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TETHERS ANCHORS IN PICKUP TRUCKS: ASSESSING USABILITY, LABELING, AND PERFORMANCE

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16. Abstract

This project investigated factors relating to tether use and misuse in pickup trucks and evaluated four interventions designed to educate consumers on proper use. The dynamic performance of four tether locations was also evaluated.

Volunteer testing was performed with 24 subjects on 4 different pickup trucks using 2 forward-facing child restraints (Britax Marathon G4.1 and the Evenflo Triumph), with each subject performing 8 child restraint installations on the set of four vehicles. Pickup trucks were selected to represent four different implementations of tether anchors in pickup trucks: Chevy Silverado (plastic wire loop routers), Dodge Ram (webbing routers), Nissan Frontier (back wall anchor), and Toyota Tundra (webbing routers plus metal anchor). Interventions included a diagram label, QR code linked to video instruction, coordinating (i.e., low contrast with interior trim) text label, and contrasting-color text tag.

Subjects used the tether in 93% of trials. However, tether use was completely correct in only 9% of trials. The installation was considered functional if the subject attached the tether to a tether anchor and had a tight installation (ignoring routing and head restraint position); 28% of subjects achieved a functional installation. The most common error was attaching the tether anchor to the anchor/router directly behind the child restraint rather than placing it through the router and attaching it to the anchor in the adjacent seating position. The Nissan Frontier, with the anchor located behind the seatback, had the highest rate of correct installations but also had the highest rate of attaching to components other than a tether anchor (seat adjustor, child restraint hardware, head restraint). None of the interventions had a significant effect on correct installation; not a single subject scanned the QR code to access the video instructions. The most successful subjects spent extensive time reviewing the vehicle manuals.

Results indicate that current implementations of tether anchors in pickup trucks are not intuitive and alternate designs should be explored. A set of impact tests was run using the proposed FMVSS No. 213 bench to evaluate the dynamic performance of the different tether anchor locations used in the subject testing, with and without 50 mm of slack. A tether anchor location simulating a roof-mounted location above the rear window of a pickup was also included in the matrix. Slack had a greater effect on head excursion compared to tether anchor location. Tether anchors located on the seatback, filler panel, or at an adjacent seating position had the lowest head excursions, followed by an anchor located above the window, followed by no tether anchor. Future research should involve testing performance of a tether anchor located above the window after being placed through a tether router.

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Introduction

Background

In 2002, the LATCH (Lower Anchors and Tethers for Children) system was required in most new US vehicles and child restraints to provide a means for easier child restraint installation compared to using the vehicle safety belt. Vehicles have two lower anchors placed near the vehicle seat bight and a top tether anchor generally located rearward of the seatback near the vehicle seat centerline. The child restraint has lower connectors that attach to the vehicle anchors using webbing or rigid connections; forward-facing child restraints also have a top tether strap which limits forward head excursion in a crash.

Because of the limited space behind the second row seats in pickup trucks, placement of tether anchors poses a challenge. In some pickups, tether anchors are located on the back wall of the cab behind the second row of seats. This requires CRS installers to tip the seatback forward, attach the tether hook, tip the seatback rearward, install the child restraint using lower anchors or seatbelt, and then tighten the tether. In addition to being difficult to use, tether anchors in this location are often overlooked and not used at all. Jermakian and Wells (2011) reviewed national data compiled from car seat checks and found that tether use is lower in pickups compared to other vehicle types. In observational surveys, tether use is lower in pickups compared with other vehicle types (Jermakian and Wells 2011) and there is evidence from volunteer studies that tether use rates are lower when tether anchors are in obscured locations. (Klinich et al. 2013b, Jermakian 2014). In a survey of 2010-11 vehicles, eight of 10 pickup trucks located the tether anchors on the back wall of the cab (Klinich et al. 2014). One of ten 2016 pickup trucks evaluated as part of the Insurance Institute for Highway Safety's LATCH ratings program had back wall mounted tether anchors.

Federal regulations require that tether anchors be located in a specified zone behind the seat. If a tether anchor is located outside the allowable tether zone, then a tether router located in the zone can be used to redirect the tether to the anchor. Because of space constraints in pickup trucks, tether routers are commonly used with tether anchors located at the top of the seatback of an adjacent seating position. The tether is threaded through the tether router (usually a loop of webbing or wire) at the top of the seatback directly behind the child restraint installation position, then attached to the router or anchor in the adjacent vehicle seating position. A problem reported with some tether routers is that the loop was too small to allow the tether adjustor hardware on the child restraint to pass through (Klinich et al. 2014). In a survey of 2010-11 vehicles, two of 10 pickup trucks used a tether router configuration with the tether anchor located in an adjacent seating position or other lateral location (Klinich et al. 2014). In IIHS's LATCH ratings of 2016 pickups, nine of 10 pickups used a tether router to reroute to an anchor in an adjacent seat position.

Previous studies of LATCH usability included evaluations of select pickup trucks. In a volunteer study examining tether use and misuse, subjects performed installations of forward-facing child restraints in 16 vehicles (Klinich et al. 2014, Jermakian et al. 2015). The Ford F-150 pickup truck, which uses tether routing loops, had the lowest rate of correct tether use at only 11% of installations. In this prior study, the correct installations recorded were completed by a single subject who had previous experience installing child restraints in pickup trucks. In a review of child restraint installations recorded at car seat checks, Cicchino and Jermakian (2015) found the lowest rate of tether use (24%) when the tether was mounted on the back wall location used in pickup trucks; pickup trucks also had the highest rates of potentially confusing hardware (50%) that could be mistaken for the tether anchor.

Objective

This project employed volunteer testing to assess whether certain pickup tether anchor configurations result in higher tether use rates or higher rates of correct use. In addition, four labeling interventions were also evaluated to determine if they improved the rate of tether use or correct use. Also, sled impact testing was performed to evaluate how dynamic performance measures vary with traditional and alternative tether locations, along with slack in the tether for the uses/misuses observed in the volunteer testing.

Methods: Volunteer Tests

Experimental Design

Vehicles

Four pickup trucks were evaluated in the study. The vehicles were selected to provide four different but common types of tether anchorage hardware in pickups, as illustrated in Figure 1 through Figure 4. The Chevy Silverado (Vehicle 1) uses plastic-coated wire as both tether routers and anchors. The tether is routed through the loop in the seating position, under the center shoulder belt if applicable, and attached to the plastic-coated wire loop in the adjacent seating position. The Dodge Ram (Vehicle 2) uses a similar approach but has routers/anchors constructed of webbing material, similar to seatbelt webbing but narrower. For the Nissan Frontier (Vehicle 3), the metal tether anchors are located on the back wall of the cab. The seatback must be folded down and the CRS tether attached before the child restraint can be installed. For the Toyota Tundra (Vehicle 4), each seating position has a center mounted metal anchor and webbing tether router. The tether is to be placed through the webbing router in the installation position and attached to the metal anchor in the adjacent seating position.

Figure 1. Chevy Silverado (vehicle 1) uses plastic-coated wire tether routers/loops.

Figure 2. Dodge Ram (vehicle 2) uses webbing tether routers/loops.

Figure 3. Nissan Frontier (vehicle 3) uses metal tether anchors attached to back wall of cab behind vehicle seat.

Figure 4. Toyota Tundra (vehicle 4) uses webbing routers and metal anchors.

Upon receipt of the test vehicles from the rental agency, the experimenter, who is a certified child passenger safety technician, installed each child restraint in the 2L position (second row behind driver) to confirm that it was possible to achieve a correct installation without extraordinary effort. Appendix A contains close up photos of the tether hardware and the tether routing for each child restraint in each vehicle.

The vehicle manuals were reviewed to identify the recommended position for the head restraint during child restraint installation and the recommended tether routing around, under, or over the head restraint. The instructions are summarized in Table 4. Only the Silverado manual addressed routing of V-style tethers.

Table 1. Summary of recommended head restraint position and recommended tether routing for each vehicle.

Code	Vehicle	Recommended head restraint position	Recommended tether routing:
1	Chevy Silverado	Remove	Through router to adjacent seating position, under center retractor
2	Dodge Ram	Removed or Up	Under head restraint, through router to adjacent seating position
3	Nissan Frontier	Removed or Up	Under head restraint (or removed) to anchor
4	Toyota Tundra	Up	Under head restraint, through router to adjacent seating position

Vehicle head restraints for the Dodge Ram, Nissan Frontier and Toyota Tundra were initially placed in the lowest position and were easily moveable and removable. For the Chevy Silverado, the manual instructs the user to remove the head restraint if needed to assist with child restraint installation, but that the head restraint removal should be performed at a vehicle dealership. Because the installations performed by the experimenter were facilitated by removal of the head restraint, we removed it for all trials.

In addition to checking that each child restraint could be properly installed in each vehicle, the rear seat of each test vehicle was documented using the forms found in Appendix B. These forms include measures of items needed to apply the SAE, ISO, and IIHS protocols for assessing LATCH usability in each vehicle.

Child restraints

Testing was performed with two child convertible restraints in forward-facing harness mode. Figure 1 shows comparative views of the two child restraints. The Evenflo Triumph was equipped with a single tether strap, while the Britax Marathon G4.1 has a V-shaped tether strap. These two products were also used in a previous study of tether usability (Jermakian et al. 2014), although a newer version of the Marathon was purchased for the pickup study. These two child restraints were chosen because while they were both convertibles, they had different shell shapes, and the attachment point of the tether on the back of the child restraint differed by approximately 50 mm in height. Installations alternated between the two models of child restraint, such that two installations in each vehicle were performed with different child restraints (each child restraint was installed once in each vehicle). The child restraints were configured for the forward-facing orientation before testing began. No child dummies were used in testing.

