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E. Acevedo Díaz, National Center for Statistics and Analysis

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National Center for Statistics and Analysis
National Highway Traffic Safety Administration
1200 New Jersey Avenue SE
Washington, DC 20590

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16. Abstract

Beginning with vehicle model year 2010, FMVSS 202a established new requirements for head restraints in passenger vehicles. This study evaluates the effectiveness of head restraints in reducing cervical spine injuries, including whiplash injuries, for passenger vehicle occupants using NHTSA's National Automotive Sampling System Crashworthiness Data System data from 2000 to 2015. The analysis found that female occupants were more likely to suffer cervical spine injuries in rear-end crashes than male occupants. Occupants in full rear-end crashes were more likely to report cervical spine injuries than occupants in partial or side rear-end crashes. The analysis found a statistically significant reduction of 11.1 percent in cervical spine injury protection for occupants in vehicles with head restraints compliant with FMVSS 202a, when compared to occupants in vehicles with a different head restraint or no head restraints. Furthermore, seating positions with FMVSS 202a-compliant head restraints were 10.9 percent more effective in preventing cervical spine injuries than seating positions with FMVSS 202-compliant head restraints.

17. Key Words

regulatory evaluation, head restraint, whiplash, neck injury, cervical spine injury, FMVSS 202, FMVSS 202a

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Acronyms

NASS-CDS	National Automotive Sampling System Crashworthiness Data System
CISS	Crash Investigation Sampling System
NASS	National Automotive Sampling System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
MY	model year
SAS	Statistical Analysis Software

Executive Summary

In 2015 there were more than 500,000 rear-end crashes in the United States, accounting for approximately 25 percent of the crashes in NHTSA's National Automotive Sampling System Crashworthiness Data System. The CDS target population is all police-reported motor vehicle crashes on public traffic ways, each involving at least one damaged passenger vehicle towed from the scene. New head restraint improvements prevent and reduce the severity of passenger vehicle occupant whiplash injuries. In 2009 NHTSA implemented Federal Motor Vehicle Safety Standard 202a (upgraded head restraints) for vehicle model years 2010 and onward. This study evaluated head restraints and their relationship in reducing cervical spine injuries in passenger vehicle occupants during rear-end crashes. Toward this end, the analysis focused on CDS data from 2000 to 2015. The data showed that less than 2 percent of the seating positions considered in this analysis had head restraints compliant with FMVSS 202a, while the other seating positions in the data set were either equipped with FMVSS 202-compliant head restraints or no head restraints. Approximately 1 million neck injuries were classified as cervical spine injuries during those years, representing 12 percent of the occupants involved in rear-end crashes. FMVSS 202a marginal effectiveness in preventing cervical spine injury was 11 percent when compared to the former FMVSS 202 standard. This analysis found a statistically significant difference (at the alpha = 0.05 level) in whiplash injury reduction when comparing FMVSS 202a-compliant head restraints to the former FMVSS 202-compliant head restraints. Seating positions equipped with FMVSS 202a-compliant head restraints were 11.1 percent more effective in preventing whiplash injuries when compared with vehicles prior to its implementation.

Key findings:

- More than 1 million occupants suffered whiplash injuries from crashes from 2000 to 2015.
- FMVSS 202a-compliant head restraints reduced whiplash injuries by 11.1 percent when compared to seating positions without the upgraded safety standard guidelines.
- Female passenger car occupants had a 43 percent higher likelihood of suffering cervical spine injuries than male occupants when adjusting by other factors.
- Occupants involved in full-width, overlap, rear-end crashes (6 o'clock direction of force), had greater likelihood of whiplash injury than occupants in partial-width, overlap, rear-end crashes, after adjusting by sex, age, delta V, seating location, and head restraint type (5 or 7 o'clock direction of force).
- There was a statistically significant difference in this analysis between the marginal effectiveness of FMVSS 202-compliant head restraints and the FMVSS 202a-compliant head restraints in their protection against whiplash injuries in rear-end crashes.
- The majority of the vehicles in the study population were from MY 1998 to 2008, thus the FMVSS 202a compliant head restraints were not equally represented.

