SUBMARINING CRITERIA FOR CHILD RESTRAINT SYSTEMS
WITH OLDER CHILDREN

B.M. Girard1, Dr. S.Cirovic, Dr. D.Abasolo

1Centre for Biomedical Engineering, Department of Mechanical Engineering Sciences
Faculty of Engineering and Physical Sciences
University of Surrey, Guildford, UK
b.girard@surrey.ac.uk

Abstract - Child Restraint Systems (CRS) help protect children in cars should an accident occur, but they can also lead to injuries. Such injuries can be the consequence of what is called submarining. Submarining consists in a complex motion where the seat belt can load the abdomen and hence cause injuries. CRS are tested using dynamic sled tests during which a sled with a crash test dummy is accelerated and stopped suddenly to mimic a crash. Dummy motion and instrumentation recordings during these tests, were used to produce novel criteria in the assessment of submarining.

I. INTRODUCTION

Within Europe, Child Restraint Systems (CRS) are approved for sale by meeting specific requirements and passing different tests, such as dynamic sled tests. Sled tests consist in mimicking a crash and can be done either by decelerating an already accelerated sled; or by propelling a sled with a specific pulse. These allow for measurement of CRS efficiency in restraining and protecting children, through the use of surrogate human dummies. These are fitted with instrumentation which can help gauge the level of injury incurred during a crash. While there are head, neck and chest criteria the CRS need to meet to be certified, the abdominal injury criteria relies solely on the presence of marks on the abdominal clay insert of the currently approved P dummy family [1]. Abdominal injuries from car accidents can range from bruising to hollow and solid organ lacerations. One specific mechanisms by which abdominal injuries consistently occur is called submarining. It is akin to slouching under the seat-belt, consequently loading and injuring the abdomen [2, 3]. This phenomenon can be observed in children using booster cushions or booster seat CRS, respectively with and without a backrest, which use the car seat-belt (Reed et al., 2013). Presently, children up to 12 years old or up to 150cm (125cm depending on countries), weighing more than 15kg, are to be restrained with these aforementioned CRS [4]. As part of the Enabling Protection for Older Children (EPOCh) project, a Seventh Framework Project, a more comprehensive understanding of submarining, as well as a more robust mean of detecting it with older children, was sought out through this research.

II. METHODS

A total of 120 frontal impact sled tests were performed at three EPOCh partner sites using currently approved european testing protocols. As such, 90 tests, inclusive of 6 submarining-inducing tests, used the European Commission for Europe Regulation 44.04 (ECER44) protocol [1], which is part of the CRS approval legislation for sale within Europe, and 30 through the New Programme for the Assessment of Child-restraint System protocol (NPACS), which is directed at consumers, providing a 5 band rating system to assess the best CRS on the market. Two dummies were used for the tests, the new Q10 dummy and the currently approved P10. The Q10 is the enhanced, more "human-like" version of the P10. They were tested on a total of 10 CRS, with 6 booster seats and 4 booster cushions, representing a cross-section of those currently in use in Europe. The dummies were labelled with stickers at key anatomical features of the head and limbs, that were tracked through video recordings in order to produce trajectories. Dynamic data were also recorded from the dummies instrumentation. Using these data, a range of statistical tests, as well as time series similarity measures were produced. These were used with the purpose of finding key criteria and a combination of those criteria that could consistently segregate between submarining and non-submarining behaviour.

III. RESULTS

Three booster seats (S3,S4,S7,SUBIND S4) and one booster cushion (C2), were considered to have submarining effects, based on the slouching dummy behaviour in the
videos, post-test comments and observations. In terms of trajectory, the lower limb displacement showed different results for these types of CRS. As shown in figure 1 the horizontal knee excursion is exaggerated and the horizontal knee velocity differs from 120ms onward. This was seen for the Q10 dummy but not for the P10. For cushions, the distance between the head and the knee also showed a clear distinction, with the distance decreasing less in the case of submarining. The statistical tests and time series analysis confirmed the difference for knee displacement, and head-knee distance, however the distinction wasn’t as clear for the knee velocity. The statistical tests of the individual dynamic data highlighted the same CRS for pelvis acceleration resultant, and chest angular velocity in Y. Chest rotation in Y did show differences, however only for cushions. Other results, such as the lumbar dynamic data, showed differences between CRS, yet without any apparent grouping; and the head and neck data showed uniform patterns among all the CRS.

Figure 1: Knee Displacement and Velocity in X (horizontal)

IV. DISCUSSION

When analysing the videos only, leg displacement was shown to be a good criteria for distinguishing submarining and non-submarining behaviour, however only for the Q10. This is most likely due to the fact that the P10 dummy is not as “human-like” as the Q10 and therefore does not move in the same way. The head-knee distance was also found to be a good criteria, however only for cushions. Since the cushions do not have a backrest, the chest can rotate freely, and so the distance between the head and the knee provides information on the chest position. These findings had been previously demonstrated for the Hybrid III dummy, which is the American dummy [5,6]. When considering the individual dynamic data, Hu et al. (2012) found that chest rotation could discriminate between submarining and non-submarining [6], however this was the case only for cushions in our findings. This confirms our result about the head-knee distance. Additionally, we found that chest angular velocity in Y, chest deflection, the pelvis acceleration as well as belt load could show the distinction between submarining and non-submarining in both seats and cushions.

V. CONCLUSION

Current means of identifying submarining in CRS for older children are lacking. The use of leg motion for detection of submarining has been proven to be a conclusive criteria for the Q10 and should be considered for CRS approval in Europe. However submarining involves the motion of the whole body in the form of slouching, and as such, a more robust criteria needs to be researched, involving other body parts. With that viewpoint we suggest combining chest, pelvis, belt data with knee displacement. Further research on the link between the aforementioned dynamic data and the leg displacement should help in better understanding the underlying mechanics of submarining.

VI. REFERENCES