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Research Note

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Updated Analysis of Pedestrian and Pedalcyclist Crashes With Hybrid Vehicles

Summary

This report updates earlier National Highway Traffic Safety Administration research that compared pedestrian and pedalcyclist crash involvement rates for hybrid and electric (HE) vehicles to rates for internal combustion engines (ICE) vehicles in 16 States. In the earlier research in 2009, the pedestrian crash odds ratios (OR) were based on only 77 pedestrian crashes of five Honda and Toyota HE vehicle models at all speeds in all types of driving maneuvers (OR=1.40). A follow-on study in 2011 using case-control methodology had the same five HE vehicles involved in 186 pedestrian crashes (OR=1.35), and the pedestrian crashes increased to 244 when all HE models were included (OR=1.22). This current report updates those earlier efforts with data from the same 16 States, some with data now available up to 2011, in which the sample size of HE vehicles in all crashes is increased to 68,950 and resulting in 420 pedestrian crashes for all HE vehicle models. Using this larger sample size for analysis results in the pedestrian crash odds ratio of 1.20 for HE versus ICE when all vehicles models and speeds/maneuvers are included. In addition to this result, if HE versions of Honda models are re-categorized as ICE (since their engines keep running during low-speed maneuvers), then the pedestrian crash odds ratio is slightly modified to 1.21. Furthermore, if additional risk factors such as city size, vehicle maneuvers, and vehicle age are considered simultaneously, the HE/ICE pedestrian crash odds ratio tends to decrease slightly (from 1.20 to 1.17 approximately). The pedestrian odds ratio would be higher if the analyses are limited to low-speed maneuvers only (OR=1.52). In this report similar analyses are also performed using pedalcyclist crash data, and hybrid vehicles had approximately 50 percent higher likelihood of pedalcyclist crashes than ICE vehicles.

Introduction

With the increased presence of hybrid and electric motor vehicles in the United States, various organizations, including the National Federation of the Blind, have raised safety concerns related to pedestrians' interactions with these vehicles because of their quieter operation when they are in electric modes, as compared to vehicles which rely on an internal combustion engine. The concern is that HE vehicles are harder to hear and therefore are less detectable than ICE vehicles, and that this heightens the risk of pedestrian collisions with HE vehicles. This Research Note tests the hypothesis that the quieter operation of HE vehicles results in a higher pedestrian crash involvement rate, especially in certain low-speed maneuvers since HE vehicles operate mainly by electrical power at lower speed.

In addition, in response to pedestrian safety concerns described above, Congress passed Public Law 111-373, the Pedestrian Safety Enhancement Act of 2010, which was signed into law by the president on January 4, 2011.

NHTSA's prior statistical analysis in 2011 and 2009 used data from 16 states that are part of NHTSA's State Data Reporting System (SDRS).[1 2] That analysis compared the crash rates of HE vehicles and ICE vehicles. Recently, some additional questions have been raised about the pedestrian crash causations and the risk factors, together with the earlier research questions, which may result in the pedestrian and pedalcyclist crashes, such as:

- Hybrid and electric vehicles are quieter and their sound pressure levels are lower than average vehicles, and lower sound levels may result in higher pedestrian crash rates. One of main concerns is the crash pattern comparison between two different engine power types of HE and ICE vehicles in this study.
- The quieter vehicles may not only include HE vehicles, but also some newer vehicles. One hypothesis suggests the newer vehicles may be quieter than older vehicles, hence, vehicle age is a possible risk factor, and the crash rate may also vary with calendar year.
- Population density and vehicle distribution density may also play important roles, e.g., big cities might tend to have higher pedestrian crash rates than other areas for both ICE and HE vehicles. Further, the crash patterns in big cities might be different from the patterns in smaller size areas.
- Larger HE vehicle sample size may have an impact on the HE versus ICE pedestrian crash odds ratio.

- Several risk factors such as power type, city size, vehicle maneuvers, and vehicle age may contribute to pedestrian or pedalcyclist crashes simultaneously.

Many risk factors may contribute to pedestrian and pedalcyclist crashes, and some emerging risk factors, such as distracted driving, distracted walking, and environmental noise level, need to be explored with much larger/newer crash data, if such data is available. State data, however, did not provide such information on environmental noise level, population density, and vehicle density, although some variables, such as vehicle age and big cities (populations >600,000) versus other areas, are helpful.

Earlier analyses[1 2] using State data from 2000 to 2008 also indicate that there are relatively larger sample sizes of HE passenger cars and light trucks than HE heavy trucks and motorcycles. Therefore, it is appropriate to compare the pedestrian crash rates using passenger cars/light trucks than other types (heavy trucks or motorcycles). This report, like NHTSA's earlier research, focuses solely on light passenger vehicles (passenger cars and light trucks).

