national estimates suggest that the percentage of drivers who test positive for alcohol has decreased significantly since 1973 (Berning et al. 2015), the proportion of fatal crashes in the United States where the blood alcohol content (BAC) level of a driver is greater than 0.08% has remained between 31 and 38% since 1994 (NHTSA 2013). In 2013, alcohol-impaired crashes accounted for 31% of all traffic fatalities in the United States (National Center for Statistics and Analysis 2014).

There is a plethora of evidence and a long history of research detailing the physical effects of alcohol, including work by Mitchell (1985), Moskowitz and Robinson (1987, 1988), Holloway (1995), and Phillips and Brewer (2011). These studies provide comprehensive details of the risks posed by driving under the influence of drugs and alcohol. Phillips and Brewer (2011) suggested that injury severities are higher with any level of alcohol in the driver's system. The continually high rates of drinking and driving have motivated research that examines alcohol-related crashes and the contributing factors of these crashes through detailed analytical approaches. Huang and Lai (2011) compared the characteristics of alcohol-related motorcycle and passenger car crashes in Taiwan. Drivers of passenger cars tended to travel on roads with higher speed limits and drive without safety restraints. Traynor (2005) estimated Tobit regression models to determine the impact of alcohol on the at-fault drivers of alcohol-related crashes. The results showed the likelihood of a fatality to increase significantly if the at-fault drivers had consumed alcohol. The study concluded that at-fault drivers who had been drinking tended to cause more severe injuries to not-at-fault drivers than at-fault drivers who were not under the influence of alcohol.

Recently, several studies, including Shyhalla (2014), have sought to examine differences between the circumstances and outcomes of crashes involving alcohol-impaired and nonimpaired drivers. Blomberg et al. (2009) and Romano, Peck, and Voas (2012) examined how geographic and roadway characteristics affected impaired and nonimpaired drivers differently at the same locations and under the same conditions. Research from Demetriades et al. (2004) and Plurad et al. (2010) discussed the factors affecting the injury severity of alcohol-related crashes. Both works look at trauma cases entering the emergency room and physical factors affecting the severity of injuries. Interestingly, these studies show that patients under the influence stand a better chance of surviving a crash than patients not

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under the influence of alcohol in similar crashes. These studies raise the question of how crash characteristics may affect impaired and nonimpaired drives differently.

This research aims to provide further insights as to differences between impaired and nonimpaired drivers. Though general alcohol injury severity has been thoroughly studied, the prior research does not fully investigate the injury severity differences in paired driver crashes where one driver is impaired. The study focuses on comparing the effects of crash-related factors on the severity of injuries sustained by impaired and nonimpaired drivers involved in the same 2-vehicle crashes. By investigating drivers involved in the same 2-vehicle crashes, the empirical setting allow(s) for a comparison of the 2 drivers while controlling for the effects of other important factors that are common to both drivers and vehicles involved in each crash.

Data

The primary sources of data used for this analysis are crash data reporting forms provided by the Ohio Department of Public Safety. The use of state-level data allows for the inclusion of serious injury and injury crashes in addition to fatal injury crashes. Though the benefits of broad geographical representation makes national-level data useful, it is often the goal of states’ departments of transportation and states’ safety offices to significantly reduce the number of fatal injury and serious injury crashes. The alternative is that the limitations of this study are bound to the geographical and socioeconomic trends of Ohio in exchange for a broad variety of injury levels. The standard OH-1 reporting form contains all of the information for the crash including driver description, vehicle description, collision type, roadway conditions and geometry, temporal factors, and the degree of injury severity sustained by each crash-involved occupant. Crash data from 2008 through the summer of 2012 are extracted for those collisions involving exactly 2 vehicles and where alcohol involvement was indicated for one of the drivers. The total number of crashes included in the analysis for this study is approximately 14,000. Two data sets are created from each 2-vehicle crash, one for the driver who was under the influence of alcohol and another data set for the nonimpaired drivers. For each driver, the degree of injury severity sustained as a result of the crash is classified into one of 5 categories, including property damage only, possible injury, nonincapacitating injury, incapacitating injury, and fatal injury.

Table 1 shows the counts and percentages of the characteristics seen in the data for both the impaired driver injury severity model and the nonimpaired driver injury severity model. It is interesting to note the high percentages of low-speed and medium-speed crashes, which are less than 35 mph and between 35 and 55 mph, respectively. Also of note is the number of crashes where the impaired driver is under 20 years of age. Despite the fact that these crashes account for 3.5% of the total number of crashes, these are cases where the impaired driver is not allowed to legally drink. These data figures may be compared with the figures for the nonimpaired driver statistics also found in Table 1.

