Child chest deflection in nominal and reclined seat-back angles during frontal impacts

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I. INTRODUCTION

Previous reclined child occupant research found that belt-positioning boosters (BPBs) can foster a lap-belt and pelvis coupling that prevents submarining in frontal impact [1], although injuries at the spine and neck could still potentially emerge [2]. Abdominal injuries are more common than thoracic injuries in motor vehicle crashes (MVCs) for children [3]. This is due to the ongoing ossification process of the ribs and sternum that makes the child's thorax more flexible than the adult's thorax [4]. However, it is unknown how reclined postures may impact chest deflection in child occupants. Furthermore, pre-crash countermeasures, such as the pre-pretensioner belt (PPT) added to the rear seat, and their interactions with children in reclined postures has not been examined. The aim of this study was to examine how different seat-back angles, the presence of a backless booster and the PPT can affect chest deflection and thorax angular displacement in the Large Omnidirectional Child (LODC) Anthropometric Test Device (ATD) during sled-simulated frontal impacts.

II. METHODS

Twelve sled-simulated frontal impact tests were performed (targeted 24 g peak, 80 ms duration, 56 km/h delta-V) with the LODC seated on a backless BPB on a production-type vehicle seat. An adjustable D-ring anchor simulated a seat-integrated belt. A fixed load-limited (targeted 4 kN) 3-point seat belt without pretensioner was used. For the tests with the simulated PPT, 100 mm of belt webbing was pulled in to pretension the webbing. To measure chest deflection, the LODC thorax utilised one laser displacement sensor at the level of the 6th thoracic vertebra (T6) [3]. Peak chest deflection and peak T6 Y angular displacement were extracted and compared for the following conditions: (a) nominal 25°, 45° and 60° seat-back angles; (b) PPT vs. no-PPT in 45° and 60° seat-back angles; c) with BPB vs no BPB (for 25° and 45° only). Chest compression multiplied by the compression rate (Cmax*Vmax) was calculated and compared to the thoracic injury curves for the LODC [3].

III. INITIAL FINDINGS

When the LODC was seated on the BPB, peak chest deflection was comparable across all seat-back angle conditions with the BPB (Table I). Without the BPB, in all seat-back angles the peak chest deflection was lower compared to all the conditions with the BPB (Table I, Fig. 1 a–c). T6 flexion decreased as seat-back angle increased from 25° to 60° for the BPB conditions with and without PPT (Fig. 1).

TABLE I
MEAN ± SD OF PEAK CHEST DEFLECTION AND T6 SAGITTAL ANGULAR DISPLACEMENT (°)

Seat-back angles (°)	BPB	# tests	Peak chest deflection (mm)	Cmax*Vmax	Peak T6 Y angular displacements (°)	Peak Shoulder Seat Belt Force (N)	Peak Lap SeatBelt Force (N)
25	Y	2	57 (21)	0.32 (0.22)	64	4212#	5345 #
45	Y	2	54 (13)	0.28 (0.13)	48 (5)	5162.0 (924.9) #	6011.5 (207.2) #
60	Y	1	59	0.34	8	5081	7714
45 with PPT	Y	2	60 (3)	0.33 (0.03)	45 (3)	5764.5 (44.5) #	5742.0 (309.7) #
60 with PPT	Y	1	52	0.26	31	5401.0	7456.0
25	N	2	12 (1)	0.02 (0.00)	29 (5)	4850.5 (364.2) #	6063.5 (50.2) #
45	N	2	20 (9)	0.04 (0.04)	28 (9)	4584.0 (210.7) #	5020.5 (495.7) #

Note: # Some peak shoulder- and lap-belt forces in Table I (#) were previously reported in [1]. We included them here for discussion.

In the 60° condition, the time series showed T6 extension at ~70 ms and flexion at ~130 ms. Thus, T6 flexion in the 60° condition occurred after the peak chest deflection (~90 ms) (Fig. 1 c) and later than in the other conditions where both peak chest deflection and peak T6 flexion occurred at ~110 ms (Fig. 1 a–c).

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Peak chest deflection was also greater in the 45° condition with the PPT than without (Fig. 1 b vs. Fig. 1 d), while the opposite was found in the 60° condition (Fig. 1 c vs. Fig. 1 e). The 60° conditions without the PPT (Fig. 1 c) showed the highest deflection with the least trunk flexion. The lap-belt forces were also highest in the 60° condition without the PPT, suggesting the LODC pelvis pushed against the lap belt and increased the forces on the pelvis. The 60° condition with the PPT had lower lap-belt forces and more T6 flexion than the 60° condition without PPT. Without the BPB, peak chest deflection was the lowest in all conditions. In the 45° condition with BPB, T6 flexion was the smallest, consistent with the lack of pelvis flexion and motion of the LODC under the lap belt previously observed in the same test data [1]. Average Cmax*Vmax demonstrated a thoracic injury risk below 5% [3].