Among statistical methods commonly used for public heath epidemiology of traffic safety, case-control studies and logistic regression are very insightful methods[3 4] that explore relative risk (RR) and odds ratio between two groups of interest. In this report, case-control studies are carried out by examining the pedestrian crash patterns of both ICE and HE vehicles. The relative risk or odds ratio, with P-values, can be obtained that provide the numerical comparison of ICE and HE vehicles regarding their risks of crashes involving pedestrians. Section 3 provides the methodological details.

Data

A large sample size of HE vehicles is desired for effective comparison. The newest available crash data (beyond 2008) from the same 16 States used for earlier NHTSA reports was added for this Research Note. Some States now have crash data available for 2009, 2010, and 2011 (Table 1). While the calendar years included in the analysis ranged from 2000 to 2011, the years of data availability varied across the 16 States under consideration. The total number of vehicles included from each State thus depended upon both the number of crashes in the State as well as the number of calendar years available for analysis. Further, the current vehicle sample has many more ICE vehicles available than HE vehicles (with the ratio of ICE/HE over 200). While smaller ICE/HE ratios (e.g., 50:1, 20:1, 10:1, 5:1, or even 1:1 comparison between ICE and hybrid-electric) are desirable, this sample size issue and its influence on statistical power were explored in the earlier technical report.[1] The HE vehicle sample size in this report is much larger than the earlier studies.

Table 1
Crash Data and Associated Calendar Years by State in Study (2000–2011)

State	Years Available	State	Years Available
Alabama	2000–2008	North Carolina	2000–2011
Florida	2002–2009	North Dakota	2003–2009
Georgia	2000–2008	New Mexico	2001–2010
Illinois	2000–2010	New Jersey	2004–2010
Kansas	2001–2010	Pennsylvania	2000–01, 2003–10
Kentucky	2000–2010	Washington	2002–2009
Maryland	2000–2010	Wisconsin	2000–2011
Michigan	2004–2009	Wyoming	2000–2007

Some additional comparisons between two different conditions will be explored in this study: comparing newer vehicles (under 4 years old) with older vehicles, and comparing the crashes between big cities (populations >600,000) and other areas. Further, one risk factor of special interest is the vehicle maneuver speed (slower versus faster), since higher pedestrian crash rates have potentially occurred at low speed. Because State crash data does not always report vehicle speed, low-speed crashes are identified as those involving low-speed vehicle maneuvers, such as when a vehicle is (1) making a left turn, right turn, or U-turn, (2) slowing or stopping, (3) backing up, (4) entering or leaving a parking space, or (5) starting in traffic. These low-speed maneuvers tend to have higher pedestrian crash rates among HE vehicles when compared to ICE vehicles.[1 2] Hybrid vehicles operate mainly by electrical power at low-speed maneuvers. The five low-speed maneuvers mentioned above form a group of "low-speed maneuvers" in order to increase sample size and statistical power. More details of crash data are given in Section 3, where case-control studies are applied to compare the crash odds and relative risks, with a much larger HE sample size (Tables 2 and 3).

Methodology Using Case-Control Studies to Compare HE With ICE Vehicles

Case-control studies, using the concepts of relative risk and odds ratio, are applied to this comparison between HE vehicles and ICE vehicles to calculate their likelihood of being in a crash involving pedestrians or pedalcyclists.[3 4] The HE vehicles are regarded as quieter vehicles, hence treated as "Case" or "Risk Exposed" group (see Table 2). ICE vehicles are regarded as not so quiet and treated as the "Control" group for comparisons. Several similar numerical examples will be provided based on Table 2.

Table 2

Case-Control Study of HE Versus ICE (Calendar Years 2000–2011)

	Vehicle in Pedestrian Crash	Vehicle in Other Crash	Total
Case (Exposed to Risk, or Quieter/HE)	A	B	A+B
Control (Not Risk-Exposed, or Noisier/ICE)	C	D	C+D
Total	A+C	B+D	A+B+C+D

Table 3

Numerical Example of Case-Control Study (All Speed Maneuvers, 2000–2011)

Comparing Groups	Vehicle in Pedestrian Crash	Vehicle in Other Crash	Total
Case (Exposed to Risk/HE)	420 (A)	68,530 (B)	68,950 (A+B)
Control (Not Risk-Exposed/ICE)	77,283 (C)	15,182,160 (D)	15,259,443 (C+D)
Total	77,703 (A+C)	15,250,690 (B+D)	15,328,393 (A+B+C+D)

Overall Trend of HE Versus ICE Vehicle Pedestrian Crashes

Case-control studies are very effective in exploring one risk factor at a time. Using the format of Table 2, Tables 3 and 4 provide overall HE versus ICE numerical comparisons regarding pedestrian crashes (all speeds/maneuvers included, using State data from 2000 to 2011). Table 3 indicates the HE/ICE vehicle crash ratio is very small (approximately 0.45%), this HE/ICE vehicle crash patterns are explained as Table 3, and discussed again using the probability tree later (Figure 1).

