Vulnerability of Female Drivers Involved in Motor Vehicle Crashes: An Analysis of US Population at Risk

Dipan Bose, PhD, Maria Segui-Gomez, ScD, MD, MPH, and Jeff R. Crandall, PhD

Objectives. Motor vehicle trauma has been effectively reduced over the past decades; however, it is unclear whether the benefits are equally realized by the vehicle users of either sex. With increases in the number of female drivers involved in fatal crashes and similarity in driving patterns and risk behavior, we sought to evaluate if advances in occupant safety technology provide equal injury protection for drivers of either sex involved in a serious or fatal crash.

Methods. We performed a retrospective cohort study with national crash data between 1998 and 2008 to determine the role of driver sex as a predictor of injury outcome when involved in a crash.

Results. The odds for a belt-restrained female driver to sustain severe injuries were 47% (95% confidence interval = 28%, 70%) higher than those for a belt-restrained male driver involved in a comparable crash.

Conclusions. To address the sex-specific disparity demonstrated in this study, health policies and vehicle regulations must focus on effective safety designs specifically tailored toward the female population for equity in injury reduction. (*Am J Public Health.* 2011;101:2368–2373. doi:10.2105/AJPH.2011.300275)

Motor vehicle–related trauma is the leading cause of unintentional injuries resulting in the highest number of fatalities among those aged 5 to 34 years in the United States.[1] The overall consequence of motor vehicle trauma on the health of the US population, as measured by the disability-adjusted life-years metric, indicates that approximately 449 healthy life-years per 100 000 population were lost as a result of premature mortality and disability attributable to the health condition.[2] To address this public health concern, the Healthy People 2020 project initiated by US Department of Health and Human Services targets reducing motor vehicle–related mortality and injury rates by 10% in the current decade (compared with figures estimated in 2007).[3] Specifically among the injuries, the project focuses on reducing fatal and nonfatal traumatic brain injuries and spinal cord injuries. To realize these objectives, the framework of the Healthy People 2020 project prioritizes certain vision-based goals, one of which specifically aims at eliminating health disparities among demographic segments including differences that occur by gender or sex. To identify steps targeted toward reducing motor vehicle–related injuries within this framework, it is of interest to evaluate whether sex-specific disparity plays a role in the effectiveness of prevalent motor vehicle safety systems.

Traffic data over the past decades have consistently demonstrated that female drivers are underrepresented in fatal or serious injury motor vehicle crashes; female drivers exhibit approximately one third the rate of fatal crash involvement per driver compared with male drivers (Figure 1).[4] Subsequently, the burden on health caused by motor vehicle trauma is 2-fold higher for males (age-adjusted disability-adjusted life-years for male and female road traffic victims were 600 and 296 life-years per 100 000 population, respectively).[2] The trends in the fatality rates between the 2 sexes is better understood by analyzing the related individual factors: crash fatality rate (proportion of fatal crashes among all crashes), crash incidence density (number of crashes per annual vehicle miles traveled), and driving exposure (annual vehicle miles traveled per licensed driver).

Data indicate that although the driving exposure among male drivers has been consistently higher (33% more annual vehicle miles traveled per driver in 2009),[5] the crash incidence density is in fact higher for female drivers (1.52 vs 1.26 injurious crashes per million vehicle miles traveled for female and male drivers, respectively, in 2009).[4,5] As studies confirm, the trend for the decreasing difference in the crash involvement rate (per licensed driver) for the 2 sexes is indicative of increasing exposure—both licensing and travel miles—and socioeconomic changes in driving behavior among female drivers.[6–8] Therefore, despite a higher fatality involvement rate for male drivers, traffic trends indicate that future female drivers may be equally as likely to be involved in a crash.

