Design and Testing of a Prototype Wheelchair-Integrated, Five-Point Occupant Restraint System for Children Who Remain Seated in Wheelchairs When Traveling in Motor Vehicles

Miriam A. Manary, Jennifer M. Whalen, Nichole L. Ritchie, and Lawrence W. Schneider
University of Michigan Transportation Research Institute

ABSTRACT

Wheelchair-integrated restraints that can be used instead of vehicle-mounted seat belts for crash protection during motor vehicle travel can improve the safety and comfort of wheelchair users, and reduce transport time. This is especially important for children for whom vehicle-anchored lap/shoulder belts do not provide adequate restraint. The proposed improvements to ANSI/RESNA WC/19 include requirements for a five-point, wheelchair-integrated harness for riders who weigh less than 22 kg (50 lb). To evaluate the requirement's feasibility, two pediatric wheelchairs were modified to include a restraint harness fitted to the three-year-old Hybrid III anthropomorphic test device (ATD or crash-test dummy). The prototypes were dynamically tested using the WC/19 frontal impact test. The first prototype did not effectively restrain the ATD due to failure of the wheelchair seatback canes, but the second prototype, with reinforced frame, provided effective restraint and met the WC/19 performance criteria.

KEYWORDS

Wheelchair, Motor Vehicle Crashes, Seatbelts, Five-Point Harness, Child Passenger Safety

BACKGROUND

The primary goal of Section 19 of ANSI RESNA WC/Volume 1 – *Wheelchairs Used as Seats in Motor Vehicles* (1) (i.e.,WC/19) is to provide a level of protection for people who use wheelchairs as seats in motor vehicles comparable to the level of safety available to occupants who use vehicle seats. In the general population, children under 22 kg (50 lb) are not well protected in crashes by vehicle-anchored lap/shoulder belts because of poor belt fit. For these reasons, children under 22 kg should be restrained in either a child safety seat with an integrated five-point harness that complies with Federal Motor Vehicle Safety Standard 213 *Child Restraint Systems,* known as FMVSS 213 (2), or, for children over 18 kg (40 lb), in a FMVSS213- compliant booster seat that improves seatbelt fit.

These same crash protection issues apply to children under 22 kg who remain seated in their wheelchair during travel. A wheelchair-anchored five-point restraint harness will offer improved restraint and safety to small children by improving belt fit and encouraging better distribution of restraint forces to the strongest skeletal regions of the body. A wheelchair-integrated restraint harness will also reduce the time involved in securing wheelchairs and restraining children who remain seated in their wheelchairs. An enhancement to WC/19 will soon require frontal-impact testing of wheelchairs intended for use by children under 22 kg (50 lb) using only a wheelchair-anchored five-point occupant restraint harness to restrain the ATD. This paper reports on a project to demonstrate the feasibility of implementing a crashworthy five-point harness into common pediatric commercial wheelchairs.

METHODS

Two prototypes of an integrated five-point restraint harness were developed for previously used manual pediatric wheelchairs. The first prototype is shown in Figure 1 with the five-point harness and three-year-old ATD before the crash test. Because this wheelchair was not equipped with WC/19-compliant securement points, these were added to the base frame. The five-point harness was obtained from a commonly available 213-compliant child safety seat and installed on the wheelchair with as few changes to the wheelchair as possible. To attach the harness to the wheelchair seating system, slots were cut in the seat, seatback, and anchoring brackets located at the junction of the seat rails and seatback canes. The crotch strap was anchored to a transverse bar bolted under the seat between the seat rails and the shoulder straps were anchored to a transverse bar bolted between the seatback posts. Two three-bar clips were used to secure the ends of the lap belt to the brackets at the seat-to-seatback junctions.

Insert Figure 1 here

The second prototype was developed after a failure of the seatback canes during a frontal-impact test of the first prototype and was implemented on a previously used pediatric wheelchair frame shown in Figure 2. Securement points were again added to the base frame. The wheelchair seatback was strengthened by replacing the angle bracket between the seat rails and seatback posts with a similar, stronger bracket as shown in Figure 3, and by inserting steel tubing inside seatback canes. To provide for anchoring the upper and lower straps of the harness, one transverse bar was bolted under the seat between the seat rails and two additional transverse bars were bolted between the seatback posts as shown in Figure 4. A five-point harness from an FVMSS 213-complaint child safety seat was used without modification and installed on the wheelchair in the same manner as prototype 1.