The sample size of all HE vehicle crashes totals 68,950 (with 420 pedestrian crashes for all HE vehicle models). Earlier samples using smaller 2000-2008 crash data totaled 24,297 crashes of all types (with 244 pedestrian crashes involved HE vehicles including all models, and 186 pedestrian crashes only by HE including five Honda and Toyota models in the 2011 report[1]). The 2009 report had only 77 pedestrian crashes involving HE vehicles using five Honda and Toyota models.[2] Figure 2 will further display this HE/ICE pedestrian crash odds ratio trend for varying HE vehicle sample sizes, summarizing two earlier reports.

Table 4

HE/ICE Relative Risk and Odds Ratio for Pedestrian Crashes[3 4] (Using Table 3 Data)

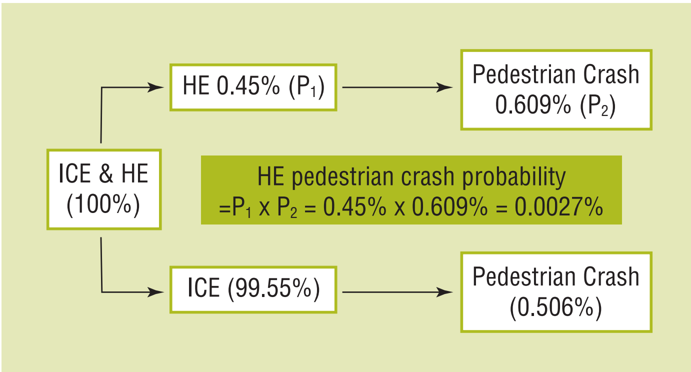
Statistic	Definition	Example from Table 3 Data
Incidence in exposed group (HE)	$\mathbf{I_e}$ = A/(A+B)	$\mathbf{I_e}$ = 420/68,950 = 0.609%
Incidence in unexposed group (ICE)	$\mathbf{I_u}$ = C/(C+D)	$\mathbf{I_u}$ = 77283/15259443 = 0.506%
Relative Risk	RR = I_e / I_u	RR = 0.609/0.506 = 1.20
Odds Ratio	**OR** = $\{I_e/(1-I_e)\}\div\{I_u/(1-I_u)\}$ = (AD)/(BC)	OR = 1.20, p = 0.0002 OR 95% CI = [1.09 – 1.33]
Incidence in population (HE & ICE)	$\mathbf{I_p}$ = (A+C)/(A+B+C+D)	$\mathbf{I_p}$ = 77703/15,328,393 = 0.507%
Attributable risk (risk difference)	**AR** = $I_e - I_u$	AR = (0.609–0.506)% = 0.103%
Attributable risk %	**AR%** = (AR/I_e)*100%	AR% = (0.103/0.609) x 100% = 16.9%
Attributable risk to the population	**PAR** = $I_p - I_u$	PAR = 0.001%
Attributable risk to the population %	**PAR%** = (PAR/I_p)*100%	PAR% = 0.20%

The interpretations for Tables 3 and 4 statistical calculations are as follows:

- The incidence and the odds of an HE vehicle being involved in a pedestrian crash are 1.20 times (20% higher) as the corresponding incidence and odds of an ICE vehicle being involved in a similar crash (OR=1.20, RR=1.20). The P-value of 0.0002 is significant (under 5% marginal value). This new odds ratio (1.20) is slightly smaller than the earlier similar study odds ratio (OR=1.22) that had 244 HE-vehicle-involved pedestrian crashes.[1]
- If all HE vehicle drivers gave up their HE vehicles and switched to ICE vehicles, their incidence of pedestrian crashes would decrease by 0.103 per 100 (AR=0.103%), which would represent a 17-percent reduction in their pedestrian crash incidence rate (AR%=16.9%).
- If all vehicles were ICE or all HE vehicles were turned into ICE (PAR=0.001%), a reduction of 0.001 new cases of vehicles involved in pedestrian crashes per 100 combined vehicles (ICE and HE) would be expected. Such reduction represents a 0.2-percent reduction of all vehicles involved in pedestrian crashes (PAR%=0.20%). Note that the HE vehicle sample size available in this study is relatively small (0.45 percent of all vehicles), and hence the HE sample has a very small impact on the overall pedestrian incidence.