Figure 5. Child restraints used during volunteer testing; Evenflo Triumph (C2) and Britax Marathon 70 (C1).

Interventions

Four different interventions were evaluated in this study. One was a bright yellow tether tag affixed to the tether anchor that is intended to be temporary, help locate the tether anchor, and refer the user to the manual for more instruction. Figure 6 includes the text on the tag, while Figure 7 shows what the tags looked like installed in each vehicle. For the Nissan, the tag was made longer so it was visible under the head restraint even though the tether anchor is further away from the top of the seatback than in the other vehicles.

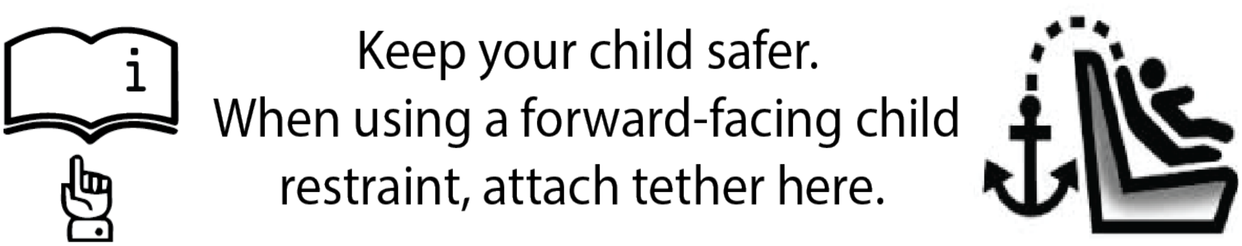

Figure 6. Information on temporary yellow tether tag.

Figure 7. Tether tags in each vehicle (Silverado top left, Ram top right, Frontier bottom left, Tundra bottom right.)

For the second intervention, the same text was used as appeared on the tether tag, but the tag was printed on a clear label so it would blend with the vehicle interior. Figure 8 shows the placement of the label near the tether anchor in each vehicle.

Figure 8. Text label installed in vehicles (Silverado top left, Ram top right, Frontier bottom left, Tundra bottom right.)

The third intervention was a diagram label applied to the tether anchor or as close as possible. This intervention was modeled after a proposed labeling change under consideration by Toyota. The diagram labels for each vehicle are shown in Figure 9 through Figure 12. The graphics provided by Toyota were used with the Tundra, while graphics from each vehicle manual were used for the other vehicles, in addition to the ISO symbols for tether anchor and checking the vehicle manual.

Figure 9. Diagram label content and installed location for the Silverado.

Figure 10. Diagram and installed position for Ram.

Figure 11. Diagram and installed position in Frontier.

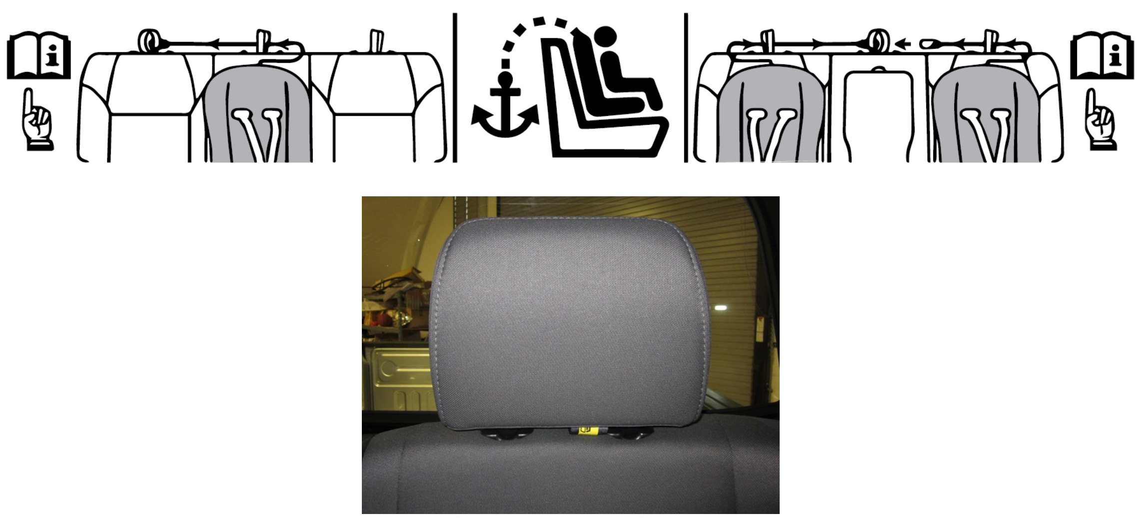

Figure 12. Diagram and installed position in Tundra.

The last intervention was a label with a QR code placed near the tether anchor. When scanned, it links to a video demonstrating how to route and attach the tether in that vehicle. The QR code label, printed on yellow, is shown in Figure 13, as well as the installed positions of the label in each vehicle. Appendix C contains transcribed script and key screen shots from each video, as well as the QR code that can be scanned to review the video. The video for the Dodge Ram was an excerpt of a proposed online video instruction provided by Fiat Chrysler, while the other three videos were produced at UMTRI.

Figure 13. Information on QR code label and labels installed in vehicles (Silverado top left, Ram top right, Frontier bottom left, Tundra bottom right.)

Test Matrix

The test matrix for the study is shown in Table 1. The trial matrix used a split-plot experimental design, with all possible combinations of vehicles, child restraints, and interventions tested across subjects. The design allows estimation of key main effects within subjects, and some interactions are assessed between subjects. Numbers designate the vehicles, while E indicates Evenflo and **B** indicates Britax. The interventions are indicated by V (video), D (diagram), L (label), C (colored tag). The order of the study vehicles, the vehicle and child restraint combinations, and interventions was varied for each volunteer to minimize learning effects. In the first four and last four tests, each subject tests each vehicle once and each child restraint twice. If the Evenflo was paired with a particular vehicle in the first four trials, the Britax was paired with that particular vehicle in the last four trials. Each subject group was exposed to the interventions in a different order. Group 1 had no intervention in first four trials, and had each intervention in the last four trials. Group 2 had interventions in the first four trials and no interventions in the last four trials. Group 3 had two interventions among the first four trials and two interventions among the last four trials.

Table 2. Test Matrix.

Group	Subject	1	2	3	4	5	6	7	8
1	1	**1BN**	2EN	**3BN**	4EN	**4BV**	**2BD**	1EC	3EL
1	2	2EN	**3BN**	**1BN**	4EN	**4BC**	1ED	3EV	**2BL**
1	3	3EN	2EN	**1BN**	**4BN**	**2BV**	**3BC**	1EL	4ED
1	4	**4BN**	**1BN**	2EN	3EN	**2BC**	4EL	**3BD**	1EV
1	5	1EN	**4BN**	3EN	**2BN**	**3BL**	4EV	2ED	**1BC**
1	6	**2BN**	3EN	**4BN**	1EN	**1BD**	2EL	4EC	**3BV**
1	7	**3BN**	4EN	1EN	**2BN**	**1BL**	3EC	2EV	**4BD**
1	8	4EN	**3BN**	**2BN**	1EN	3ED	**1BV**	**4BL**	2EC
2	1	**2BD**	3EL	**4BV**	1EC	**3BN**	**1BN**	2EN	4EN
2	2	3EV	**4BC**	1ED	**2BL**	4EN	**1BN**	**3BN**	2EN
2	3	4ED	1EL	**2BV**	**3BC**	**1BN**	**4BN**	2EN	3EN
2	4	1EV	**2BC**	4EL	**3BD**	2EN	**4BN**	**1BN**	3EN
2	5	**1BC**	4EV	**3BL**	2ED	1EN	**2BN**	3EN	**4BN**
2	6	2EL	**1BD**	4EC	**3BV**	**4BN**	3EN	1EN	**2BN**
2	7	3EC	2EV	**4BD**	**1BL**	1EN	**2BN**	**3BN**	4EN
2	8	**4BL**	3ED	2EC	**1BV**	**2BN**	**3BN**	1EN	4EN
3	1	1EC	**2BD**	4EN	**3BN**	3EL	**4BV**	**1BN**	2EN
3	2	2EN	**1BN**	3EV	**4BC**	1ED	**2BL**	**3BN**	4EN
3	3	**4BN**	**3BC**	1EL	2EN	**2BV**	**1BN**	4ED	3EN
3	4	**3BD**	4EL	2EN	**1BN**	**4BN**	3EN	**2BC**	1EV
3	5	4EV	**2BN**	1EN	**3BL**	3EN	**1BC**	**4BN**	2ED
3	6	2EL	3EN	**4BN**	**1BD**	4EC	**2BN**	**3BV**	1EN
3	7	1EN	**3BN**	**4BD**	2EV	4EN	**2BN**	**1BL**	3EC
3	8	4EN	**1BV**	2EC	**3BN**	**2BN**	3ED	1EN	**4BL**

Test Protocol

The detailed test protocol is found in Appendix D. The subject was directed to install the first child restraint using LATCH. If the subject asked what LATCH is, the experimenter directed them to consult the vehicle and child restraint manuals.