Introduction

Rear end crashes

In 2015 there were more than 500,000 rear-end crashes in the United States, accounting for approximately 25 percent of the crashes in the CDS annually. From 2000 to 2015 there were approximately 8 million rear-end crashes. Rear-end crashes are the leading cause of whiplash injuries in passenger vehicles (Mayor Clinic Staff, 2022).

Evaluation of Head Restraints

The purpose of vehicle head restraints is to prevent neck injuries in rear-end crashes caused by an excessive rearward displacement of an occupant's head relative to their upper torso, including whiplash injuries (Desapriya et al., 2011). Passenger vehicles manufactured after January 1, 1969, for sale in the United States must meet FMVSS 202, including head restraints for all front outboard seating positions. On September 1, 1991, this standard was extended to light truck vehicles (pickup trucks, vans, and SUVs weighing less than 10,000 pounds). The standard requires that front outboard seating positions for these vehicles must have at least 27.5 inches in the lowest setting position, measured from the H-point[1] to the top of the head restraint (FMVSS No. 202).

On December 7, 2004, NHTSA published new requirements for head restraints in passenger vehicles, known as FMVSS 202a. The FMVSS 202a requirement changes apply to vehicles produced and manufactured at the beginning of September 1, 2009. These vehicles were subject, with a few exceptions, to the following criteria:

- All front outboard designated seating positions: the top of an adjustable head restraint in all the seating positions must have a height not less than 800 mm in at least one position.
- All rear outboard designated seating positions: the top of an adjustable head restraint in all the seating positions must have a height not less than 750 mm in any position.
- For front outboard seating positions, the distance between the back of the head of an occupant[2] in a normal seated position and the head restraint, must be no farther than 50 mm in any adjustment.

It is important to note that in some cases auto manufacturers choose to implement FMVSS requirements early. In those cases, the relevant vehicles are identified in the analysis.

The Government Performance and Results Act of 1993 requires government agencies to evaluate existing programs and regulations and determine the actual benefits and costs of additional equipment required on vehicles. The purpose of this study is to assess the effect of these revised head restraint requirements on the frequency of cervical spine injuries in real-world crashes.

[1] The H-point is defined by a test machine placed in the vehicle seat (Society of Automotive Engineers, 1995). From the side, the H-point represents the pivot point between the torso and upper leg portions of the test machine. It can be thought of, roughly, as the hip joint of a 50th percentile male occupant viewed laterally.

[2] Representing the position of a 50th percentile head.

Literature Review

NHTSA has performed several studies evaluating head restraint effectiveness in preventing neck injuries in rear-end crashes. Fixed head restraints had reduced the overall risk of injury to drivers by 17 percent but adjustable restraints reduced risk by only 10 percent (Chaudhary et al., 2015). It was noted that occupants in 75 percent of seating positions with adjustable head restraints were not using it properly for the occupant's height. In April 2001 the evaluation division performed a head restraint effectiveness evaluation on light trucks (Walz, 2001), 10 years after the FMVSS 202 was extended to this type of vehicle. This evaluation was based on eight State files for the calendar years 1993–1998, and estimated that head restraints reduced overall neck injury risk in light truck vehicles by 6.08 percent.

Studies have shown that female occupants have a higher risk of whiplash injuries in rear-end crashes than male occupants. Some factors other than sex have been associated with neck injuries, such as direction of force (full-overlap rear-end versus partial-overlap rear-end crashes), crash severity, and delta V (Gabauer & Gabler, 2006).

Current Evaluation

The main goal of this document is to compare the previous FMVSS 202 head restraints with the new and improved FMVSS 202a head restraints in reducing cervical spine injuries.We will generate an updated overall head restraint effectiveness in preventing cervical spine injuries in rear-end crashes. A logistic regression analysis will also be conducted to explain the relationship between these variables, adjusting by sex, age, direction of force, delta V, and seating position.

