

Comparisons between Child Safety Regulatory Tests and Vehicle Crash Test Pulses using Contemporary Data

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I. INTRODUCTION

While the child passenger safety community has made significant strides in mitigating motor vehicle injuries among child occupants, motor vehicle crashes continue to be the leading cause of death and a leading cause of non-fatal injury for children (1–8 years) [1-2]. Change in velocity (Delta V) is strongly predictive of injury in child occupants [3]. Recent research has shown that occupant loading has increased compared to prior decades [4]. Locey *et al.* [4] found that frontal crash test vehicle accelerations increased by 0.4 g to 1.57 g per year and that crash pulse durations decreased by 0.74 ms to 2.51 ms per year while holding closing speed constant. This study aims to compare the sled test pulses of US FMVSS 213, the ECE R44 and the Consumer Reports (CR) child-restraint evaluation pulse with full-scale vehicle crash tests for post-2000 models. The aim is to understand the extent to which they are representative of contemporary vehicle crashes.

II. METHODS

National Highway Traffic Safety Administration (NHTSA) vehicle crash test data were used. Inclusion criteria for the test cases to be compared to the sled crash pulses were: post-2000 models of passenger vehicles subject to a full frontal rigid barrier impact at 0 degrees angle at 48 kph closing speed for FMVSS 213 and R44, and at 56 kph closing speed for CR pulse. The acceleration data were filtered at CFC 60 Hz (as per SAE J211 standard). The following crash pulse characteristics were extracted: Maximum deceleration (G); Time of maximum deceleration (ms); Jerk (G/s); Pulse duration (ms); and Delta V (kph). To compare the specific crash pulse characteristics of the vehicle tests with the characteristics of the sled crash pulses, a one-sample t-test was used for the pulse characteristics that showed a normal distribution and a one-sample Wilcoxon signed rank test was used for the pulse characteristics not normally distributed. P-level was set to 0.05. To determine the similarity between each vehicle crash pulse with the FMVSS 213, R44 and CR pulses, cross-correlation was used.

III. INITIAL FINDINGS

For comparisons with the FMVSS 213 and R44 pulses, 48 vehicle tests from the NHTSA vehicle crash test database met the inclusion criteria and had available data. For comparisons with the CR pulse, 667 vehicle tests from the NHTSA New Car Assessment Program (NCAP) vehicle crash test database met the inclusion criteria. The pulse characteristics of the three sled pulses show several statistically significant differences as compared to the pulse characteristics of the vehicle crash tests (Table I).

TABLE I
PULSE CHARACTERISTIC COMPARISONS

	Max. Deceleration (G)	Time of Max. Deceleration (ms)	Jerk (G/s)	Pulse duration (ms)	Delta V (kph)
Crash tests at 48 kph (mean ± SD)	33.8 ± 7.2 ^{*,+}	45.9 ± 14.9 ^{*,+}	922.9 ± 594.7 ⁺	93.1 ± 10.4 ^{*,+}	51.6 ± 4.1 [*]
FMVSS 213	24.1	28.6	841.63	86.7	48.3
ECE R44	24.6	58.5	421.1	106.1	51.9
Crash tests at 56 kph (mean ± SD)	42.8 ± 9.2 ^{&}	46.1 ± 14.4 ^{&}	1179.1 ± 1018.1	93.4 ± 14.9 ^{&}	63.9 ± 2.8 ^{&}
CR	34.3	35	981.3	76.6	55.7

*p<0.001 comparisons with FMVSS 213; + p<0.001 comparisons with ECE R44; & p<0.001 comparisons with CR.

FMVSS 213, ECE R44 and CR deceleration-time histories showed high cross-correlation confident values with the deceleration-time history of the vehicle crash tests (Table II).

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TABLE II
CROSS-CORRELATION COEFFICIENT VALUES

Deceleration-time history		Cross-correlation coefficient (mean ±SD)
FMVSS 213	Crash tests at 48 kph	0.88 (0.06)
ECE R44	Crash tests at 48 kph	0.89 (0.07)
CR	Crash tests at 56 kph	0.89 (0.09)

The deceleration-time history of all vehicle tests at 48 kph compared to the FMVSS 213 and ECE R44 pulse and the deceleration-time history of all vehicle tests at 56 kph compared with the CR pulse are shown in Fig. 1.

