Analyzing the Influence of Trial Order on Seat Belt Fit for Pediatric Occupants in Reclined Vehicle Configurations

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Introduction: As autonomous vehicle technologies are developed, there are increased possibilities of vehicle seats with recline capabilities. Recent work has begun to investigate recline child configurations during frontal and lateral impacts2, but the initial position of the child in these tests was likely not naturalistic. The effect of seat recline angle on static belt fit for children in boosters has not been assessed particularly when multiple reclined trials are proposed. The examination of reclined static postures can inform the initial child position in future sled testing and finite element simulations. Children may "slouch" as they settle into their comfortable posture3. Measuring child posture in recline conditions over multiple trials could potentially be biased due to a child's "slouching" behavior which may also influence belt fit. Therefore, it is crucial to evaluate if the order of conditions influenced belt fit measurements.

Objective: Evaluate the influence of condition order on child seatbelt fit in reclined vehicle configurations.

Methodology: Institutional Review Board (IRB) approval was obtained (2023H0261). Forty-three children between 4-12y were recruited. Each child was evaluated in a mock-up vehicle seat under six conditions: with and without a backless booster in each of three recline angles (upright (25°), moderately reclined (45°), and reclined (60°)). The order of the trials for each participant was randomized; however, all booster or vehicle trials were grouped together. During each trial, the child assumed a comfortable position and settled into their self-selected posture. A 3D coordinate measurement device was then used to measure anatomic and seatbelt landmarks (such as left and right anterior superior iliac spine (ASIS), sternal notch, etc.) according to the SAE J211 coordinate system4.Seatbelt fit metrics included the Y and Z positions of the shoulder belt with respect to (wrt) sternal notch and the X and Z positions of the lap belt wrt the ASIS. The "detailed order" variable represents the sequence of each condition (1–6) corresponding to the order the participant completed the trials. The "simple order" (1 or 2) represents the overall order of seating conditions (booster or vehicle) for each participant, without considering recline angle. Variation in belt fit with seating configuration order and the order of the all trials was assessed using nonparametric Wilcoxon/Kruskal-Wallis tests (alpha=0.05).

Results: Detailed or simple order were not significantly related to most belt fit variables, with a few exceptions (highlighted in yellow, Table 1). The left lap belt wrt ASIS Z was significant across condition order on the booster. Similarly, the right lap belt wrt ASIS Z in the vehicle condition. While the differences in means were relatively small, it may indicate changes in child posture and belt fit throughout all the trials.

Conclusions: Overall, the condition order may influence some aspects of seatbelt fit for this test methodology. This suggests that condition order may need to be considered in future comparisons of the belt fit observed across recline angles in this test setup. In addition, other aspects, such as variation in child behavior in posture in the reclined configurations over time, must also be considered.

Table 1: Wilcoxon/Kruskal-Wallis Tests Results

Variable	Direction	Condition	Simple Order Results			Detailed Order Results						
			p Value	Seating Condition 1 (mm)	Seating Condition 2 (mm)	p Value	Trial 1 (mm)	Trial 2 (mm)	Trial 3 (mm)	Trial 4 (mm)	Trial 5 (mm)	Trial 6 (mm)
Shoulder Belt wrt Sternal Notch	Y	Booster	0.4102	47.33 ±18.60	43.71 ±20.90	0.4420	44.57 ±17.07	48.99 ±20.64	48.42 ±18.36	44.87 ±25.58	37.41 ±14.55	48.86 ±20.59
		Vehicle	0.0297	-0.71 ±18.34	5.94 ±19.19	0.1958	-0.01 ±16.97	-0.51 ±21.14	-1.61 ±17.66	6.61 ±18.11	8.89 ±19.73	2.32 ±19.86
	Z	Booster	0.7185	-11.09 ±8.80	-10.46 ±8.10	0.7208	-11.65 ±8.57	-11.84 ±7.35	-9.77 ±10.42	-8.54 ±7.17	-10.40 ±8.53	-12.45 ±8.48
		Vehicle	0.4102	-16.33 ±7.84	-17.99 ±7.88	0.6140	-14.37 ±6.30	-17.88 ±9.26	-16.74 ±7.70	-18.3 ±8.46	-18.16 ±6.33	-17.54 ±8.93
Lap Belt wrt Left ASIS	X	Booster	0.4843	49.04 ±20.75	45.71 ±18.30	0.6183	52.67 ±22.34	50.10 ±19.23	44.37 ±20.52	45.24 ±15.85	44.08 ±15.49	47.81 ±23.35
		Vehicle	0.2058	-9.98 ±12.63	-13.98 ±16.64	0.2730	-7.67 ±13.13	-8.97 ±9.33	-13.31 ±14.81	-11.12 ±15.43	-12.21 ±16.30	-18.62 ±17.76
	Z	Booster	0.0004	-7.79 ±7.60	-12.63 ±6.91	0.0035	-8.31 ± 8.71	-9.19 ± 5.88	-5.87 ±7.85	-13.06 ±6.33	-11.43 ±6.78	-13.42 ±7.79
		Vehicle	0.1555	-11.49 ±9.90	-8.27 ±5.62	0.6241	-10.78 ±10.25	-11.71 ±8.35	-11.99 ±11.40	-7.71 ±6.05	-7.96 ±5.10	-9.12 ±5.79
Lap Belt wrt Right ASIS	X	Booster	0.7221	57.52 ±20.95	55.32 ±20.78	0.3982	62.25 ±20.22	58.89 ±21.75	51.41 ±20.17	56.80 ±21.11	51.23 ±16.10	57.93 ±24.79
		Vehicle	0.1260	-2.06 ±13.61	-6.89 ±17.17	0.5510	-1.13 ±15.13	-1.24 ±10.37	-3.83 ±15.36	-4.62 ±15.75	-6.5 ±18.06	-9.55 ±17.95
	Z	Booster	0.0167	-7.71 ±8.51	-11.58 ±7.52	0.0625	-8.85 ±8.27	-9.21 ±8.65	-5.08 ±8.33	-12.78 ±7.55	-10.32 ±6.78	-11.63 ±8.37
		Vehicle	0.0016	-6.42 ±7.08	-3.2 ±5.15	0.0267	-5.47 ±5.25	-6.78 ±4.97	-7.01 ±10.14	-2.88 ±5.72	-2.70 ±3.31	-4.03 ±6.08

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