After each installation, the experimenter assessed the installation using the same general criteria used in the previous LATCH studies conducted for the Insurance Institute for Highway Safety (IIHS) (Klinich et al. 2012, Klinich et al. 2013a, Jermakian et al. 2013) using the form in Appendix E.

After the subject installed the child restraint, the amount of slack in the tether was measured by pinching the excess webbing in the tether strap, measuring the height of the loop, and doubling the resulting measurement. To document installation tightness, the 1" test for looseness used by child passenger safety technicians was used. As a supplement to this test, the amount of lateral displacement that occurred when the child restraint was loaded at the belt path with a horizontal force of 40 lbf was also measured.

All of the forms completed by the subjects are included in Appendix F. In the last four trials, the subject filled out a questionnaire regarding elements of the installation. In the first four trials, the subjects did not fill out the questionnaire to avoid providing education regarding LATCH. After completing all eight trials, the subject filled out another questionnaire that collected details regarding their previous LATCH and child restraint installation experience, as well as a race/ethnicity form. They also filled out a general form regarding the interventions. Upon completion of the questionnaires, subjects were provided with information regarding child restraint checkups and proper installation that are included in Appendix G.

Subject Groups

Subjects

Twenty-four subjects were recruited and divided into three groups of 8 subjects each. Subjects were eligible for the study if they were currently transporting a child in a child restraint and had installed the seat themselves. Each test session lasted approximately two hours, with subjects compensated $40 for their time. All test protocols were approved by the University of Michigan Institutional Review Board. Appendix H contains the text used to screen subjects, while Appendix I contains the consent form.

At least one of each subject group was required to have previous experience installing a child restraint in a pickup truck, and there were at least two men in each group. Although education was originally considered as a recruiting factor, timing of the project led us to recruit only subjects who had some college or higher education. During recruitment, the subjects were asked how they usually installed their child restraint in an effort to learn whether they had LATCH experience, but without educating them about LATCH. Efforts were made to have varied levels of previous LATCH experience and a variety of ages in each subject group.

Subjects were given a questionnaire after testing that asked for more details regarding their previous experience with pickup trucks, lower anchors, tethers, and different types of child restraint installations.

Results were generally consistent with the pre-test screening questionnaire, except for one subject who was not currently transporting a child in a pickup truck reported that she had previous experience with child restraint installation in pickup trucks.

Table 2 summarizes the number of subjects in each group by gender and previous child restraint experience as well as average age. Backgrounds of subjects were similar for each group. The average age of subjects was higher than in previous studies, as more grandparents volunteered for the current study. Subject ages ranged from 24 to 73.

Table 3. Subject Characteristics by Group

Subject characteristic	Subject Group		
	1	2	3
Men	2	3	2
Pickup Experience	3	1	2
Tether Experience	3	5	5
FFCRS Experience	3	5	4
Average Age	47	55	45

Data Analysis

As a first step, univariate analysis was conducted to identify possible associations between potential predictors and child restraint installation outcomes. The following outcomes were assessed, while Table 4 lists the variables considered as potential predictors:

- Tether use: Tether on the child restraint was attached to something.
- Tether attached to correct hardware: tether on the child restraint was attached to the correct tether anchor.
- Tether correct: tether attached to correct vehicle hardware in the correct orientation, tether routed correctly (with respect to the router and head restraint), webbing flat, tether tight so there was less than 25 mm of slack, head restraint in correct position.
- Tether functional: errors on tether routing or head restraint position but not likely to affect tether performance in a crash. Tether is tight, attached to a tether anchor in the correct orientation, webbing flat. Ignores tether routing and head restraint position.
- Installation correct: tether correct, as well as tight installation and no errors when using lower anchors or seatbelt.

Table 4. List of potential predictors considered in data analysis.

Type	Potential Predictor
Subject	Gender
	FFCRS Experience
	LA Experience
	TA Experience
	Subject Group
	Pickup Experience
Testing	Installation number
	Intervention
	Child restraint
	Vehicle

Subsequent analysis was performed using mixed models that account for repeated testing among subjects. The regression models were performed using SAS 9.2 PROC GLIMMIX.

Results: Volunteer Tests

Subjects used the CRS tether in 93% of the 192 installations, and there were no test or subject factors associated with tether use. However, only 17 trials (9%) had no installation errors. Another 7 percent of installations did not use the tether at all, 61 percent had only tether errors, and the remaining 23 percent had tether errors as well as other installations errors.

Table 5 lists the trials where the subjects made no errors. Two subjects performed 12 of the correct installations. Based on experimenter observations, the two subjects with the most correct installations spent a substantial amount of time reviewing the vehicle manuals. Eight of the correct trials had no intervention, and nine of the correct trials were among the last three installations performed by subjects. Six of the correct installations were in the Frontier, three in the Tundra, four in the Ram, and four in the Silverado. No variables were identified to be significant predictors of correct installation.

Table 5. Trials without errors.

Subject	Installation	CRS	Intervention	Vehicle
F24H17	8	C2	D	Tundra
F33H37	8	C1	C	Frontier
F39H18	3	C2	N	Ram
F39H18	5	C1	D	Frontier
F39H18	8	C1	C	Ram
F68H38	2	C2	V	Silverado
F68H38	3	C1	C	Ram
F68H38	4	C2	N	Frontier
F68H38	6	C1	D	Frontier
F68H38	7	C1	N	Silverado
M43H21	3	C2	V	Tundra
M43H21	4	C1	C	Silverado
M43H21	5	C2	N	Frontier
M43H21	6	C2	N	Silverado
M43H21	7	C1	N	Ram
M43H21	8	C1	N	Tundra
M57H25	7	C1	N	Frontier

In 28% of trials, subjects achieved a functional tether installation that would probably be effective in a crash. As defined previously, this means that the subject attached the tether hook to hardware that has been tested for use as a tether anchor, but did not use the correct routing and/or head restraint position. After accounting for the experimental design, subjects were more likely to achieve a functional installation in the 3rd through 8th trials compared to the first two ($p=0.0021$). As shown in Figure 14, subjects attached the tether to the tether router behind the child restraint more than twice as often as they attached the tether to the correct tether anchor.

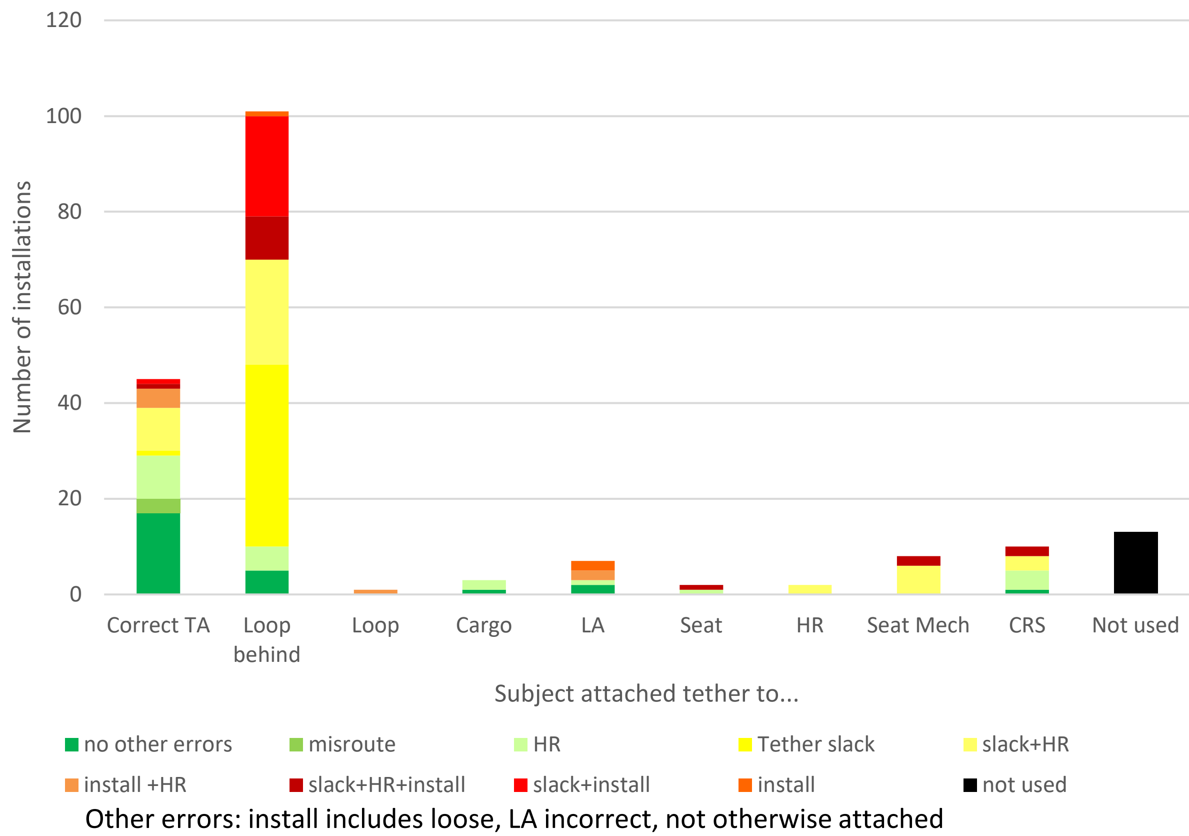

Figure 14. Distribution of installations by tether attachment and other installation errors.