From a point of view of probability tree, Figure 1 may visually help explain the concept of "Attributable Risk to the Population" and the overall pedestrian crash contributions by HE vehicles. The conditional probability from hybrid vehicle is small (0.0027%), and this conditional probability would further be reduced to 0.0023 percent if all HEs had the same crash rate as ICEs. Figure 1 also hints at the challenge of reducing overall pedestrian crashes by improving the HE pedestrian crash rate, i.e., HEs have a 20 percent relatively higher likelihood of hitting pedestrian; however, the HEs have a tiny impact on the overall number of pedestrian crashes by both HE and ICE vehicles.

Figure 1
Probability Tree of Pedestrian Crashes by HE and ICE Vehicles



Pedestrian Crash Comparison Focusing on Low-Speed Maneuvers

Pedestrian crashes usually occur at low speed, such as when a vehicle is making a turn (left, right, U-turn), backing up, slowing or stopping, entering or leaving a parking space, or starting in traffic (see Table 5a for detailed distributions in Appendix). These form a group called “maneuvers at low speeds” in this study in order to increase sample size and statistical power, as described in Tables 5 and 6.

Table 5
Case-Control Study of HE/ICE During 2000-2011 (Low-Speed Maneuvers)

Comparing Groups	Vehicle in Pedestrian Crash	Vehicle in Other Crash	Total
Case (Exposed to Risk/HE)	216 (A)	19,932 (B)	20,148 (A+B)
Control (Not Risk-Exposed/ICE)	28,784 (C)	4,036,115 (D)	4,064,899 (C+D)
Total	29,000 (A+C)	4,056,047 (B+D)	4,085,047 (A+B+C+D)

The following Table 6, using Table 5 data, shows that HE vehicles have approximately 50 percent higher likelihood of hitting pedestrians than ICE vehicle in low-speed maneuvers (OR=1.52, RR=1.51). The earlier study in 2011 had much smaller samples of low-speed maneuver HE vehicles (10,320 for all crashes and 114 for pedestrian crashes considering all models) from 2000 to 2008 State crash data.[1]

Table 6
HE/ICE Comparison of Pedestrian Crashes Using Table 5 (Low-Speed Maneuvers)

Statistic	Definition	From Data of Table 5
Incidence in case or exposed group (HE)	$I_e = A / (A+B)$	216/20148 = 1.07%
Incidence in control or unexposed group (ICE)	$I_u = C / (C+D)$	28,784/4064899 = 0.71%
Relative risk	$RR = I_e / I_u$	RR = 1.51
Odds Ratio	$OR = \{I_e /(1 - I_e)\} \div \{I_u /(1 - I_u)\} = (AD)/(BC)$	OR = 1.52, p<0.0001 95% CI = [1.33 – 1.74]

Case-Control Studies of Pedalcyclist Crashes

Similar studies were performed on pedalcyclist crash data (Table 7) as on the pedestrian crashes. The odds of an HE vehicle being involved in a pedalcyclist crash are 1.51 times (51% higher, OR=1.51, all speed maneuvers included) as much as the corresponding incidence and odds of an ICE vehicle being involved in a similar crash. The odds ratio is 1.46 while at low-speed maneuvers. The earlier analysis using 2000-to-2008 data had 116 pedalcyclist crashes only, including all speed maneuvers and using the five Honda and Toyota models,[1] with OR=1.57.

Table 7
Comparison of HE and ICE Pedalcyclist Crashes (2000–2011)

Considering All speed Maneuvers of HE/ICE Vehicles			
Comparing Groups	**Vehicle in Pedalcyclist Crash**	**Vehicle in Other Crash**	**Total**
Case (Exposed to Risk/HE)	280 (A)	68,670 (B)	68,950 (A+B)
Control (Not Risk-Exposed/ICE)	41,086 (C)	15,218,357 (D)	15,259,443 (C+D)
Total	41,366 (A+C)	15,287,027 (B+D)	15,328,393 (A+B+C+D)
OR = 1.51, OR 95% CI = [1.34 to 1.70], P-Value<0.0001			
Considering Low-Speed Maneuvers Only of HE/ICE Vehicles			
Comparing Groups	**Vehicle in Pedalcyclist Crash**	**Vehicle in Other Crash**	**Total**
Case (Exposed to Risk/HE)	125 (A)	20,023 (B)	20,148 (A+B)
Control (Not Risk-Exposed/ICE)	17,356 (C)	4,047,543 (D)	4,064,899 (C+D)
Total	17,481 (A+C)	4,067,566 (B+D)	4,085,047 (A+B+C+D)
OR = 1.46, OR 95% CI = [1.22 to 1.74], P-Value<0.0001			

Re-Categorization of Some Honda Hybrid Vehicles

Hybrid models including the Honda Civic and Honda Accord are not regarded as "full hybrid" vehicles since their engines keep running, and they could be re-categorized as ICE vehicles instead. If such re-categorization is applied to Table 3, then 80 vehicles will be moved to cell "C" from cell "A," and 13,205 vehicles will be moved to cell "D" from cell "B,"." The new odds ratio of HE versus ICE pedestrian crash is slightly modified to 1.21 (95% CI between 1.09 and 1.34) including all speed maneuvers. Similarly, the new odds ratio of HE versus ICE pedestrian crash is 1.52 (95% CI between 1.31 and 1.77) for low-speed maneuvers after this re-categorization is applied to Table 5.

