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LATCH Usability in Vehicles

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16. Abstract

This project investigated the usability of Lower Anchors and Tethers for CHildren (LATCH) hardware by measuring LATCH implementations in 98 2011 or 2010 model-year vehicles. ISO and SAE LATCH usability rating systems were used to assess all vehicles using data from the second row left position. Child restraint/vehicle interaction was assessed using both ISO and NHTSA proposed procedures. Volunteer testing was performed with 36 subjects on 12 different vehicles using 3 different child restraints, with each subject performing 8 child restraint installations.

The results from the vehicle survey indicate that most vehicle manufacturers provide LATCH hardware at only the minimum number of locations required by FMVSS 225. Only 7 vehicles had three sets of LATCH hardware in the second row, while most of the remaining 91 vehicles were only equipped with LATCH in each outboard position and a tether anchor in the center position. In the 21 vehicles with a third row, four had no tether anchors and 11 had no lower anchors in the third row. The SAE child restraint fixture could not be installed in 27 vehicles, although head restraint interference was the cause of interference in only one vehicle. Fifty-nine vehicles met the SAE recommended lower attachment force of 75 N (16.9 lb) or less, while 15 vehicles required forces from 2 to 8 times this value. Only 2 vehicles met SAE recommendations for clearance angle of at least 75 degrees around the lower anchors. The depth of the lower anchors relative to the bight is less than 2 cm in 28 vehicles, 2-4 cm in 34 vehicles, and greater than 4 cm in 36 vehicles. The most common location for the tether anchor is the seatback (42) and package shelf (35). The lower anchors are marked in 77 vehicles, while the tether anchors are marked in 68 vehicles. Only Ford products clearly specify weight ranges for use of LATCH hardware in their manuals. Many vehicle manuals are not clear on how the head restraint should be positioned during child restraint installation.

ISO ratings of vehicle LATCH usability ranged from 41% to 78%, while vehicles assessed using the SAE draft recommended practice met between 2 and all 10 of the recommendations. There was a slight correlation between vehicles meeting SAE recommended practices and ISO usability ratings. Twenty vehicles with a range of vehicle features were assessed using the ISO vehicle/child restraint form and 7 child restraints; ISO vehicle/child restraint interaction scores ranged from 14% to 86%. Based on these interaction scores, the Cosco Alpha Omega, the Chicco KeyFit, and Evenflo Maestro were used with a subset of 12 vehicles to perform volunteer testing and assess the quality of subject installations. No vehicle factors predicted tether use or correct use of tether. However, the correct use of lower anchors was associated with a lower anchor clearance angle greater than 54°, an attachment force of 40 lb or less, and lower anchor depth within the bight of less than 2 cm. Correct lower anchor use also had 3.3 times higher odds of tight installation compared to incorrect use.

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Executive Summary

The LATCH (Lower Anchors and Tethers for Children) system was mandated by FMVSS 225 in an effort to standardize the attachment of child restraints to vehicles and thereby make it easier to install child restraints. While many vehicles do allow easier child restraint installation with LATCH compared to seatbelts, in other vehicles the LATCH hardware makes child restraint installation difficult, and outright incompatibilities between child restraints and particular vehicles have been documented.

The purpose of this study was to identify the characteristics of LATCH systems in vehicles that make them easier to use. The first phase involved a survey of 98 top-selling 2010-11 model year vehicles to document the characteristics of the LATCH systems. Using 20 of these vehicles and 7 different child restraints, the second phase involved using and evaluating the proposed ISO, SAE, and NHTSA systems for assessing the ease-of-use of LATCH systems and vehicle/child restraint compatibility. The third phase involved volunteer testing using 12 vehicles, chosen to provide a variety of LATCH hardware characteristics, to evaluate the quality of child restraint installations performed by the volunteers using vehicle features as the independent measures.

The following protocols for evaluating LATCH ease-of-use and vehicle/child restraint compatibility were used and assessed:

- The SAE Child Restraint System committee has drafted "Guidelines for Implementation of the Child Restraint Anchor System or LATCH System in Motor Vehicles and Child Restraint Systems." The proposed guidelines include tools and protocols for evaluating LATCH hardware in vehicles that were used to assess the 98 vehicles in the survey.
- The ISO TC 22/SC 12/WG1 published ISO 29061-1:2010 "Road vehicles -- Methods and criteria for usability evaluation of child restraint systems and their interface with vehicle anchor systems -- Part 1: Vehicles and child restraint systems equipped with ISOFIX anchors and attachments" in November 2010. The document provides forms for assessing the child restraint, vehicle, and child restraint/vehicle interaction. The vehicle assessment forms were used in the current study to rate the 98 vehicles measured, and the restraint/vehicle interaction form was used to evaluate the 20 vehicles with 7 different child restraints.
- In February 2011 the National Highway Traffic Safety Administration (NHTSA) proposed a vehicle/child restraint fit evaluation program. The evaluation procedures were used to assess the fit of 7 child restraints in 12 vehicles.

In addition to the factors assessed based on current and proposed protocols, a measurement fixture approximating the manikin-measured H-point of the rear outboard seats was developed to provide a common reference across vehicles. Locations of the lower anchors, seatbelts, seat bight and seating surface, head restraint, and tether anchors were measured relative to the fixture.

Eighty- eight 2011 model year and ten 2010 model year vehicles were measured in the vehicle survey. Most vehicles have only the minimum number of seating positions equipped with LATCH hardware

required by federal regulation. The most common implementation was lower and tether anchors in the two outboard second row positions and a tether anchor in the center second-row position. Only 7 vehicles had three full sets of LATCH hardware in the second row. In the 21 vehicles with a third row, 4 had no LATCH hardware, and 11 had no lower anchors. Most of the quantitative results from this study are based on the hardware measured in the second-row left (2L) seating position.

The child restraint fixture could not be installed (using the tools and recommendations of SAE) in at least one LATCH position in 27 of the 98 vehicles measured. The head restraint caused the interference in only one vehicle; the contour of the seatback was the most common cause of interference. Fifty-nine of the 98 vehicles met the SAE recommended lower attachment force of 75 N (16.9 lbf) or less, while 15 vehicles had forces from 2 to 8 times this value. Only 2 vehicles met SAE recommendations for clearance angle around the lower anchors of 75 degrees. The depth of the lower anchors relative to the bight (a measure developed for this study) is less than 2 cm in 28 vehicles, 2-4 cm in 34 vehicles, and greater than 4 cm in 36 vehicles.

The main measurement to quantify tether location is the wrap distance measured relative to the estimated R-point (a shoulder reference point on the H-point manikin). The mean value of measured tether wrap distance is 551 mm (standard deviation 212), with a range from 245 to 1194 mm. The most common locations for the tether anchor are the seatback (42) and package shelf (35).

The lower anchors are marked in 77 vehicles, while the tether anchors are marked in 68 vehicles. Only Ford products clearly specify weight ranges for use of LATCH hardware in their manuals. Many vehicle manuals are not clear on how the head restraint should be positioned during child restraint installation. There were no strong relationships between LATCH hardware characteristics and vehicle type.

ISO overall ratings of vehicle LATCH usability ranged from 41% to 78% (out of 100%), while vehicles assessed using the SAE draft recommended practices met between 2 and 10 of the 10 recommendations. There was a slight correlation between ISO usability ratings and the percentage of SAE recommended practices that were met (R^2=0.0245).

A sample of 20 vehicles with a range of vehicle features was selected, primarily based on lower anchor clearance angle, tether wrap distance, and angle from estimated H-point to bight. These vehicles were assessed using the ISO vehicle/child restraint form and 7 child restraints chosen to provide a variety of restraint types and features. ISO vehicle/child restraint interaction scores ranged from 14% to 86% (out of 100%). Based on these interaction scores, the Cosco Alpha Omega, the Chicco KeyFit, and Evenflo Maestro were used with a subset of 12 vehicles to perform volunteer testing and assess the quality of installations.

When the 7 child restraints and the subset of these 12 vehicles were evaluated by researchers using the proposed NHTSA fit criteria for the 2L seating position, the most challenging installations involved rear-facing convertibles. Of the 24 pairings of vehicles and two rear-facing convertibles, only one installation passed all of the proposed NHTSA criteria. Of the 48 vehicle/booster pairings, one failed; of the 24 vehicle/infant seat pairings, one failed; of the 48 vehicle/forward-facing harnessed restraint pairs, 3 failed. The most common cause of failure for the rear-facing convertibles was the inability to achieve the correct angle without using additional materials such as pool noodles.

Each volunteer subject performed eight child restraint installations among three vehicles using either the LATCH lower anchors or the seatbelt. Overall among applicable trials, subjects correctly used the lower anchors in 60% of trials and correctly used the seatbelt 33% of the time. Subjects had the highest rates of correct lower anchor use in vehicles with a clearance angle around the anchors greater than 54°, an attachment force of 40 lb or less, and an anchor depth within the bight of 2 cm or less. When reviewing the factors contributing to the 85 instances of incorrect lower anchor use, 74% were improperly oriented connectors, 57% were installations without the LATCH belt webbing flat, 35% were connectors attached to incorrect vehicle hardware, and 31% were installations without full engagement.

Overall, subjects used the tethers in 48% of forward-facing installations. Subjects used the tether in 54% of installations with the LATCH lower anchors and 33% of seatbelt installations (p=0.080). When the tether was used, subjects used the tether completely correctly 46% of the time (22% of all forward-facing installations). When reviewing the errors, 22% were tethers attached to incorrect hardware, 22% were incorrect orientations of the tether hook, 26% were incompletely tightened tethers, and 44% were incorrectly routed tethers relative to the head restraint. The small number of tether installations made it difficult to identify features of tether anchors that made them easier to use. Better labeling of tether anchors and fewer restrictions on allowable tether routing paths may increase use and correct use of tethers.

Subjects obtained a tight fit (meeting the 1" tightness test used in child seat checks) during LATCH installations 3.3 times as often when they correctly used the lower anchors. Thus efforts to improve usability of lower anchor may also help resolve the installation error of a loose attachment to the vehicle.

Neither the ISO vehicle rating nor the ISO vehicle/child restraint interaction ratings were correlated with the quality of the volunteer installations. The total number of proposed SAE recommended practices passed by each vehicle also did not predict the quality of installation. However, two measures proposed by SAE were associated with improved rates of correct lower anchor use (clearance angle and attachment force), but at less stringent threshold levels as those suggested by SAE (54 vs. 75° clearance angle and <40 lb vs. <17 lb attachment force). For vehicle/child restraint pairings failing the proposed NHTSA fit criteria, only 4% of installations had error-free installations compared to 16% of installations that passed the proposed NHTSA fit criteria.

To assess usability, vehicles with lower anchors less than 2 cm within the bight, an attachment force of 40 lb or less, and a clearance angle of 54° or more would be expected to achieve the highest rates of correct lower anchor usage. Using the vehicle survey results, 21 of the 98 measured vehicles would meet all these criteria. We propose a multi-pronged approach for improving tether use, including education programs, providing temporary "tether tags" in new vehicles to draw attention to the hardware, and marking tether locations in vehicles. When considering LATCH usability, vehicles providing more than the minimum number of LATCH seating positions should be considered as having better usability.

I. Introduction

A. The LATCH System

In the 1990's, while rates of child restraint use increased in the US, rates of child restraint misuse remained high because of the challenges of installing child restraints with seatbelts designed to restrain adults. In response to these challenges, the National Highway Traffic Safety Administration (NHTSA) implemented a new child restraint securement system, Lower Anchors and Tethers for Children, known as LATCH. The LATCH concept originated from a similar effort by the International Standards Organization (ISO), which proposed a universal anchor system for installing child restraints termed ISOFix. Implementation of LATCH, an adapted version of ISOFix, in the United States is established in Federal Motor Vehicle Safety Standard (FMVSS) 225, "Child Restraint Anchor Systems."

LATCH has two distinct components: lower attachments on child restraints that connect to lower anchor points located at the seat bight, and top tethers on forward-facing restraints that attach to anchors located on the rear shelf, seat back, floor, cargo area, or ceiling. The LATCH lower attachment webbing is designed to replace the vehicle seat belt as the primary attachment to the vehicle. Attaching the top tether achieves a more secure installation when installing a forward-facing restraint with either the lower attachment webbing or vehicle seat belt and provides safety benefits by reducing head excursion.

Effective in 2002, all child restraints sold in the United States have to be equipped with tethers and lower connectors. Effective with the 2003 model year, passenger vehicles have to have at least two seating positions with LATCH lower and tether anchor hardware. A modification to the testing requirements for the anchors was made in June 2004, so the 2005 model year was the first in which all non-exempt vehicles (e.g., convertibles and heavy pickup trucks) were required to meet the most recent version of the standard.