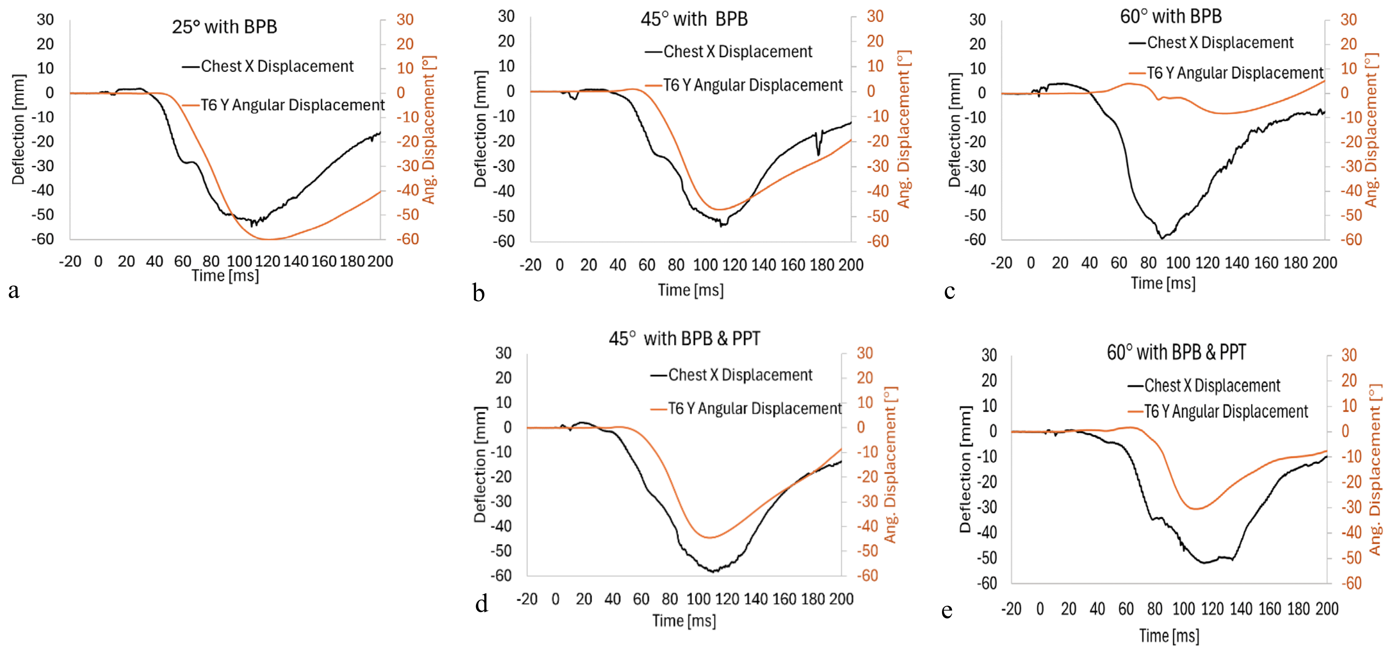

Fig. 1. Time series of chest deflection (mm) and T6 angular displacement (°) averaged across repetitions for the BPB conditions.

IV. DISCUSSION

Our findings suggest that reclined BPB-seated children might experience similar chest deflection, with a low risk of thoracic injury, to nominally BPB-seated children in frontal impacts. Previous work compared cardiopulmonary resuscitation (CPR) chest deflection in children (41–72 mm) to the chest deflection occurring in children in MVCs (31.5–73 mm) [4]. Our chest deflection values are within the chest deflection ranges for both CPR and MVCs. This finding suggests that chest deflection in reclined postures may fall within current corridors established for nominally seated children. The simulated PPT in our study led to increased deflection in the 45° condition, but decreased deflection and lap-belt forces in the 60° condition. With the BPB and PPT, some of the lap-belt forces might have transferred to the shoulder (slight shoulder-belt force increase, and lap-belt decrease in the 45° and 60° conditions with the PPT vs. no PPT) rather than loading the pelvis. Belt loading and chest deflections appear to be more consistent with the other seat-back conditions in the 60° condition with the PPT than in the 60° condition without the PPT. Although this finding demonstrated a potential benefit of the PPT in reclined conditions, it needs further examination, particularly in cases where the PPT activation precedes the pretensioner activation (which we did not include in our study). The one-point chest deflection sensor was a limitation, particularly in the conditions without the BPB, as the seat belt did not overlap with the chest sensor in the no-BPB conditions (Table I). Future studies should consider an evaluation of chest deflection in the reclined LODC equipped with three chest sensors.

V. REFERENCES

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