Insert Figures 2 to 4 here

Each prototype was tested using the 48-kph/20-*g* (30-mph) frontal-impact test protocol in Annex A of ANSI/RESNA WC/19 with a 15-kg (33-lb) Hybrid III, three-year-old ATD seated in the wheelchair seat and restrained by only the five-point harness. The wheelchairs were secured facing forward on the sled platform using the surrogate, four-point, strap-type wheelchair tiedown system specified in Annex D of WC/19. The occupant restraint harness was placed on the ATD and tightened as specified for testing of child safety seats in FMVSS 213. For each test, a side-view high-speed video camera was used to document wheelchair and ATD kinematics during impact loading at 1000 frames per second, and webbing load cells were placed on the shoulder, lap, and crotch portions of the restraint harness. The ATD was also instrumented with triaxial head and chest accelerometers.

RESULTS

The frontal-impact test of the first prototype resulted in failure near the base of both seatback posts, as shown in Figure 5, due to seatback loading by the upper harness belts. Figure 6 shows a sequence of images from the side-view high-speed video that shows the kinematics of the wheelchair and ATD during impact loading. As indicated, the lower torso of the ATD was effectively restrained, but the seatback failure compromised the performance of the upper-torso belts, which resulted in a high forward head excursion and contact of the ATD's head with the lower extremities.

Insert Figures 5 and 6 here.

As shown in Figure 7, the frontal-impact test of the second prototype resulted in improved restraint of the ATD's upper torso. Table 1 compares peak head and knee excursions from this test with WC/19-proposed excursion limits for the three-year-old ATD. As indicated, all excursions are within the proposed limits. Although measures of Head Injury Criteria (HIC) and the 3-ms clip of resultant chest acceleration are not included in current or proposed pass/fail of WC/19, they are required performance criteria in FMVSS 213. Table 2 compares these metrics for the test of the second prototype with the 213 limits, and also lists peak forces measured in lap and shoulder belts of the five-point harness. As indicated, both HIC and peak resultant chest acceleration are below FMVSS 213 limits.

Insert Figure 7 and Table 1 and Table 2 here

DISCUSSION

Wheelchair-integrated five-point harnesses have the potential to improve occupant protection for small children who remain in their wheelchairs when traveling in motor vehicles. Toward this goal, ANSI/RESNA WC/19 is being revised to include wheelchairs for children who weigh less than 22 kg (50lb) by requiring frontal-impact testing with a wheelchair-integrated, five-point harness.

The development and testing of the prototype systems in this study demonstrate the feasibility of this requirement for pediatric wheelchairs and provide data on the restraint loads generated by a 15-kg (33-lb) occupant. Both prototypes used five-point harnesses from FMVSS 213-compliant child safety seats that were integrated into production wheelchair seats and frames with relatively minor modifications. In order to achieve acceptable restraint of the upper torso, reinforcement of wheelchair seatback posts will usually be needed. This was accomplished in the second prototype by reinforcing each seatback post with a length of steel tubing and by replacing the angle bracket between the seat rails and seatback posts with a similar part made of stronger material. Good fit of the harness to the ATD was accomplished by cutting slots in the seat and seatback to make paths to anchor points for the crotch and shoulder straps, respectively, and adding wheelchair frame members that provided anchoring points for the harness.

The information from these tests will be combined with child anthropometry data from a pediatric belt-and-harness fit study to develop design guidelines for wheelchair-integrated harnesses. Future work will include testing the second prototype using a 22-kg (50 lb) six-year-old child ATD and working with manufacturers to implement and test integrated pediatric restraint harnesses on other types of wheelchairs.

REFERENCES

1. American National Standards Institute/Rehabilitation Engineering and Assistive Technology Society of North America (ANSI/RESNA). (2000). Section 19 ANSI/RESNA WC/Volume 1: *Wheelchairs Used as Seats in Motor Vehicles*. Arlington, VA.

2. Code of Federal Regulations, Title 49, Transportation, Part 571.213; *Child restraint systems*. Washington, D.C. 2003 National Archives and Records Service, Office of the Federal Register.

ACKNOWLEDGEMENTS

This study was funded by the National Institute on Disability and Rehabilitation Research (NIDRR) and the Rehabilitation Engineering Research Center (RERC) on Wheelchair Transportation, grant # H133E010302. The opinions expressed herein are those of the authors and are not necessarily reflected of NIDRR opinions. The authors would like to thank Brian Eby, Stewart Simonett, and Charles Bradley for their assistance in designing and fabricating the prototypes and conducting the dynamic tests.