Becauses male and female drivers are expected to have comparable exposure to traffic crashes, it is necessary that motor vehicle safety systems provide equitable injury protection to occupants of either sex involved in moderate to serious crashes. Owing to the relatively high exposure and fatal crash involvement rate, standard adult occupant safety systems (seatbelt, airbags, and other passive safety devices) have been designed and evaluated with a focus on the occupant characteristics typically representing the male population. It should be noted that the effectiveness and the performance of such safety devices is, however, sensitive to biological and biomechanical considerations including occupant age, anthropometric size, injury tolerance, and the mechanical response of the affected body region. Because sex is expected to be highly correlated with these variables (except age), it is hypothesized that current advances in safety technology optimized for male characteristics may not be equally effective in protecting female occupants.

Our objective was to evaluate whether a female driver restrained by the safety belt sustains a similar risk of moderate to serious injuries compared with a belt-restrained male driver when involved in a comparable crash. The results would highlight the importance of future advances in occupant safety technology to specifically focus on reducing the sex-specific

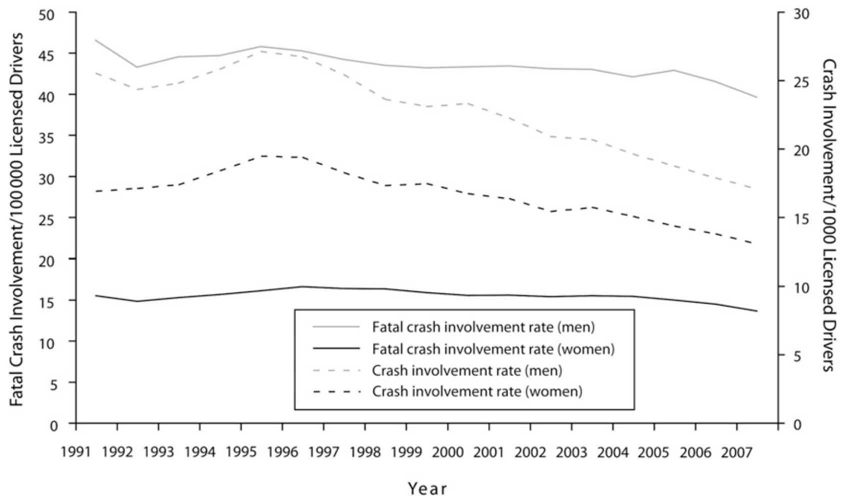

FIGURE 1—Fatal crash involvement rate and crash involvement rate in the US population by sex.

disparity, if any, as an important step toward the mitigation of overall traffic injury–related health burden.

METHODS

We obtained crash information on adult drivers grouped by their sex from the National Highway Traffic Safety Administration's 1998–2008 National Automotive Sampling System Crashworthiness Data System (NASS CDS). NASS CDS provides nationally representative data regarding motor vehicle crashes based on a weighted annual sample of approximately 5000 police-reported tow-away crashes.[9] NASS CDS includes detailed information regarding the occupant characteristics, restraint usage, vehicle properties, crash conditions, and the injury outcome for each individual occupant case. For the purposes of the study, occupant cases were filtered from the NASS CDS to include only adult drivers (≥16 years) and driving a motor vehicle less than 15 years old. To remove the confounding effects of belt usage rates on the predicted risk of injury, drivers who were properly belted and did not eject out of the vehicle during the crash were enrolled in the study. The survey selection criteria yielded 45 445 occupant samples representing approximately 23 million adult drivers at the national level.