Methods

Data Source

The data used for this evaluation was the CDS data for 2000 to 2015. Data show that the cervical spine injuries rate has decreased through the years, from 500,000 weighted cases in the CDS data in 2000, to near 160,000 cases in 2015. Other vehicle safety technologies (not examined in this analysis) that have played a major role in reducing rear-end crashes (and corresponding cervical spine injuries) such as forward collision warning systems and collision avoidance systems, have started development and rolled out in more recent years. The choice of data for this evaluation was a difficult one. This analysis seeks to isolate the effect of FMVSS 202a by not adding vehicles with more recent model years and their other beneficial vehicle safety countermeasures, which is the focus of the NASS-CDS successor dataset, the CISS. The choice of datasets was made deliberately to focus exclusively on the difference in injury outcomes between vehicles with FMVSS 202a compliant head restraints and those vehicles without such head restraints. Using CISS for the evaluation would have made estimating and understanding the singular effect of FMVSS 202a much harder. Moreover, the target population for CISS is all police-reported motor vehicle crashes on trafficways involving passenger vehicles where at least one passenger vehicle was towed from the scene for any reason. The CISS and CDS target populations differ in that CDS focuses on cars towed from the scene due to damage.

This analysis will focus on neck injuries for occupants of passenger cars, light trucks, and vans in rear-end crashes. Head restraint type (FMVSS 202 or FMVSS 202a compliant) was assigned by information provided by manufacturers for vehicles' make, model, and model year. For those vehicles whose manufacturers did not have this information, a visual inspection of stock pictures of the vehicles from the Edmunds website was done and the head restraint types were manually assigned in an SAS code.

Exclusions

Since head restraints are primarily designed to reduce extension injuries in rear-end crashes, other types of crashes were excluded from this analysis (Curatolo et al., 2011), and only struck vehicles in rear-end crashes were included. The types of crashes excluded were crashes that were: non-rear-end crashes, rollovers, and crashes where the vehicles departed the roadway.

Analytical Variables

The interest variable in this analysis, cervical spine injury, was taken from the occupant injury file. Injuries reported as neck injuries for the *BODYREG* were classified as cervical spine injuries. Conversely, injuries other than whiplash can occur in the neck and back regions, with similar coding descriptions. However, we believe that limiting the analysis to rear-end crashes reduces the probability that neck injuries represent something other than whiplash (Gabauer & Gabler, 2006), and this is the main injury for which the head restraint was updated.

The main variable used to compare cervical spine injury in occupants was the head restraint type of the crash seating position. Three types of head restraint statuses were assigned to all the occupants in crashes from 2000 to 2015; seating positions without any head restraint, head restraint compliant with the FMVSS 202 regulations, and head restraints compliant with FMVSS 202a regulations. According to FMVSS 202, all front outboard sitting positions in passenger cars manufactured after January 1, 1969, and light trucks manufactured after September 1, 1991, were required to have head restraints. This implies that head restraints in front outboard seating positions were mandatory on all model year 1970 or later passenger cars, and all model year 1991 and later light trucks. The information on head restraints for the other seating positions was sorted by make, model, and production year and specified in the dataset.

Various studies have shown that other variables might impact the incidence of whiplash injuries in crashes. Female occupants have been associated with a higher whiplash likelihood when compared to men. This could be attributed to females having generally smaller neck bones and muscles than males, on average. Age has also been strongly associated with head restraints and neck injuries, where occupants younger than 64 years old had a greater neck injury likelihood reduction from head restraints (Trempel et al., 2016). Delta V has long been associated as a predictor of occupant injury severity in crashes (Curatolo et al., 2011). Another study showed that rear-end crashes where the direction of force occurred in full-width overlap (6 o'clock), rather than in partial-width overlap (5 or 7 o'clock), resulted in more neck injuries (Farmer et al., 1999; Walz, 2001), see Figure 1. These variables were also included in this analysis.

Figure 1. Vehicle Direction of Force

This analysis used logistic regression analysis to measure the association between these independent variables and the neck injury outcome (the analytical dependent variable). The logistic regression followed the form:

$$P = \frac{e^{\alpha+\beta_i X}}{1 + e^{\alpha+\beta_i X}}$$

Where α and β_i are the parameters of the model for the predictor variables for sex, age group (33 years and older versus younger; median of age in the study population), seating location (front vs rear), head restraint type (none, FMVSS 202-compliant, and FMVSS 202a-compliant), delta V (more than 32 mph versus less than 32 mph; delta V above or below median in the study population), and direction of force (full-width overlap versus partial-width overlap).