Contact Information: Miriam A. Manary. Biosciences Division, University of Michigan Transportation Research Institute, 2901 Baxter Road, Ann Arbor, MI, 48109-2150

Figure 1. Pre-test photo of first prototype

Figure 2. Pre-test photo of the second prototype

Figure 3. Side view of second prototype showing stronger bracket between seatback post and seat rail with slot for anchoring lap belt using three-bar clip.

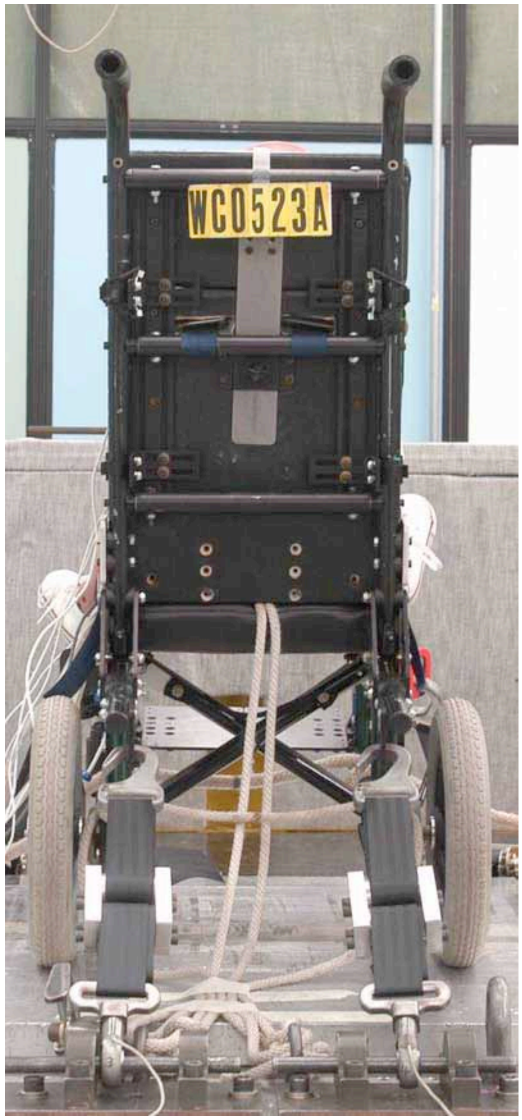

Figure 4. Rear view of second prototype showing the two transverse bars added to provide for anchoring the upper-torso belts.

Figure 5. Rear view of seatback posts for the first prototype showing fracture of the tubing on both sides.