From Table 1, it may be seen that the vehicle speeds at the time of the crash differ between the nonimpaired driver and the impaired driver. In 28% of crashes, the nonimpaired driver is traveling at speeds of 35 mph or greater, compared to 34% of impaired drivers. An interesting comparison is the rate of seat belt use. In 91% of the crashes, the nonimpaired driver was found to be wearing a seat belt, whereas only 65% of the impaired drivers were wearing seat belts. Across all age groups in 2-vehicle crashes, the rate of seat belt use is consistently higher for nonimpaired drivers compared to those drivers who made the decision to drink and drive. Collectively, these results suggest that impaired drivers are likely to engage in other high-risk behaviors while driving as well, a finding that is consistent with prior work by Shyhalla (2014) and Schneider et al. (2012).

Statistical methodology

In order to compare the factors affecting the degree of injury severity sustained by impaired and nonimpaired drivers, discrete outcome models are estimated. Such models provide an appealing framework for the analysis of injury severity data as detailed in a recent review paper by Savolainen et al. (2011). The mixed logit model is the most flexible such model for the analysis of injury severity data. The mixed logit is a more general form of the multinomial logit, which addresses potential concerns by relaxing the assumption of independent and identically distributed error terms, which gives rise to the independence of irrelevant alternatives property as noted in the works of Revelt and Train (1998), Chsng and Mannering (1999), Brownstone et al. (2000), McFadden and Train (2000), and Hensher and Green (2001).

Multinomial logit models are estimated as a starting point for both subpopulations of drivers (i.e., impaired and nonimpaired). The general form of the multinomial logit is

\[ U_{in} = \beta_iX_{in} + \epsilon_{in}, \]  

(1)

where \( U_{in} \) is a linear-in-parameters function of covariates that determines the injury severity level \( i \) for driver \( n \), \( \beta_i \) is a vector of estimable parameters, \( X \) is a vector of crash attribute (e.g., vehicle type, road conditions, etc.), and \( \epsilon_{in} \) is an error term. The 2 resultant multinomial logit models (impaired and nonimpaired) are used as the initial model specifications for the mixed logit models. The mixed logit allows for the parameters to vary across drivers. In effect, this allows specific factors to exhibit heterogeneous effects, which could be due to a variety of unobserved factors that affect injury outcomes (e.g., driver physiological and health factors). The probability of a driver \( n \) sustaining and injury of severity level \( i \) can be determined as shown in Equation (2) and detailed elsewhere by Train (1999) and Moore et al. (2011):

\[ P_{in} = \frac{\exp [\beta_iX_{in}]}{\sum_i \exp [\beta_iX_{in}]} f(\varphi | \beta), \]  

(2)

where \( \varphi \) is a vector of parameters that define the density function \( f(\beta | \varphi) \). Because estimation by maximum likelihood is computationally difficult, simulation-based methods are utilized. A series of 500 Halton draws is used as an efficient alternative to purely random draws (Bhat 2001, 2003; Revelt...
Table 1. Description data relating to the non-impaired and impaired drivers.

| Factor                                      | Non-Impaired Count (%) | Impaired Count (%) |
|---------------------------------------------|------------------------|--------------------|
| Crash Characteristics                       |                        |                    |
| Airbag deployed                             | 1973 (14)              | 3060 (22)          |
| Struck side impact collision                | 3242 (23)              | 809 (6)            |
| Head-on collision                           | 1282 (9)               | 1282 (9)           |
| Striking side impact collision              | 809 (6)                | 3242 (23)          |
| No contact collision                        | 97 (1)                 | 97 (1)             |
| Curve on grade                              | 563 (4)                | 563 (4)            |
| Level curve                                 | 540 (4)                | 540 (4)            |
| Rear-end collision                          | 5324 (38)              | 5324 (38)          |
| Side-swipe opposite direction               | 1010 (7)               | 1010 (7)           |
| Side-swipe same direction                   | 1044 (7)               | 1044 (7)           |
| Operator Characteristics                    |                        |                    |
| Operating a car                             | 7399 (52)              | 8067 (57)          |
| Operating a SUV                             | 2525 (18)              | 2249 (16)          |
| Operating a pickup truck                    | 1740 (12)              | 2503 (18)          |
| Operator left of center                     | —                      | 1418 (10)          |
| Operator ran red light                      | —                      | 988 (7)            |
| Operator wearing seatbelt                   | 12843 (91)             | 9041 (65)          |
| Speed of Vehicle                            |                        |                    |
| Less than 35 MPH                            | 10014 (73)             | 9317 (66)          |
| 35 to 55 MPH                                | 3176 (23)              | 3878 (28)          |
| Greater than 55 MPH                         | 622 (5)                | 900 (6)            |
| Operator Age                                |                        |                    |
| Under 20 years of age                       | 1170 (8)               | 477 (3)            |
| 20–29 years                                 | 3606 (26)              | 3687 (26)          |
| 30–39 years                                 | 2859 (20)              | 3083 (22)          |
| 40–49 years                                 | 2804 (20)              | 3337 (24)          |
| 50–59 years                                 | 2169 (15)              | 2337 (17)          |
| 60–69 years                                 | 1030 (7)               | 721 (5)            |
| 70–79 years                                 | 359 (3)                | 190 (1)            |
| Greater than 80 years of age                | 98 (1)                 | 30 (2)             |
| Driver Seatbelt Use by Age                  |                        |                    |
| Less than 20 years of age                   | 1073 (92)              | 326 (68)           |
| 20–29 years                                 | 3249 (90)              | 2341 (64)          |
| 30–39 years                                 | 2608 (91)              | 1941 (63)          |
| 40–49 years                                 | 2557 (91)              | 2172 (65)          |
| 50–59 years                                 | 1967 (91)              | 1596 (68)          |
| 60–69 years                                 | 964 (94)               | 503 (70)           |
| 70–79 years                                 | 332 (92)               | 139 (73)           |
| Greater than 80 years of age                | 93 (95)                | 23 (77)            |