Of the 45 trials where the subject attached the tether anchor to the correct anchor, only 17 installations had no other errors; 7 of these were in the Nissan. In three trials, the installation was correct except for routing the tether over rather than under the center seatbelt. In nine trials, the installation was correct except for placement and/or routing with respect to the head restraint. In another nine trials, the tether had more than 50 mm slack and also had head restraint errors. In six trials with the tether attached to the correct tether hardware, the subject made additional errors when attaching the child restraint to the lower anchors, as well as other tether errors.

When subjects attached the tether to the loop behind the child restraint, five trials had no other errors and five other trials only had head restraint position/routing errors. 38 of these trials had tether strap slack as the only other error, and 22 had slack and head restraint as the other errors. 30 had errors with the general installation as well as the tether.

Figure 14 also tabulates trials where the subject attached the tether to something other than the tether anchor. Examples of attaching to the seat adjustor hardware, cargo hook, storage hook, lower anchor, head restraint, and child restraint storage hook are shown in Figure 15.

Figure 15. Examples of incorrect attaching to non-tethers: seat adjustor, cargo hook, storage hook, lower anchor, around head restraint, child restraint storage hook.

Figure 16 illustrates how the tether attachment location varies by vehicle. Results were similar among the three vehicles that used the tether router, with the most common attachment to the tether router behind the child restraint rather than to the tether anchor in the adjacent position. This occurred in 67, 65, and 75 percent of the installations for the Silverado, Ram, and Tundra respectively. The Nissan Frontier, with its tether anchors located behind the vehicle seatback, had the highest rate of attachment to the correct tether anchor (60%), but also had the highest rate of attachment to hardware that was not a tether anchor (29%). As shown in Figure 17, subjects attached the tether to the seat adjustor and head restraint fairly often in the Frontier.

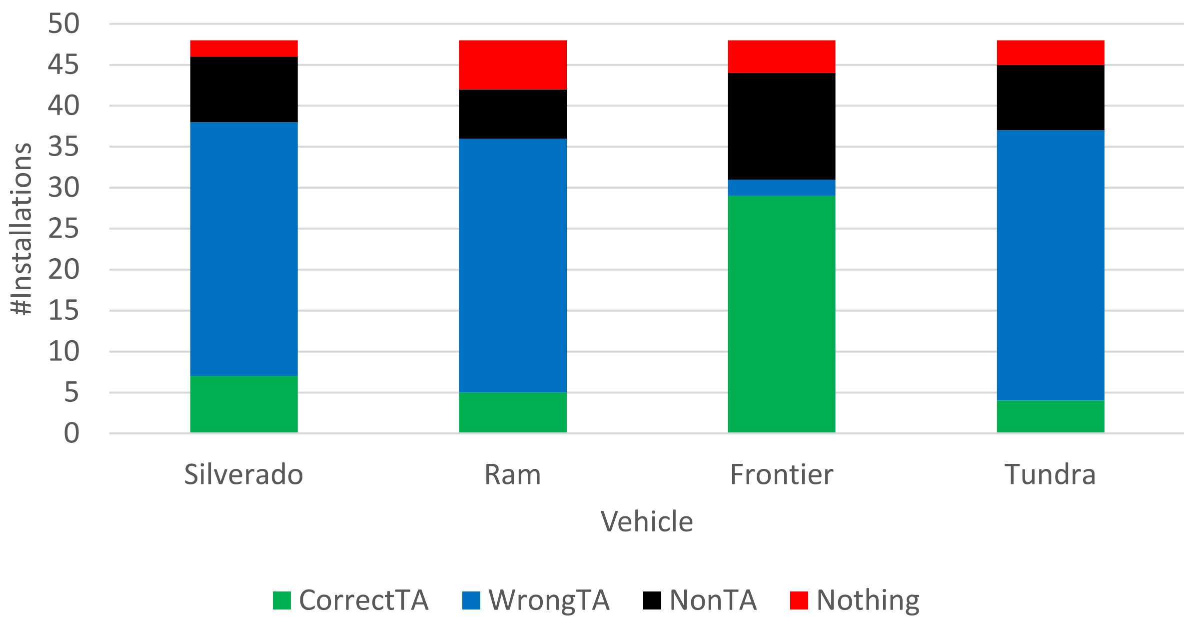

Figure 16. Tether attachment location by vehicle.

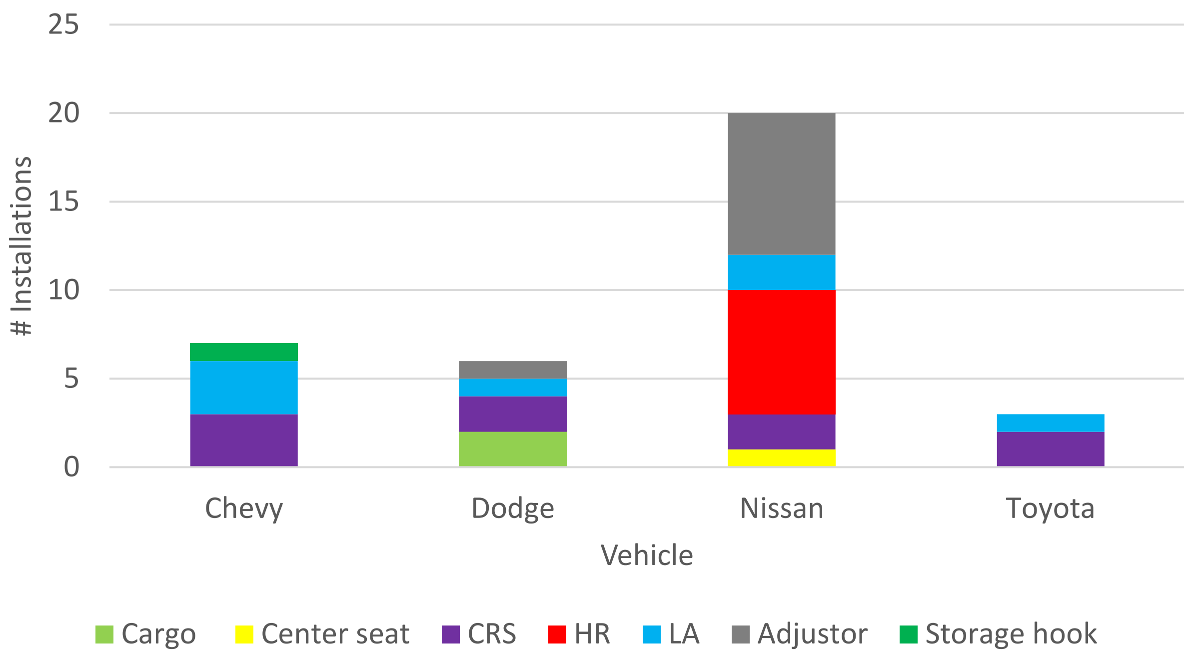

Figure 17. Attachment to hardware other than tether anchors by vehicle.

None of the interventions had an effect on tether use, attaching the tether to the correct anchor, or correct tether use. When filling out the post-session questionnaire, several subjects indicated that they had not noticed the labeling, even those printed on bright yellow paper. Not a single subject tried to scan the QR code label to access the video instruction. Two subjects asked to try out the QR code at the end of the session and indicated that they thought the videos were clear.

Methods: Sled Tests

Motivation

In the volunteer subject testing portion of this study of tether use and usability in pickup trucks, we examined four different tether anchoring schemes and four different instructional interventions. None of the interventions proved effective, and the most common error on the pickup trucks with tether routers was that subjects hooked the tether anchor to the routing feature directly behind the child restraint instead of threading the tether through the router and hooking it to the tether anchor in the adjacent seating position. While installations with this error would probably be more effective than no tether in a crash, the tether would typically be slack because it is difficult or impossible to tighten a tether when the anchor is too close to the child restraint.

Because it is intuitive to attach a tether directly behind a child restraint, we conducted a series of dynamic sled tests to determine whether a tether anchor located in the center of the seating position behind the child restraint, but located on the roof above the back window so it is more accessible, more identifiable, and easier to tighten, would provide a benefit in terms of reducing head excursion in a crash. Currently, tethers are not located in this manner because of the tether zone defined in FMVSS 225.

Test Bench

The dynamic tests were performed using the new test bench (shown in Figure 18) that has been proposed as a potential replacement for the FMVSS 213 frontal impact bench (hereafter referred to as the proposed 213 bench). It consists of the vehicle seat portion of the side impact buck assembly described in the Notice of Proposed Rulemaking (NPRM) of Federal Docket #NHTSA-2014-0012. The bench is mounted to the sled forward-facing without the intruding door assembly but with its height adjusted upward by 50 mm risers. The bench also differs from the NPRM specification in that the seat back has been extended upwards to create a longer/taller seat back support surface. This bench was mounted facing forward on the impact sled at The University of Michigan Transportation Research Institute (UMTRI). It was positioned so excursion measurements of ATDs with this bench would be consistent and comparable with those measured in tests performed on the current FMVSS 213 bench. The test bench was equipped with lower anchor bar instrumentation, so that load time histories of the lower anchors were measured. Belt load cells were used to pretension and measure dynamic loads for the tether and lower anchor belt.

