STAPP CAR CRASH CONFERENCE
SHORT COMMUNICATION

SC17-07

Pedestrian Flex-PLI Legform Test Performance for Seven Early 2000s' Small Cars

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ABSTRACT – IIHS is examining the potential real-world benefit of vehicle-based pedestrian tests, such as those proposed by NHTSA for future safety ratings. Laboratory pedestrian headform tests of seven popular small cars from the early 2000s predicted a range of pedestrian head protection for these vehicles. Comparing test results to fatal and incapacitating injury rates for these vehicles from US police-reported vehicle-to-pedestrian crashes data indicated a moderately strong correlation between real-world injury rates and laboratory headform-predicted head injury risks for these vehicles. This study examined the predicted pedestrian leg injury risk for these same small cars, based on laboratory legform tests. The vehicles had similar front-end geometry and bumper materials, which contributed to matching observations of legform kinematics. In all vehicles, regardless of impact location, leg sensors measured high risks of tibia and knee injuries, typically above Euro NCAP-established injury thresholds. The vehicles did not produce a relative range of performance, even with tests at a lower impact speed. These results suggest that the bumper designs for these seven vehicles pose similarly high risks for pedestrian leg injury.

INTRODUCTION

In 2015, 5,376 pedestrians were killed on US roadways, accounting for 15% of traffic fatalities (National Highway Traffic Safety Administration, 2016). Previous studies of seriously injured pedestrians in the US, Europe, and Asia have shown the most commonly injured body region is the head followed by the lower extremities (Mueller et al. 2013; Ono et al. 2005; Zhang and Hu 2008). Serious head injuries contributed to fatalities in nearly 80% of crashes while $^2/_3$ of these pedestrians also had serious torso injuries (Ehrlich et al., 2009).

Vehicle-based countermeasures may address injuries sustained by pedestrians. The concept of designing vehicles with energy absorbing structures (crushable hoods and padded bumpers) on the vehicle's front end has been around since the 1970s, but gained traction in the 2000s with the implementation of component tests for consumer and regulatory evaluations by NCAPs in the European Union, Korea, and Japan. In 2008, the United Nations agreed to adopt the Global Technical Regulation No. 9 (GTR 9), a subset of the tests conducted for Euro NCAP, including head-to-hood and leg-to-bumper impacts with globally harmonized test conditions (United Nations Economic Commission for Europe, 2009). NHTSA issued their support for the GTR 9, but no further advancement has been made toward rulemaking. In 2015, NHTSA announced the inclusion of a passive pedestrian protection evaluation for their proposed future NCAP revisions. An implementation date has not been set.

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Attempts have been made to relate vehicle design changes to real-world injury risks. Studies looking at real-world pedestrian crashes in Germany (Pastor, 2013) and Sweden (Standroth et al, 2011) have found a relationship between Euro NCAP pedestrian headform and legform test results and real-world incidence of injury. Mueller et al. (2013) compared head component test results of seven small cars sold in the US with a range of real-world injury rates, finding a moderately strong statistically significant correlation between laboratory scores and real-world injury rates. The correlation was stronger when all vehicle front-end components were evaluated, not just the GTR 9 hood zone.

The objective of the current study was to compare the level of pedestrian leg protection provided for seven early 2000s' popular small cars based on Euro NCAP-style laboratory legform test assessments.

METHODS

Seven small cars from the early 2000s, labeled A-G in this study, were selected because they are associated with a range of real-world incapacitating injury rates from the police-reported crash data of 14 states. (Mueller et. al., 2013). In an earlier study of the same vehicles, rates per hundred pedestrians struck with incapacitating injuries (disabling injuries such as broken bones and internal organ injuries) were computed and standardized based on vehicle make and model, state, and pedestrian age group. The incapacitating injury rates for each vehicle are listed in Appendix A.

Laboratory Flex legform testing

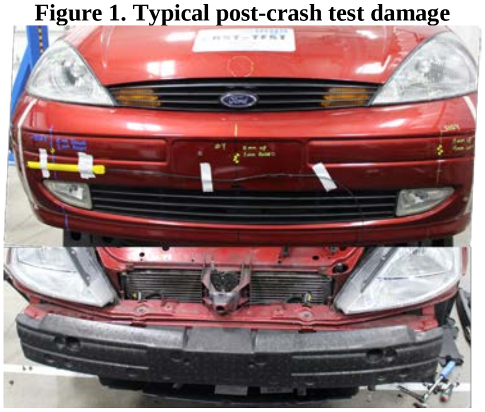
Three Euro NCAP style Flex-PLI legform-to-bumper impact tests were performed on each vehicle with sensors measuring femur bending, knee elongation, and tibia bending. An impact to the center of the vehicle and frame rail were performed at the standard test speed of 40 km/h. An additional impact was performed to the other frame rail at a lower test speed of 30 km/h. High-speed video footage captured the leg kinematics during impact.

Prior to testing, the bumper system construction including geometry and materials were documented. The front profile shape along the vehicle's longitudinal centerline was also measured. Damage to the vehicle was documented post-impact.

RESULTS

Vehicle bumper systems were similar in shape and construction, with a flexible plastic bumper cover and foam-bead energy absorber. None of the bumper systems sustained damage during impact (Figure 1). Legform kinematics were similar among vehicles (Figure 2). Peak sensor measures by leg component are shown in Table 1.

Figure 1. Typical post-crash test damage



DISCUSSION

Impact location had little influence on sensor measurements. The center impact, expected to be a softer location, produced similar leg sensor measures as the outboard frame rail location, expected to be the stiffest point across the bumper. Lack of bumper absorber damage for either location suggests it remained too stiff to provide meaningful energy absorption to the legform. The different stiffness of components behind the absorber is irrelevant.