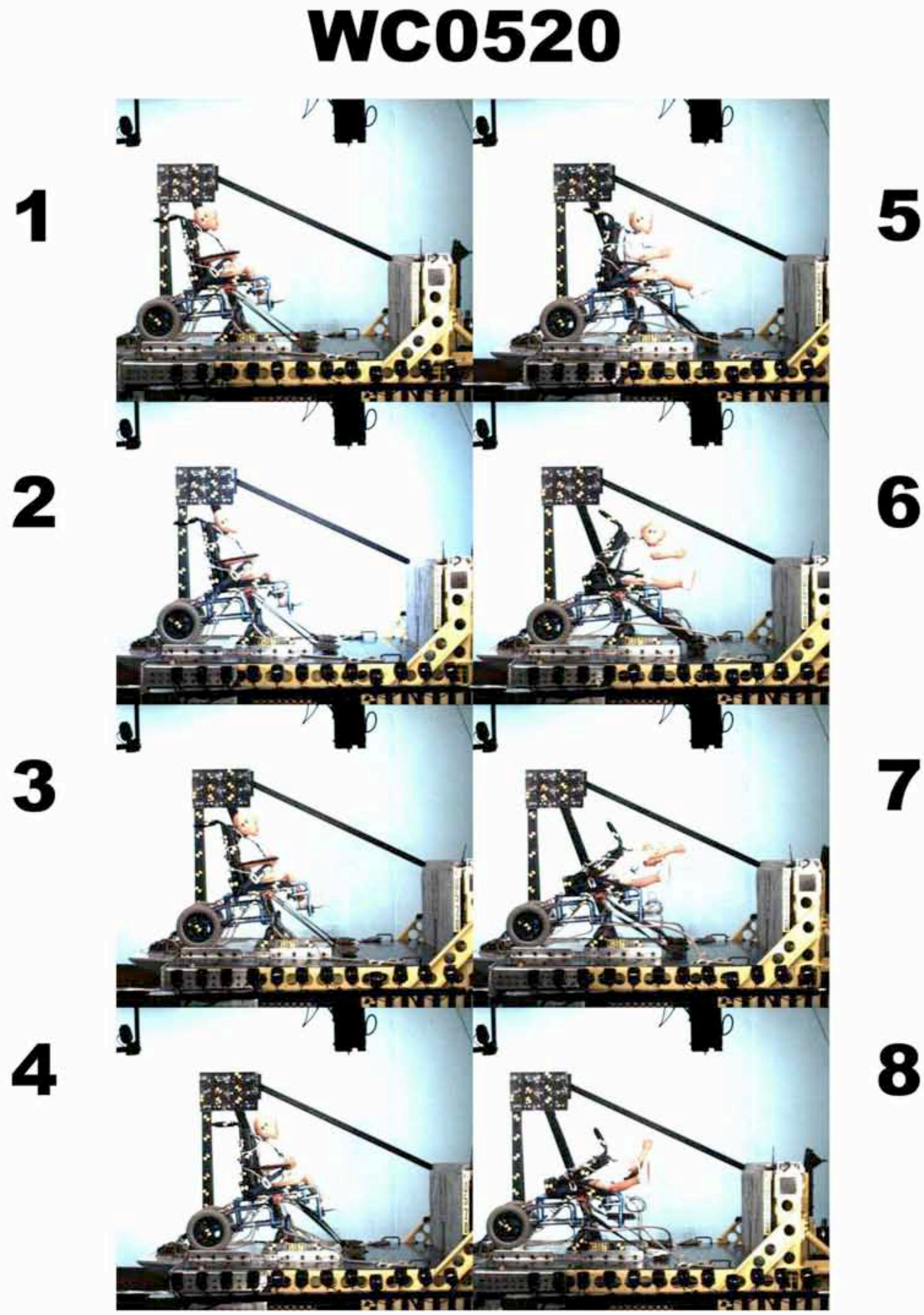

Figure 6. Time-sequence photos from test of first prototype showing high forward head excursion and head contact with lower extremities due to failure of seatback posts.