Similar re-categorization can be applied to pedalcyclist crashes (Table 7). The new odds ratio of HE versus ICE pedalcyclist crash is 1.58 including all speed maneuvers (95% CI between 1.39 to 1.80), and 1.50 for low-speed maneuvers (95% CI between 1.24 to 1.82). This re-categorization of Honda hybrid vehicles makes the HE share even smaller among all vehicles, and the conditional probability of HE pedestrian crashes out of all vehicle crashes is also smaller.

Pedestrian Crash Model Considering Multiple Factors Simultaneously

Many risk factors may contribute to pedestrian crashes besides the sound pressure level or engine/power type. For example, one key hypothesis is that the pedestrian crash rate may be higher in the areas of higher vehicle/pedestrian densities or in big cities, and HE vehicles may have even higher rate than ICE vehicles. In State data, however, the vehicle and pedestrian density variables are not available but one variable, "big city >600,000 populations" versus "other areas," provides certain insight of pedestrian crashes nevertheless. Following Table 8, where data are divided into "Big City" versus "Other Areas" and also HE vehicles versus ICE vehicles, provides the pedestrian crash rates by either HE or ICE in either "Big City" or "Other Areas."

Table 8
Pedestrian Crashes by HE and ICE in Big Cities versus "Other Areas" (Data in Tables 3 and 5 further divided into "Big Cities, populations >600,000" and "Other Areas")

All Speed Maneuvers Included (Table 3 Data)					
	HE Vehicles		**ICE Vehicles**		
Location	**Vehicle in Pedestrian Crash**	**Vehicle in Other Crash**	**Vehicle in Pedestrian Crash**	**Vehicle in Other Crash**	**All Crashes**
Big Cities	155 (R_1=1.004%)	15,281	27,589 (R_2=0.994%)	2,749,187	2,792,212 (18.2%)
Other Areas	265(R_3=0.495%)	53,249	49,694 (R_4=0.398%)	12,432,973	12,536,181(81.8%)
Total	420	68,530	77,283	15,182,160	15,328,393 (100%)
Only Slow-Speed Maneuver Vehicles (Table 5 Data)					
	HE Vehicles		**ICE Vehicles**		
Location	**Vehicle in Pedestrian Crash**	**Vehicle in Other Crash**	**Vehicle in Pedestrian Crash**	**Vehicle in Other Crash**	**All Crashes**
Big Cities	77 (R_1=1.828%)	4136	10,758 (R_2=1.516%)	698,840	713,811 (17.47%)
Other Areas	139(R_3=0.872%)	15,796	18,026 (R_4=0.537%)	3,337,275	3,371,236(82.53%)
Total	216	19,932	28,784	4,036,115	4,085,047

From Table 8, approximately 36 percent of all vehicles involving pedestrian crashes are located in big cities >600,000 populations, but only approximately 18.2 percent of all types of crashes happen in big cities as Table 8 (all maneuvers). In big cities, the pedestrian crash rate difference between HE and ICE is relatively smaller (pedestrian crash rate of R_1=1.004 percent versus R_2=0.994 percent, or odds ratio =1.011, odds ratio 95 percent confidence interval 0.863~1.185, and p-value=0.8948) if all maneuvers are included, however, HE vehicles still have approximately 20 percent higher risk of pedestrian crashes if only smaller sample size of low-speed maneuvers are considered (1.828% versus 1.516%, or odds ratio =1.209, odds ratio 95% confidence interval = 0.9645 to 1.5164, p-value =0.0991, Table 8). In "other areas," HE vehicles have higher pedestrian crash rates than ICE vehicles, either if vehicles are in low-speed maneuvers only (OR=1.629, 95% CI=1.378~1.926, p-value<0.0001), or if all maneuvers are included (OR=1.245, 95% CI=1.103~1.405, p-value=0.0004).