Results

The analytical data set derived from CDS shows that from 2000 to 2015 there were approximately 1 million cervical spine injuries in rear-end crashes. Table 1 shows the percentage of cervical spine injuries in occupants and the distribution of head restraint types, by vehicle model year. Figure 2 presents a visual representation of Table 1, where in red is the rate of cervical spine injuries per model year occupant. Vehicles produced after 2010 are required to have head restraints with the FMVSS 202a specifications in all outboard seating positions and middle rear seats. The majority of the seating positions in vehicles in the study data (79 percent) had head restraints compliant with the FMVSS 202 specifications, while there were about 16 percent of occupants with an FMVSS 202a-compliant head restraint. Figure 2 shows cervical spine incident percentages fluctuate without a clear pattern for vehicles with model years 1998 to 2016. This pattern seems to stabilize in vehicles with model years 1998 through 2008. This could be attributed to the fact that these are the model years more prevalent in the analyzed data.

Table 1. Cervical Spine Injury Prevalence and Head Restraint Type Distribution by Vehicle Model Year

Vehicle Model Year	Cervical Spine Injury Rate*	Head Restraint Type Distribution†		
		No head restraint	FMVSS 202 Compliant	FMVSS 202a Compliant
1998	9.6	6.6	78.6	0.0
1999	13.0	8.6	84.1	0.1
2000	9.7	6.6	81.6	1.2
2001	11.3	3.1	90.3	4.4
2002	8.2	0.5	96.4	2.9
2003	8.9	6.2	86.7	6.4
2004	9.0	1.6	91.9	6.2
2005	15.5	0.8	53.7	45.4
2006	11.8	0.4	56.7	42.8
2007	10.8	0.8	51.0	48.2
2008	9.4	0.3	28.4	71.0
2009	9.0	0.8	7.2	92.0
2010	17.5	1.6	0.0	98.4
2011	9.9	0.9	0.4	98.6
2012	5.6	2.8	0.0	97.1
2013	11.9	0.8	0.0	99.2
2014	16.4	0.9	0.0	99.1
2015	10.9	0.0	0.0	100.0
2016††	0.0	0.0	0.0	100.0

* Rates are for every one hundred occupants in rear-end crashes $\hat{I} = (\sum_{h=1}^{H}\sum_{i=1}^{n_h}\sum_{j=1}^{m_{hi}} injuries_{year_{hij}} \times W_{hij}) / (\sum_{h=1}^{H}\sum_{i=1}^{n_h}\sum_{j=1}^{m_{hi}} occupants_{year_{hij}} \times W_{hij})$; where h is the PSU strata. i is the PSU, and j is the year.

† Unknown head restraint types are not presented in this table, therefore each row may not sum to 100.

†† There are vehicles 2016 model year vehicles in the 2015 CDS dataset.