Analysis Methodology

We performed a retrospective cohort study by using multivariate logistic regression models to analyze the effect of driver sex as a predictor for injury outcomes while we controlled for the effect of remaining crash-related explanatory variables. We analyzed 6 binomial injury metrics in this study based on the risk-of-fatality injury severity score—Abbreviated Injury Scale (AIS).[10] The 3 whole-body injury metrics were the incidence of fatality, maximum whole-body AIS score of 2 or higher (MAIS 2+), and MAIS 3+, and the 3 regional injury metrics were the incidence of AIS 2+ injuries to the head, chest, and spine regions. The explanatory variables considered in each of the regression models included relevant occupant and vehicle and crash properties (Table 1). The occupant predictors included variables related to sex, age, and anthropometry including categorical body types based on the body mass index (BMI; weight in kilograms divided by height in meters squared). The vehicle predictors included the age of the vehicle at crash and 4 categories of vehicle body types—passenger cars, sports utility vehicles (SUVs), light trucks, and minivans. The crash predictors included Δv (differential velocity before and after impact), roadway category based on posted speed limit, incidence of rollover (more than 1 roof inversion), airbag deployment, type of crash by vehicle damage pattern, and number of events (sequence in a crash causing substantial injury or vehicle damage) in a crash.

Multivariate Model

We chose significant predictors for the multivariate model by using the backward stepwise regression method with an inclusion and retaining threshold of $P<.05$. We performed an assessment for multicollinearity in the model by estimating the variance inflation factor statistic for each of the predictors in a multivariate linear regression model. We performed survey-based logistic regression analysis by using the sampling information and the ratio inflation factor (provided in NASS CDS) associated with each of the sampled cases to predict the risk estimates at the national level. Multivariate regression models estimated the effect of each significant predictor on the 6 injury metrics in terms of adjusted odds ratio with the 95% confidence intervals (95% CIs). We performed the analysis in 2010 with SAS software, version 9.1.3 (SAS Institute Inc, Cary, NC).

RESULTS

Among the weighted population of drivers selected in this study, 43% were female, the overall mean age was 36 years, and 11% were older than 60 years. The crashes considered in this study mostly involved passenger cars (67%), followed by SUVs (15%), light trucks (11%), and vans (6%). The average age of the vehicles at the time of crash was 6 years. The average Δv of the selected crashes was 20 kilometers per hour with the most frequent crash direction being the side crash (43%), followed by rear (23%) and frontal (3%). Approximately 7% of the drivers were involved in a rollover crash with at least 1 roof inversion of the vehicle. At least 1 airbag deployed in 36% of the cases as a result of the impact. Most occupant cases sustained whole body MAIS-1 injury (88%) and another 9% sustained MAIS-2 injury. Less than 1% of the occupant cases sustained fatal injuries. Cases with AIS 2+ injury to the head, chest, and spine region comprised 1.6%, 1.2%, and 0.6%, respectively, of the overall weighted sample. A complete description of all the explanatory and outcome variables for all drivers and separately grouped by sex is provided in Table

TABLE 1—Descriptive Statistics Summary for All Adult Drivers (≥16 Years) Using a 3-Point Safety Belt System and Not Ejected From the Vehicle During the Crash: National Data, United States, 1998–2008