B. LATCH Studies

LATCH Use and Performance in the Field

In 2003, the Insurance Institute for Highway Safety reported on the ease-of-use of LATCH hardware as well as an observational study of LATCH use in the field (IIHS 2003). The problems and use rates reported then are similar to those reported in more recent studies described below. To study if LATCH made child restraint installation easier, Institute researchers installed six models of child restraints in ten vehicles. Installation problems included lower anchors that were difficult to access and use, interference from seatbelt hardware, and unmarked tether anchors that were difficult to reach. In the observational survey, tethers were used with only 47% of the forward-facing child restraints known to have tethers.

In 2007, Decina and Lococo published the results of an observational survey focusing on LATCH. Their findings show that in situations where the tether hardware was available, only 51% of forward-facing restraints were installed with the top tether. Loose tethers were observed in 18% of cases and loose LATCH straps were seen in 30% of cases. In 20% of cases, child restraints were installed using both lower anchors and seatbelt. This study demonstrated that the availability of LATCH did not eliminate child restraint misuse.

The Partners for Child Passenger Safety 2008 Fact and Trend report shows that among crash-involved children in child restraints and LATCH-equipped vehicles, tether use increased from 9% in 2002 to 43% and lower anchor use ranged from 26% to 39% over the same time period, although the 2007 data showed a rate of only 29% for lower anchors (PCPS 2007).

Arbogast and Jermakian (2007) reported on the field performance of child restraints installed with LATCH. In five of the seven crashes where in-depth investigations were conducted, there were child restraint installation errors. However, the error contributing most often to incorrect restraint use was loose harness straps, which would not necessarily be affected by the use of the LATCH system to attach the restraint to the vehicle. In two of the crashes where LATCH was used, there were significant injuries to the children, although the use of the LATCH system did not necessarily contribute to the injuries.

Jermakian and Wells (2010) conducted an observational study of top tether use in metropolitan Washington DC over a two-month period. Researchers collected information on the vehicle type, seating position, and tether use. A total of 1,543 forward-facing child restraints were observed in 1,321 passenger vehicles. Top tethers were used with 43% of all forward-facing restraints, and the rate of tether use was similar (42.7-45.4%) among cars, minivans, and sport utility vehicles but lower (17.2%) for pickups. The authors suggest educational efforts to encourage tether use with seatbelt installations and retrofitting of older vehicles.

LATCH Performance in Laboratory Testing

While extensive laboratory sled and vehicle testing was performed to demonstrate the benefits of lower anchors and tethers before LATCH hardware was required by federal regulations, only a limited number of studies on the performance of child restraints installed with LATCH have been published in the last decade. The early testing was typically performed using prototype or early production hardware, and relatively few programs tested production child restraint or vehicle hardware designs that had evolved since the first implementations in the US market.

Manary et al. (2006) reported on the benefits of tethering rear-facing restraints, with results showing improved performance for any rear-facing tether configuration compared to the no tether condition. Tethering rearward over the top of the seat rather than down to the floor performed better than other conditions. Menon et al. (2007) conducted sled tests to examine the effects of LATCH misuse on child restraint performance. The use of a tether provided benefits even if the lower attachments are loose. Slack in the LATCH belt webbing degraded performance.

Transport Canada has performed several series of tests to examine the performance of child restraints installed with LATCH in production vehicles that were crash tested. Their findings are documented on the Transport Canada website (Transport Canada, 2009). Overall, researchers found acceptable performance of child restraints installed with LATCH, even when using dummies weighing more than 65 lbs. Compared to child restraints installed with the seatbelt, excursions were reduced for child restraints installed with LATCH.

LATCH Usability

Klinich et al. (2010a and 2010b) performed tests with volunteer subjects to identify factors that contribute to child restraint installation errors. Testing was conducted in three phases, with 32 subjects recruited in each phase based on their child restraint installation experience or education level. The first phase examined different child restraint features, the second phase looked at alternate labels and child restraint manuals, and the third phase looked at different types of vehicle hardware.

For the results associated with child restraint features, LATCH connector type, LATCH belt adjustor type, and the presence of belt lockoffs were associated with the tightness of the child restraint installation. The type of harness shoulder height adjuster was associated with the rate of achieving a snug harness. Correct tether use was associated with the tether storage method.

None of the modified labels or instructions resulted in improved installation compared to the original labels and manuals. Compared to the effects of different child restraint designs, variations in labels and manuals have a small effect on installation error.

In the phase examining vehicle differences, vehicles requiring higher forces to attach connectors to lower anchors were more likely to be attached incorrectly. Vehicle seats with a bightline waterfall (which places the lower anchor above the seating surface) increased rates of tight child restraint installation for both seatbelt and LATCH installations. Seatbelt installations were tight (and locked) more frequently when the buckle stalk was located close to the bight rather than further forward. Subjects used the tether correctly in 30% of installations. Subjects used the tether more frequently during LATCH installations compared to seatbelt installations, and in sedans (with anchor locations on the package shelf) than in vehicles with the tether anchor located on the seatback. However, when the tether was used, it was routed correctly more often in vehicles with the tether anchor on the seatback. A tether wrap distance of 210 mm was sufficient to allow tightening of the tether with the two child restraints tested, but additional testing of 16 child restraints showed that 5 out the 16 could not be tightened sufficiently with this tether wrap distance. Subjects used the vehicle manual in 38% of installations, and were more likely to do so when the tether anchor was located on the vehicle seatback. Subjects reported that tether anchors on seatbacks were more difficult to locate than those on the package shelf.

C. Efforts to Improve LATCH

Vehicle manufacturers have used a variety of approaches to provide and locate LATCH anchors that meet federal requirements, with varying success in terms of producing a system that is usable and accessible. Although almost all of the LATCH hardware in the fleet meets the requirements of FMVSS 225, there have been many problems reported from the field (IIHS 2003). Each year the November-December issue of Safe Ride News , reports on new challenges with LATCH, based on a survey of new vehicles at the Seattle auto show (SafeRideNews 2011), such as:

- lower LATCH anchors that are incompatible and cannot connect with the connector hardware on child restraint systems (CRS),
- lower LATCH anchors that are embedded so far into the vehicle seat bight so as to be unusable,
- top tether anchors that are unlabeled and positioned near similar looking hardware (such as cargo tie down anchors) that is not intended for securing a CRS.

In addition, most LATCH-equipped seating positions in the second row outboard locations, but it is recommended that installing the child restraint in the center of the vehicle is safest (Braver et al. 1998, Kallan et al. 2008). This creates confusion with parents and caregivers who want to follow recommended installation practices and also want to use LATCH. While a minimum of two LATCH positions must be provided in vehicles, some manufacturers have voluntarily provided LATCH in additional seating positions to aid families with more than two children. So while all vehicles have LATCH, some offer more LATCH choices that could benefit consumers and improve safety.

The SAE Child Restraint Systems (CRS) Subcommittee and ISO TC22/SC12/WG1/TF2 have drafted procedures and tools for assessing LATCH usability and the compatibility between vehicle and CRS when using LATCH. The SAE procedures generally have tools and procedures for quantifying hardware, while the ISO procedures focus on instructions and labeling and more qualitative assessments of hardware usability. While some manufacturers and agencies may have used these procedures as design guidelines, no comprehensive assessment of LATCH usability based on these procedures and tools has been published. NHTSA has also recently proposed a consumer information program (NHTSA, March 2011) whereby vehicle manufacturers would provide a list of child restraints that fit in each vehicle model beginning with 2012 model year vehicles. It has provided sample evaluation forms and procedures, but has not demonstrated that installation errors would be reduced when using recommended child restraints in each vehicle. NHTSA has requested comments on the proposed procedures, but has not yet issued response to comments as of February 2012.

D. Project Objectives and Tasks

Recent studies indicate that LATCH has not eliminated child restraint misuse and challenges with the ease of using LATCH remain. The protocols developed by SAE, ISO, and NHTSA have not been evaluated. The current study was undertaken to define the characteristics of LATCH systems that are most effective at improving child restraint installation. The objectives were as follows:

1) document characteristics of LATCH hardware in the current vehicle fleet
2) evaluate proposed ISO, SAE, and NHTSA protocols for assessing LATCH usability in vehicles and vehicle/child restraint compatibility

3) determine if usability ratings using these protocols are associated with the quality of installations by volunteer subjects

These objectives were accomplished through the completion of the following tasks:

1) Survey of the LATCH hardware and rear-seat geometry of 98 vehicles
2) Calculation of LATCH usability scores for each vehicle using the ISO and SAE proposed protocols and the data from the vehicle survey
3) Calculation of ISO vehicle/child restraint interaction scores for 20 vehicles and 7 child restraints
4) Calculation of the NHTSA vehicle/child restraint fit ratings for 12 vehicles and 7 child restraints
5) Assessment of the association between the scores and ratings and the usability of LATCH systems using 36 volunteer subjects, 12 vehicles, and 3 child restraints

This research document the range of LATCH hardware in the vehicle fleet. One of the key questions to be answered was whether vehicles that meet SAE recommended practices achieve good scores using the ISO rating system. These tasks also provide the foundation to identify whether good SAE, ISO, and proposed NHTSA ratings predict higher usability and good child restraint installation by volunteer subjects, or whether an alternate rating system can be developed using the vehicle measurements shown to be correlated with volunteer performance.

II. Methods

A. Vehicle Survey

1. Vehicle Selection

The goal of the vehicle selection process was to identify a large sample of new vehicles that are often used for transporting children and that represent a wide range of LATCH hardware implementations. Vehicles were selected for inclusion based on high recent sales figures, 2010 or 2011 model year availability, and recommendation as a family vehicle by prominent websites and magazines (e.g. AAA and Parents). The 2008 Ward's Automotive yearbook, the most recent sales data available, was used to identify the top sellers. For each top seller, the manufacturer's website was then reviewed to determine which models were still in production, and to add any new vehicle models to the list. Finally, several consumer websites were checked and vehicles recommended for families were tagged for inclusion in the study.

A preliminary list of 76 vehicles included all of the vehicles that were family-recommended, with 2009 sales over 75,000 and still in production. These vehicles represent approximately two-thirds of the passenger vehicles sold in 2009. The list was expanded to add at least one or two vehicles from product lines not initially selected (most of them higher-priced), including Mercedes, Volvo, Range Rover, Jaguar, Cadillac, Suzuki, Mitsubishi, Subaru, Lexus, Audi, and Porsche. A few more were added based on an informal survey of several child passenger safety technicians to identify vehicles with challenging LATCH systems. Based on the feedback, the BMW Mini Cooper, Cadillac Escalade, Honda Ridgeline, and Mitsubishi Eclipse were added to the list. Next, the Polk registration data were reviewed to identify which editions of each model comprised the vehicle sales. Based on these data, particular editions of each vehicle were selected for testing. In some cases, multiple editions of the same vehicle were targeted for measurements. In all, 106 vehicles were identified for inclusion in the study. A few of these vehicles were discontinued in 2011, while one vehicle (F-250) did not include LATCH because its vehicle mass exempts it from the requirements of FMVSS 225. Appendix A lists the 98 vehicles that were measured.

2. Vehicle Measurements

Appendix B contains the test protocol used to measure the vehicles. Some of the measures are based on procedures in the SAE draft recommended practice, described in Appendix C. Other measures are based on the ISO LATCH usability procedures, which are described in Appendix D. Additional measures developed for the current study are described below.

Documenting the LATCH hardware geometry in vehicles required a common measurement origin across vehicles. The original plan had been to use the bight as the l reference, but examination of recent vehicles indicated that many vehicles have a bight positioned above the seating surface, as shown in

Figure 1, which complicates its use as a vehicle reference landmark. A bight located above the seating surface is referred to as a bightline waterfall (or tootsie roll).

Figure 1. Examples of bightline waterfalls with the bight above the seating surface.

Vehicle manufacturers and federal regulations use the SAE J826 H-point manikin to establish the H-point of a vehicle seat as an origin. However, time constraints prevented measurement of the H-point of each vehicle at dealerships with the manikin. Instead, a reference measurement tool was designed to provide an origin near the average H-point of rear seating positions for measurements in the XZ plane. The design is similar to a fixture used by Huang and Reed (2006) to measure cushion length and angle in a study of vehicle rear seat geometry.

To determine where to position the tool origin relative to an undeflected seat contour, data from a prior UMTRI study were used (Reed 2011). In that study, a FARO Arm coordinate digitizer was used to record the centerline profiles of the left, outboard, second-row seats in a convenience sample of 37 passenger cars, 4 minivans, and 15 SUVs. Vehicle model years were 1988 to 2007, with a median model year of 2002. The seat H-point location was obtained using the SAE J826 H-point manikin, which was also used to measure back angle (SAE A40) and manikin hip angle. The deflected seat profiles were recorded at a centerline seat position defined by the center of the head restraint. If the head restraint was not readily identifiable, the lateral center of any visible seat insert or contouring identifying the seating position was used. Adjustable head restraints were measured in the full-down position. The contour was analyzed in side view relative to the seat H-point.