More generally than above Tables 3-8 that considered one factor once a time only, such as engine/power types (HE versus ICE), or speed maneuvers (slow versus fast), or city size (large cities versus other areas), logistic regression, on the other hand, is used in modeling binary outcome of "pedestrian crash" or 'not-pedestrian crash" while considering multiple risk factors simultaneously. Multiple risk factors may include the HE vehicles versus ICE vehicles, vehicle maneuvers (slow versus fast), city size (big cities with populations >600,000 versus other areas), vehicle age (under 4 years versus older), calendar year, driver age, and others. Furthermore, both HE vehicles and pedestrian crashes comprise a relatively small percentage of their respective population universe, which makes it more challenging when a multiple factor model is considered. The main intention here is to verify whether the power type or engine type (HE versus ICE) is still a significant factor that results in higher pedestrian crash rate while analyzing multiple risk factors simultaneously. It is also not practical to include all possible risk factors. Missing data is commonplace in State crash data. Same data from Table 3 are used.

The correlations between the pedestrian crash probability and risk factors can be described by Eq. (1) - where "p" stands for the probability of "pedestrian crash," "1-p" stands for the probability of "not-pedestrian crash," and "p/(1-p)" is the "odds" of the "pedestrian crash" versus "not-pedestrian crash." The model included additional risk factors or predictors (X_i) that may lead to the pedestrian crashes, such as power type (HE versus ICE), big city versus smaller one, or newer vehicle versus older. Regression coefficient, β_i (i=1,2,3,..,n) is termed as "log odds ratio" of predictor (X_i) , i.e., "OR" of any risk predictor (X_i) is from $e^{\beta i}$. The OR value of larger than 1.0 indicates the higher chance of pedestrian crash while less than 1.0 for lower chance of pedestrian crash.[3]

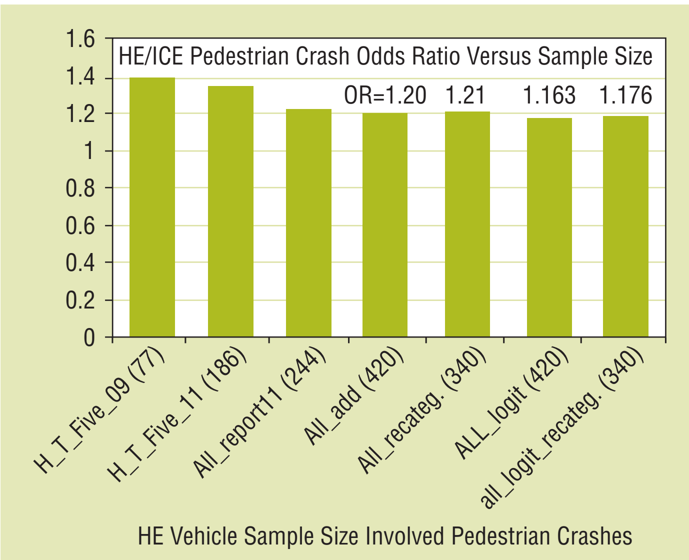
$$\frac{p}{1-p} = \exp\,(\beta_0 + \beta_1 EngineType + \beta_2 Maneuver + \beta_3 CitySize + \beta_4 VehAge + \beta_5 Year + \beta_6 DrAge) \quad \text{Eq. (1)}$$

The correlations and effects between the pedestrian crash likelihood and the risk, possibly confounding factors simultaneously can be described by using numerical OR. For example, the OR associated with "HE versus ICE" comparison (Table 10, Re-Categorization of Honda HE) is 1.176 (P-value=0.0098, and 95 percent confidence interval (CI) is between 1.040 and 1.330). The interpretation is that an HE vehicle has 17.6 percent higher odds of hitting a pedestrian than an ICE, with a significant P-value <5 percent, when all other confounding risk factors are also considered simultaneously. If a vehicle is in low-speed maneuvers (maneuvers OR=1.127, P-value<0.0001, and 95 percent CI between 1.110 and 1.145), the odds of hitting a pedestrian by a low-speed maneuver vehicle are 13 percent higher as compared to the corresponding odds involving a faster vehicle. In bigger cities (populations>600,000), the odds of being involved in a pedestrian crash is 2.66 times the odds of the other areas (city size OR=2.662, P-value <0.0001, and 95 percent CI between 2.619 and 2.706). Also from the logit model, newer vehicles (under 4 years old) and older vehicles have similar odds of being involved in a pedestrian crash (vehicle age OR=1.006, P-value=0.4820 or 48.2 percent, that is over 5 percent and is not significant, 95 percent CI between 0.989 and 1.024). Overall, the multiple logit modeling indicated that engine power type (HE versus ICE), maneuvers associated with speeds, and city size have significant association with pedestrian crashes but vehicle age does not. Similar logit modeling, without re-categorization of Honda HE vehicles, is also provided as Table 9. The multiple logit analysis simultaneously considers the impacts of all possible risk factors on the likelihood of pedestrian crashes.