Figure 18. The NHTSA-proposed new 213 bench used for the test series

In a previous UMTRI study performed for NHTSA, we found that when varying tether location and routing with respect to the head restraint, the length of tether webbing between the child restraint and tether anchor was one predictor of head excursion, regardless of the particular combination of tether location or routing (Klinich, et al, under review). For this reason, we evaluated different tether locations while documenting and, when possible, controlling the tether length. Four tether locations were evaluated, three of which were aligned with the centerline of the seating position used for installation of the CRS. The tether anchor locations used were: above the rear window, on the filler panel (as found in a sedan), and on the back of the seat, along with an anchor in the adjacent seating position that uses a tether router. Because the active length of tether was a predictor of head excursion in our previous study, we tried to maintain a distance between the R-point and the tether anchor of 350 mm for the three locations located behind the seating position, and a distance of 700 mm for the anchor located in the simulated adjacent seating positions. Figure 19 shows the locations of four tether anchor conditions.

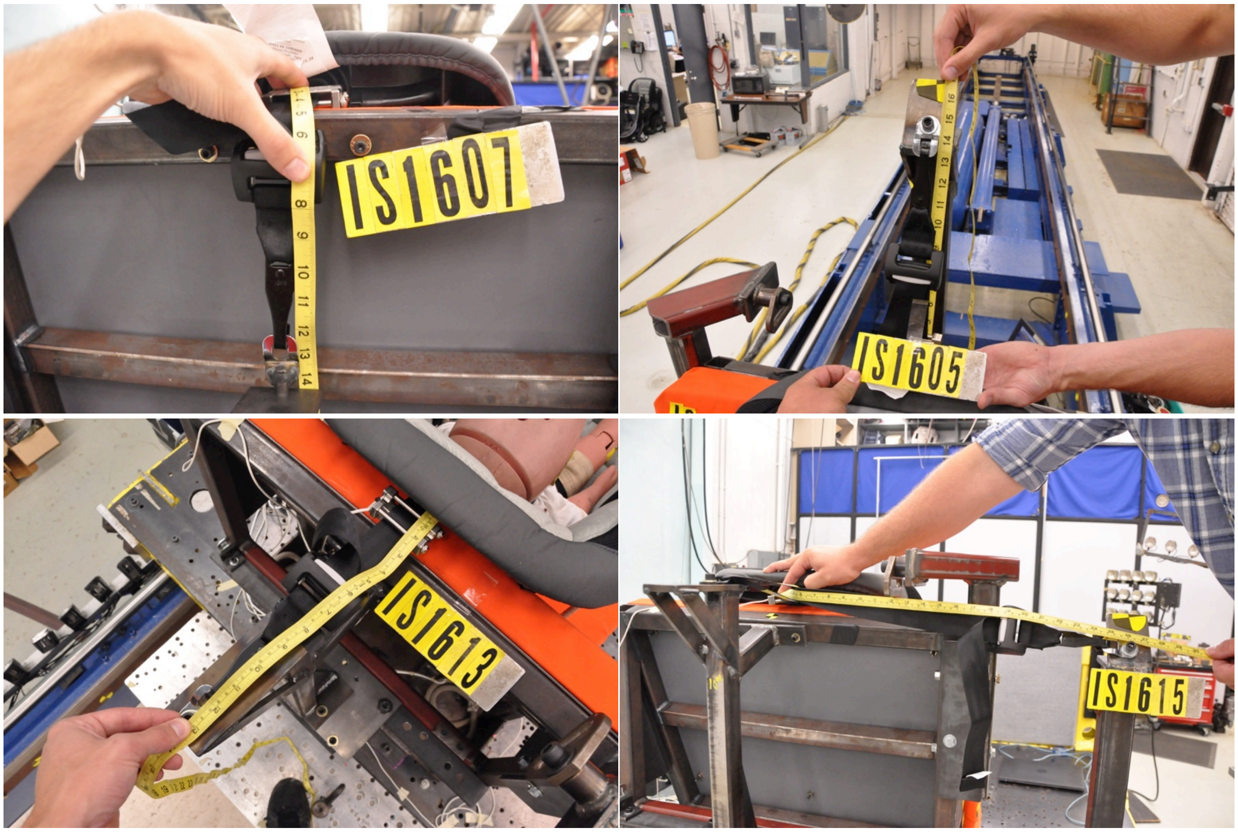

Figure 19. Tether anchor conditions, clockwise from upper left: down, up, back and adjacent.

ATD Selection, Data Collection, and Positioning

Tests were performed with the Hybrid III 3-year-old ATD (part 572, subpart P). The ATD was instrumented with head and chest accelerometers. The current FMVSS 213 test protocol was used to place the CRS on the bench and the Hybrid III 3YO ATD was placed in the CRS using the current 213 dummy positioning process (TP-213). A FARO arm 3D coordinate measurement system was used to document the position of the ATD, booster, and test bench landmark locations in each test. The lower anchor and tether attachments were tensioned to 53-67 N (12-15 lbf) in the baseline conditions. The sled pulse used for testing was consistent across tests and close to that used for standard 213 testing. For each test, head and chest accelerations were measured and the corresponding injury criteria of HIC and 3-ms chest clip were calculated. For forward-facing tests, head and knee excursions were measured.

Test Matrix

Table 6 lists the test conditions for the 22 sled tests performed in this series. Half of the tests used the Britax Marathon, while the other half used the Evenflo SureRide. For each anchor condition, one test was run with the tether tight, and a second one was run with 50 mm of slack (see Figure 19). For each child restraint, a test was performed without the tether, plus two repeats of the tethered conditions with the highest and lowest head excursions (runs IS1619-22).

Figure 19. Illustration of methods for documenting tether length and setting belt slack for test series.

Table 6. Test Matrix

Test #	CRS Type	Tether Adjustment Tight/Slack/None	Tether Anchor Location
IS1601	Evenflo	none	none
IS1602	Britax	none	none
IS1603	Britax	tight	roof
IS1604	Britax	loose	roof
IS1605	Evenflo	tight	roof
IS1606	Evenflo	loose	roof
IS1607	Evenflo	tight	down
IS1608	Evenflo	loose	down
IS1609	Britax	tight	down
IS1610	Britax	loose	down
IS1611	Britax	tight	back
IS1612	Britax	loose	back
IS1613	Evenflo	tight	back
IS1614	Evenflo	loose	back
IS1615	Evenflo	tight	adjacent
IS1616	Evenflo	loose	adjacent
IS1617	Britax	tight	adjacent
IS1618	Britax	loose	adjacent
IS1619	Britax	tight	back
IS1620	Evenflo	tight	back
IS1621	Britax	loose	back
IS1622	Evenflo	loose	roof

Results: Sled Testing

Table 6 lists the key ATD response measures for each test condition. The Britax CRS included a rip stitch tether feature that deployed in all but two of the conditions (no tether and roof). The amount of added tether length release in each test is listed in the last column of the table. In every condition, these ATD responses meet the criteria established by FMVSS 213.

Table 7. Results of Sled Tests

Test	HIC (36 ms)	Chest Accleration 3ms clip	Excursion		Additional tether length added by ripstitch
		g	Head (mm)	Knee (mm)	mm
IS1601	585	45	681	771	na
IS1602	643	50	654	737	0
IS1603	637	53	641	713	35
IS1604	530	46	642	743	0
IS1605	633	45	639	728	na
IS1606	736	53	660	760	na
IS1607	407	43	586	737	na
IS1608	574	52	628	769	na
IS1609	501	45	641	691	140
IS1610	556	57	638	688	60
IS1611	394	47	598	705	110
IS1612	596	60	653	731	60
IS1613	426	42	566	736	na
IS1614	533	49	624	763	na
IS1615	450	45	597	764	na
IS1616	582	49	631	759	na
IS1617	513	51	637	726	58
IS1618	581	51	652	717	38
IS1619	411	49	621	700	140
IS1620	418	42	574	734	na
IS1621	541	55	643	717	60
IS1622	672	49	664	743	na

Figure 21 through Figure 23 show box plots that illustrate the effect of CRS Type on ATD response. There is overlap in all the distributions but some notable trends. The Britax CRS produced similar HIC values, somewhat higher chest accelerations, less variable head excursions, and lower knee excursions than the Evenflo. Even though the responses show the potential for systematic differences between the two CRS, the patterns of change in response to tether location and tether slack for each CRS was similar.