Note: 14,095 total observations, percentages given in parentheses.

Direct elasticities are calculated for continuous variables, such as driver age and speed of each vehicle, using the following equation (Washington et al. 2010):

\[
E_{X_{in}}^{P_{n}(i)} = [1 - P_{n}(i)] \beta_i X_{in}.
\]  

(3)

Pseudo-elasticities are calculated for indicator variables using the following equation (Jung et al. 2013):

\[
E(X_{in}) = \left[ \frac{P_{n}(X_{in} = 1)}{P_{n}(X_{in} = 0)} - 1 \right] \times 100,
\]

(4)

where all model parameters are previously defined.

The elasticities indicate the percentage change in the probability of a specific injury outcome corresponding to a 1% change in the predictor variable. For example, the results show that the probability of a crash resulting in a fatal injury increase by 0.54% and Train 1998; Train 1999). Random parameters are identified through the use of the LaGrange multiplier test outlined in McFadden and Train (2000) and Hensher and Greene (2001).

Abbreviated parameter estimates from the mixed logit models are shown in Tables 2 and 3 for the impaired driver (Table 2) and nonimpaired driver (Table 3), respectively. Tables A1 and A2 (see online supplement) include all parameters. In instances where the effects are not significantly different across categories, parameters are constrained to be equal. For example, several variables were found to result in similar impacts on the likelihood of fatal and incapacitating injuries. Postestimation, elasticity and pseudo-elasticity values are calculated to quantify the average effects of model parameters on specific injury outcome categories (Washington et al. 2010).
Table 2. Model coefficients (standard errors) by severity level associated with the impaired driver.

| Factor                          | Property Damage Only (PDO) | Possible (POS) | Non-incapacitating (NON) | Incapacitating (INC) | Fatal (FAT) |
|---------------------------------|---------------------------|---------------|-------------------------|---------------------|-------------|
| Constant term                   | 4.23 (0.29)               | 1.79 (0.30)   | 1.47 (0.30)             | 1.86 (0.27)         | —           |
| Crash Characteristics           |                           |               |                         |                     |             |
| No contact                      | 1.01 (0.36)               | —             | —                       | —                   | —           |
| Head-on collision               | —                         | —             | 0.62 (0.13)             | 0.67 (0.19)         | —           |
| Impact to side of vehicle       | —                         | —             | 0.40 (0.13)             | 1.12 (0.23)         | —           |
| Rear-end collision              | 0.62 (0.16)               | 0.39 (0.14)   | 0.39 (0.14)             | 0.89 (0.12)         | —           |
| Side-swipe opposite direction   | 1.54 (0.25)               | 1.15 (0.28)   | 0.82 (0.25)             | 0.89 (0.12)         | —           |
| Side-swipe same direction       | 0.89 (0.12)               | —             | —                       | —                   | —           |
| Roadway Geometry                |                           |               |                         |                     |             |
| Curve on grade                  | —                         | —             | 0.34 (0.16)             | 0.64 (0.21)         | 1.26 (0.26) |
| Level curve                     | —                         | —             | —                       | 0.74 (0.23)         | 1.41 (0.27) |
| Impaired Driver                 |                           |               |                         |                     |             |
| Airbag deployed in vehicle      | —                         | 1.57 (0.11)   | 1.73 (0.14)             | 1.73 (0.14)         | 1.52 (0.36) |
| Driver age                      | —                         | —             | —                       | —                   | —           |
| Driver following too closely    | 0.25 (0.11)               | 0.42 (0.12)   | 0.50 (0.11)             | 3.46 (0.18)         | 3.46 (0.18) |
| Driving a car                   | 0.53 (0.12)               | 0.50 (0.11)   | —                       | 3.46 (0.18)         | 3.46 (0.18) |
| Operating a motorcycle          | —                         | —             | 0.32 (0.10)             | 0.35 (0.10)         | 0.35 (0.10) |
| Driving a pickup truck          | —                         | —             | 0.32 (0.10)             | 0.45 (0.11)         | 0.45 (0.11) |
| Driver is struck                | —                         | 0.65 (0.11)   | 0.35 (0.10)             | 0.45 (0.11)         | 0.45 (0.11) |
| Driver left of center           | —                         | —             | 0.29 (0.11)             | 0.29 (0.11)         | —           |
| Driver ran red light            | —                         | —             | 0.29 (0.11)             | 0.29 (0.11)         | —           |
| Driver wearing seatbelt         | 2.00 (0.13)               | 1.22 (0.11)   | 1.22 (0.11)             | —                   | —           |
| Speed of vehicle                | —                         | 0.01 (<0.01)  | 0.02 (<0.01)            | —0.03 (0.01)        | —0.03 (0.01) |
| Non-impaired Driver             |                           |               |                         |                     |             |
| Driving a car                   | 0.91 (0.10)               | 0.68 (0.11)   | 0.54 (0.11)             | —                   | —           |
| Driving a SUV                   | —                         | 0.34 (0.08)   | 0.08                    | 4.25                | 0.00        |
| Speed of vehicle                | —                         | —             | 0.01 (<0.01)            | 0.03 (<0.01)        | 0.03 (<0.01) |