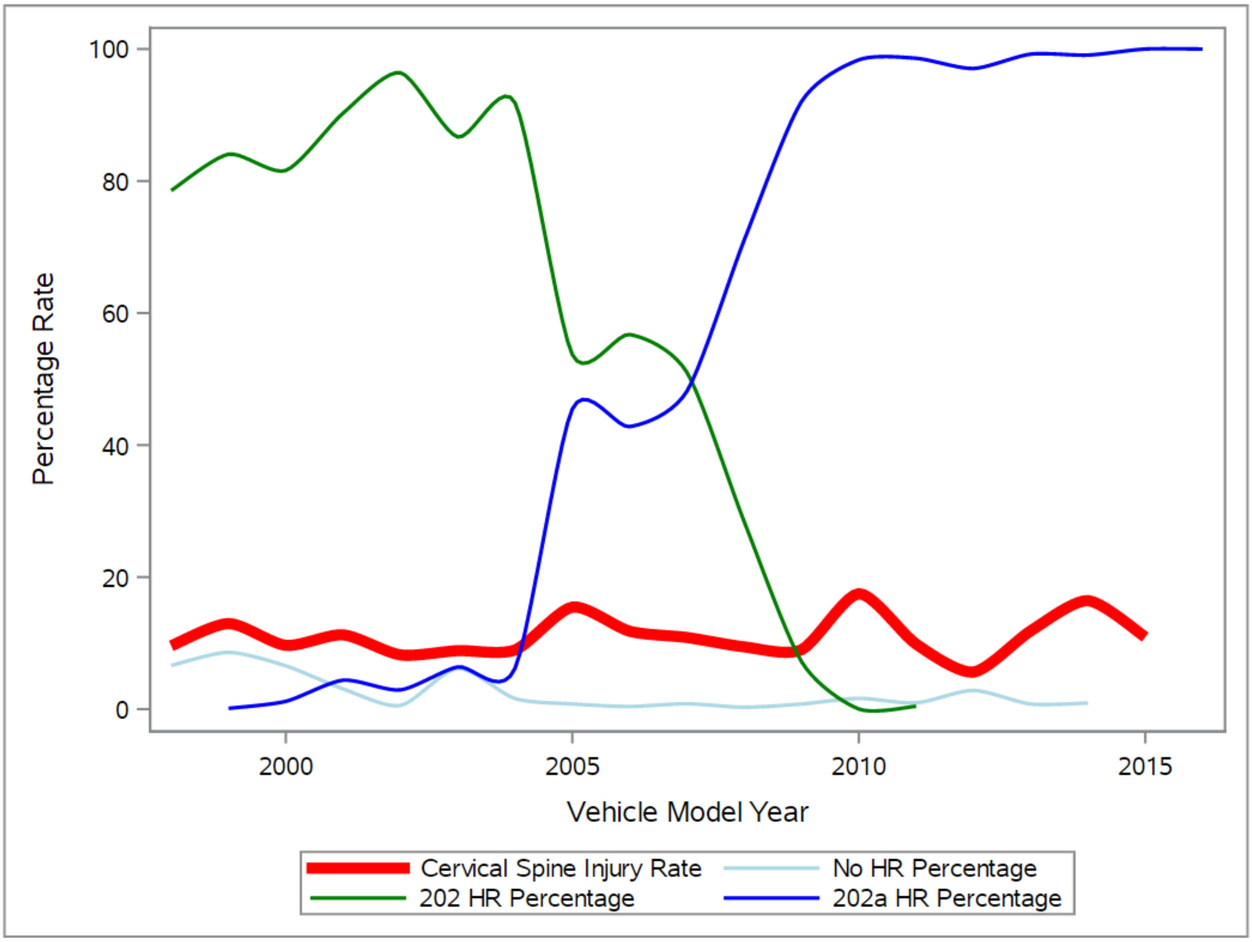

Figure 2. Percentage of Head Restraint Types and Cervical Spine Injury Incidence by Vehicle Model Year 1998–2016

Table 2 presents the weighted frequencies and percentage of occupants that sustain cervical spine injuries, as well as the odds ratios of the logistic regression including all these variables. Approximately 12 percent of the people involved in rear-end crashes where at least one vehicle was towed from the crash scene, suffered from neck injuries. Among the people that sustain cervical spine injuries, around 40 percent were males, and 60 percent were female. Females are at higher odds than males to experience cervical spine injuries in rear-end crashes. This difference was found to be statistically significant (at a level of 0.05). Drivers and front row passengers were more likely to suffer cervical spine injuries in rear-end crashes than occupants in rear outboard seats. Most occupants that suffer cervical spine injuriers during a rear-end crash, were in a seat location that had a head restraint with specifications and requirements of the FMVSS 202, dating back to 1991. Delta V was not statistically significant at the alpha=0.05 level and there was not sufficient evidence to support the idea that low-speed crashes (prevalent in the analytical dataset) consistently minimized cervical spine injuries, holding other factors in the model constant. However, that does not mean that delta V could not be an important factor in crashes for which data were not available. Occupants in a full-width overlap direction of force (6 o'clock) had a significantly higher chance of having a cervical spine injury than those involved in a partial width impact (5 or 7 o'clock direction of force).