Descriptive Statistics	All Drivers, Mean (95% CI) or %[a] (95% CI)	Male Drivers, Mean (95% CI) or %[a] (95% CI)	Female Drivers, Mean (95% CI) or %[a] (95% CI)
Occupant			
Age, y	36.50 (36.04, 36.96)	36.35 (35.77, 36.93)	36.66 (36.17, 37.15)
Senior drivers (>60 y)	11.14 (9.99, 12.29)	11.47 (10.00, 12.95)	10.78 (9.67, 11.88)
Male sex	52.67 (51.00, 54.35)	...	...
Stature, cm	171.36 (170.79, 171.92)	177.81 (176.90, 178.73)	164.21 (163.60, 164.80)
Mass, kg	76.34 (75.43, 77.25)	83.92 (83.29, 84.54)	67.95 (66.17, 69.74)
Body mass index[b]			
Underweight (<18.5 kg/m^2)	12.40 (9.16, 15.65)	10.41 (6.04, 14.78)	14.61 (12.39, 16.83)
Normal body type (≥18.5 but <25 kg/m^2)	41.17 (38.76, 43.58)	35.70 (33.23, 38.16)	47.18 (43.98, 50.38)
Overweight (≥25 but <30 kg/m^2)	29.92 (27.45, 32.39)	37.32 (32.57, 42.07)	21.77 (20.24, 23.30)
Obese (≥30 kg/m^2)	16.50 (14.44, 18.57)	16.58 (15.36, 17.79)	16.44 (11.74, 21.14)
Vehicle			
Type			
Passenger car	67.48 (63.90, 71.06)	61.41 (54.18, 68.63)	74.23 (72.62, 75.83)
SUV	14.78 (12.70, 16.86)	14.19 (11.84, 16.53)	15.45 (13.10, 17.80)
Van (including minivans)	6.49 (5.57, 7.42)	6.05 (5.43, 6.68)	6.98 (5.24, 8.72)
Light truck	11.25 (8.65, 13.84)	18.35 (13.27, 23.43)	3.35 (2.34, 4.35)
Vehicle age at crash, y	6.09 (5.88, 6.30)	6.35 (6.16, 6.54)	5.80 (5.54, 6.06)
Crash			
Delta-V (total), km/h	19.68 (19.26, 20.10)	19.54 (18.79, 20.29)	19.83 (19.22, 20.45)
Crash direction			
Frontal crash	2.58 (2.20, 2.97)	2.68 (2.08, 3.29)	2.47 (1.79, 3.16)
Side crash	42.71 (39.52, 45.91)	41.19 (38.22, 44.16)	44.37 (39.60, 49.15)
Rear crash	22.87 (21.12, 24.62)	21.35 (18.92, 23.78)	24.58 (22.33, 26.83)
Rollover (≥1 roof inversion)	6.65 (5.00, 8.29)	7.56 (5.75, 9.36)	5.63 (3.94, 7.31)
Airbag deployed in crash	36.34 (33.10, 39.59)	36.17 (30.98, 41.36)	36.55 (34.58, 38.53)
Posted speed limit			
≤56 km/h	2.60 (1.98, 3.21)	2.80 (2.00, 3.59)	2.37 (1.61, 3.13)
>56 km/h but <105 km/h	83.20 (75.93, 90.46)	81.24 (72.08, 90.40)	85.40 (79.91, 90.90)
≥105 km/h	14.21 (7.38, 21.03)	15.96 (7.54, 24.39)	12.23 (6.96, 17.49)
Injury			
Fatality	0.31 (0.21, 0.42)	0.29 (0.22, 0.36)	0.33 (0.12, 0.55)
Maximum AIS (whole body)			
1	87.56 (85.58, 89.27)	87.44 (86.36, 88.52)	87.66 (84.65, 90.67)
2	8.50 (6.98, 10.02)	8.30 (7.52, 9.07)	8.66 (5.98, 11.34)
3	2.68 (2.40, 2.96)	2.74 (2.26, 3.22)	2.63 (2.14, 3.12)
4	0.55 (0.40, 0.70)	0.66 (0.49, 0.83)	0.46 (0.29, 0.63)
5	0.26 (0.20, 0.31)	0.34 (0.26, 0.43)	0.19 (0.15, 0.24)
6	0.06 (0.04, 0.08)	0.08 (0.05, 0.11)	0.04 (0.02, 0.06)
Head injury (AIS 2+)	1.55 (1.21, 1.89)	1.52 (1.28, 1.76)	1.58 (1.02, 2.14)
Chest injury (AIS 2+)	1.17 (0.90, 1.44)	1.10 (0.86, 1.34)	1.25 (0.81, 1.68)
Spine injury (AIS 2+)	0.56 (0.35, 0.76)	0.54 (0.34, 0.75)	0.58 (0.36, 0.79)

Notes. AIS = Abbreviated Injury Scale; BMI = body mass index; CI = confidence interval. Weighted frequency = 23 234 794; for categorical variables, the estimates are percentage of cases corresponding to the value indicated in the first column.
[a]Estimates are reported as mean and percentage values for continuous and categorical variables, respectively.
[b]The BMI classification is based on the National Institutes of Health guidelines.[11]

1. We observed significant differences ($P<.05$) between male and female drivers in terms of anthropometry, vehicle type, and vehicle age. Compared with males, females in the cohort were an average of 14 centimeters shorter and 16 kilograms lighter, 11% more had a normal BMI, 15% fewer were overweight, 13% more were driving passenger cars, 15% less were driving light trucks, and their vehicle was newer by an average of 6 months at the time of the crash (Table 1).