for a 1% increase in driver age. For binary indicator variables, the pseudo-elasticity provides the percentage change in a specific injury outcome that corresponds to changing the indicator variable from zero to one. The (pseudo) elasticities indicate average effects across the entire sample. The abbreviated parameter elasticities used in the results section may be seen in Tables 4 and 5, and the complete list may be found in Table A3 (see online supplement).

Results

Collision characteristics

The 2 collision configurations that result in the most severe injuries are angle and head-on collisions. Angle crashes where a vehicle was struck in a side-impact collision are more likely to result in severe injuries for both nonimpaired and impaired drivers. The dangers of side-impact collisions detailed in Laberge-Nadeau et al. (2009) indicate the extreme dynamics of these crashes. It is interesting to note that the nonimpaired driver tends to sustain worse injuries in such collisions, whether they are the struck vehicle or the striking vehicle. Head-on collisions are also found to be very severe regardless of the level of impairment. However, the nonimpaired drivers again tend to sustain more severe injuries, which may be reflective of the dynamics involved in such crashes.

Rear-end collisions are also shown to have a greater impact on nonimpaired drivers, who are likely to be struck from behind at higher speed from an impaired trailing driver. This likely explains the lesser impact on injury severity for impaired drivers. There are 2 types of side-swipe collisions: those occurring when 2 vehicles are traveling in the same direction and those occurring when 2 vehicles are traveling in opposite directions. Same-direction side-swipe collisions are more likely to be property damage–only crashes for nonimpaired and impaired drivers alike. Due to the nature of these crashes and the direction of energy in relation to the contact areas, this is to be expected.

Roadway geometry characteristics

Injury severity was also found to be affected by roadway geometry characteristics among both the nonimpaired and impaired drivers. Horizontal and vertical curvature was each found to increase the level of injury sustained by each driver. Level horizontal curves increased the likelihood of a nonincapacitating or incapacitating injury for the impaired driver. Interestingly, level curves increased the risk of less serious injuries among nonimpaired drivers. These differences may be reflective of the more aggressive, high-risk behaviors of impaired drivers.

The risk of serious or fatal injuries was most pronounced in the presence of both horizontal and vertical curves. Crashes that occur on a curve along a vertical grade increased the probability of an incapacitating or fatal injury by 72% for nonimpaired drivers. For the impaired driver, such crashes increased the probabilities of incapacitating and fatal injuries by 82 and 239%, respectively. These results are consistent with the basis...
Table 3. Model coefficients (standard errors) by severity level associated with the non-impaired driver.

| Variable                              | Property Damage Only (PDO) | Possible (POS) | Non-incapacitating (NON) | Incapacitating (INC) | Fatal (FAT) |
|---------------------------------------|----------------------------|----------------|--------------------------|----------------------|-------------|
| Constant term                         | 5.73 (0.46)                | 3.74 (0.46)    | 3.35 (0.46)              | 2.72 (0.47)          | —           |

Crash Characteristics

| Collision                              | PDO                         | POS                         | NON                        | INC                        | FAT                      |
|----------------------------------------|-----------------------------|-----------------------------|----------------------------|----------------------------|--------------------------|
| Struck side impact collision           | —                           | 0.51 (0.12)                 | —                          | 1.11 (0.20)                | —                        |
| Head-on collision                      | —                           | 0.56 (0.20)                 | 0.74 (0.18)                | 1.55 (0.28)               | 2.03 (0.43)              |
| Striking side impact collision         | —                           | 0.45 (0.09)                 | 0.60 (0.09)                | 1.02 (0.17)               | 1.78 (0.33)              |
| Rear-end collision                     | —                           | 0.57 (0.07)                 | 0.57 (0.07)                | 0.52 (0.18)               | —                        |
| Side-swipe opposite direction         | 0.26 (0.11)                 | —                           | —                          | —                         | —                        |
| Side-swipe same direction              | 0.75 (0.12)                 | —                           | —                          | —                         | —                        |