Table 2. Weighted Frequencies of Occupants with Cervical Spine Injuries

	Frequency	**Weighted Frequency**	**Standard Error of Weighted Freq**	**Percent of Injured Occupants†**	**Odds Ratio**	**95% Confidence Interval**	
						Lower	**Upper**
Sex							
Male	1,102	397,371	74,128	4.94	-	**-**	**-**
Female	1,538	610,494	135,131	7.59	**1.428**	**1.156**	**1.764**
Age Group							
Less than 33	1,294	455,276	87,382	5.84	-	-	-
33 and older	1,287	525,028	116,818	6.74	1.081	0.839	1.393
Seat location							
Rear rows	432	159,464	44,973	2.07	-	-	-
Front row	2,202	845,811	171,279	10.97	1.192	0.713	1.993
Head Restraint							
202	2,013	794,528	185,443	9.77	0.824	0.422	1.608
202a	486	148,714	24,081	1.83	0.681	0.191	2.428
None	148	65,734	21,018	0.80	-	-	-
delta V							
Less than 32 mph	1,343	611,321	127,530	11.36	-	-	-
32 mph or more	452	108,552	18,331	2.02	0.893	0.735	1.084
Rear Impact							
Partial Rear Impact	565	132,568	31,213	2.07	-	-	-
Full Rear Impact	2,082	876,408	183,245	10.35	**1.651**	**1.191**	**2.290**
Total	**2,660**	**1,010,270**	**206,367**	**12.42**	**-**	**-**	**-**

Bold indicates statistically significant difference with an alpha level of 0.05

†Percentage of injury occupants within categories. Adjusted neck-injury may not add to overall injury rate due to missing values in adjusted variables.

FMVSS 202a Improvement Over FMVSS 202

Additionally, we measure the overall head restraint improvement in reducing a cervical spine injury comparing the previous head restraint standards (FMVSS 202 and no head restraint) versus the updated versions (FMVSS 202a). For this we apply the following formula:

$$\text{Effectiveness (E)} = \frac{p_1 - p_2}{p_1} = 1 - \frac{p_2}{p_1} \tag{1}$$

where p_i = percentage of injured occupants as:

> i = 1 for the group of head restraints prior to FMVSS 202a (FMVSS 202 and no head restraint), and
>
> i = 2 for the group with updated head restraints

So, for the 2 groups:

$$p_1 = \frac{860{,}262}{6{,}521{,}067} = 0.131920$$

$$p_2 = \frac{148{,}714}{1{,}268{,}626} = 0.117224$$

We now add these values to equation (1) and calculate:

$$E = 1 - \frac{0.117224}{0.131920} = 1 - 0.8886 = 0.1114$$

Therefore, the introduction of the new FMVSS 202a standard presents an overall cervical spine injury reduction of 11.1 percent with respect to the grouping of head restraints designed according to FMVSS 202 and seating positions without head restraints. To estimate how much the new standard improved over the previous, we removed the no head restraint cases from the p1 group to estimate the effectiveness of the FMVSS 202a with regard to FMVSS 202. Following the previous methodology, we get:

$$p_1 = \frac{794{,}528}{6{,}038{,}374} = 0.131580$$

Therefore,

$$E = 1 - \frac{0.117224}{0.131580} = 1 - 0.8909 = 0.1091$$

Head restraints compliant with the FMVSS 202a provided an additional 10.9 percent protection from cervical spine injuries when compared to the FMVSS 202 compliant head restraints. The variance of the effectiveness would be the variance of p_2/p_1. The linear approximation of this variance is calculated as:

$$\sigma_E^2 = \frac{p_2^2 \times \sigma_{p_1}^2}{p_1^4} + \frac{\sigma_{p_2}^2}{p_1^2} \tag{2}$$