The lower test speed produced lower peak sensor measures than the higher speed but did not differentiate between vehicles, and values often remained above the sensor-predicted injury reference values.

Testing did not reveal a significant range of performance across the seven vehicle models, even at the lower test speed. Leg test performance is highly dependent on leg kinematics, wrapping around the vehicle profile, and energy absorption along the legform. With the observed uniformity of front-end geometry and bumper materials for these vehicles, the similarity in legform evaluations is not surprising.

Figure 2. Typical legform kinematics

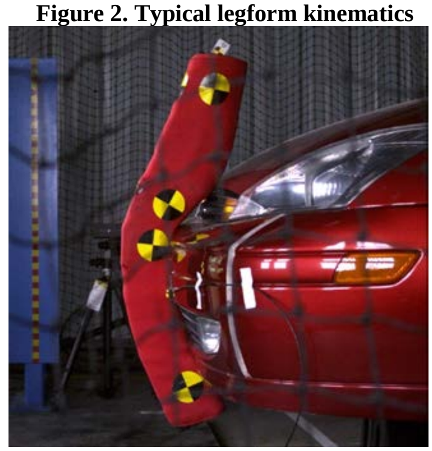


Table 1. Peak Flex-PLI leg sensor measures

Impact location		Reference value	A	B	C	D	E	F	G	Pearson correlations (p-value)
Center	Max Femur (Nm)		266	278	304	185	277	331	311	-0.08 (0.86)
	Max knee (mm)	22	27	25	29	17	30	34	24	-0.17 (0.71)
	Max tibia (Nm)	340	468	419	456	455	506	414	447	0.36 (0.42)
Frame rail	Max Femur (Nm)		253	228	269	200	279	306	274	0.06 (0.88)
	Max knee (mm)	22	24	25	27	17	28	31	23	-0.02 (0.95)
	Max tibia (Nm)	340	443	419	461	440	505	415	444	0.09 (0.83)
Frame rail 30 km/h	Max Femur (Nm)		212	212	257	166	253	280	219	-0.05 (0.9)
	Max knee (mm)	22	21	20	25	13	25	28	22	-0.17 (0.71)
	Max tibia (Nm)	340	359	332	373	360	352	337	371	0.34 (0.44)

The test method doesn't discriminate between performance in these seven vehicles but may be likely to show differences between these and newer vehicles, specifically designed for this kind of test assessment.

The study vehicles show a range of pedestrian incapacitating injury rates in real-world crash data, and headform tests of the same vehicles showed a range of performance that correlated with the real-world injury data (Mueller et. al., 2013). The lower extremity is second to the head as the most commonly injured body region in pedestrian crashes, so the current study was undertaken to determine whether bumper performance in legform tests could further explain the real-world incapacitating injury rates. However, the test vehicles showed uniformly high sensor measures in the legform tests, suggesting high risk of leg injury regardless of test speed. This, combined with the inability to determine lower-extremity-specific real-world injury rates, made a comparison of test and real-world data difficult. For completeness, correlations between test data and real-world incapacitating injury rates were calculated and no relationship was found. Revising this study to compare legform impactor test results from more varied vehicle designs to field data that specifically identifies leg injuries would produce a more robust understanding of the real-world effectiveness of the test assessment.

CONCLUSION

High sensor measures, exceeding Euro NCAP-established injury risks, observed in laboratory legform tests for seven early 2000s' small cars sold in the US suggest that the bumper designs for these seven vehicles pose similarly high risk for pedestrian leg injury.

REFERENCES

Ehrlich, E., Tischer, A., and Maxeiner, H. (2009) Lethal pedestrian-passenger car collisions in Berlin: changed injury patterns in two different time intervals. *Legal Medicine* 11(suppl 1): S324-6.

Mueller, B., Farmer, C., Jermakian, J., and Zuby, D. (2013) Relationship between pedestrian headform tests and injury and fatality rates in vehicle-to-pedestrian crashes in the United States. *Stapp Car Crash Journal* 57: 13S-22.

National Highway Traffic Safety Administration, (2016) Traffic safety facts, Research note, Highlight of 2015 motor vehicle crashes, Report no. DOT HS-811-625, U.S. Department of Transportation, Washington, DC.

Ono, Y., Komiyama, Y., and Yamazaki, K. (2005) Introduction of pedestrian head protection performance test in J-NCAP. Paper no. 0307. *Proceedings of the 19th International ESV Conference*, National Highway Traffic Safety Administration, Washington, DC.

Pastor, C. (2013) Correlation between pedestrian injury severity in real-life crashes and Euro NCAP pedestrian test results. *Proceedings of the 23rd International ESV Conference*, National Highway Traffic Safety Administration, Washington, DC.

Strandroth, J., Rizzi, M., Sternlund, S., Lie, A., and Tingvall, C. (2011) The correlation between pedestrian injury severity in real-life crashes and Euro NCAP pedestrian test results. *Traffic Injury Prevention* 12: 604-13.

United Nations Economic Commission for Europe. (2009) Transport: Vehicle Regulations; 1998 Agreement on Global Technical Regulations, Appendix to Global Technical Regulation No. 9 Pedestrian Safety (ECE/TRANS/180/Add.9/ Appendix 1). Geneva, Switzerland.

Zhang, G. and Hu, J. (2008) A field data analysis of risk factors affecting the injury risks in vehicle-to pedestrian crashes. *Proceedings of the 52nd Annual AAAM Conference*, pp.199-214. Association for the Advancement of Automotive Medicine, Des Plaines, IL.

Appendix A. Incapacitating injury rates (Mueller et.al, 2013)

Vehicle	Crashes	Weighted Rate
A	693	10.62
B	911	14.54
C	2,142	15.25
D	844	17.06
E	703	18.80
F	1,133	15.98
G	929	19.38