Roadway Geometry

| Curve on grade                         | PDO                         | POS                         | NON                        | INC                        | FAT                      |
|----------------------------------------|-----------------------------|-----------------------------|----------------------------|----------------------------|--------------------------|
| Level curve                            | —                           | —                           | 0.39 (0.13)                | 0.39 (0.13)                | —                        |

Impaired Driver

| Airbag deployed in vehicle             | PDO                         | POS                         | NON                        | INC                        | FAT                      |
|----------------------------------------|-----------------------------|-----------------------------|----------------------------|----------------------------|--------------------------|
| Driving a pickup truck                 | —                           | —                           | —                          | —                         | —                        |
| Driving a SUV                           | —                           | —                           | —                          | —                          | —                        |
| Driver left of center                   | —                           | 0.30 (0.11)                 | 0.30 (0.11)                | 0.30 (0.11)               | 0.53 (0.10)              |
| Driver ran red light                   | —                           | 0.47 (0.10)                 | 0.55 (0.19)                | 0.55 (0.19)               | —                        |
| Driving a car                           | 0.17 (0.04)                 | —                           | —                          | —                          | —                        |
| Speed of vehicle                       | —                           | 0.01 (<0.01)                | 0.01 (<0.01)               | 0.01 (<0.01)               | 0.01 (<0.01)             |

Non-impaired Driver

| Airbag deployed in vehicle             | PDO                         | POS                         | NON                        | INC                        | FAT                      |
|----------------------------------------|-----------------------------|-----------------------------|----------------------------|----------------------------|--------------------------|
| Driving a pickup truck                 | —                           | —                           | —                          | —                          | —                        |
| Driving a SUV                           | —                           | —                           | —                          | —                          | —                        |
| Driver following too closely           | 6%                          | —                           | —                          | —                          | —                        |
| Driving a car                           | —                           | 4%                          | —                          | —                          | —                        |
| Operating a motorcycle                 | —                           | —                           | 94%                        | 94%                        | 94%                      |
| Driving a pickup truck                 | —                           | —                           | 32%                        | —                          | —                        |
| Driver is struck                       | —                           | 71%                         | 27%                        | 27%                        | 20%                      |
| Driver left of center                  | —                           | —                           | 46%                        | 46%                        | 46%                      |
| Driver ran red light                   | —                           | —                           | 28%                        | —                          | —                        |
| Driver wearing seatbelt                | 30%                         | —                           | —                          | —                          | —                        |
| Speed of vehicle                       | —                           | 0.41%                       | 0.45%                      | 0.83%                      | 0.83%                    |

Table 4. Model elasticities and pseudo-elasticities relating to the impaired driver.

| Factor                                | Property Damage Only (PDO) | Possible (POS) | Non-incapacitating (NON) | Incapacitating (INC) | Fatal (FAT) |
|---------------------------------------|-----------------------------|----------------|----------------------------|----------------------|-------------|
| Collision                              | PDO                         | POS                         | NON                        | INC                        | FAT                      |
| Struck side impact collision           | —                           | 21%                        | 27%                        | 27%                   | 20%                      |
| Head-on collision                      | —                           | 55%                        | 63%                        | 157%                 | 27%                      |
| No contact                            | 20.30%                      | —                           | —                          | —                     | —                        |
| Rear-end collision                     | 6.70%                       | —                           | 14.80%                     | 14.80%                | 16.40%                   |
| Side-swipe opposite direction         | —                           | 21.80%                     | 43.30%                     | —                     | —                        |
| Side-swipe same direction              | 18.70%                      | —                           | —                          | —                     | —                        |

Roadway Geometry

| Curve on grade                         | PDO                         | POS                         | NON                        | INC                        | FAT                      |
|----------------------------------------|-----------------------------|-----------------------------|----------------------------|----------------------------|--------------------------|
| Level curve                            | —                           | —                           | 29%                        | 91%                     | 274%                     |

Impaired Driver

| Airbag deployed in vehicle             | PDO                         | POS                         | NON                        | INC                        | FAT                      |
|----------------------------------------|-----------------------------|-----------------------------|----------------------------|----------------------------|--------------------------|
| Driver age                             | —                           | —                           | —                          | —                          | —                        |
| Driver following too closely           | 6%                          | —                           | —                          | —                          | —                        |
| Driving a car                           | —                           | 4%                          | —                          | —                          | —                        |
| Operating a motorcycle                 | —                           | —                           | 947%                       | 947%                    | 947%                      |
| Driving a pickup truck                 | —                           | —                           | 32%                        | —                          | —                        |
| Driver is struck                       | —                           | 71%                         | 27%                        | 27%                   | 20%                      |
| Driver left of center                  | —                           | —                           | 46%                        | 46%                     | 46%                      |
| Driver ran red light                   | —                           | —                           | 28%                        | —                          | —                        |
| Driver wearing seatbelt                | 30%                         | —                           | —                          | —                          | —                        |
| Speed of vehicle                       | —                           | 0.41%                       | 0.45%                      | 0.83%                  | 0.83%                    |

Non-impaired Driver

| Driving a car                           | 10.60%                      | —                           | 12.10%                     | 23.80%                  | —                        |
| Driving a SUV                           | 7.40%                       | —                           | —                          | —                        | —                        |
| Speed of vehicle                        | —                           | 0.90%                       | 2.20%                      | 2.20%                  | —                        |
for impairment because roadway features that require more effort by drivers tend to present a greater challenge for impaired drivers.