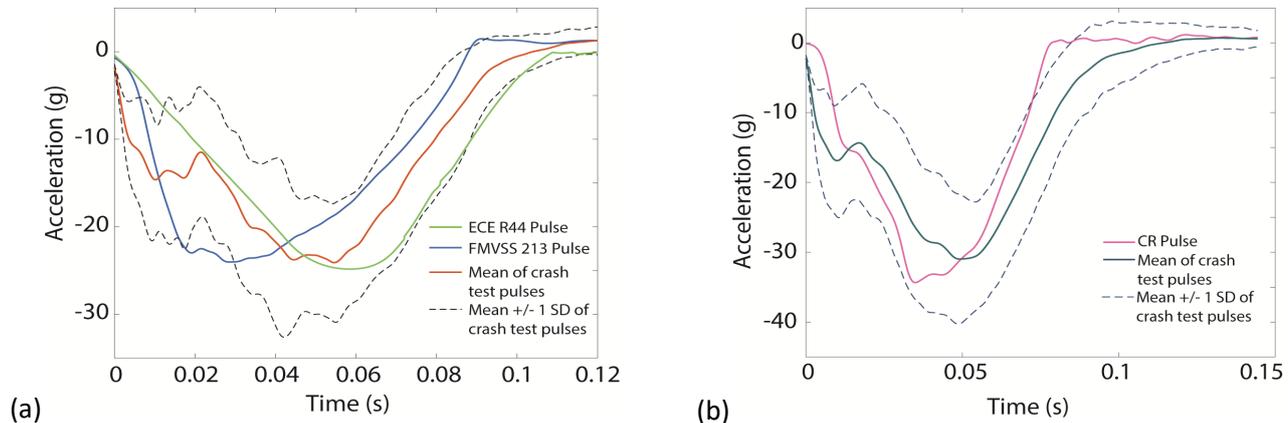


Fig. 1. (a) Mean (SD) of the deceleration-time history of the 48 kph vehicle crash test pulses compared to FMVSS 213 and ECE R44 pulses; (b) Mean (SD) of the deceleration-time history of the 56 kph vehicle crash test pulses compared to the CR pulse.

IV. DISCUSSION

Similarities exist between the shapes of the regulatory and CR acceleration pulses with the vehicle crash tests (Fig. 1), as evidenced by cross-correlation coefficients of approximately 0.9 (Table II). However, there are statistically significant differences between the characteristics of the sled pulses and the vehicle crash acceleration pulses. Not surprisingly, the FMVSS 213 pulse showed a significant difference in Delta V, since the FMVSS 213 test procedure specifies that Delta V shall be 48 km/h (+ 0, -3.2 km/h). Maximum deceleration and Jerk were also greater in the vehicle test crash pulses compared to FMVSS 213, ECE R44, and CR pulses. The pulse characteristics analysis (Table I) showed that the vehicle and sled pulses were largely different when discrete points in the curve were compared, whereas the cross-correlation analysis (Table II) showed that the vehicle and regulatory pulses were highly similar when the shape of the curves was compared. This analysis also presents some limitations. We were only able to extract 48 vehicle tests from the NHTSA database for the comparisons between the FMVSS 213 and ECE R44 pulse. Future research should focus on developing mathematical models that allow a comparison of crash pulse shape that is independent of closing speed.

In summary, these findings highlight the similarities and differences between the vehicle crash testing and regulatory and CR crash pulses.

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VI. REFERENCES

- [1] CDC, 2017. <https://www.cdc.gov/injury/wisqars/LeadingCauses.html>.
- [2] Lyons, R., et al., *Curr Paediatr*, 2005.
- [3] Nance, M., et al., *Ann Surg*, 2006.
- [4] Locey, C., et al., *Ann Adv Automot Med Assoc Adv Automot Med Annu Sci Conf*, 2012.