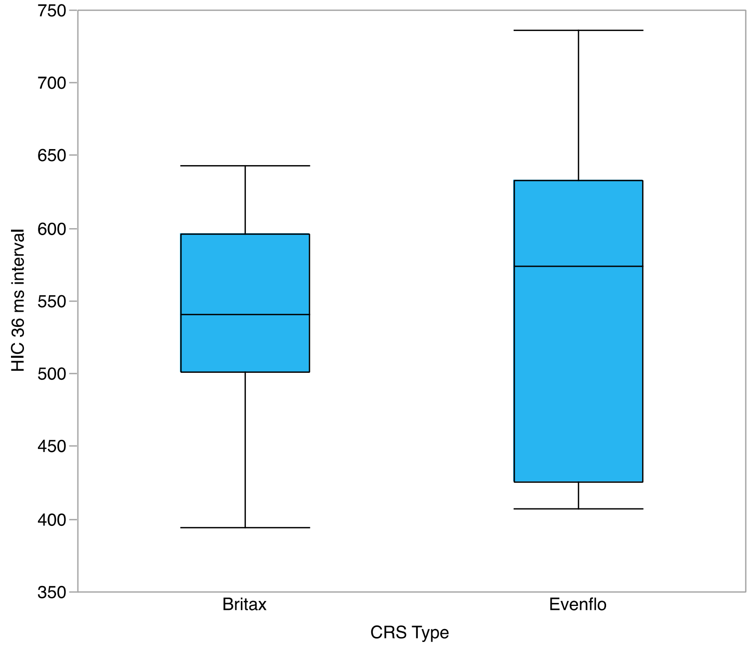

Figure 20. HIC by CRS Type

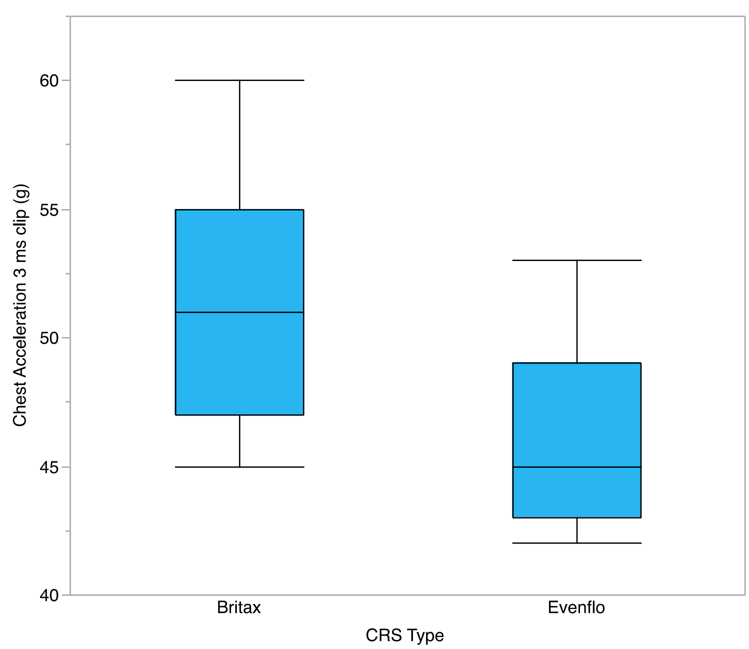

Figure 21. Chest Acceleration (3 ms clip) by CRS Type

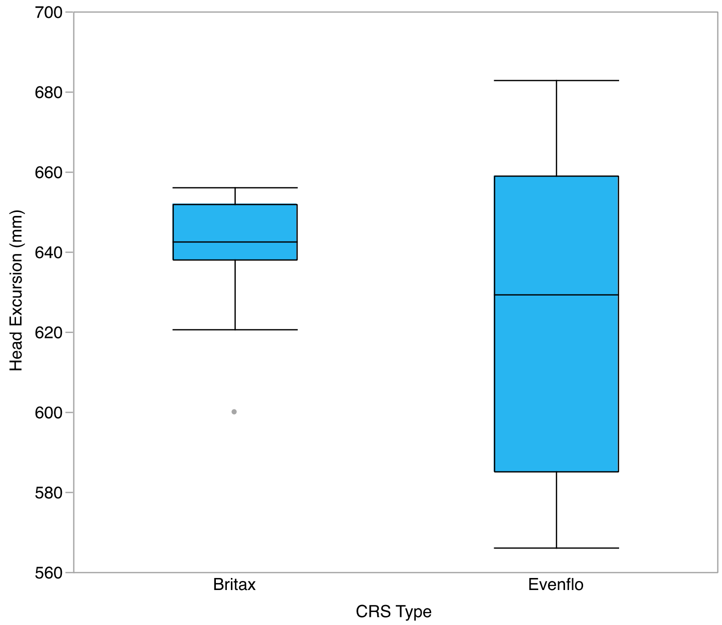

Figure 22. Head Excursion by CRS Type

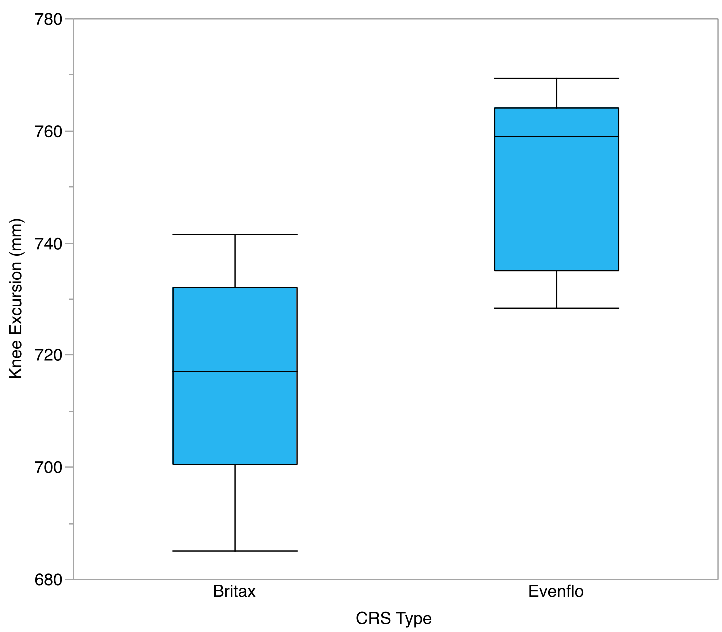

Figure 23. Knee Excursion by CRS Type

Figure 24 through Figure 27 show the relationship between tether anchor location and ATD response. Head excursion and HIC are lower in the back, down and adjacent locations. Taking a closer look at head excursion with a box plot shows that the no tether and the roof locations produce the highest excursions, while the back, down and adjacent conditions perform similarly to reduce head excursion. The roof anchored tether reduces head excursion compared to the no tether condition but not as much as the back, down and adjacent configurations. The values for chest peak acceleration and knee excursion were similar for all conditions.