The significant predictors ($P<.05$) determined through the backward stepwise regression process included driver characteristics—sex, age, mass, and BMI category—as well as Δv, vehicle body type, number of events in the crash, and the crash direction. The variance inflation factor calculated for each of the predictors was less than 10 indicating the absence of multicollinearity in the model (Table 2). We retained these variables as the explanatory variables in the regression models to predict the outcome of MAIS 3+, MAIS 2+, chest AIS 2+, and spine AIS 2+ injuries. We could not calculate models corresponding to fatality and head AIS 2+ injuries at the $P<.05$ significance level. The effect of each significant predictor on the 4 injury outcome measures evaluated using multivariate regression models is shown in Table 2.

Results from the multivariate regression analysis indicated that the odds of a belt-restrained female driver sustaining an MAIS 3+ and MAIS 2+ injury were 47% (95% CI=27%, 70%) and 71% (95% CI=44%, 102%) higher, respectively, than those of a belt-restrained male driver when we controlled for the effects of age, mass, BMI category, crash Δv, vehicle body type, number of events, and crash direction. When we controlled for the remaining explanatory variables, occupant age and mass had a marginal effect in increasing the odds of serious injury (<5%). Similarly, a unit increase in the Δv increased the odds of sustaining MAIS 3+ and MAIS 2+ injury by 11% and 9%, respectively. Drivers of SUVs, vans, and light trucks had 20% lower odds of sustaining an MAIS injury compared with drivers of passenger cars. With the increase in each crash event, the odds of sustaining a serious injury increased by 36%. For chest and spine AIS 2+ injuries, the odds of an effectively belted female driver to sustain the injury was 38% (95% CI=1%, 89%) and 67% (95% CI=34%, 109%) higher, respectively, than those of a belted male driver in comparable crash conditions.

DISCUSSION

Advances in vehicle safety technology have produced impressive results in reducing injuries and fatalities among occupants involved in motor vehicle crashes. Primary restraint devices such as the 3-point seat belt system are approximately 42% to 45% effective at preventing fatal injuries and approximately 65% effective in preventing serious injuries among occupants.[12,13] In addition, supplementary restraint devices, such as airbags, in combination with seat belts, may reduce the risk of fatality in frontal collisions by approximately 68%.[14] It is, however, anticipated that this overall effectiveness of occupant safety devices is biased toward the male occupants as they are disproportionately more likely (3 times) to be involved in a motor vehicle crash yielding serious to fatal injuries. To this effect, fewer studies have investigated whether the reduction in motor vehicle trauma has equally benefitted occupants of either sex.[15] This is particularly important because over the past few decades researchers have emphasized the increase in involvement rates of female drivers in fatal crashes.[6,7] Most of these gender-based studies have looked into changes in driving patterns and risk-taking behavior among female drivers over the years as factors contributing to their rising numbers of fatalities and injuries. Although such factors determine the gender-specific risk of being involved in a crash, the effectiveness of safety devices to mitigate the severity of injuries for either during a crash is relatively unclear. The sex-specific effectiveness of safety systems is dependent on anthropometric measures, injury tolerance, and associated biomechanical response. The primary goal of this study was to provide results that demonstrate the sex-specific disparity in the effectiveness of preventing injuries when involved in a motor vehicle crash.

