The Contribution of the Booster Seat Motion to the Pelvis Angular Displacement in Reclined Seating Configurations during Far-Side Lateral-Oblique Impacts

Valentina Graci, John Humm, Hans Hauschild

I. INTRODUCTION

Previous reclined child occupant research found that Belt-Positioning Boosters (BPB) can foster good lap-belt and pelvis coupling and prevent submarining [1-3]. On the other hand, during far-side lateral oblique impacts, taller BPBs lead to greater head displacements compared to when small occupants sit on shorter BPBs [2] or directly on a vehicle seat [4]. In these above-mentioned studies, the BPB was not secured via LATCH. Previous studies found that in nominal seatback configurations, far-side lateral-oblique impacts facilitated the rotation and tipping of the BPB [5] while the LATCH reduced head excursion [5]. It is unclear how and if the BPB also rotate and tip when placed in a seat with a reclined seatback. The aim of this study was to examine the BPB motion and to understand if/how the BPB movement contributes to the child's lateral motion when the seatback is reclined and the LATCH is not used during far-side lateral-oblique impacts.

II. METHODS

The Large Omni-Directional Child (LODC) Anthropomorphic Test Device (ATD), representing an 8-10 y.o. child, was tested in nine lateral-oblique impact sled tests (80° from frontal and 32 km/h, duration 60 ms, peak acceleration 21 g, FMVSS213a side impact pulse). Three seatback angles (25°, 45° and 60°) were tested: 45° and 60° were tested with the BPB (without LATCH) and without the BPB. Each test was repeated, except for 60° without BPB. A production minivan passenger seat with a 3-point integrated seatbelt was used. During the simulated far-side lateral-oblique impact, the LODC moved toward the buckle side. A 27 camera-3D motion capture system (1000 Hz, Vicon Motion System Ltd, UK) was used to track head motion. Lateral peak head displacement was extracted from the 3D motion capture system and referred to the LODC's initial head position. Lateral pelvis and BPB angular displacements were integrated from the pelvis and BPB rotational velocity obtained by angular rate sensors. All peaks for lateral head, pelvis and BPB displacements were within the window of interest of 100 ms in the time series.

III. INITIAL FINDINGS

Overall, the BPB rotated from 10° to 15° toward the far-side direction. Unlike the peak lateral head displacements and lateral pelvis angular displacements, the peak BPB angular displacement did not appear to decrease with the increased seatback angle (Table I).

TABLE I

MEAN ± SD OF THE OUTCOME MEASURES

Seatback angles (°)	BPB presence	Peak lateral BPB angular displacement (°)	Peak lateral pelvis angular displacement (°)	Peak lateral head displacement (mm)
25	Y	9.8*	36.6 ± 0.1	980.5 ± 17.7
45	Y	15.7 ± 3.3	34.8 ± 3.1	973 ± 19.8
60	Y	12.0 ± 2.0	31.0 ± 1.8	952.5 ± 2.1
45	N	na	-4.8 ± 0.3	848.0 ± 11.3
60	N	na	-4.6	851

*A technical issue with the BPB angular rate sensor prevented data collection in 1 repetition form the 25° with BPB condition.

When examining the time series, in all conditions the peak lateral BPB rotation occurred early in the pulse (around 60 ms), with a subsequent decrease in rotation. The lateral pelvis angular displacement increased at a similar time as the peak lateral BPB rotation and continued to rise further afterwards (Fig. 1). In the reclined conditions, the peak BPB lateral rotation was greater than the pelvis lateral rotation when examined at the same time point until approximately 70 ms, while that was not the case for the nominal condition (Fig. 1, top left).

V. Graci (e-mail: graciv@chop.edu) is an Assistant Research Professor at Drexel University and Children's Hospital of Philadelphia, USA. J. Humm and H. Hauschild were Assistant Professor and Senior Research Engineer, respectively, at the Medical College of Wisconsin when conducting this project.

Without the BPB, minimal lateral rotation was present in the pelvis and the LODC slides laterally and remains flat on the vehicle seat rather than rotating in the frontal plane (Fig. 2, right).