**Safety equipment**

The use of seat belts and the deployment of airbags were also shown to have marked impacts on injury outcomes. Nonimpaired drivers who wear a seat belt are 46% less likely to be injured. This is promising, considering that 91% of nonimpaired drivers are found to wear seat belts in this study. The use of a seat belt by the impaired driver also decreases the likelihood of an injury by 30%.

In contrast, injuries tended to be more severe when airbags were deployed. When the airbag deploys in a vehicle of a nonimpaired driver, the crash is 3 times more likely to result in a fatal injury. The impact required for airbags to be deployed would indicate that the overall crash would be more severe for both vehicles. When airbags are deployed in the impaired driver’s vehicle, the likelihoods of nonincapacitating, incapacitating, and fatal injuries all increase significantly (Jernigan and Duma 2003). Injuries among nonimpaired drivers tended to be more severe in crashes where the airbags deploy in the impaired driver’s vehicle. This is indicative of the impact forces that lead to airbag deployment.

**Vehicle type**

The type of vehicle has implications on injury outcomes for both the impaired and nonimpaired drivers based simply on the mass and absorptive properties of the 2 vehicles. Interestingly, the size of the vehicle the nonimpaired driver is driving has little effect on injury severity. Nonimpaired drivers are less likely to be injured when in a pickup truck, whereas possible injuries were more likely among occupants of passenger cars and SUVs.

Consistent with intuition, impaired drivers of motorcycles and pickup trucks tended to sustain the most and least severe injuries, respectively. Impaired motorcycle riders are nearly 10 times more likely to sustain nonincapacitating, incapacitating, or fatal injuries. This finding is reflective of the greater coordination required to operate a motorcycle, as well as the greater level of protection provided by larger vehicles. Interestingly, these same injury trends were not reflected among nonimpaired drivers. This may be reflective of greater focus among such riders, who could be capable of taking evasive actions to mitigate the severity of a crash.

On the other end of the vehicle size spectrum are pickup trucks. Because pickup trucks offer much more protection to the driver inside of the truck, due to size alone, impaired drivers tend to suffer less severe injuries. For similar reasons, incapacitating and fatal injuries among nonimpaired drivers are more likely when the impaired driver is in a larger vehicle, such as a pickup truck or SUV.

**Speed**

Dynamics generally suggest that higher speeds result in greater impact forces and more severe injuries. Interestingly, there are substantive differences in the effects of speed on the injury level of the nonimpaired and impaired drivers. When examining the

### Table 5. Model elasticities and pseudo-elasticities relating to the non-impaired driver.

| Factor                          | Property Damage Only (PDO) | Possible (POS) | Non-incapacitating (NON) | Incapacitating (INC) | Fatal (FAT) |
|--------------------------------|-----------------------------|----------------|--------------------------|----------------------|-------------|
| **Collision**                  |                             |                |                          |                      |             |
| Struck side impact collision   | —                           | 45%            | —                        | 161%                 | —           |
| Head-on collision              | —                           | 30%            | 56%                      | 252%                 | 469%        |
| Striking side impact collision | —                           | 27%            | 49%                      | 126%                 | 381%        |
| Rear-end collision             | —                           | 48%            | 48%                      | 40%                  | —           |
| Side-swap opposite direction   | 8%                          | —              | —                        | —                    | —           |
| Side-swap same direction       | 23%                         | —              | —                        | —                    | —           |
| **Roadway Geometry**           |                             |                |                          |                      |             |
| Curve on grade                 | —                           | —              | —                        | 72%                  | 72%         |
| Level curve                    | —                           | 37%            | 37%                      | —                    | —           |
| **Impaired Driver**            |                             |                |                          |                      |             |
| Airbag deployed in vehicle     | —                           | 60%            | 286%                     | 286%                 | —           |
| Driver following too closely   | 6%                          | —              | —                        | —                    | —           |
| Driving a pickup truck         | —                           | —              | —                        | 44%                  | 44%         |
| Driving a SUV                  | —                           | —              | —                        | —                    | 78%         |
| Driver left of center          | —                           | 17%            | 46%                      | 46%                  | 46%         |
| Driver ran red light           | —                           | 35%            | 45%                      | 45%                  | —           |
| Speed of vehicle               | —                           | 0.33%          | 0.32%                    | 0.37%                | 0.37%       |
| **Non-impaired Driver**        |                             |                |                          |                      |             |
| Airbag deployed in vehicle     | —                           | —              | —                        | —                    | 32%         |
| Driver age                     | —                           | 2%             | 2%                       | —                    | 2%          |
| Driving a car                  | —                           | 46%            | —                        | —                    | —           |
| Driving a pickup truck         | 3%                          | 11%            | —10%                     | —                    | —           |
| Driving a SUV                  | —                           | 30%            | —                        | —                    | —           |
| Driver wearing seatbelt        | 46%                         | —18%           | 0.47%                    | 0.47%                | —           |
| Speed of vehicle               | —                           | —              | —                        | —                    | —           |
speed of the vehicle driven by the nonimpaired driver, the likelihood of a more serious injury (nonincapacitating, incapacitating, or fatal) increased by 0.47% for each 1% increase in speed. The speed of the nonimpaired driver actually has a larger impact on the injury outcome of the impaired driver, because the probability of a fatal or incapacitating injury increases by 2.2% for a 1% increase in speed.