To appropriately investigate sex-specific disparity in the effectiveness of occupant safety devices it is necessary to consider the usage

TABLE 2—Multivariate Associations Between Crash Characteristics and Injury Outcome: National Data, United States, 1998–2008

Weighted Sample Explanatory Variable (Baseline Value)	VIF	MAIS 3+, AOR (95% CI)	MAIS 2+, AOR (95% CI)	Chest AIS 2+, AOR (95% CI)	Spine AIS 2+, AOR (95% CI)
Driver sex (Ref = male)	1.37	1.47 (1.27, 1.70)	1.71 (1.44, 2.02)	1.38 (1.01, 1.89)	1.67 (1.34, 2.09)
Driver age (Ref = 16 y)	1.04	1.03 (1.03, 1.04)	1.02 (1.02, 1.03)	1.05 (1.04, 1.06)	1.03 (1.02, 1.05)
Driver mass (Ref = 38 kg)	3.10	1.02 (1.01, 1.02)	1.02 (1.01, 1.02)	1.03 (1.00, 1.05)	1.00* (0.97, 1.03)
Driver BMI category (Ref = < 18.5 kg/m^2)	2.66	0.79 (0.65, 0.95)	0.80 (0.71, 0.90)	0.62 (0.45, 0.83)	0.99* (0.58, 1.67)
Total Δv of crash (Ref = 1 km/h)	1.04	1.11 (1.09, 1.12)	1.09 (1.07, 1.11)	1.10 (1.09, 1.11)	1.08 (1.07, 1.09)
Vehicle body type (Ref = car)	1.06	0.82 (0.73, 0.92)	0.88* (0.75, 1.02)	0.77 (0.66, 0.90)	1.17* (0.93, 1.49)
Number of crash events (Ref = single event)	1.03	1.36 (1.22, 1.52)	1.19 (1.09, 1.31)	1.19 (1.02, 1.39)	1.31 (1.08, 1.59)
Crash direction (Ref = head-on)	1.05	0.99 (0.98, 0.99)	0.99 (0.99, 1.00)	0.99 (0.99, 0.99)	0.99 (0.99, 0.99)

Notes. AIS = Abbreviated Injury Scale; AOR = adjusted odds ratio; BMI = body mass index; CI = confidence interval; MAIS = maximum whole-body Abbreviated Injury Scale score; VIF = variance inflation factor. Sample size was n = 21 771 out of 10 354 990 respondents.
*Point estimates are not significant at $P < .05$.

rates of passive safety devices (e.g., safety belt) between the 2 sexes. This may indicate potential differences between the "field-effectiveness" (accounting for usage rates) and the "when-used" effectiveness (assuming 100% usage rate). According to 2003 traffic survey data, adult female occupants were had a 7% higher belt usage rate ($P < .05$) compared with males.[16] However, when one considers only adult crash victims (years 1998 to 2008), the belt usage rate was 86.0% (95% CI = 83.2%, 88.7%) and 90.5% (95% CI = 87.6%, 93.4%) for males and females, respectively. Because the belt usage rates when involved in a crash were not significantly different between the sexes, the study focused only on effectively belted drivers to evaluate the risk of injury. The results from this study suggest that belted female drivers are more susceptible to injuries (47%–71%; $P < .05$) compared with belted male drivers when involved in a comparable motor vehicle crash. Similarly, the belted female drivers exhibited a higher risk of chest and spine AIS 2+ injuries (38%–67%; $P < .05$) compared with their male counterparts in comparable crashes.