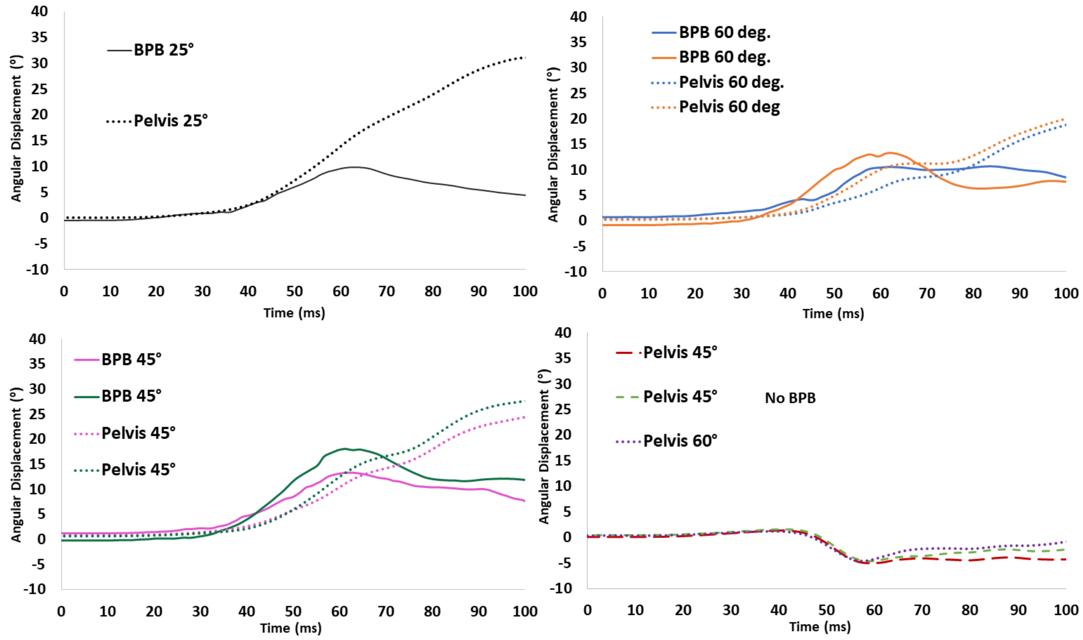

Fig. 1. Time series of the Pelvis and BPB lateral angular displacement in all seatback conditions.

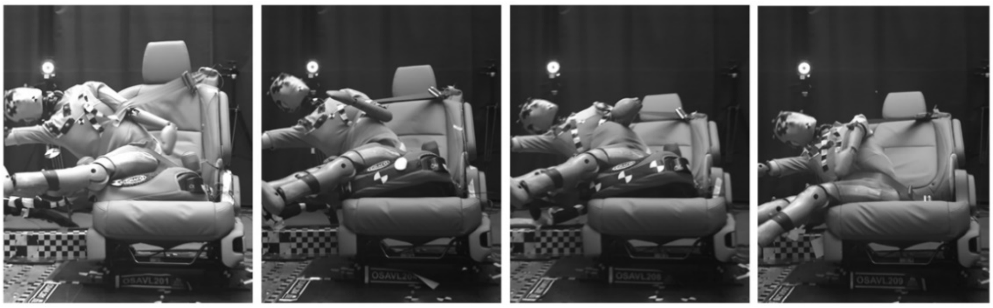

Fig. 2. LODC around the instant of peak motion. From left to right: 25° with BPB, 45° with BPB, 60° with BPB, 60° no BPB.

IV. DISCUSSION

Our findings showed that the BPB rotation and tipping might have contributed to the early rise (60 ms) of the LODC pelvis angular displacement, particularly in the reclined conditions. This may have consequentially led to greater lateral head displacement with the BPB (Table I). A potential explanation for the greater BPB motion in the reclined conditions compared to the nominal is that current BPBs are not designed for reclined configurations. Additionally, the back of the BPB was likely in less contact with the reclined seatback, leading to decreased friction, which might have contributed to increased BPB rotation. The BPB in this study was not attached via LATCH to the vehicle seat. Previous research revealed that in far-side lateral-oblique impacts when LATCH was not used, the BPB tipping and rotation were present and head excursion increased [5]. More recently, it was found that the ISOFIX did not produce a relevant difference in reclined BPB children in frontal crashes while the belt pretensioner did [3]. Future research on reclined BPB-seated children is needed to explore the feasibility and effectiveness of the LATCH systems to keep the child restraint systems in place, specifically in far-side lateral-oblique impacts, in both nominal and reclined conditions.

V. REFERENCES

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