Where,

σ_E^2 = variance of effectiveness estimate

p_1 = cervical spine injury rate with head restraint 202

p_2 = cervical spine injury rate with head restraint 202a

$\sigma_{p_i}^2$ = variance of cervical spine injury rate within group

The variance for each injury group is first calculated with the following formula:

$$\sigma_{p_i}^2 = \frac{p_i \times (1 - p_i)}{N_i}$$

Where,

p_i = percent of occupant cervical spine injury

N_i = Number of occupants involved

i = 1 in 202 and no head restraint group; i = 2 in 202a group)

Therefore,

$$\sigma_{p_1}^2 = \frac{0.131580 \times (1 - 0.131580)}{6{,}038{,}374} = \frac{0.11427}{6{,}038{,}374} = 0.0000000189$$

$$\sigma_{p_2}^2 = \frac{0.117224 \times (1 - 0.117224)}{1{,}268{,}626} = \frac{0.10348}{1{,}268{,}626} = 0.0000000816$$

Using these numbers in equation (2), we get:

$$\sigma_E^2 = \frac{0.01374 \times 0.0000000189}{0.0002998} + \frac{0.0000000816}{0.01731} = 0.000000866 + 0.000004714 = 0.00000558$$

To determine the significance of this estimate, a z-score is calculated as:

$$z = \frac{E}{\sigma_E} = \frac{0.1091}{0.002362} = 46.19;$$

which is statistically significant with an α level of 0.05. Therefore, occupants with FMVSS 202a updated head restraints showed an estimated 11 percent reduction in cervical spine injuries in rear-end crashes when compared to vehicles equipped with FMVSS 202-compliant head restraint systems.

Conclusions

This analysis has demonstrated that the FMVSS 202a-compliant head restraint systems are statistically significant more likely to reduce cervical spine injuries in rear-end crashes from 2000 to 2015. In both this analysis and previous studies (Chaudhary et al., 2015; Walz, 2001), female occupants are 43 percent more likely to suffer cervical spine injuries than male occupants. Previous studies indicate that this disparity could be due to different levels of muscle density in the neck for male bodies versus female bodies (Stemper & Corner, 2016). Additionally, full rear impacts (at the 6 o'clock position) are 65 percent more likely to produce a cervical spine neck injury when compared to the partial width direction of force (5 and 7 o'clock). These differences are statistically significant when the rest of the variables are held constant. Our final estimate for the overall observed cervical spine injury reduction is statistically significant (at an alpha level of 0.05%). We found that the new standard reduced occupants with cervical spine injuries by an 11.1 percent with respect to what was the vehicle fleet before its implementation. Furthermore, the FMVSS 202a standard provided a significant marginal improvement to the previous FMVSS 202 standard in preventing cervical spine injuries by 10.9 percent in rear-end crashes.

Limitations

Although this evaluation was done following standard statistical methodology, the analysis has some limitations worth noting. The data included in this analysis comes exclusively from CDS data, a comprehensive sampled dataset of vehicles towed from the crash scene. Other studies (Kullgren et al., 2007) have shown that cervical spine-effect injuries mostly occur in low-speed crashes. This might suggest that the types of crashes resulting in cervical spine injuries, including whiplash-effect injuries, are largely underrepresented in our data(Freeman & Leith, 2020), since CDS collects data from vehicles that were towed away due to damage. Furthermore, the vehicles that were involved in rear-end crashes in the CDS data period from 2000 to 2015 were mostly those with model years from 1998 to 2008. This fact explains the lower annual fluctuation seen in Figure 2 between the vehicle model years for this period. Additionally, cervical spine injuries, including whiplash injuries, are not explicitly defined in the CDS data as there is not necessarily a medical record associated with each crash. It is, rather, more of an interpretation of multiple factors. Additionally, interior inspection data for vehicles with model years older than 10 years at the time of collection, are not available in CDS data for data years 2009 to 2015. Lastly, a portion of the classification of head restraint types (FMVSS 202, FMVSS 202a compliant, or non-head restraint) in this analysis was done by crash data collectors observing and recording the head restraint types in vehicles older than 2009 and analyzing the type of head restraint in every seating position. This was then coded into a SAS program for the final assignment. Although this was rigorously done, there could have been classification errors in the assignment of head restraint types.

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