Biomechanical studies involving postmortem tests, volunteer surveys, and computational simulations provide insight into the effect of sex-specific differences that may contribute to the bias in performance of safety systems in the case of female occupants. The published biomechanical data (1990 to 2009) on sex-specific injury tolerances to impact loading mostly involved males (70%; J.L. Forman, verbal communication, January 2011). To account for the correlation between sex and anthropometric size, the regression methodology used in the study specifically controlled for the effects of BMI and overall mass as measures of size. Tolerance to traumatic injury may also be predicted as a function of sex-specific properties. Specifically, female occupants are at a higher risk for sustaining whiplash injuries because of differences in neck anthropometry, strength, and musculature, and the relative positioning of the head restraint.[17,18] Similarly, a higher risk of lower extremity injuries has been reported for female drivers as a result of their relatively short stature, preferred seating posture, and a combination of these factors yielding lower safety protection from the standard restraint devices.[19,20]

To address these concerns, vehicle safety engineers assess the risk of injury during a crash by using a family of anthropometric test devices (e.g., crash test dummies) designed to represent occupants of both sexes and varying anthropometries. Recent changes to the federal regulations include compliance testing using the small female dummy,[21] but design modifications and performance testing of safety devices mostly rely on the midsized adult male dummy. The 5th-percentile female dummy is primarily used to estimate risk of injury in a compromised condition attributed to the small stature of the occupant (e.g., risk of head injury in side impacts or out-of-position airbag deployment). Corroborated with the results shown in the present study, the performance range of future advanced safety systems must be tailored specifically to provide adaptive protection focusing on the female occupant characteristics under all crash conditions. Future modifications to the dummy or other surrogate models must involve design changes that address differences in the biomechanical properties of either sex in addition to their anthropometric variations.

The primary strength of this study is the focus on the disparity in injury protection that may be attributable to the sex-related factors. Whereas previous studies have primarily focused on the likelihood of being involved in a crash, the results presented here discuss the risk of sustaining injuries when involved in a crash. Multivariate regression strategies allowed us to control for the effects of additional confounding factors while we investigated the role of sex as a predictor of injury. Selection of nationally representative crash data illustrates the disparity evaluated at the population level while reducing errors associated with sampling bias. The data set used in the study, NASS CDS, is arguably the most exhaustive, reliable, and well-researched resource available on US-based motor vehicle crashes; the interdisciplinary nature of the study provides detailed information on reconstructed crash conditions, vehicle damage details, and medical injury reports among other police-recorded details.

The limitations of the study include the inability to investigate the confounding effects of seating position (front passenger or rear seat), differences in safety technology (pyrotechnic devices, side-impact protection, etc.) and the influence of precrash occupant behavior (distraction, posture, alcohol- or drug-related effects, etc.). Future recommendations to this work include analyzing male and female cohorts for their risk of injury within categorical groups of anthropometrical sizes and body types.

Female motor vehicle drivers today may not be as safe as their male counterparts; therefore, the relative higher vulnerability of female drivers (approximately 50% or higher odds of sustaining injuries) when exposed to moderate and serious crashes must be taken into account. To reduce the sex-specific disparity in providing effective means to lower the health burden attributable to motor vehicle crashes, potential improvements to the area of occupant safety systems must be realized. Steps toward the conceptualization of an occupant-specific adaptable safety technology may be necessary in the future to provide significant benefit to the overall demographics of motor vehicle occupants involved in traffic-related incidents. ■

About the Authors

Dipan Bose and Jeff R. Crandall are with the Center for Applied Biomechanics, University of Virginia, Charlottesville. Maria Segui-Gomez is with the European Center for Injury Prevention, Universidad de Navarra, Pamplona, Spain.

Correspondence should be sent to Dipan Bose, Center for Applied Biomechanics, University of Virginia, 4040 Lewis and Clark Dr, Charlottesville, VA 22911 (e-mail: dbose@virginia.edu). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints/Eprints" link.

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Contributors

D. Bose was the principal investigator of the study and was involved with the overall conceptualization of the methodology, performed the statistical analysis, and held the lead role in writing the article. M. Segui-Gomez assisted with the motivational background as well as analytical methods used in the study. J.R. Crandall assisted with the interpretation of the results and translation of the findings in terms of latest research in this field.

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Human Participant Protection

No human participants were involved in this study.

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