Effect of Hybrid Vehicle Sample Size

Many other risk factors or predictors such as weather, light, engine/tire/environmental noises, and road condition may contribute to pedestrian crashes. Missing data are commonplace for State data; therefore, it is not very possible to include all risk factors into the multiple factor modeling. Earlier research obtained the pedestrian crash odds ratios of HE versus ICE vehicle with relatively much smaller sample sizes. The report in 2009 had 77 pedestrian crashes by HE vehicles at all speeds (considering five Honda and Toyota models, OR=1.40)[2]; the similar case-control study in 2011 had 186 HE vehicles involving pedestrian crashes with the same five models (OR=1.35); and the HE pedestrian crashes increased to 244 if all models were included in the 2011 report[1] (OR=1.22, similar to the results by Insurance Institute for Highway Safety[5 6 8]). This current analysis had a total of 420 HE vehicles involving pedestrian crashes when all models and maneuvers were included (OR=1.20); and this odds ratio of 1.20 is slightly higher after re-categorization of Honda HE vehicles due to smaller HE sample size (OR=1.21, with 340 HE vehicles involving pedestrian crashes as Section 3.4). If multiple confounding factors were considered simultaneously in a logit model, the pedestrian crash odds ratio of HE versus ICE is slightly reduced to 1.163 from 1.20 (reduced to 1.176 from 1.21 if re-categorizing Honda HE vehicles). Figure 2 summarizes this odds ratio varying trend versus HE vehicle sample sizes that involved pedestrians crashes, and this odds ratio value tends to decreases slightly, from 1.40 to 1.16, if HE vehicle sample sizes increase and multiple factors are considered simultaneously.

Figure 2
HE Versus ICE Odds Ratios of Pedestrian Crashes Associated With Different HE Vehicle Sample Sizes (Case-Control Studies and Multiple Logit Model)



Conclusions and Discussions

- The results from the HE versus ICE relative comparisons and case-control study indicate that HE vehicles have approximately 20 percent higher likelihood (OR=1.20) of pedestrian crashes than ICE vehicles if all speed maneuvers are included and only the engine type (HE or ICE) is considered, and this likelihood of pedestrian crash of HE vehicles is approximately 50 percent higher if only low-speed maneuvers are considered.
- Larger HE vehicle samples and more risk predictors considered simultaneously tend to make HE /ICE crash odds ratio smaller, but the HE versus ICE odds ratio is still larger than 1.0 (1.17 or 17% higher crash risk approximately and all speed maneuvers included). The multiple logit modeling provides certain insights and significant impacts of additional risk predictors such as vehicle maneuvers and city sizes, although it is desirable to have larger sample size of HE vehicles that involved in pedestrian crashes.
- Larger cities tend to have higher pedestrian crash rates for both HE and ICE vehicles. The percentage of HE vehicles in big cities is also higher than other areas. If only slow-speed maneuvers are included, HE vehicles have approximately 20 percent higher pedestrian crash risk than ICE vehicles in big cities, and the pedestrian crash rates by HE and ICE vehicles are similar if all maneuvers are included in big cities. Approximately 64 percent of pedestrian crashes and 81.8 percent of all types of crashes happened in the "other areas" but not in the big cities, and in these "other areas" HE vehicles had higher pedestrian crash rates than ICE vehicles, either in slow-speed maneuvers or all maneuvers included, based on the city size definition of big cities (>600,000 people) versus other areas. If additional information of vehicle and pedestrian densities are available, the future research will provide more details of urban/rural crash patterns.
- The vehicle age (4 years or older) is not a significant factor regarding pedestrian crashes.
- Hybrid vehicles had approximately 50 percent higher likelihood of pedalcyclist crashes than ICEs, and this likelihood is similar at different speed maneuvers.
- Overall the crash ratio of HE versus ICE is very small in this report (approximately 0.5%). The small HE vehicle sample had a very small impact on the overall pedestrian crash incidences if all vehicle populations (HE+ICE) are under consideration, as suggested by Attributable Risk to the Population (PAR% =0.2%), or by the concepts of probability tree and conditional probability.
- The results from this updated analysis share the similar trends as the 2009 and 2011 NHTSA reports, while this updated analysis pays special attentions to these areas: the current HE vehicle sample size in this report is almost twice the HE sample size in 2011 report (more than 5 times the 2009 report HE size). The methodologies of case-control study and multiple logistic regression are applied to HE/ICE crash rate comparison, with the considerations of possible confounding multiple factors. The effort of modeling pedestrian crashes using some possible sound-related data (such as new versus older vehicles, and big city versus smaller one) were also made, and detailed interpretations of the odds ratios and relative risks are given. Furthermore, this study investigates the pedestrian crash rates associated with low-speed maneuvers, and the trend of HE/ICE pedestrian crash odds ratio varying with the HE vehicle sample sizes that involved pedestrian crashes. Additional information of pedestrian fatalities, associated with higher speed mainly, is also provided in the appendix.

