Parametric Study of 3-Year-Olds in a Child Restraint System with Harness Pretensioner and Load Limiter

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I. INTRODUCTION

Although, fatalities and severe injuries to child occupants in motor vehicle crashes have decreased over recent years (in developed countries), motor vehicle crashes remain one of the leading causes of death and long-term health consequences for children 1-12 years old, despite of the use of child restraints. The effectiveness of child restraints in reducing injury or death varies by the type of restraint. Severe injuries are less frequent in frontal impact with rear-facing child restraints compared to forward-facing child restraint systems (FF CRSs) [1]. Rear-facing CRSs reduce injury risk for children up to 3-4 years old by almost 90% compared to an unrestrained child [2]. Unfortunately, only in Scandinavian countries, children stay rear-facing until they are 4-5 years old. Despite of awareness campaigns, most parents in other European countries still put their children into FF seats as soon as possible. Parents prefer to sit facing towards the direction of motion when they travel and tend to seat children the same way. As long as the National Law and National Regulations allow it and parents prefer FF CRSs, these safety systems should be improved. One way to reduce the risk of severe injury and death is to apply crash forces early and to keep magnitudes low. It can be done by the use of a pretensioner and load limiter. Recent research has shown that the application of the pretensioner and load limiter resulted in reduction of the injury response of a child dummy and its model [3-5]. Designing an optimal child restraint system is difficult due to many parameters that have influence on child occupant safety. The purpose of this study was to indicate which variables have a significant effect on Q3 dummy model response. A 3-year-old in a FF CRS with harness pretensioner and load limiter in the rear seat of a passenger car was considered.

II. METHODS

This study has been conducted using Madymo v7.5.2 and HyperWorks v13 software [6-7]. The Madymo model for frontal impact analysis consisted of the Q3 dummy in FF CRS model, facet seat model, 5-point hybrid belts. The impact pulses according to the ECE R129 regulation with ΔV 50 km/h and peak acceleration 27g were used. A Design of Experiments (DOE) in HyperStudy was set up with Full Factorial method at two levels. Seven independent variables (factors) presented in Table I have been defined: three parameters related to the child seat (seat motion (*REVO*), friction coefficient (*FRIC*) and cushion stiffness (*STIFF*)), four related to the child safety belt (slack in left (*SL_L*) and right (*SL_R*) shoulder belts, pretensioner fire time (*PT_FT*), constant load limiter (*LL*). All possible combinations of the factor levels were investigated.

TABLE I
PROPOSED INDEPENDENT VARIABLES AND THEIR RANGES

Name	Units	Low	High
SL_L	mm	5	30
SL_R	mm	5	30
FRIC	-	0,35	0,7
STIFF	%	80	140
LL	kN	0,75	5
PT_FT	ms	8	15
REVO	-	No	*Yes*

The Head Injury Criterion with the time interval of 15ms (*HIC_15*), Head resultant acceleration that is exceeded during at least 3ms (*H_Cum3*), thorax resultant acceleration (*T_Cum3*), Chest Deflection (*C_D*), upper neck tension force (*Fz*), and upper neck flexion moment (*My*) were used as dependent variables (responses). To make the evaluation more robust, more than one Q3 dummy model response for each body region was considered. These responses were based on the parameters that may directly interact with the Q3 dummy

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measurements. All signals were filtered according to the SAE J211-1 (CFC filters).

III. INITIAL FINDINGS

In this research, responses chosen to represents injuries to the head were the most important (based on injury frequency). Injury criteria corresponding to a 20% risk of an AIS3+ injury were used [8-10] (Table II).

TABLE II

PROPOSED DEPENDENT VARIABLE AND THEIR CRITICAL VALUES AND CONSTANT TERMS

Name	Units	Critical Value	Constant Term
HIC_15	-	780	301,86
H_Cum3	g	84	46,27
T_Cum3	g	55	36,97
C_D	mm	38	38,88
Fz	N	1550	1,63
My	Nm	79	17,14

Main effects (the influence of the factors on the responses) relative to the constant term (Table II) in linear regression analysis are presented in Table III. The highest values are bolded. The load limiter has the greatest effect on most responses (higher levels of LL had great increase of head and neck injury responses). Harness slack and friction coefficient are also significant parameters (higher levels of friction coefficient showed a reduction of all responses while belt slack showed an increase of chest resultant acceleration). CRS stiffness, pretensioner fire time and motion of the CRS had marginal effect on the responses. The greatest interaction effects were noticed between shoulder belt slack, load limiter and seat friction coefficient. Head excursions in all simulations did not reach the limit of 550 mm.

TABLE III

THE MAIN EFFECTS FROM EACH PARAMETER [%]

Effects	HIC_15	H_Cum3	T_Cum3	C_D	Fz	My
SL_L	1,48	-1,28	**5,24**	0,34	-0,31	1,71
SL_R	1,94	-0,73	**5,12**	0,70	0,12	0,52
FRIC	**-7,90**	-1,09	-0,75	**-12,69**	-4,52	**-6,04**
STIFF	-0,99	-0,68	-0,69	-2,18	-0,72	-0,75
LL	**12,27**	**17,01**	**5,83**	3,10	**11,50**	-1,47
PT_FT	0,25	0,01	1,27	-0,04	-0,11	-0,16
REVO	2,12	-1,71	-3,08	3,94	3,10	-4,37

IV. DISCUSSION

The pretensioner and load limiter may improve child occupant protection by removing belt slack, applying crash forces early and keeping magnitudes low. These safety devices are able to keep child occupants in better position and prevent head injuries due to contact with the vehicle interior during the crash event. It was found that the load limiter has the greatest overall effect on injury responses. It was indicated that in many cases the critical value of neck injury criteria was exceeded. It remains uncertain whether the model is able to predict all child dummy model measurements accurately (especially neck responses and chest deflection are considered not to be good representatives of the injury potential). However, this study as the comparative study (the trends were taken into account), should still be valuable. Main effects depend on the defined range of independent variables. Moreover, other variables may need further investigation (i.e., CRS pitch angle as a factor and abdominal response). Future research will include a range of pre-crash seated positions.

V. REFERENCES

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