The rear seat profiles were analyzed using principle components analysis. Figure 2 shows the effects of manipulating the first five principle components (accounting for 90 percent of the variance) independently over the range in the data. From left to right, variations in backrest height, seatback angle, head restraint prominence, back contour, and seat cushion stiffness are the principle components that describe primary variations in seat geometry.

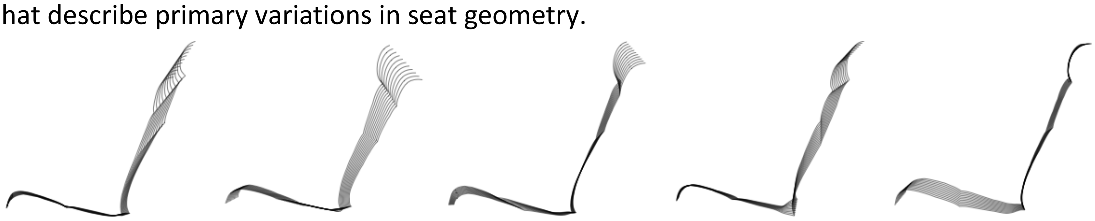

Figure 2. Effects of manipulating each of the first five principal components (left to right) in 10 steps across the range in the data.

On the H-point manikin, the vertical distance from the bottom of the buttock shell contour to the H-point is 100 mm. However, when positioned in a vehicle and weighted, the H-point manikin deflects the seat cushion. The dataset of scanned rear-seat contours was used to estimate the average distance between the H-point and the undeflected seating surface. As shown in Figure 3, the average height between the H-point and undeflected seat contour was 50 mm, with a standard deviation of 16 mm. Thus the heights of the standoffs on the reference fixture were set to be 50 mm. Note that this is different from the standoff height used by Huang and Reed, which was 75 mm based on estimates rather than measured vehicle data.

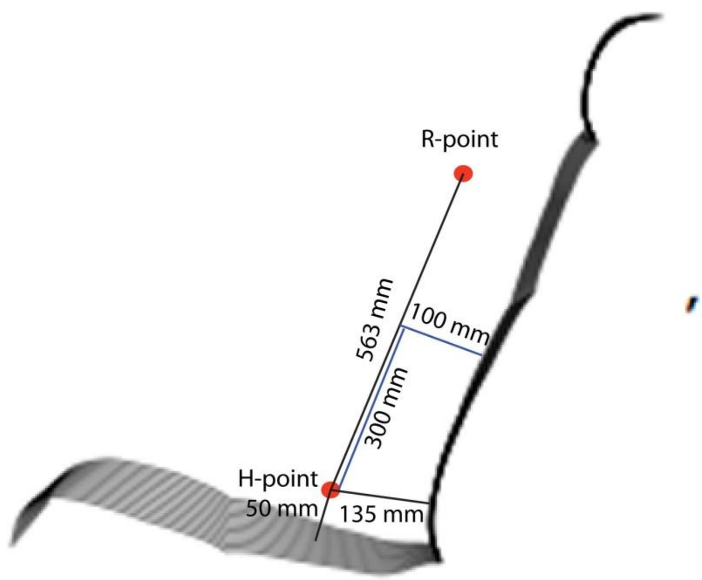

Figure 3. Illustrated of average location of H-point and R-point.

The installed reference measurement fixture is shown in Figure 4. The contour of the clear T-plate that rests against the seatback matches the contour of the H-point manikin at the level of the H-point. Because the back edge of the T-plate could become trapped in a seatback with a bight above the seating surface, a vertical plate was added to the back so it would better represent how the H-point manikin would fit on the seat. The fore-aft distance between the back of the T-plates and the H-point origin is set to be 135 mm, which is the distance on the H-point manikin between the H-point and rear buttock shell contour measured along the thigh line.

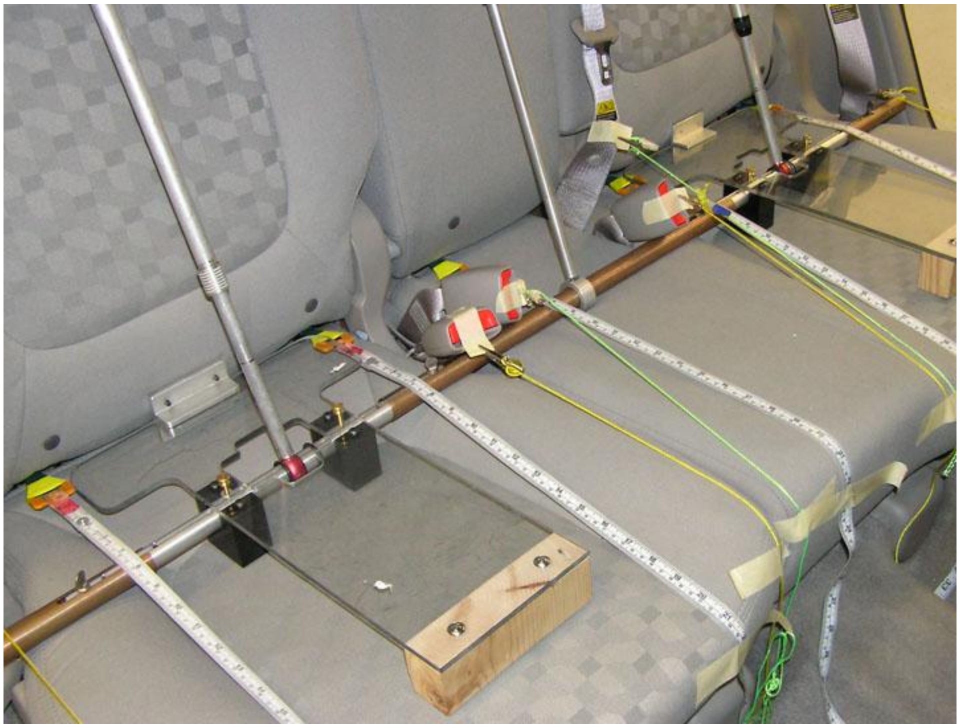

Figure 4. Reference measurement fixture.

The reference fixture is designed so the top centerline of the bar that extends across the seating row approximates the location of the H-point. If the population of vehicle rear seats being measured is similar to the 54 vehicles that are the basis for the origin location on the reference fixture, the origin of the reference fixture would be expected to be within 16 mm of the vertical H-point location in 68% of the vehicles. The bar extends so that the centerlines of the T-plates can be positioned and locked at the centerline of each outboard seating position.

The reference fixture is used for a number of measurements. As shown in Figure 5, a hook-on lower anchor connector with a measuring tape is attached to each lower anchor, and a clip with a string is attached to the center of each belt buckle and webbing component. The lateral locations are measured along the origin bar. The distance and angle to each lower anchor are also measured relative to the estimated H-point.

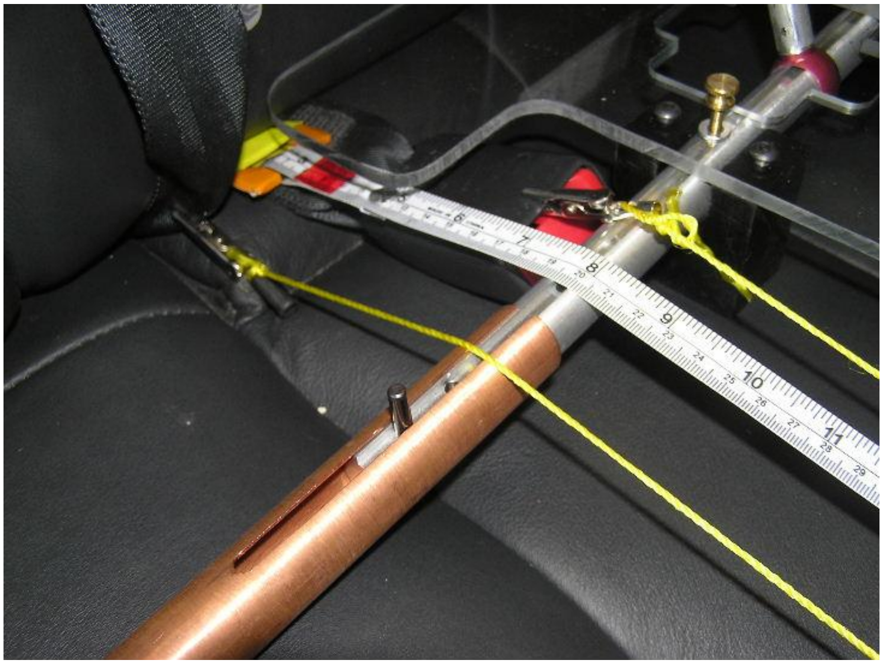

Figure 5. Documenting location of lower anchors and lateral locations of belt hardware.

The hooks used to attach the measuring tape to the lower anchors were also marked with colored electrical tape as shown in Figure 6. The width of the tape is 2 cm, so the depth of the anchors within the bight can be estimated by what color is visible. The center photo of Figure 6 illustrates an anchor with less than 2 cm of depth because the blue tape is visible, while the right photo in the figure depicts an anchor with 4-6 cm of depth because the yellow tape is visible.

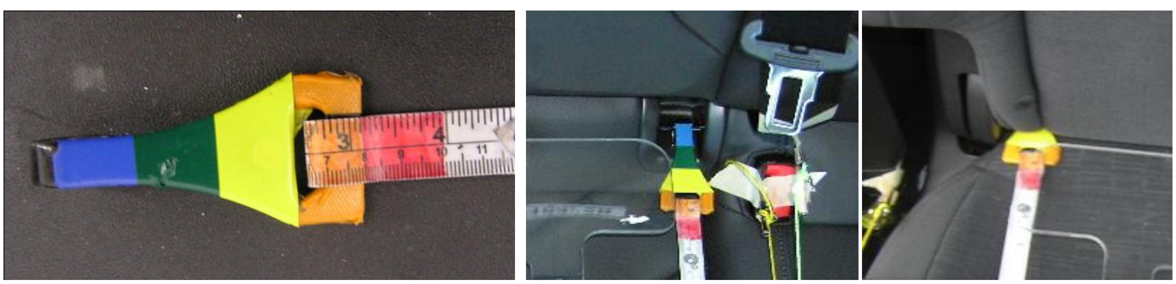

Figure 6. Colored marking of lower anchor measurement tape. Center picture shows lower anchors with less than 2 cm depth, while right picture shows lower anchors with 4-6 cm depth.

Measuring the location of the bight relative to the estimated H-point is illustrated in Figure 7. Because the space between the seatback and seat cushion varies considerably among vehicles, a 1-in diameter cylinder was affixed to the end of the measurement bar to provide more consistent placement in each vehicle. The distance and angle from the estimated H-point to the bight was recorded for each vehicle. In vehicles with a bightline waterfall feature, the distance to the seating surface was also measured using the same technique.

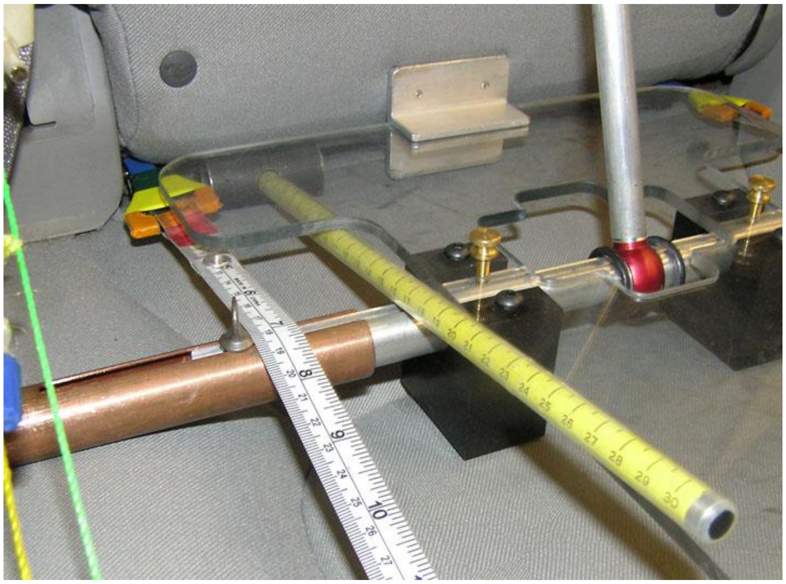

Figure 7. Measuring distance and angle to bight.