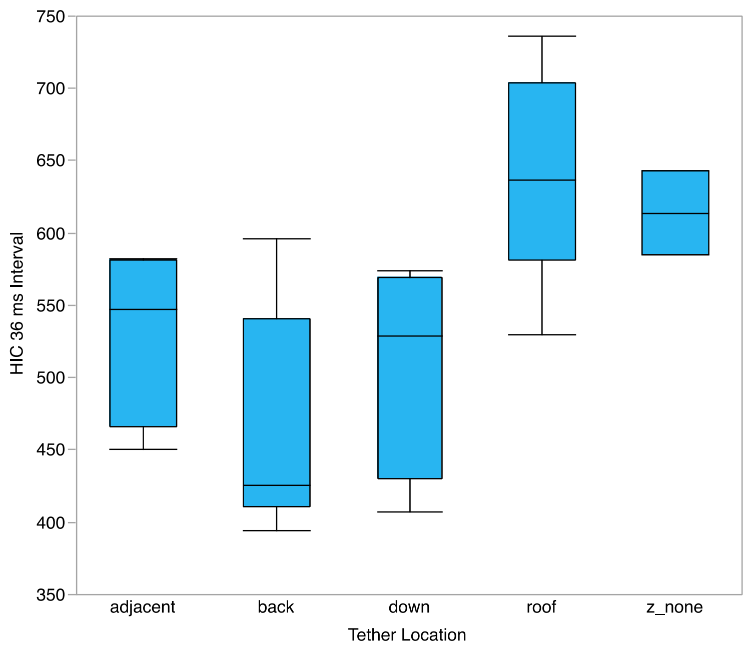

Figure 24. HIC by Tether Location

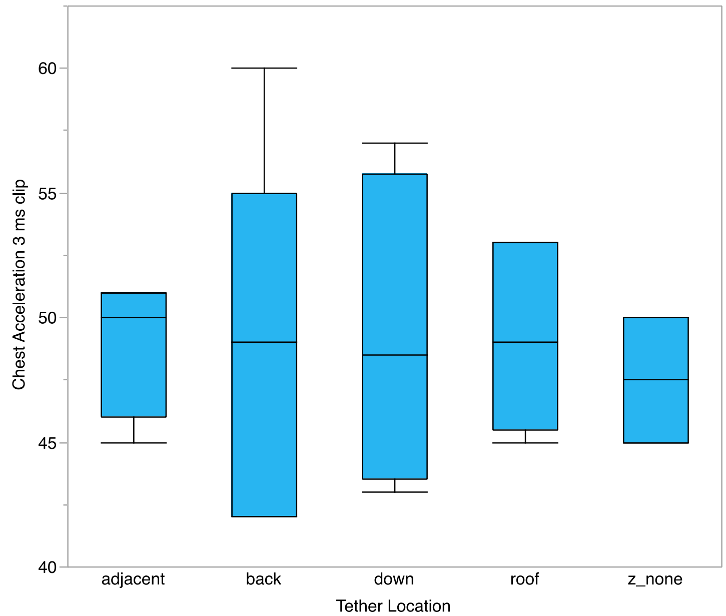

Figure 25. Chest Acceleration (3 ms clip) by Tether Location

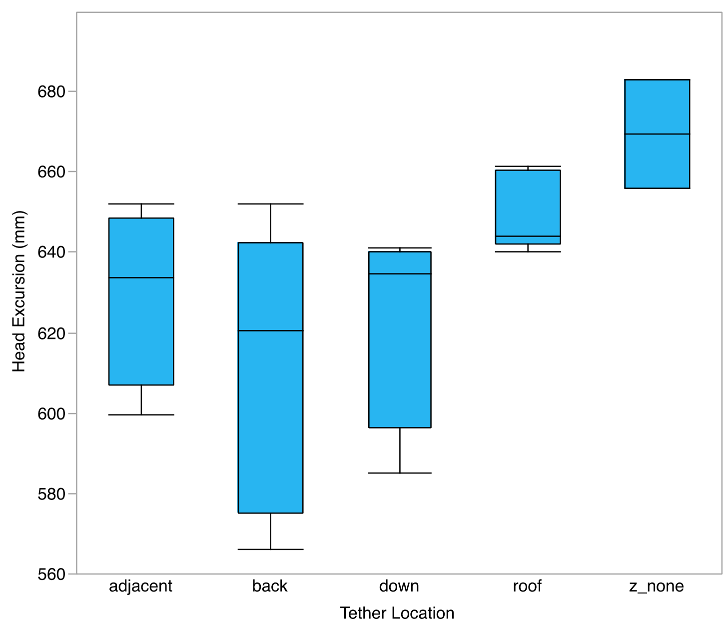

Figure 26. Head Excursion by Tether Location

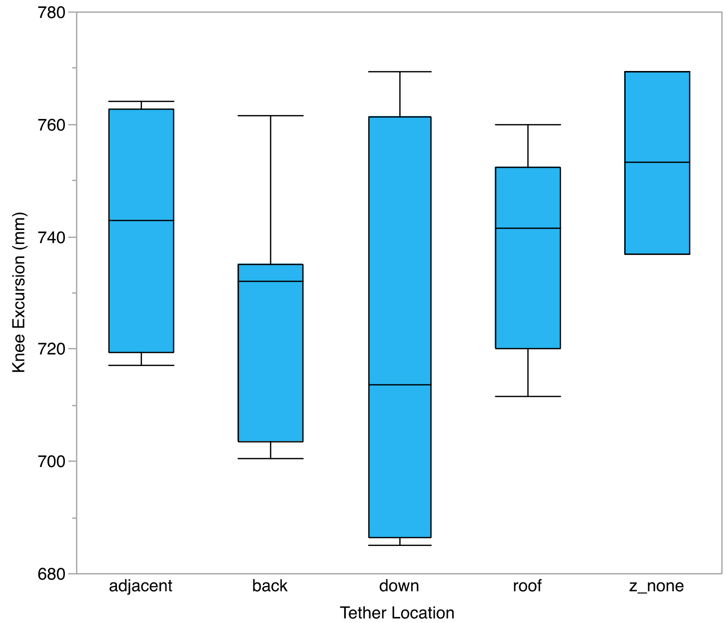

Figure 27. Knee Excursion by Tether Location

The effect of tether slack is illustrated in Figure 28 through Figure 31. As expected, the tight tether condition produces the best ATD responses in forward excursions and HIC. The no tether condition is associated with the worst responses in all areas except chest acceleration where the chest clip acceleration is highest with a loose tether. The positive effect of a tight tether is most pronounced in the head excursion response.

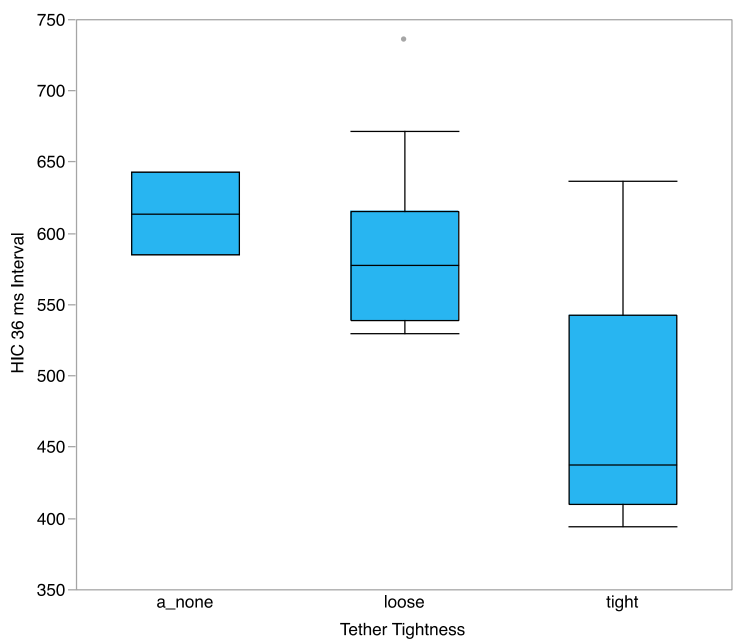

Figure 28. HIC by Tether Tightness

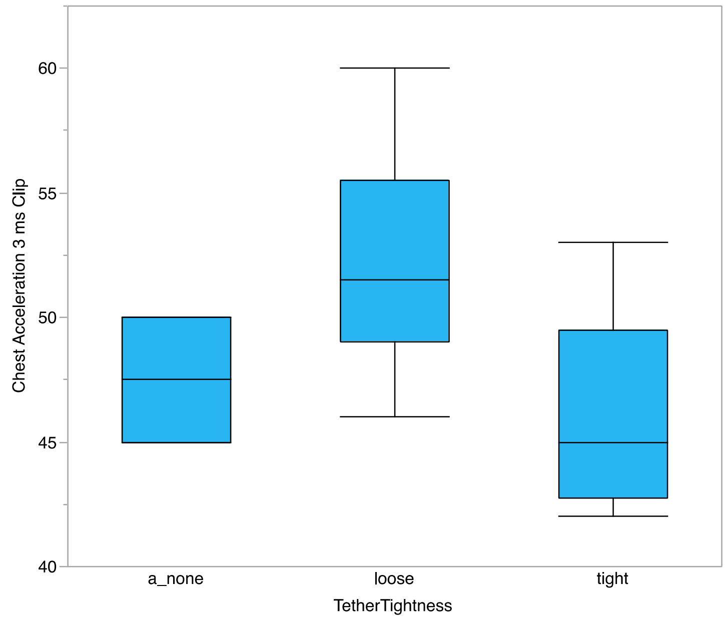

Figure 29. Chest Acceleration (3 ms clip) by Tether Tightness

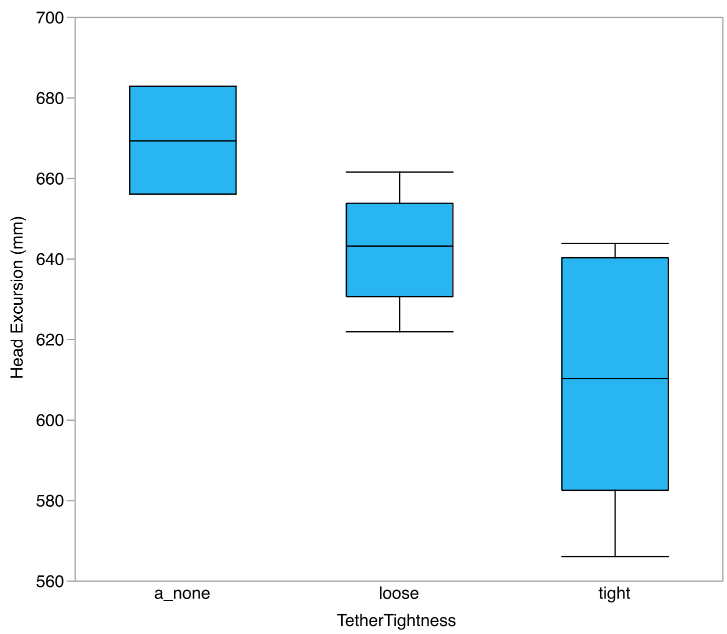

Figure 30. Head Excursion by Tether Tightness

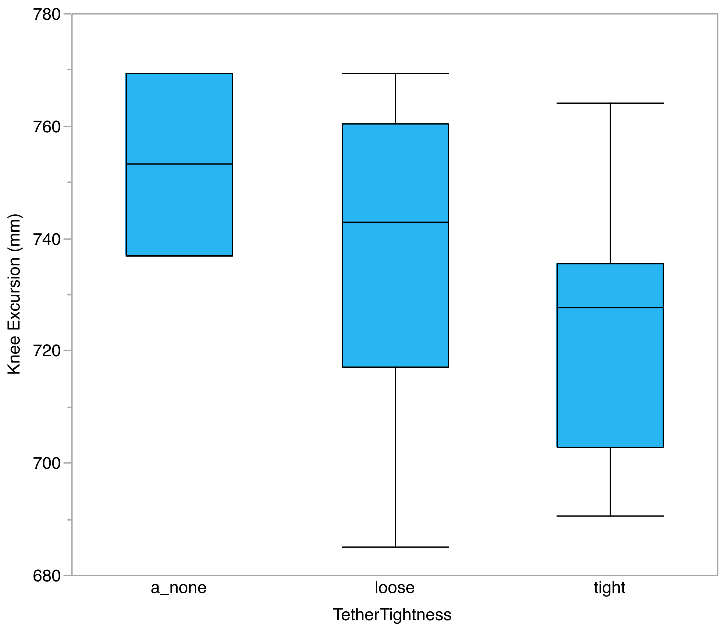

Figure 31. Knee Excursion by Tether Tightness

A comparison of ATD kinematics for the no tether, roof tether, and back tether conditions is shown in Figure 32.