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Acknowledgement and Contact Information

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Appendix I

Table 5a

Vehicles With Low-Speed Maneuvers in Table 5

Slower Maneuver Distribution of Hybrid Vehicles in Table 5					
Crash Type	Turning (left/right/U)	slowing	backing	Enter/exit parking	Starting up
Pedestrian Crashes	138	15	39	10	14
Other Crashes	7,630	7,517	3,248	614	923
Slower Maneuver Distribution of ICE Vehicles in Table 5					
Crash Type	Turning (left/right/U)	slowing	backing	Enter/exit parking	Starting up
Pedestrian Crashes	18,159	2,536	5,327	1,459	1,276
Other Crashes	1,628,615	1,351,894	725,473	159,534	170,599

Table 9

Pedestrian Odds Ratios From Logit Model Using Table 3 Data (Without Recategorization of Honda HE, Year 2000–11)

Effect	OR Point Estimate	OR 95% Wald Confidence Limits		P-value
Engine type (HE vs. ICE)	1.163	1.040	1.300	0.0079
Low-Speed Maneuvers vs. Faster	1.127	1.110	1.145	<.0001
Bigger Cities vs. Other Areas	2.662	2.619	2.706	<.0001
Newer vs. Older Vehicles	1.006	0.989	1.024	0.4820
Calendar Year	0.973	0.970	0.976	<.0001
Driver age	1.001	1.001	1.001	<.0001

Table 10

Pedestrian Odds Ratios From Logit Model Using Table 3 Data (After Recategorization of Honda HE as Section 3.4, Year 2000–2011)

Effect	OR Point Estimate	OR 95% Wald Confidence Limits		P-value
Engine type (HE vs. ICE)	1.176	1.040	1.330	0.0098
Low-Speed Maneuvers vs. Faster	1.127	1.110	1.145	<.0001
Bigger Cities vs. Other Areas	2.662	2.619	2.706	<.0001
Newer vs. Older Vehicles	1.006	0.989	1.024	0.4769
Calendar Year	0.973	0.970	0.977	<.0001
Driver Age	1.001	1.001	1.001	<.0001

Appendix II: Hybrid and Electric Vehicles Involved in Pedestrian Fatalities

by Rory Austin, Ph.D., NHTSA

Hybrid and electric vehicles involved in fatal crashes were identified using a "fuel code" derived from PCVINA (FARS 2001-09). During this period there were 50 pedestrian fatalities related to 47 hybrid and 3 electric vehicles. Tables 11-14 provide some key statistics regarding these vehicles and fatalities.

Table 11

Hybrid and Electric Pedestrian Fatalities by Year (FARS 2001–2009)

Year	Vehicles	Fatalities
2001	1	1
2002	3	3
2003	1	1
2004	4	4
2005	3	3
2006	9	11
2007	8	9
2008	10	10
2009	11	11
Total	**50**	**53**

Model	Vehicles	Fatalities
Toyota Prius	21	24
Honda Civic	11	11
Honda Insight	3	3
Toyota Highlander	3	3
Ford Escape	2	2
Other Various Models	10	10
Total	**50**	**53**

Table 12

Hybrid and Electric Pedestrian Fatalities by Speed Limit /Maneuvers (FARS 2001–2009)

Speed Limit	Vehicles	Fatalities	Vehicle Maneuver	Vehicles	Fatalities
≤35 mph	15	17	Low-Speed Maneuver	6	6
>35 mph	33	34	Going Straight	40	43
Unknown or Missing	2	2	Unknown/Other	4	4
Total	50	53	Total	50	53

Table 13

Comparison of Several Hybrid and ICE Vehicles

Model	Fatalities (FARS 2001-2009)	Registration Years (Polk NVPP 2001-2009)	Fatalities per 100,000 Registration Years
Toyota Prius	24	2,341,051	1.0
Toyota Corolla	502	33,741,153	1.5
Honda Civic Hybrid	11	734,903	1.5
Honda Civic	694	38,892,214	1.8

Table 14

ICE (Gasoline, Diesel or Flexible Fuel) Pedestrian Fatalities by Speed Limit (FARS 2001–09)

Speed Limit	All Striking Vehicles	All Striking Vehicle Fatalities	Striking Passenger Vehicles	Striking Passenger Vehicle Fatalities
≤35 mph	12,841	13,015	12,125	12,296
>35 mph	20,868	21,291	19,236	19,611
No Statutory Limit / Non-Traffic Area	101	101	91	91
Unknown or Missing	1,524	1,555	1,378	1,407
Total	35,334	35,962	32,830	33,405

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This research note and other general information on highway traffic safety are located at: www-nrd.nhtsa.dot.gov/CATS/index.aspx