The reference fixture was also used to estimate the R-point (a manikin shoulder point reference), which is the origin of the tether anchor zone defined by FMVSS 225. The R-point is located 563 mm up from the H-point along a line oriented parallel to the design seatback angle of the vehicle seat. The dataset used to estimate the average H-point was also used to design components of the fixture to estimate the R-point. A standoff spacer 100 mm in length that was positioned 300 mm above the origin oriented the vertical post of the fixture at the design seatback angle of the seat. For fixed back seats, the seatback angle can be measured using the vertical posts. For adjustable seatbacks, the reference tool can be used to adjust the fixture to the mean design seatback angle of 25.5 degrees from vertical. This mean value is taken from the same set of 54 scanned vehicle rear seats in the UMTRI database.

Once the reference tool was adjusted to approximate the R-point, the tether wrap distance from the vehicle tether anchor to the R-point was measured as shown in Figure 8. The end of the measuring tape was attached to a tether hook to provide a realistic attachment. The lateral distance between the tether anchor and the seat centerline was also measured as shown in Figure 9.

Figure 8. Measuring the wrap distance from tether anchor to the estimated R-point.

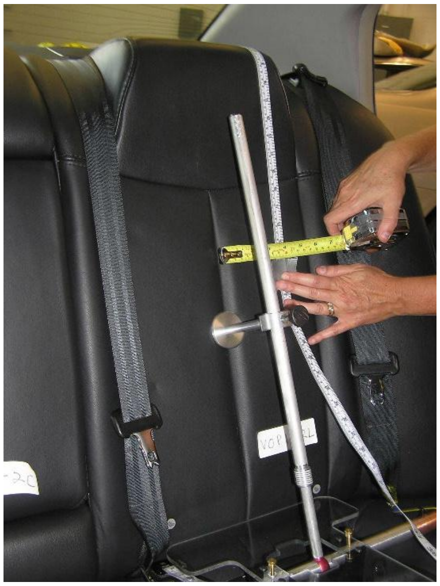

Figure 9. Measuring lateral distance from tether anchor to vehicle seat centerline.

The components used to provide a reference for tether anchor location were also used to characterize head restraint geometry. As shown in Figure 10, the vertical rod was adjusted to provide a tangent to the head restraint, and the angle and distance were recorded. The rod was then adjusted to the base of the head restraint and the distance and angle were recorded.

Figure 10. Measuring the angle and distance to the tangent of the head restraint.

Because the shape of the vehicle seat could affect child restraint fit, a method to document the centerline profile of the vehicle seat using the child restraint fixture was developed as shown in Figure 11. The fixture was attached to the lower anchors. Using holes drilled in the fixture centerline every 10 cm, the distance between the fixture base and seat surface was recorded. This series of measurements allows development of a centerline profile of the vehicle seat.

Figure 11. Measuring seat profile relative to surface of child restraint fixture.

A few items were measured because they may have general relevance to child restraint installation. These include seat cushion depth, seat cushion angle, and floor height. For the cushion depth measurement shown in Figure 12, the reference tool is installed in the seating row and a square is placed on the fixture so it contacts the front edge of the seat cushion. The distance from the edge to the estimated H-point is recorded. For cushion angle shown in Figure 13, the angle of the reference tool is recorded. For floor height shown in Figure 14, the perpendicular distance from the floor to the estimated H-point was recorded. These measurements approximate the cushion depth and angle measured with the SAE J826 H-point manikin.

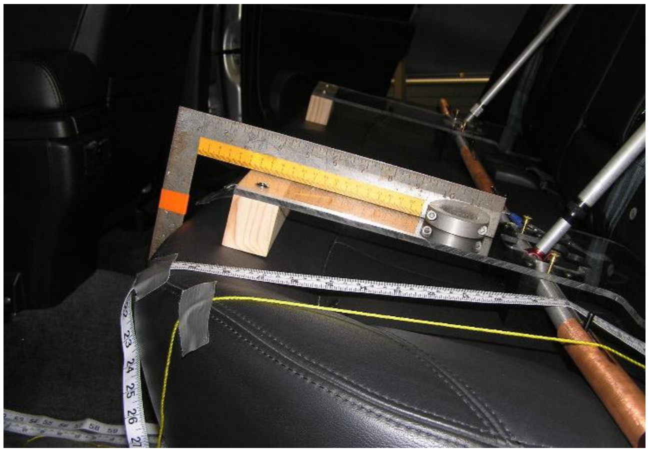

Figure 12. Measuring seat cushion length.

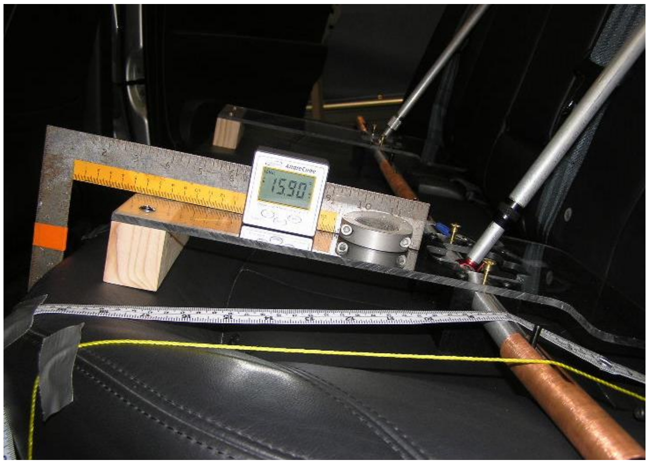

Figure 13. Measuring seat cushion angle.

Figure 14. Measuring floor height.

The proposed ISO vehicle assessment protocol requires a review of the vehicle owner's manuals to determine how they illustrate the locations of the lower and tether anchors and how the tether is to be routed. The following other points from the manuals also were recorded:

- Does the manual provide any instruction on rear-facing tethering?
- Does the manual provide weight-limit restrictions for use of lower or tether anchors?
- Does the manual use the term ISOFIX, LATCH, or both?
- Does the manual specify a position for the head restraint during child restraint installation? Are there multiple options?
- Does the manual allow use of both the seatbelt and LATCH to secure child restraints?
- Does the manual address both single and V-shaped tether routing?
- Are directions for LATCH installation separate from directions for seatbelt installation?
- Are there any restrictions on seating positions where child restraints can be installed?
- Are there any requirements for seatback angle during child restraint installations?
- Record the total number of manual pages, as well as the number of pages dedicated to child restraint installation.

Although both the SAE and ISO proposed procedures recommend that lower and tether anchors be visible and marked, additional information regarding the characteristics of the anchors and the markings was recorded. For the lower anchor markings, the method of applying the marking (button, patch, tag, imprint), the type of covering (slit, door, flap, none), whether the marking matched or contrasted with the color of the vehicle seat, and whether the ISO or some other marking was used were all documented. The presence of any potentially confusing hardware near the lower anchors also was documented. For the tether anchors, the location of the anchor (package shelf, seatback, floor, under seat, roof, cargo area, back wall) and covering type (door, flap, panel, none) were recorded in addition to the visibility and whether the tether anchor was marked.

3. Analysis

The number of seating positions equipped with LATCH varies from 2 to 5 in the vehicles measured. For the current study, we chose one seating position to use for comparisons among vehicles. Seating position 2L (i.e., second row seating position behind the driver) was selected because all but one of the vehicles had LATCH hardware in that position. For the single vehicle that did not have LATCH in the 2L position (the Chevrolet Tahoe), the data from the 2R seating position were used in the analysis.

For the measured variables, calculations include mean, standard deviation, minimum, maximum, and quartile values. Distributions of categorical variables are also presented. Throughout the measurement process, photographs to further document each vehicle were taken. Appendix E contains an example set of pictures for one vehicle. A full set of pictures for all vehicles will be submitted to the IIHS on CD.

B. LATCH Usability Assessments

1. SAE Draft Recommended Practice

The SAE Child Restraint Standards Committee drafted "Guidelines for Implementation of the Child Restraint Anchor System or LATCH System in Motor Vehicles and Child Restraint Systems." The intent is to help vehicle and child restraint manufacturers improve the compatibility of child restraints and vehicles using LATCH. This project focuses on SAE's proposed recommended practices dealing with vehicle design rather than child restraint design. The factors considered by SAE are described in Appendix B and summarized below.

1) Can the child restraint fixture attach to the lower anchors?
2) Is the force to attach lower anchors less than 75 N (16.9 lbf)?
3) Is the clearance angle as measured with the specified angle measurement tool greater than 75 degrees?
4) When resting unattached on the vehicle seat, is the lateral angle of the child restraint fixture less than 5 degrees?
5) When installed on the lower anchors, is the pitch angle of the child restraint between 5 and 20 degrees?
6) Does the collinearity tool attach to the lower anchors?
7) Does the angle measurement tool contact any rigid structure around the lower anchors?
8) When installed, is the distance from the Z-point on the child restraint fixture to the seat cushion less than 51 mm?
9) Are tether anchors marked with the ISO symbol?
10) Are lower anchors marked with the ISO symbol?
11) If a tether router is present, does it accommodate the tether hardware clearance tool?

Although the SAE draft recommended practice does not address how to derive a composite rating for each vehicle, a method was developed for doing so in this study. For each vehicle, the number of factors it passed was tabulated, and a percentage score out of 10 or 11 (if a tether router is present) was calculated and is referred to as the SAE Grade. If one of the factors could not be evaluated, it was counted as not passing.

2. ISO LATCH Usability Rating System

The ISO TC 22/SC 12/WG1 published a final version ISO 29061-1:2010 “Road vehicles -- Methods and criteria for usability evaluation of child restraint systems and their interface with vehicle anchor systems -- Part 1: Vehicles and child restraint systems equipped with ISOFIX anchors and attachments” in November 2010. This report will refer to this document as the ISO LATCH Usability Rating System. There is also a supplementary document that gives additional details and examples of how to score each item.

The ISO LATCH Usability rating system provides forms for assessing the child restraint, the vehicle, and the child restraint/vehicle interaction. Each assessed item receives scores of 3, 1, or 0, and each item has an assigned weighting factor of 1, 2, or 3 based on its safety impact. A percentage rating across all the items is calculated using the sum of the scores times the weight, divided by the total possible highest score. The highest possible scores vary based on the vehicle and child restraint combinations. For example, with the vehicle/child restraint interaction ratings, the highest possible scores were 60 for a rear-facing convertible or 84 for a rear-facing infant seat with separate base. Scores are calculated separately for each child restraint, vehicle, and vehicle/child restraint interaction in a particular seating position. There is no specific method for combining the different scores, or for developing an overall vehicle rating based on multiple seating positions. Descriptions of each form are summarized in Appendix C. Table 1 shows an example of the ISO Vehicle/child restraint interaction form using the Britax Frontier and the Kia Soul, which scored 54% out of a possible 90 points.

Table 1. ISO vehicle/child restraint interaction rating form

	Evaluation Item	Weight	Possible Scores	Example: Frontier /Soul	Weighted score	Best possible score	ISO % Rating
3.1.1	ISOFIX anchors usable (on child restraint)	3	3/1/0	1	3	9	
3.1.2	Are ISOFIX attachments accessible during process?	3	3/0	3	9	9	
3.1.3	Feedback on correct ISOFIX attachment	3	3/1/0	1	3	9	
3.1.4	Can ISOFIX attachments be tightened?	3	3/1/0	1	3	9	
3.1.5	Hidden slack possible?	3	3/1/0	1	3	9	
3.1.6	Harness fully operable?	3	3/0	3	9	9	
3.2.1	Actions required to attach tether	2	3/1/0	3	6	6	
3.2.2	Can top tether be tightened properly?	3	3/1/0	1	3	9	
3.2.3	Clear feedback on tether attachment	3	3/1/0	1	3	9	
3.3.1	Actions for primary ARD	2	3/1/0	NA			
3.3.2	Actions for secondary ARD	2	3/1/0	NA			
3.4.1	Child restraint base and shell ready for install	2	3/1/0	NA			
3.4.2	Actions to attach child restraint to base	2	3/0	NA			
3.4.3	Feedback on correct locking to Base	3	3/1/0	NA			
3.4.4	Actions to detach child restraint base	1	3/1/0	NA			
3.5.1	Ease of releasing top tether tension	1	3/1/0	0	0	3	
3.5.2	Actions to detach and store top tether	1	3/1/0	3	3	3	
3.5.3	Ease of releasing tension of flexible child restraint	1	3/1/0	1	1	3	
3.5.4	Actions to remove and store primary ARD	1	3/1/0	NA			
3.5.5	Actions to remove and store secondary ARD	1	3/1/0	NA			
3.5.6	Actions to detach from lower anchors	1	3/1/0	3	3	3	
				Sums of weighted scores:	49	90	54%

Items listed in gray do not usually apply to US products. ARD=anti rotation device

3. Proposed NHTSA Vehicle/Child Restraint Fit program

In February 2011, NHTSA proposed a consumer information program for assessing vehicle/child restraint fit (NHTSA 2011). They have proposed criteria for assessing the fit between a vehicle and child restraint, although usability is not directly addressed. To be listed by a vehicle manufacturer as fitting in a specific vehicle, the child restraint must be able to be installed in all rear seating positions, using any available installation method (seatbelt or LATCH). In addition, to participate in the program to list their vehicle/child restraint fit data on NHTSA's safercar.gov website, manufacturers must recommend at least three child restraints in three categories (rear-facing, forward-facing, booster), each in a different price range.