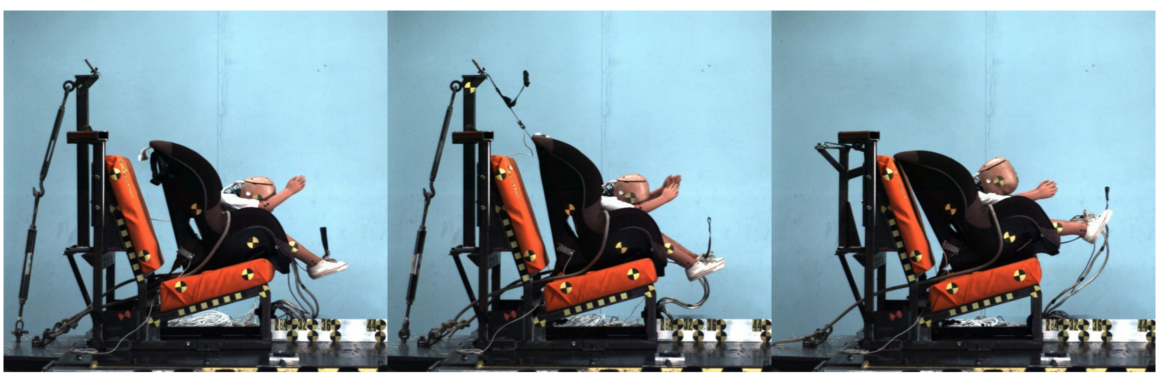

Figure 32. Peak of action still frame for no tether (left), roof tether, (middle) and back tether (right) conditions.

Discussion

Interventions

Despite some high visibility labeling interventions, none of the interventions had an influence on correct use of tethers in pickup trucks. Subjects did have a higher rate of tether use in this study (at 93%) compared to previous studies of volunteers and in the field, where tether use rates with forward-facing child restraints tend to be closer to 50%. It is possible that the intervention labels may have increased the rate of tether use, although subject responses in post-test questionnaires did not indicate that they found the labels to be helpful.

An unexpected result was that not a single subject scanned the QR code label. Several subjects commented at the end of the study that they did not know the purpose of a QR code. We hypothesized that the older average age of our subjects might be contributing to the lack of QR code use, but the youngest subject (aged 24) was one of the people who stated she did not know what a QR code was. One of the vehicles used in the study also had a QR code on the inside of the door to provide a source of additional vehicle information. Despite the preponderance of QR codes on products and advertising, results from the study indicate that they may not be used to access the information very often among people who transport children in vehicles.

Usability Issues

Our previous study on tether use and usability showed that the presence of potentially confusing hardware led to lower rates of correct tether use. The current study's results are consistent with the previous study. In 17% of trials, subjects attached the tether to something that was not a tether anchor. More than half of these trials were In the Nissan Frontier where the tether anchor is located behind the seatback. The adjustor to recline the seatback is visible next to head restraint, and subjects attached the tether to this webbing loop in 7 trials. This study also had ten trials where the subjects attached the tether back to the storage hook on the child restraint, which was not observed in previous studies of child restraint installation errors (though four of these trials were done by a single subject.)

In our previous study of tether usability, subjects more often correctly used single-strap tether design than the V-style tether design. In the current study, there was no significant difference in correct tether use (including tightening the tether) between the two styles of tether.

As in previous studies, subjects often did not follow instructions for positioning the head restraint after attaching the tether. If head restraint placement is not critical to safety performance, allowing multiple options for correct position would increase the rate of correct installations that follow directions.

Two of the pickup trucks in this study allow removal of the head restraint for child restraint installation, and one requires it. However, the Silverado, which requires head restraint removal, tells the user to take the vehicle to a dealer for removal. For the current study, we were able to remove the head restraint prior to testing using a paperclip. Given that many other head restraints can be removed without tools, these types of designs should be considered if the head restraint should be removed for child restraint installation.

In the vehicles that use the tether router, two of them have retractors for the center seatbelt integrated within the seatback, while the Silverado has a retractor housing mounted to the top of the seatback. The instructions specify routing under the center seatbelt when attaching to the center tether anchorage; there were three trials where the only error was routing over the center seatbelt instead. If tether routing to the adjacent position is used, it is more straightforward in vehicles with an integrated center seatbelt router.

Subject Factors

To expedite subject recruiting, all subjects had at least some college education. It is possible that subjects with lower education level might have had a different response to interventions. However, a previous study of child restraint installation errors (Klinich et al. 2011) did not find a difference in use of instruction manuals by education levels, and only a few installation outcomes showed greater levels of correct use with higher education.

Intuitive Design

In two thirds of trials, subjects attached the tether to the tether anchor located behind the child restraint seating position and near the seat centerline. Results were fairly consistent across vehicles, even though the tether was supposed to be attached to the tether router in the adjacent seating position in three of the four vehicles. Half of subjects had previous tether experience, which may explain the natural inclination to hook the tether to a location behind the child restraint. But it also seems to be intuitive for subjects without previous tether experience to choose a tether location directly behind the child restraint.

Some vehicles (other than pickups) do have tether anchors anchored on the roof. Placing a tether anchor on the roof of the pickup truck above the rear window would provide the tether anchor directly behind the child restraint, and routing the tether over the head restraint to the anchor would allow relatively straightforward tightening of the tether. While the current tether zone of FMVSS 225 would not allow placement of tether in this location, a roof-mounted tether anchor could be used in pickup trucks if the tether was first placed through a router in the seating position that falls within the allowable tether zone before attaching it to the anchor. We hypothesize that it would be more intuitive to route and attach the tether in the installation seating position rather than attaching to an anchor in an adjacent seating position.

The data from the sled tests help evaluate the relative merit of the possible alternatives. In these data, head excursion is the metric most closely related to the head contact injury, which is the most common serious injury mode in the field. All of the tether anchoring conditions reduce head excursion from the no tether condition with the back, down and adjacent conditions being most effective. These data also show that a tight tether is the most beneficial but a loose tether can still provide reductions in head excursion.

Because the router creates a load path that resists forward motion effectively, it would be of interest to test a roof-anchored tether that goes through the router. This condition was not part of the test matrix for the current study. However, a visible, centered roof anchor is consistent with the most commonly selected anchoring locations of the subject pool, so a tether that is directed through the routing loop that then connects to a roof tether shows promise to be a configuration that would be used correctly more often. In the misuse case where the tether was not passed through the router, there would be still be some safety benefit from a tight tether strap.

Recommendations

- If head restraint must be removed to install a child restraint, caregivers should be able to do it themselves and not have to take it to a dealer.
- Cargo and storage hooks can be confused for tether anchors and should be clearly labeled if they cannot be moved.

Acknowledgements

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References

Decina LE, Lococo KH (2007) Observed LATCH use and misuse characteristics of child restraint systems in seven states. *J Safety Res* 38:271-81.

International Standards Organization (2010a) Road vehicles -- Methods and criteria for usability evaluation of child restraint systems and their interface with vehicle anchorage systems -- Part 2: Manual to assist the usability assessments of ISO 29061-1 *ISO/NP TR 29061-2*, Geneva, Switzerland.

International Standards Organization (2010b) Road Vehicles – Methods and Criteria for Usability Evaluation of Child Restraint Systems and Their Interface With Vehicle Anchorage Systems – Part 1 Vehicles and Child Restraints Equipped with ISOFIX Anchorages and Attachments, *CD 29061-1*, Geneva, Switzerland.

Jermakian JS and Wells JK (2011) Observed use of tethers in forward-facing child restraint systems, *Injury Prevention*; 17:371-74.

Klinich KD, Manary MA, Flannagan CAC, Ebert SM, Malik LA, Green PA, Reed MP (2010a) *Labels, Instructions, and Features of Convertible Child Restraint Systems (CRS): Evaluating their Effects on CRS Installation Errors* UM-2010-37

Klinich KD, Manary MA, Flannagan CAC, Malik LA, Reed MP (2010b) *Effect of Vehicle Features on CRS Installation Errors* UM-2010-38

Klinich KD, Flannagan CAC, Manary MA, Moore JL (2012) *LATCH Usability in Vehicles* UMTRI-2012-7

Klinich, KD, Manary MA, Flannagan CAC, Moore JL, Jermakian J (2013a) Evaluation of proposed protocols for assessing vehicle LATCH system usability. *SAE Int. J. Trans. Safety* 1(1) doi:10.4271/2013-01-1155.

Klinich KD, Flannagan CAC, Jermakian JS, McCartt AT, Manary MA, Moore JL, Wells JK (2013b) Vehicle LATCH system features associated with correct child restraint installations *Traffic Injury Prevention* 14(5):520-31 doi: 10.1080/15389588.2012.701030

Klinich KD, Manary MA, Flannagan CA, Ebert SM, Malik LA, Green PA, Reed MP. (2013c) Effects of child restraint features on installation errors. *Applied Ergonomics*. May 31. doi:pii: S0003-6870(13)00077-X. 10.1016/j.apergo.2013.04.005.

Klinich KD, Manary MA, Orton NR Effect of Tether Routing and Anchor Location on ATD Response in Forward-Facing Child Restraints, UMTRI 2013-27, DOT HS 812 467, 2017

NHTSA (2011) Consumer Information; Program for Child Restraint Systems, *Federal Register Docket # NHTSA-2010-00062* 76(38), 2/25/2011, US Department of Transportation, Washington DC.

Society of Automotive Engineers Child Restraints Systems Committee (2009) *Guidelines for Implementation of the Child Restraint Anchorage System or LATCH System in Motor Vehicles and Child Restraint Systems*. Draft recommended practice no J2893, versions #1 and #2.

Stewart DD, Donaldson D, Lang NJ, Rose K, White, L. (2011) The LATCH manual: using lower anchors and tethers for child restraints. Safe Ride News Publications.