Injury assessment of child restraint systems in realistic conditions

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I. INTRODUCTION

The main objective of this work is to assess and compare the injury criteria measured in a frontal impact with a Q10 dummy placed in a booster seat and in seat belt alone on a rear car seat. Previous findings [1] showed that Q-series dummies on a test bench offer limited capability of discriminating between child restraint systems and seat belt alone in regulatory tests which increases the risk that unsafe CRSs are able to enter the market To improve the selectivity of testing procedures we investigated the outcome of dynamic tests executed under realistic conditions by substituting the test bench with a rear car seat. Results show that the dynamic behaviour of the dummy is significantly different between the two different restraint devices in a car seat. In particular, the head resultant acceleration, the neck tension force, the neck tension moment and the abdominal pressure have significantly safer values in the booster seat than in seat belt alone device. The dynamics of each recorded parameter were compared through machine learning techniques, which further confirm the differences between the two different restraint solutions. It can be concluded that during a frontal impact test with the real car seat, the Q10 dummy can discriminate among different restraint solutions despite the regulatory conditions applied.

II. METHODS

Four frontal impact tests were conducted, as prescribed in the UNECE Regulation 129, on an acceleration sled at the CSI S.p.A. facility in Bollate (Italy). To reproduce a "real-life" environment, the universal test bench was replaced with a vehicle shell, its rear seat and its seat belt system.

A survey was carried out to provide information about the seats and buckle position. The outcome of the survey lead to the selection of a "worst-case" seat, i.e. the longest buckle (100 mm) and the softest cushion vehicle representing ca. 10% of the vehicles surveyed.

The tests were performed with a Q10 dummy manufactured by Humanetics (USA) equipped with head, thorax and pelvis accelerometers, lower and upper neck tension load cell, rib deflection sensor, lower lumbar spine load cell, abdomen pressure sensor. Two restraint devices were tested: a universal category booster seat and seat belt alone.

During the tests, we measured 48 different parameters to compare the behaviour of the two different restraint devices. All tests were also recorded with five high-speed, high-resolution cameras (1000 fps). The cameras were used to measure the displacement of the manikin's head and knee in the vertical and horizontal direction and to assess if the lap belt passed the pelvic structure (submarining phenomenon).

III. INITIAL FINDINGS

We applied the injury thresholds defined for the Q10 dummy in the UNECE Regulation 129 to assess the risk of the two restraint devices. Table 1 summarizes the absolute values of the relevant parameters. The booster seat values were lower than the permissible thresholds for all parameters. However, for the seat belt alone restraint device, the abdominal pressure and the head acceleration during the 3 ms period defined by the UNECE Regulation 129 exceeded the threshold by 250% and 25%, respectively.

TABLE I. Absolute values of injury parameters

	Threshold for Q10	**Seat belt alone**		**Booster Seat**	
Devices		**SL3689**	**SL3692**	**SL3688**	**SL3694**
Head performance criterion	**800**	667.72	668.46	271.57	180,58
Head acceleration 3 ms [g]	**80**	96.36	91.37	57.35	47.24
Upper neck tension force Fz [kN]	-	6.52	6.30	3.89	2.69
Upper neck flexion moment My [Nm]	-	14.9	3.17	5.86	6.19
Chest acceleration 3 ms [g]	**55**	47.42	44.23	42.16	39.43
Chest deflection resultant [mm] (Upper – Lower)	-	39.32 - 29.18	40.89 - 29.23	29.23 - 15.80	37.35 - 35.89
Abdominal pressure [bar] (Left – Right)	**1.2**	1.82 - 1.73	2.59 - 1.91	0.38 - 0.39	0.28 - 0.88

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The visual assessment of the dummy in the seat belt alone restraint device confirmed the submarining of the dummy at the period of the maximum horizontal head excursion (Fig. 1 and Fig.2) and the jack-knife effect during the rebounding phase (Fig 3 and Fig 4). None of these phenomena were observed with the booster seat.

Fig. 1 Frame of the video at the time of the maximum horizontal head excursion with booster seat (106 ms)

Fig. 2 Frame of the video at the time of maximum horizontal head excursion with seat belt alone (100 ms)

Fig. 3 Frame of the video during the rebounding phase with booster seat (284 ms)

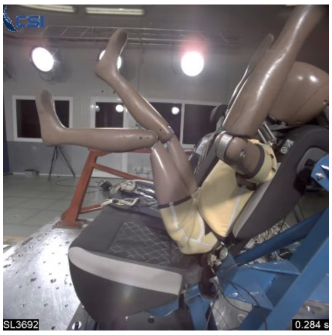

Fig. 4 Frame of the video during the rebounding phase with seat belt alone (284 ms)

Finally, we extended the comparison of the dynamics of the devices by using both minimum and maximum values of all the recorded parameters. In order to have a global overview of the behaviour of the different configurations tested, we carried out a principal components analysis and K-means clustering for the 96 extracted features applying the Wide method with covariance (Fig. 5). The density plot shows that “seat belt alone” and “booster seat” belong to significantly different clusters.

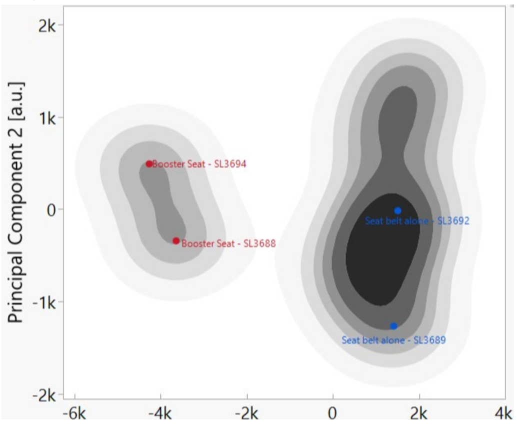

Fig. 5 Principal components analysis and cluster analysis for booster seat and seat belt alone

IV. DISCUSSION

Results show that the real car seat (used in the tests) allows the Q10 dummy to discriminate between different restraint systems. Visual observation of the video frames confirmed the occurrence of the submarining and jack-knife phenomena in the “seat belt alone” device. The visual observation of submarining for seat belt alone device matches the extremely high measured abdominal pressure up to 2.59 bar. In the principal components analysis, all the recorded parameters show that the two restraining devices belong to two different clusters and thus have significantly different dynamic behaviour. However, the analysis is limited to the Q10 dummy on only one type of rear car seat. For comprehensive study, tests on the Q3 and Q6 dummy, with other car seats, seating positions (e.g. according to UMTRI[2]), different pulse combinations will be necessary to improve the assessment of realistic submarining effects. Finally, the comparison of different realistic tests with regulatory test bench results is desirable to understand the advantages and limitations of using a vehicle shell with a real car seat on a trolley in regulation.

V. REFERENCES

[1] Visvikis C. et al. , IRCOBI conference, 2020.

[2] Yaguchi M, et al., 23rd ESV, Paper Number 13-0333, 2013