In contrast, the speed of the vehicle with the impaired driver was also found to have a greater impact on that driver's own injury outcome. A 1% increase in the speed of the vehicle driven by the impaired driver was found to increase the probability of possible, nonincapacitating, and incapacitating/fatal injuries among the nonimpaired driver by 0.33, 0.32, and 0.37%, respectively. Impacts on the impaired drivers themselves were slightly more pronounced as evidenced by 0.41, 0.45, and 0.83% increases in the probability of a possible, nonincapacitating, or incapacitating/fatal injury, respectively.

These results are interesting because they indicate that the speed of the vehicle driven by a nonimpaired driver generally has a more significant impact on crash-related injuries. The nature of this relationship is somewhat unclear, though it is interesting to note the set of choices involved and the implications. This may be due, in part, to differences in reaction time (and the resultant impact speeds) between impaired and nonimpaired drivers. This highlights a prospective area of opportunity for further research. For example, driving simulators or naturalistic driving studies present areas where human factors issues may be investigated within the context of driver impairment.

Discussion

Five key factors were found to affect the injury severity sustained by crash-involved drivers among 14,000 2-vehicle crashes involving one impaired and one nonimpaired driver. Collision type and the use of safety equipment result in similar effects for both impaired and nonimpaired drivers, though the magnitude of these impacts varies based on impairment status. Head-on collisions are particularly dangerous, regardless of impairment, though injuries tend to be most severe among the nonimpaired drivers. The deployment of an airbag indicates a crash with high impact forces and, as such, crashes resulting in airbag deployment are more severe. The use of seat belts is a major factor in all crashes. In the crashes studied in this research, it is found that seat belts reduce the injury severity of both the impaired and nonimpaired drivers. It is also found that impaired drivers are far less likely to be wearing their seat belts than nonimpaired drivers.

The type of vehicle, roadway geometry, and speed have varying effects on the nonimpaired and impaired drivers. Among impaired drivers, injuries tended to be less severe in larger vehicles, whereas vehicle type had less of an influence on the injury outcomes of the nonimpaired driver. The nonimpaired driver is better suited to handle varying roadway conditions, such as roadway curves, whereas an impaired driver faces a greater risk when having to change the vehicle's heading through a curve. The speed of the vehicle driven by the impaired driver had a more substantive impact on the other (i.e., impaired) driver. In contrast, the speed of the vehicle driven by the impaired driver is shown to have a more pronounced effect on his or her own injury outcomes.

Ultimately, this research highlights the dangers associated with drinking and driving, providing quantitative estimates of the impacts on injury outcomes among both impaired and nonimpaired drivers. The results of this article provide strong support for programs targeted toward a variety of factors associated with impaired driving fatalities, serious injuries, and crashes in general. These findings support the expansion of existing safety programs to include additional efforts focused on impaired driving. It is important to note that the results show that those who are driving under the influence of alcohol also tend to partake in other high-risk behaviors such as speeding and not wearing a seat belt, each of which also increase the likelihood of more severe crashes. This is consistent with prior research (Schneider et al. 2012) and suggests that programs targeted toward these types of behaviors and the drivers who engage in them are of particular importance. For example, enforcement programs jointly targeted toward alcohol use, seat belt nonuse, and other such behaviors may present a promising avenue for intervention.

Given the recent enactment of the Fixing America’s Surface Transportation Act, states now have the ability to make more effective use of funds targeted toward impaired driving, which is among the areas with the largest amount of government authorized funds. A state may be able to increase their efforts to reduce speeding-related crashes by focusing on the collective impacts of speeding and impaired driving.