Different assessment forms are used for each general style of child restraint produced. The forms review whether tethers can be appropriately attached and tightened. For LATCH installations, the forms document whether the lower anchors can be attached properly, and be tightened, and if the seatbelts in the adjacent seating position can be used. For seatbelt installations, possible problems with belt geometry, seatbelt length, buckle interference, or latch plate button interference are documented. (A latch plate button is the plastic button inserted through belt webbing to keep the latch plate easily accessible, but sometimes does not allow a seatbelt to be sufficiently tightened during child restraint installation.) For any type of installation, the amount of contact with the vehicle seat (at least 80%) and the tightness of the installation are assessed, as well as the ability to operate the harness. For rear-facing installations, the ability to meet manufacturer's instructions regarding contact with the vehicle front seat is evaluated. The ability to be installed at the correct recline angle (without using pool noodles) and the proper use of available anti-rotational devices, usually tethers, are also assessed. Finally, the form notes whether the child restraint can be installed while following the instructions of both the restraint manufacturer and the vehicle manufacturer. For forward-facing installations, potential interference with head restraints is evaluated. For booster seat evaluation, belt fit provided by the booster is not assessed, and the form primarily assesses whether the booster can be placed in a stable manner with access to the seatbelts.

4. Child Restraint Selection for Usability Assessments

When choosing child restraints for performing assessments of child restraint/ vehicle interaction, the primary goal was to select restraints that provided a variety of interactions with vehicles. Testing with a rear-facing infant seat with base, a convertible child restraint (installed both forward-facing and rear-facing), and a combination seat (used as a forward-facing restraint with harness) would represent each of the main types of child restraints, with the combination seat likely providing a taller profile (and potential for head restraint interaction) than the forward-facing convertible. In addition, the child restraints used should provide examples of the current types of lower connector hardware. Two infant child restraints, two convertible child restraints, and two forward-facing only child restraints were selected that met the following criteria:

- One of each pair had hook-on and the other push-on lower connectors
- Six different manufacturers
- A variety of widths, heights, contours, and tether attachment locations
- Some popular products included
- Range of prices
- Excluded models used most extensively in the Klinich et al. (2010a, 2010b) NHTSA-sponsored study of child restraint installations (Evenflo Titan, Graco ComfortSport, Recaro Signo, Evenflo Triumph)

Table 2 shows the six child restraints that were selected for assessment. The information below each illustration shows the approximate price range; the product height, width, and depth; and the weight range and location where the tether attaches to the child restraint relative to the floor.

All of these child restraints use some type of webbing that attach a hook-on or push-on connector to the child restraint, but none have a rigid lower connector. This type of connector hardware consists of two anchors rigidly attached to the child restraint that do not have any webbing that needs tightening. At the time the study was performed, there were no harnessed child restraints produced in the US that use a rigid lower connector. However, there were a few booster seats that do. A Magna Clek Olli booster was also evaluated for its interaction in the potential test vehicles, although it was not used for subject testing. Checking to see if a booster with a rigid lower connector could be installed in vehicles with a range of lower anchor configurations helped identify any potential problems if rigid lower connectors became more widespread in the US.

These seven child restraints were used with the ISO vehicle/child restraint interaction form. They were also used in the evaluation of the NHTSA child restraint/vehicle fit forms.

Table 2. Six child restraints selected for assessing vehicle/child restraint interaction.

	Infant CRS	Convertible	Combination
Hook-on lower connector			
	Graco SnugRide 30 $130-$140 4-30 # RF	Alpha Omega Elite $160-$185, Tether Height 19.5”, H 24”, W 18”, D 17.5” 5-35# RF, 22-40# FF, 40-100# booster	Evenflo Maestro $80, Tether Height 24” H 26-28”, W 19”, D 16”, 20-50# FF, 40-100# Booster
Push-on lower connector			
	Chicco KeyFit 3 $180 4-30 # RF	Learning Curve Compass TrueFit $190, Tether Height 20”, H 27.5”, W 19.5”, D 14.5” 5-35 # RF, 23-65# FF	Britax Frontier $280, Tether Height 23” H 26.5”, W 19.5”, D 17.5” 25-85# FF, 40-120# Booster

5. Vehicle Selection for Usability Assessments

During the first phase of the study, over 80 measurements for each seating position evaluated were collected from the 98 study vehicles. The goal of selecting vehicles for the assessment of vehicle/child restraint interactions and the subsequent subject testing was to have a sample of vehicles with a wide variety of LATCH systems as well as vehicle seat characteristics that may also affect child restraint installation. Choosing a wide range of vehicle features would hopefully allow identification of which had the greatest affect on installation ease. It was necessary to distill the large amount of data on vehicle features into a few key criteria that would best represent the vehicle factors most likely to affect LATCH usability. The three main categories of measures were those that characterize the lower anchor hardware, the tether, and the vehicle seat. From the several candidate measures for each of these categories, those used were the clearance angle around the lower anchors, the tether wrap distance, and the angle from the H-point to the bight. Each vehicle was classified into one of using the lower (quartiles 1 and 2) or higher (quartiles 3 and 4) range of values measured in seat position 2L. This divided the vehicle list into eight groupings (2 x 2 x 2 combinations of high and low of three measures) with 8 to 18 vehicles in each category. Other measures were considered for classifying the vehicles, but these three measures produced the most even distribution of categories.

To select 20 vehicles for the vehicle/child restraint interaction assessments, two or three were chosen from each of the eight groupings while trying to obtain a variety of vehicle manufacturers and vehicle types. In addition, efforts were made to ensure that a range of quartiles were represented for other key variables in addition to the three main measures, and only 2011 vehicles were included. Table 3 lists the vehicles selected for evaluation. The column marked “grouping” indicates whether each vehicle was in the high (H) or low (L) category of clearance angle, tether wrap distance, and angle from estimated H-point to bight.

The twelve vehicles selected for subject testing (described in section II.C.2) were also used to evaluate the NHTSA vehicle/child restraint fit procedure.

Table 3. Vehicles selected for assessing ISO vehicle/child restraint interaction

CODE	Make	Model	IIHS Size	IIHS Class	Grouping	Clearance	Tether Wrap Distance	Angle To H-Pt
V010	Dodge	Grand Caravan	Very Large	Minivan	HHH	Q4	Q4	Q4
V014	Jeep	Liberty	Mid-size	SUV	HLH	Q4	Q2	Q3
V022	Ford	Explorer	Mid-size	SUV	HHL	Q3	Q4	Q2
V023	Ford	F 150	Large	Pickup	HLL	Q4	Q2	Q1
V027	Ford	Focus	Small	2 Door	HLH	Q3	Q1	Q4
V030	Ford	Taurus	Large	4 Door	LLL	Q1	Q2	Q2
V041	Chevrolet	Impala	Large	4 Door	LLH	Q1	Q2	Q3
V044	Chevrolet	Silverado	Large	Pickup	LLH	Q1	Q2	Q4
V047	Chevrolet	Tahoe	Large	SUV	HHH	Q4	Q4	Q3
V052	Honda	Accord	Mid-size	2 Door	LLL	Q1	Q1	Q1
V058	Honda	Odyssey	Very Large	Minivan	LHL	Q1	Q4	Q2
V059	Honda	Pilot	Mid-size	SUV	HHL	Q4	Q3	Q2
V064	Hyundai	Sonata	Mid-size	4 Door	LLL	Q1	Q1	Q2
V067	Kia	Soul	Small	Station Wagon	HLL	Q4	Q2	Q1
V070	Mazda	3	Small	4 Door	HLH	Q4	Q1	Q3
V075	Mitsubishi	Lancer	Small	4 Door	HLL	Q4	Q1	Q1
V080	Nissan	Versa	Small	4 Door	LHL	Q1	Q4	Q2
V085	Subaru	Outback	Mid-size	Station Wagon	LHL	Q1	Q3	Q1
V098	Toyota	RAV4	Small	SUV	LHH	Q2	Q4	Q3
V099	Toyota	Sienna	Very Large	Minivan	LHH	Q2	Q4	Q3

C. Volunteer Testing

1. Study Design

Thirty-six subjects were recruited to participate in the volunteer testing. The main criterion for subjects was that they were currently transporting a child in a child restraint in their vehicle. The subjects were divided into four groups, with each group testing three vehicles and four child restraint configurations (infant seat, rear-facing convertible, forward-facing convertible, and combination seat). During the three-hour test window, subjects were directed to perform installations in the left second-row position using LATCH or using the seatbelt. Seatbelt installations were included partly to document tether use with seatbelt installations and partly to serve as a control group for the LATCH installations

The test matrix is shown in Table 4 for one subject group testing vehicles A, B, and C. The letters designate different vehicles, while the numbers designate different child restraints. The 4th and 8th installations are performed with a seatbelt, while the remaining installations are performed with LATCH. The experimental design is a split plot design, with all possible combinations covered across subjects. Every set of three subjects sees all 12 combinations in the first four trials and all 12 combinations in the last four trials. The design allows estimation of key main effects within subjects, while some interactions are assessed between subjects.

Table 4. Example test matrix for one subject group.

Subject	TRIAL							
	1	2	3	4	5	6	7	8
1	A1	B2	C4	**B3**	A2	B3	C1	**B4**
2	C2	A3	B1	**A4**	C3	A4	B2	**A1**
3	B4	C1	A2	**C3**	B1	C2	A3	**C4**
4	A2	B3	C1	**B4**	A3	B4	C2	**B1**
5	C3	A4	B2	**A1**	C4	A1	B3	**A2**
6	B1	C2	A3	**C4**	B2	C3	A4	**C1**
7	A3	B4	C2	**B1**	A1	B2	C4	**B3**
8	C4	A1	B3	**A2**	C2	A3	B1	**A4**
9	B2	C3	A4	**C1**	B4	C1	A2	**C3**

Bold text indicates a seatbelt installation, letters refer to vehicles, numbers refer to child restraints

2. Selection of Vehicles and Child Restraints

The child restraints were to include one infant restraint, one convertible restraint, and one combination restraint; the Clek was not considered for subject testing because it could only be used as a booster. The goal was to choose three child restraints and twelve vehicles that provide a broad range of ISO vehicle/child restraint interaction ratings so we could determine if this rating was associated with volunteer performance. The Alpha Omega was chosen as the convertible restraint because of all the restraints tested in vehicles, it most frequently had the worst vehicle/child restraint interaction rating of all products. For the infant restraints, the Key Fit usually had a rating 12 percentage points higher than the SnugRide, but either would be acceptable choices because they had the highest interaction ratings compared to all products. The interaction ratings for the Frontier and Maestro were similar across vehicles, and the dimensions of these child restraints are fairly similar to each other and different from the Alpha Omega when used forward-facing, so either of these combination child restraints was also an acceptable choice for the combination category.

The other requirement was to have at least one product with push-on anchors and at least one with hook-on anchors. Since the Alpha Omega has hook-on anchors, one of the other restraints must have push-on anchors. Three different sets of child restraints were considered, and different sets of vehicles for each set of child restraints were proposed that provide a range of interaction and vehicle ratings. The three sets of child restraints were:

1) Alpha Omega, SnugRide, Frontier
2) Alpha Omega, KeyFit30, Maestro
3) Alpha Omega, KeyFit30, Frontier

Table 5 shows the vehicles that were considered for testing with each of these sets of child restraints, with those that would be selected for each set indicated by "Y". Twelve vehicles were selected for each set of child restraints that provide a range of child-restraint-to-vehicle interaction levels and vehicle LATCH features. For each set of child restraints, the range of interaction scores is listed, as well as a composite score for interaction ratings within each vehicle calculated by summing the interaction scores for each vehicle. The goal was to select vehicles with a range of composite interaction scores, a range of SAE grades, and a range of vehicle types. So that the vehicle types represented the distribution of the 98 measured vehicles, the goal was to include one pickup, one station wagon, two minivans, at least one two-door vehicle, at least 2 SUVs, and at least 3 4-door vehicles. All three proposed sets of 12 vehicles provide a range of vehicle/child restraint interactions that are reflective of those seen among all 20 vehicles used for testing vehicle/restraint interactions. Based on all these considerations, the Alpha Omega, KeyFit, and Maestro were selected the subject testing. The group number next to the vehicle name indicates the vehicles that were selected and which vehicles were evaluated by the four groups of subjects.