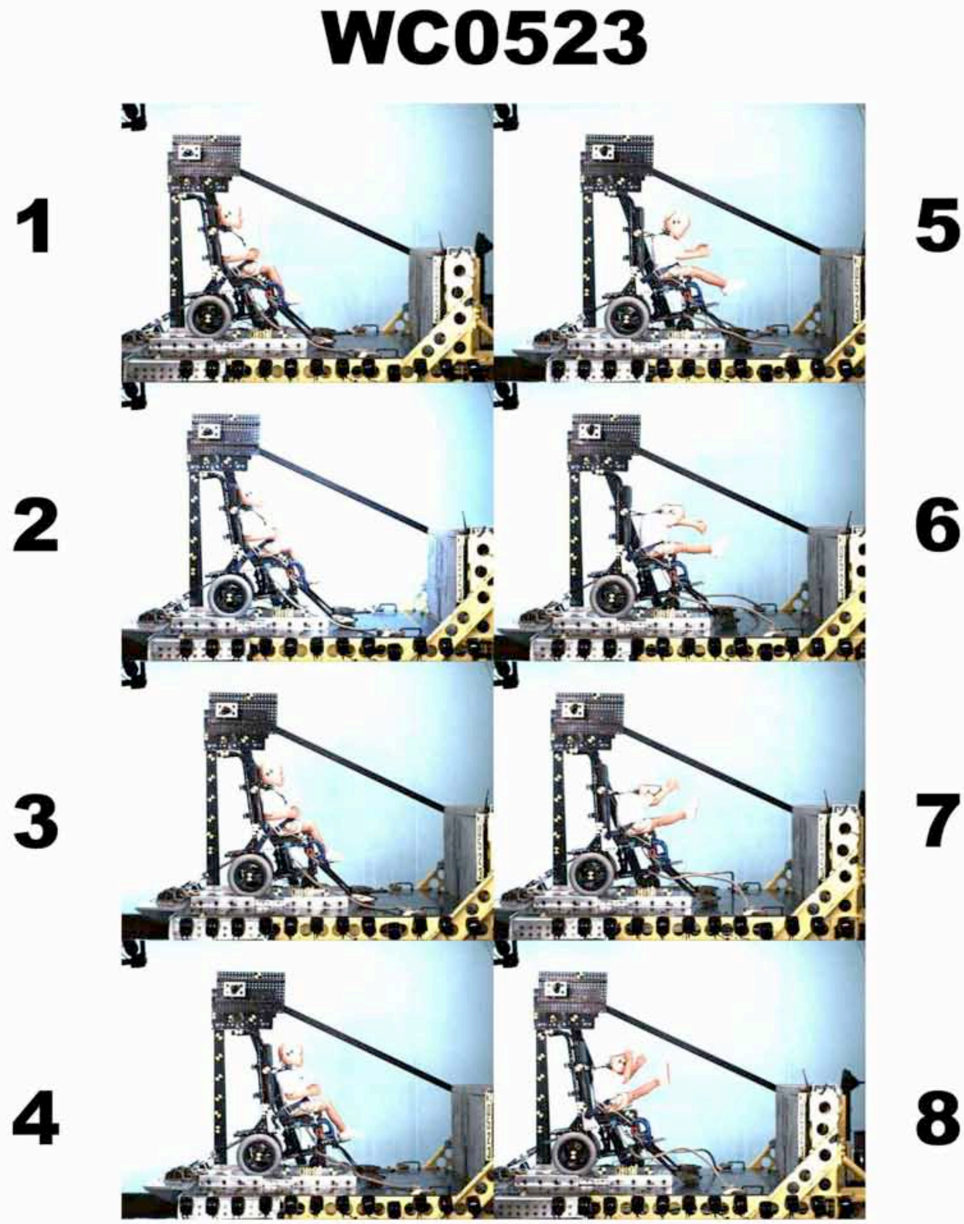

Figure 7. Time-sequence photos from the test of the second prototype showing good upper- and lower-torso restraint of the ATD.

Table 1
Summary of Wheelchair/Restraint Performance Compared to WC/19 Requirements

Requirement		Observed Performance	
WC/19 Clause	Description	Description	Pass/Fail
5.3a	WC securement points cannot show material failure, other than deformation or yielding	No sign of material failure	Pass
5.3b	Deformation of WC securement points must not prevent disengagement of hook	Little to no deformation and no hindrance to disengagement	Pass
5.3c	WC upright and on test platform	WC upright and on sled	Pass
5.3d	ATD must be in WC seat with torso reclined not more than 45˚	ATD upright and seated in WC	Pass
5.3e	Detached hardware cannot exceed 100g	No detached hardware	Pass
5.3f	No sharp edges with potential for occupant contact	No sharp edges exposed	Pass
5.3g	Primary WC components cannot show signs of failure that is not anticipated by WC design	No WC load-carrying components failed	Pass
5.3h	Forward excursion of Point P<150 mm	85 mm	Pass
	Forward knee excursion <300 mm	127 mm	Pass
	Forward head excursion <450 mm	239 mm	Pass
	Rearward head excursion <350 mm	213 mm	Pass
5.3i	Ratio of ATD knee excursion to Point P excursion must exceed 1.1.	Ratio of ATD knee excursion to Point P excursion = 1.5	Pass
5.3j	Posttest height of ATD H-point at least 80% of pretest height	ATD H-point decreased by 0.6%	Pass
5.3k	Detachable seating inserts must stay secured to WC	Seating system remained attached	Pass
5.3l	Batteries must be within WC footprint, remain attached to WC, and away from user space	na	na
5.3 m	WC cannot cause failure of the surrogate WTORS.	No WTORS failure	Pass

Note: WC = wheelchair, WTORS = wheelchair tiedown and occupant restraint system

Table 2
HIC, Peak Resultant Chest *G*s, and
Peak Harness Loads from Test of Second Prototype

Measure	**Test Result**	**FMVSS 213 Limit**
HIC	448	1000
Chest acceleration, 3-ms clip	37 *g*	60 *g*
Peak harness loads		
Left Shoulder	1345 N (302 lb)	-
Right Shoulder	1433 N (322 lb)	-
Left Lap	975 N (219 lb)	-
Right Lap	952 N (214 lb)	-
Crotch	867 N (194 lb)	-