This research also makes several important analytical contributions by distinguishing differences between the factors associated with impaired and nonimpaired drivers. Given the varying injury risk and general driving profiles, further research is warranted to better understand the behaviors and attitudes of those who drive tend to drive while impaired. It may be particularly interesting to compare differences between drivers in other states with those in Ohio, where legislation authorizes the use of sobriety checkpoints and other countermeasures oriented toward impaired driving.

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The research was performed at the University of Akron, and the contents reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the USDOT, ODOT, and Ohio Department of Public Safety.

References

Berning A, Compton R, Wochinger K. Results of the 2013–2014 National Roadside Survey of Alcohol and Drug Use by Drivers. Washington, DC: NHTSA; 2015. Report No. DOT HS 812 118.

Bhat CR. Quasi-random maximum simulated likelihood estimation of the mixed multinomial logit model. Transp Res Part B Methodological. 2001;35:677–693.

Bhat CR. Simulation estimation of mixed discrete choice models using randomized and scrambled Halton sequences. Transp Res. 2003;37:837–855.

Blomberg RD, Peck RC, Moskowitz H, Burns M, Fiorentino D. The Long Beach/Fort Lauderdale Relative Risk Study. J Safety Res. 2009;40(4):285–292.
Brownstone D, Bunch DS, Train K. Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles. *Transp Res.* 2000;34B:315–338.

Chang LY, Mannering F. Analysis of injury severity and vehicle occupancy in truck- and non-truck-involved accidents. *Accid Anal Prev.* 1999;31:579–592.

Demetriades D, Gkiokas G, Velmahos GC, Brown C, Murray J, Noguchi T. Alcohol and illicit drugs in traumatic deaths: prevalence and association with type and severity of injuries. *J Am Coll Surg.* 2004;199:687–692.

Hensher DA, Greene WH. The mixed logit model: the state of practice and warnings for the unwary. In: *Proceedings of Institution of Transportation Studies of Sydney University.* 2001;1:12–14.

Holloway FA. Low-dose alcohol effects on human behavior and performance. *Alcohol Drugs Driving.* 1995;11:39–56.

Huang W, Lai C. Survival risk factors for fatal injured car and motorcycle drivers in single alcohol-related and alcohol-unrelated vehicle crashes. *J Safety Res.* 2011;42(2):93–99.

Jernigan MV, Duma SM. The effects of airbag deployment on severe upper extremity injuries in frontal automobile crashes. *Am J Emerg Med.* 2003;21(2):100–105.

Jung S, Xiao Q, Yoon Y. Evaluation of motorcycle safety strategies using the severity of injuries. *Accid Anal Prev.* 2013;59:357–364.

Laberge-Nadeau C, Bellavance F, Messier S, Vézina L, Pichette F. Occupant injury severity from lateral collisions: a literature review. *J Safety Res.* 2009;40:427–435.

McFadden D, Train K. Mixed MNL models for discrete response. *J Appl Econom.* 2000;15:447–470.

Mitchell MC. Alcohol-induced impairment of central nervous system function: behavioral skills involved in driving. *J Stud Alcohol.* 1985;10:109–116.

Moore D, Schneider WH IV, Savolainen P, Farzaneh M. Mixed logit analysis of bicyclist injury severity resulting from motor vehicle crashes at intersection and non-intersection locations. *Accid Anal Prev.* 2011;43:621–630.

Moskowitz H, Robinson CD. *Effects of Low Doses of Alcohol on Driving-Related Skills: A Review of the Evidence.* Washington, DC: NHTSA; 1988. Report No. DOT HS 807 280.

Phillips D, Brewer K. The relationship between serious injury and blood alcohol concentration (BAC) in fatal motor vehicle accidents: BAC = 0.01% is associated with significantly more dangerous accidents than BAC = 0.00%. *Addiction.* 2011;106:1614–1622.

Plurad D, Demetriades D, Gruzinski G, et al. Motor vehicle crashes: the association of alcohol consumption with the type and severity of injuries and outcomes. *J Emerg Med.* 2010;38:12–17.

Revelt D, Train K. Mixed logit with repeated choices: households’ choice of appliance efficiency level. *Rev Econ Stat.* 1998;80:647–657.

Romano EO, Peck RC, Vos RB. Traffic environment and demographic factors affecting impaired driving and crashes. *J Safety Res.* 2012;43:75–82.

Savolainen P, Mannering F, lord D, Quddus M. The statistical analysis of crash-injury severities: a review and assessment of methodological alternatives. *Accid Anal Prev.* 2011;43:1666–1676.

Shyhalla K. Alcohol involvement and other risky driver behaviors: effects on crash initiation and crash severity. *Traffic Inj Prev.* 2014;15:325–334.

Traynor TL. The impact of driver alcohol use on crash severity: a crash specific analysis. *Transp Res Part E Logistics Transp Rev.* 2005;41:421–437.

Washington SP, Karlaftis MG, Mannering FL. *Statistical and Econometric Methods for Transportation Data Analysis* 2nd ed. Danvers, MA: CRC Press; 2010.