Table 5. ISO vehicle/child restraint interaction scores for proposed vehicles and each group of three child restraints

		CRS group		AO/SR/F			AO/KF/M			AO/KF/F		
Vehicle	Group	Vehicle Type	SAE Grade	Range	Sum	Choose?	Range	Sum	Choose?	Range	Sum	Choose?
2011 Chevrolet Impala	3	Large 4 door	60%	33-63	208	Y	33-75	224	Y	33-75	219	Y
2011 Chevrolet Silverado		Large pickup	50%	57-74	247		56-86	256		57-86	258	
2011 Chevrolet Tahoe	4	Large SUV	60%	63-74	275	Y	63-86	285	Y	63-86	287	Y
2011 Dodge Grand Caravan	2	Very Large Minivan	50%	58-74	263	Y	58-86	282	Y	58-86	275	Y
2011 Ford Explorer	3	Mid-size SUV	40%	43-74	255		43-86	246	Y	43-86	267	
2011 Ford F150 SuperCab	4	Large Pickup	45%	50-74	237	Y	49-86	243	Y	50-86	248	Y
2011 Ford Focus		Small 2 door	70%	43-74	253		43-86	262		43-86	265	Y
2011 Ford Taurus	1	Large 4 door	80%	33-67	210		33-79	233	Y	33-79	222	
2011 Honda Accord 2 dr		Mid-size 2 door	80%	61-74	267	Y	63-86	287		61-86	279	Y
2011 Honda Odyssey		Very Large Minivan	60%	58-74	249	Y	58-86	262		58-86	261	
2011 Honda Pilot		Mid-size SUV	90%	48-60	210	Y	48-75	233		48-75	226	Y
2011 Hyundai Sonata	1	Mid-size 4-door	70%	48-74	255	Y	48-86	272	Y	48-86	267	Y
2011 Jeep Liberty		Mid-size SUV	70%	63-70	261		63-86	283		59-86	277	
2011 Kia Soul	2	Small station Wagon	90%	53-67	236		53-79	250	Y	53-79	247	Y
2011 Mazda 3	4	Small 4-door	80%	33-63	214	Y	33-79	227	Y	33-79	230	Y
2011 Mitsubishi Lancer	3	Small 4-door	100%	48-73	259	Y	48-86	272	Y	48-86	272	
2011 Nissan Versa	2	Small 4-door	70%	43-74	230		43-86	240	Y	43-86	242	
2011 Subaru Outback		Mid-size station wagon	80%	43-74	253	Y	43-86	262		43-86	265	
2011 Toyota Rav4		Small SUV	80%	48-74	231	Y	38-86	233		51-86	243	Y
2011 Toyota Sienna	1	Very Large Minivan	50%	47-63	214		43-68	215	Y	47-68	219	Y

3. Test Protocol

The testing scripts and forms are found in Appendices F through H. The subject was directed to install a particular child restraint in the 2L seating position using LATCH or using the seatbelt (Appendix F). After the subject completed the installation, the experimenter evaluated the quality of the installation (Appendix G). At the same time, the subject filled out a questionnaire regarding the experience (Appendix H). The process was repeated for up to 8 trials. At the end of the trials, the subject filled out a subject information form and an overall evaluation (Appendix I).

The six-month-old CRABI anthropomorphic test device (ATD, or crash test dummy) was used in installations with the infant seat, while the 18-month-old CRABI ATD was used for installations in the rear-facing convertible seat. Dummies were used in the rear-facing installations because they can affect the installation angle, which is a key installation outcome for rear-facing child restraints. However, to save time and increase the amount of child restraint installation data collected in the study, the dummies were not used in forward-facing installations where the occupant weight has less affect on installation and installation angle is not a key installation outcome. In all cases with dummy use, the harness straps were adjusted to accommodate the dummy ahead of time.

For the vehicle setup, head restraints were initially positioned in the lowest position. Adjustable seatbacks were placed near the design seatback angle. The front seats were adjusted to the mid-track position with the seatback two notches rearward of full upright.

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 and measuring the height of the loop. 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.

4. Analysis

Because the focus was installing the child restraint in the vehicle, factors related to securing the child were not assessed. For this study, child restraint installations were considered completely correct if they met the following criteria:

1) Tight installation – Child restraint installations were considered tight if the restraint did not move more than 1 inch laterally or fore/aft when tested with a moderate pull/push applied at the restraint belt path.
2) Correct use of lower anchors (if applicable) – Lower anchors were correctly used if the child restraint connectors were fully engaged with the correct vehicle hardware in the correct orientation and the LATCH belt webbing was flat.
3) Correct use of seatbelt (if applicable) – The seat belt was correctly used if it was routed through the correct belt path, was not twisted, and was buckled and locked correctly.
4) Correct use of tether anchor (if applicable) – Tether anchors were correctly used if the tether was attached to the correct vehicle hardware in the correct orientation, routed around the head

restraint as directed by the vehicle manual, and tightened so that there was 10 mm or less of slack (measured by pinching the slack and measuring the height of the loop).

5) Correct installation angle – Installation angle was considered correct for rear-facing installations if the restraint indicator was at the correct level and considered correct for forward-facing installations if the recline foot was in the forward-facing position.

Mixed-models logistic regression was used to identify potential predictors of tight installation, correct use of lower anchors or seat belt, correct use of tether anchor, and completely correct installation (meeting all applicable criteria above). Potential predictor variables included the following, where italics indicate continuous measures were used:

1) Subject variables: gender, *age*, education (high school graduate or less, some college, college graduate, post-graduate), LATCH experience (yes/no)
2) Experimental variables: child restraint model, vehicle make and model, vehicle type, trial number, installation orientation (rear-facing or forward-facing), installation method (seat belt or LATCH)
3) Lower anchor characteristics: *attachment force*, *clearance angle*, visibility (yes/no), labeling (yes/no), depth within bight (0-2, 2-4, 4-6 cm),
4) Tether anchor characteristics: *wrap-around distance*, general location (such as seatback or package shelf), labeling (yes/no), head restraint routing directions (under, over, around, remove)
5) Vehicle seat characteristics: *size/presence of bightline waterfall (*a bolster cushion located directly behind the seated pelvis location that places the lower anchors above the seating surface), *distance to base of head restraint from estimated H-point, angle from estimated H-point to bight*

The regression models were performed using SAS 9.2 PROC GLIMMIX. Each model was used to predict the probability of correct installation and random effects were used to account for the within-subject elements of the experimental design. For some key predictors, preliminary categorical analysis was conducted first, followed by use of continuous variables to identify thresholds corresponding to 50% levels of correct use.

III. Results

A. Vehicle Survey

1. Vehicles Measured

A total of 98 vehicles were measured in the LATCH hardware survey as listed in Appendix A. Eighty-eight of the vehicles were 2011 model year, while 10 were 2010 model year. The distribution of the vehicles measured according to IIHS vehicle class and size is shown in Figure 15. A range of vehicle sizes within each class was measured. Twenty-one of the vehicles had a third row of seating, and two of these vehicles had only two seating positions in the third row. Five vehicles had only two seating positions in the second row.

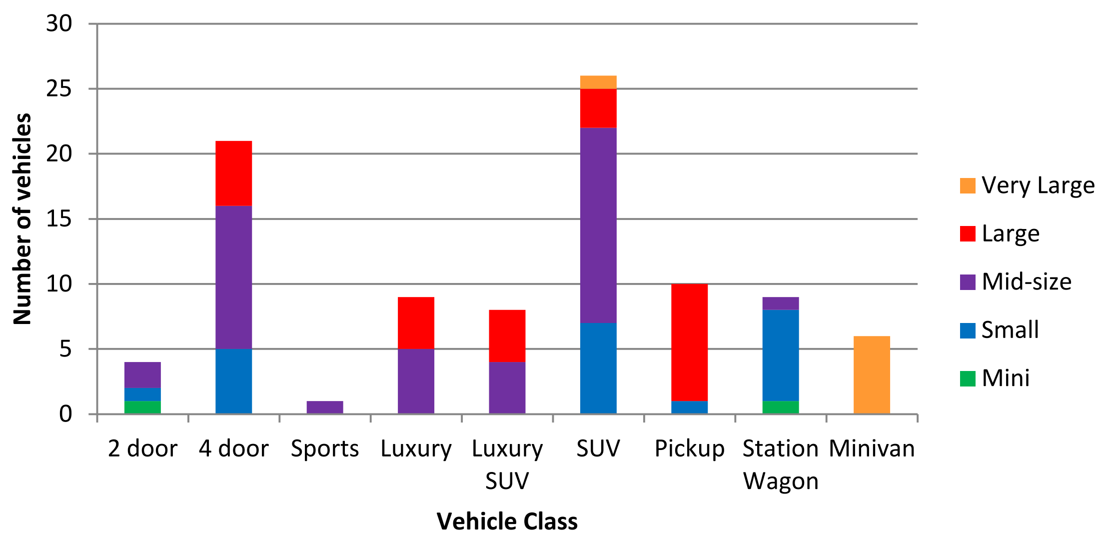

Figure 15. Distribution of vehicles measured by vehicle class and size.

2. LATCH Locations

Table 6 summarizes the seating positions with LATCH hardware. Only 16 vehicles had more than the minimum number of lower anchors. Only seven vehicles were equipped with three sets of LATCH anchors in the second row: Acura MDS, Chevrolet Impala, Chevrolet Malibu, Chrysler 300, Dodge Charger, Honda Odyssey, and Honda Pilot. Of the 21 vehicles with third rows, two vehicles had two positions with lower anchors in the third row and eight vehicles had one set of lower anchors in the third row. The most common combination of second-row LATCH hardware, seen in 89 vehicles, consisted of lower anchors in the two outboard positions and tethers in all available second-row seating positions. The most common 3rd row LATCH hardware installation was one set of lower anchors and tether anchor. For the 21 vehicles with third rows, four vehicles had no tether anchors in the third row, while 11 had no lower anchors. Only two vehicles had tether anchors in 3 seating positions of the third row.

Table 6. Summary of seating positions with LATCH hardware.

Vehicle rows	
Two	77
Three	21
Lower anchor availability	
2 seating positions	82
3 or more seating positions	16
Top tether availability	
2 seating positions	4
3 seating positions	84
4 or more seating positions	10

3. Anchor Geometry

Lateral locations of the lower anchors and the belt hardware were measured. Figure 16 shows how the lateral locations of the hardware were marked with measuring tape (lower anchors) and strings (belt anchors) and a coding method used in the subsequent graph to illustrate the geometry. Lower anchors are depicted by triangles, belt buckles by squares, and belt webbing by circles. Blue indicates right outboard lower anchors, red indicates left outboard lower anchors, and yellow indicates center position lower anchors. Orange, purple, and green indicate the right, center, and left belt anchor locations, respectively. A sample of the measured data for 20 vehicles is shown in Figure 17. The vehicles are divided into three groupings (with blue horizontal lines) based on the smallest distance between the lower anchors in the 2L seating position and the closest seatbelt hardware. Usually comparing the orange square and closest blue triangle, the vehicles on the bottom have seatbelt hardware very close to at least one of the 2L lower anchors, and receive a poor rating in terms of potential interference from the seatbelt. The vehicles in the center section receive a fair rating, while those on the top receive a good rating.

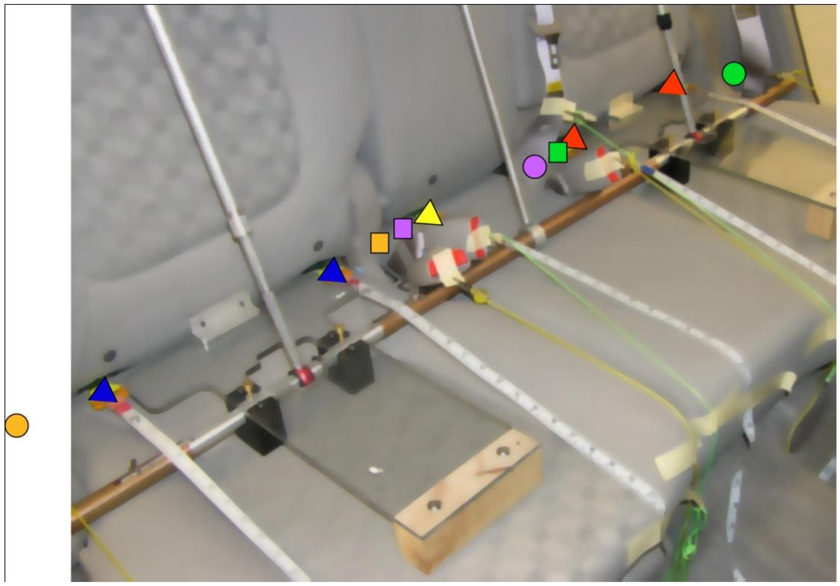

Figure 16. Illustration of anchor hardware measured and symbols used in subsequent plots.

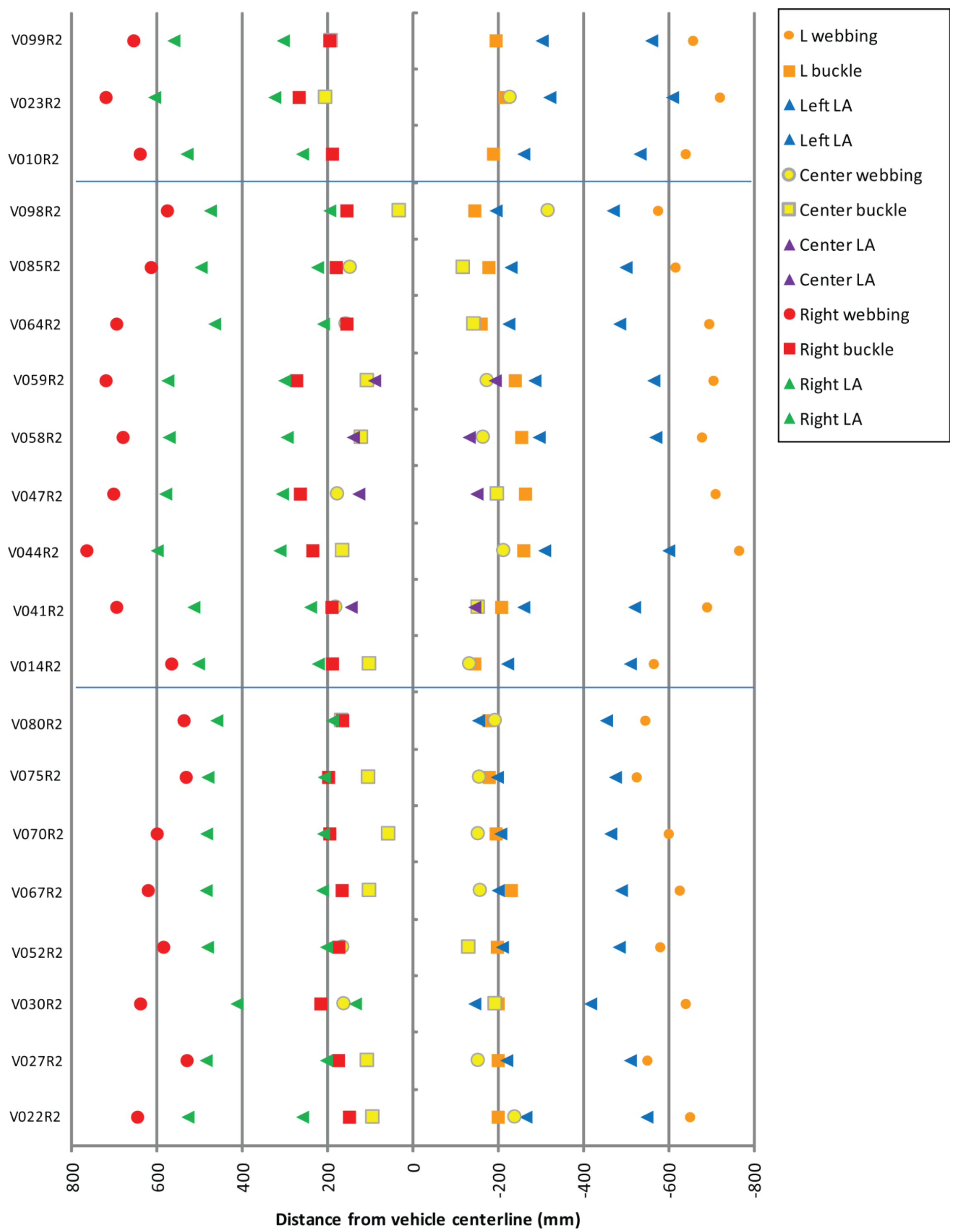

Figure 17. Lateral locations of lower anchors, seatbelt webbing, and seatbelt buckles. LA=lower anchor

4. Seat Geometry

43 vehicles had bightline waterfall, with examples shown in Figure 18. The bight can be located at the top or bottom of this seating feature. As described in the methods, the distance and angle to the bight and seating surface were measured for these seats. In vehicles without a bightline waterfall, the distance to the bight and the seating surface are the same. Figure 19 shows the differences between the two types of measurements.

Figure 18. Different types of bightline waterfalls.

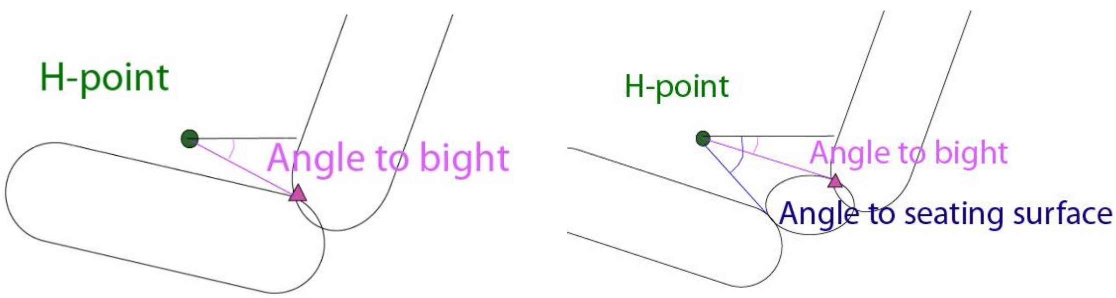

Figure 19. Illustration of angle to bight and angle to seating surface (when different).

Table 7 summarizes the results of the bight and seating surface measurements, while Figure 20 shows the relationship between the measured angles and distances. There is less variation in the distance compared to the angle for the bight location, as well as the seating surface location. In the 43 vehicles with a measurable difference between the location of the bight and the seating surface, the average distance to the bight is 161 mm and average angle is 17.5°, indicating that the seating surface is usually 15.5° degrees lower than the bight (relative to the estimated H-point) and 28 mm closer to the H-point.

Table 7. Location of bight and seating surface relative to estimated H-point for 2L seating position.

	N	Measure	Mean	Std	Min	Max	Q1	Q2	Q3
Bight	98	Distance (mm)	158	16	139	255	149	155	164
		Angle (deg)	23	8	0	37	18.4	24.9	28.7
Seating Surface	43	Distance (mm)	133	10	114	165	126	134	137
		(Angle)	33	11	-16	47	29.5	35.4	38.7

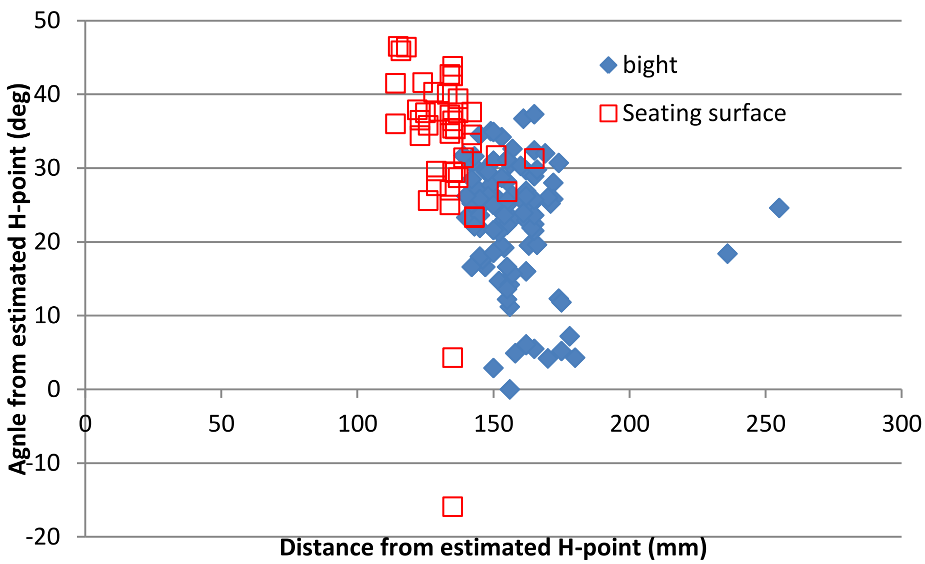

Figure 20. Angle vs. distance from estimated H-point to bight and seating surface (when different).

The child restraint fixture could not attach to the lower anchors in 27 vehicles, even when the sides of the fixture were removed and reattached in the rear seat to allow easier installation into the rear seat of the vehicle. Appendix J lists the vehicles and seating positions in which the fixture could not be attached. Reasons include low roof, a short fore-aft depth of the rear seat, a vehicle seat width narrower than the fixture, lower anchors that were too deep in the seat cushion, excessive seat stiffness or interference with the seatback contour, seat cushion contour, rigid buckles, and plastic trim around the lower anchors.

The lateral angle and pitch angle measured with the fixture are listed in Table 8. In ten vehicles, the fixture could not be placed in the 2L seating position to document lateral angle; in 28 vehicles, the fixture could not be attached to the lower anchors to measure pitch angle in the 2L seating position. One vehicle exceeded the lateral angle requirement of 5 degrees, while 10% (n=7) exceeded the maximum recommended pitch angle of 20 degrees.

Table 8. Child restraint fixture lateral and pitch angle measurements in 2L position.

	N	Mean	Std	Min	Max	Q1	Q2	Q3
Lateral angle	88	1.54	1.23	0	5.2	0.58	1.30	2.23
Pitch angle	70	14.9	3.5	6.3	22.2	12.5	14.8	17.5

Measurements characterizing the head restraint are illustrated in Figure 21 and summarized in Table 9. The intent of these two measures was to document how much the head restraint protrudes. On average, the tangent to the head restraint is 108 mm above the base of the head restraint. The difference between the tangent and base angles was calculated to quantify how much the head restraint protrudes forward. The average difference in all vehicles is 7 degrees, with a range from 2.3 to 15.1 degrees. The difference in angle vs. the difference in distance between the head restraint tangent and base is shown in Figure 22. Taller head restraints (greater difference between tangent and base distance) usually protrude more than shorter head restraints.

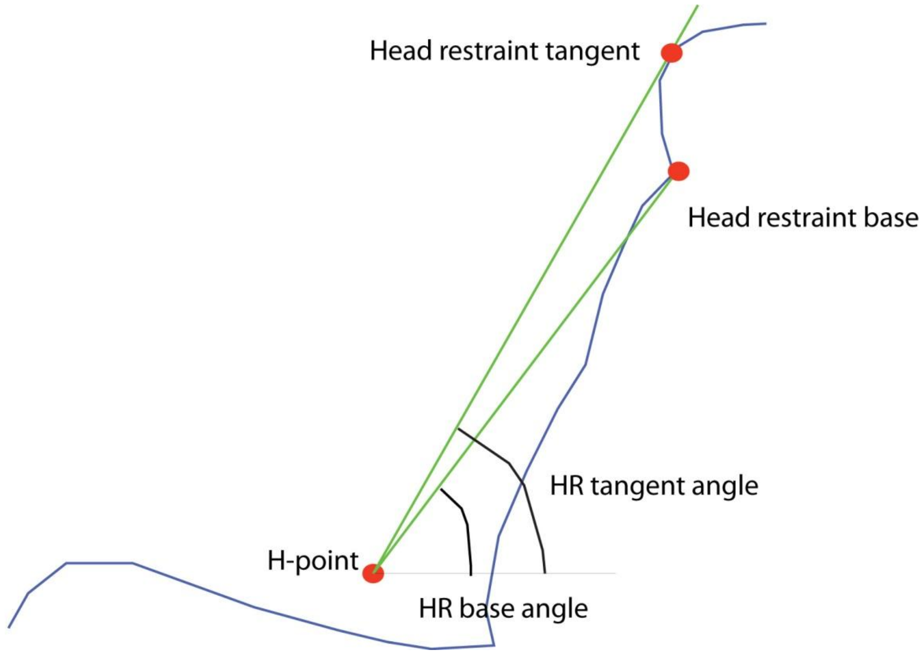

Figure 21. Illustration of head restraint measurements.

Table 9. Summary of measurements characterizing head restraint geometry.

	Measure	Mean	Std	Min	Max	Q1	Q2	Q3
Base of head restraint	Distance (mm)	633	44.4	520	710	605	638	666
	Angle (deg)	32	3.3	19.4	40.7	30.7	32.8	34.6
Tangent of head restraint	Distance (mm)	741	39.7	615	820	725	742	770
	Angle (deg)	26	3.6	9.9	34.6	24.3	26.1	27.6
Difference between tangent and base	Distance (mm)	108	35.5	60	220	79	101	133
	Angle (deg)	7	2.3	2.3	15.1	5.1	6.7	8.3

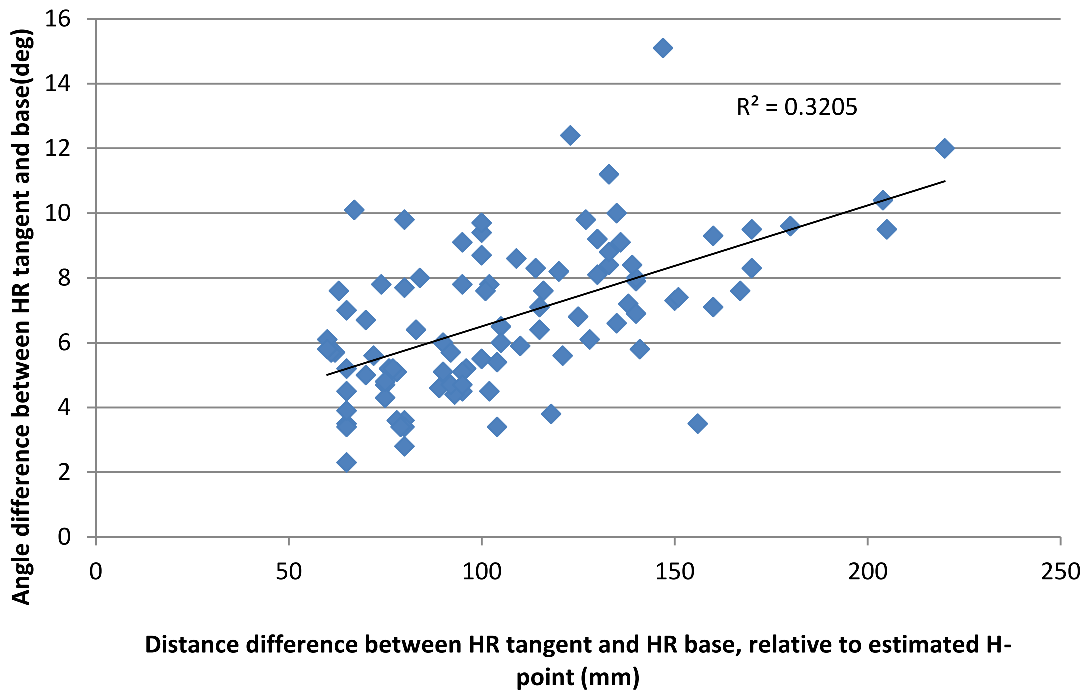

Figure 22. Difference in angle vs. difference in distance between head restraint tangent and head restraint base, measured relative to estimated H-point.

5. Lower Anchor Measurements

A summary of the lower anchor measurements is in Figure 23. For the peak force, the larger measure from the left or right anchor of the 2L seating position was used. For the clearance angle, the smaller of the two values was selected. Fifty-nine vehicles met the SAE specification for an attachment force of 75 N (16.9 lbf) or below. Seventeen vehicles had attachment forces from 30 to 150 lbf, or 2 to 8 times higher than recommended. A modification was made to the SAE protocol for measuring lower anchor attachment force so that the force was measured at the angle producing the lowest force value. The SAE recommended practice calls for approaching the lower anchor at an angle near zero degrees, which is not possible in most vehicles. The average approach angle was 27.6 degrees, with a range from 13.2 to 44.9. Only two vehicles met the SAE recommended clearance angle of 75 degrees. Almost one-third of vehicles have less than 50 degrees of clearance.

Figure 23. Summary of lower anchor measurements.

	N	Mean	Min	Max	Q1	Q2	Q3
Force	96	21.4	1.4	144.3	10.1	13.8	21.6
Force approach angle	96	27.6	13.2	44.9	23.1	26.8	31.7
Clearance angle	93	55.2	21.2	83.6	46.6	57.0	64.7

The clearance angle could not be measured for nine vehicles in the 2L position because the tool could not be attached for the reasons indicated below:

- BMW 328: Seatbelt buckle interfered
- BMW Mini: access hole around lower anchor too narrow for clearance angle tool
- Chrysler 300: outboard anchors deep and high
- Mercedes C300: could not get covers off outboard lower anchors
- Mercedes GL450: plastic around lower anchors
- Mercedes ML350: plastic around lower anchors
- Nissan Sentra: right lower anchor in position 2L, material behind Lower anchor
- Jaguar XF: slits too narrow for tool
- Volkswagen Routan: leather behind lower anchor

To identify whether there was a correlation between clearance angle and attachment force, the two measures were plotted against each other, as shown in Figure 24. Most of the vehicles with clearance above 70 degrees have forces less than 10 lbf, and the vehicle with the lowest clearance angle also has an excessive force (Chevrolet Impala). While the R^2 value for the data is 0.1699, there is a wide range of angles (~25 to 85°) for vehicles with forces less than 25 lbf.

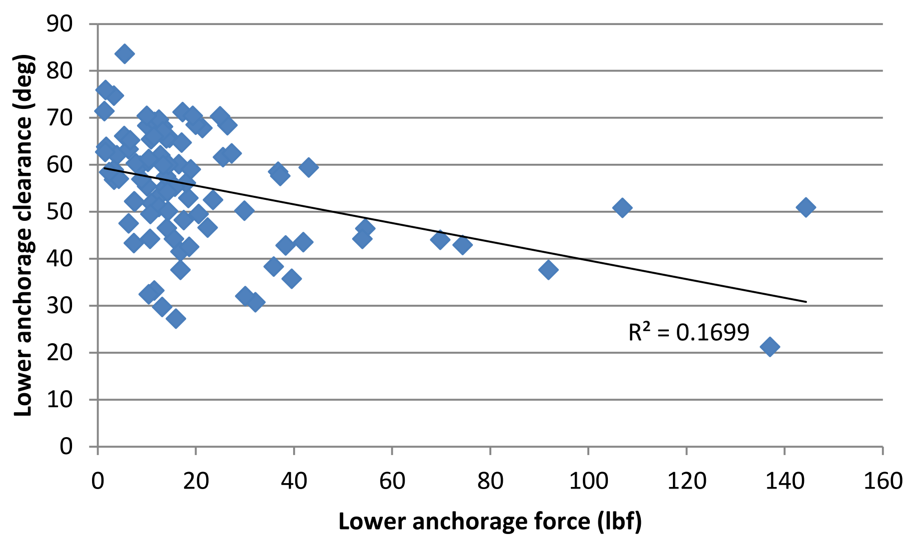

Figure 24. Lower anchor clearance angle vs. lower anchor force.

Appendix K contains descriptions of and illustrations of the lower anchors where there is potential for contact between a rigid vehicle seat component and a lower connector. Vehicles with extremely stiff seat components (though not completely rigid) near the lower anchors are also listed.

The distribution of vehicles according to the depth of the lower anchors is shown in Figure 25. Blue corresponds to a less than 2 cm depth, green 2-4 cm, yellow 4-6 cm, and orange 6-8 cm. In 86 vehicles, the left and right lower anchors in the 2L position had the same depth relative to the bight, indicated by the bars labeled BB, GG, YY, or OO. However, in 13 vehicles, the left and right lower anchors were at different depths relative to the bight (BG, BY, GY, OY).

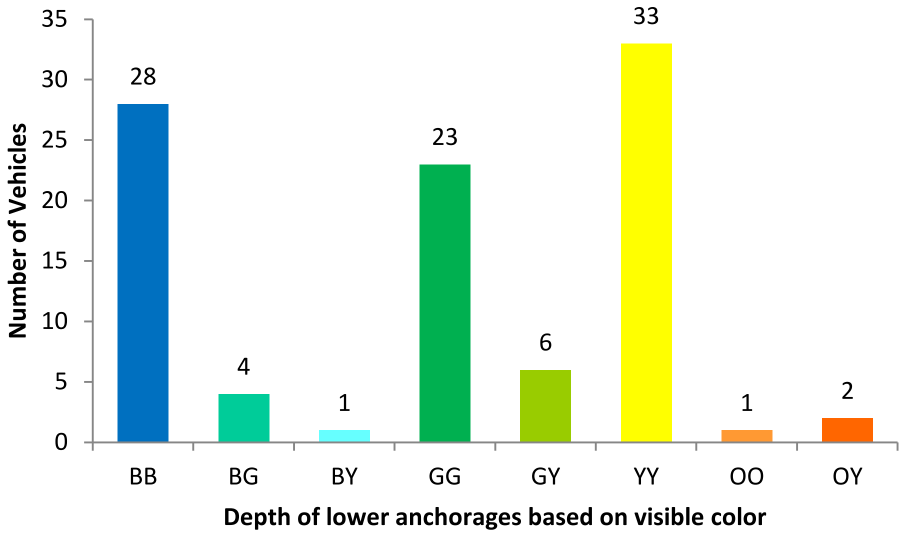

Figure 25. Distribution of vehicles by depth of lower anchors.

Almost all of the vehicles were able to pass the collinearity requirement using the SAE tool. Two vehicles did not pass, and in another the tool could not reach the lower anchors to perform the assessment.

Lower anchors were visible in 36 of the 98 vehicles. 16 vehicles had lower anchors with some type of covering in the 2L position. Examples of different types are shown in Figure 26. Four vehicles use slits, 5 vehicles have doors, and 6 vehicles use some type of flap.

Figure 26. Types of lower anchor coverings: slit, door, flap (open and shut).

Figure 27 illustrates both the types of lower anchor markings used and the methods used to affix the markings to the vehicle. From left to right, methods of attachment are a tag (n=5), button (n=61), patch (n=1), and imprint (n=9). Twelve vehicles did not mark the lower anchor location, which is allowed because the anchors are visible. The photographs also show how text (n=1) and the ISO symbol (n=74) are used. One vehicle not shown used only a blank button as a marker. Thirty-nine vehicles used a contrasting color from the vehicle seat for the marking, 36 use a matching color, and one vehicle uses different colors (matching and contrasting) for the inboard and outboard in a pair of lower anchors.

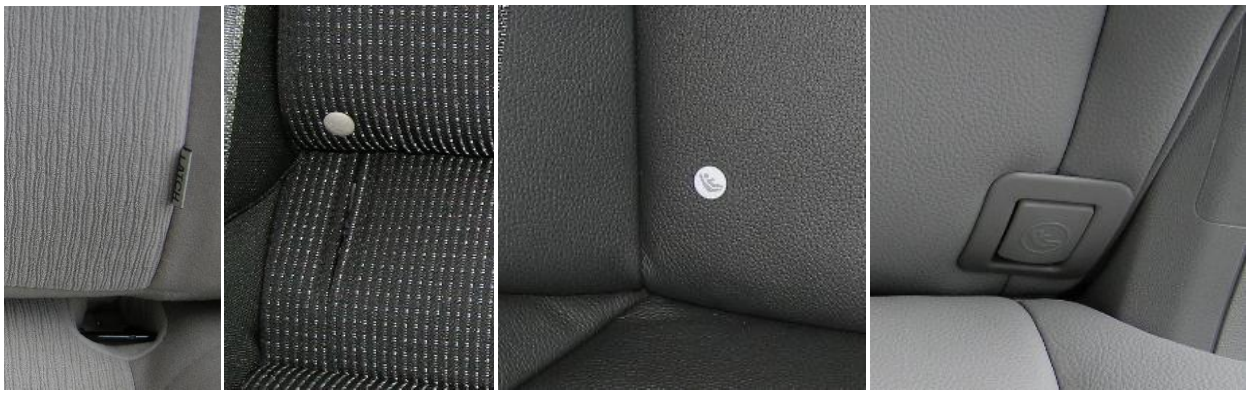

Figure 27. Types of lower anchor markings: tag, button patch, imprint, illustrating use of text and ISO symbol (right three) as markings.

6. Tether Anchor Measurements

Tether anchors in the 2L position were most often located on the seatback (42 vehicles) or package shelf (35 vehicles). Some of the more unusual tether locations are shown in Figure 28. The 3 vehicles with roof-mounted tether anchors were small SUVs or station wagons. Eight of the 10 pickup trucks mounted the tether anchor on the back wall of the passenger cab. One exception to this location among the pickup trucks was the Toyota Tacoma, pictured on the lower left, which used a tether routing device located under the 2L head restraint to redirect the tether hook to an anchor located inboard of the seating position. The last pickup used a seatback-mounted tether. Five vehicles had tether anchors mounted to the floor, and 4 located them underneath the vehicle seat.

Figure 28. Tether locations on the roof, back wall, 2nd row, floor, and under seat.

The main measurement used to quantify tether location was the wrap distance measured relative to the estimated R-point. The mean value of tether wrap distance for this sample was 551 mm (standard deviation 212), with a range from 245 to 1194 mm. The distribution of tether wrap distance by vehicle type is shown in Figure 29. Four-door sedans and luxury sedans were most likely to have shorter distances, while minivans had higher distances. Interestingly, 2-door sedans had tether wrap distances in the lowest and highest categories. SUVs and station wagons had a wide range of tether wrap distances. Pickup trucks were most often in the mid-range, with the exception of one that was in the highest category.

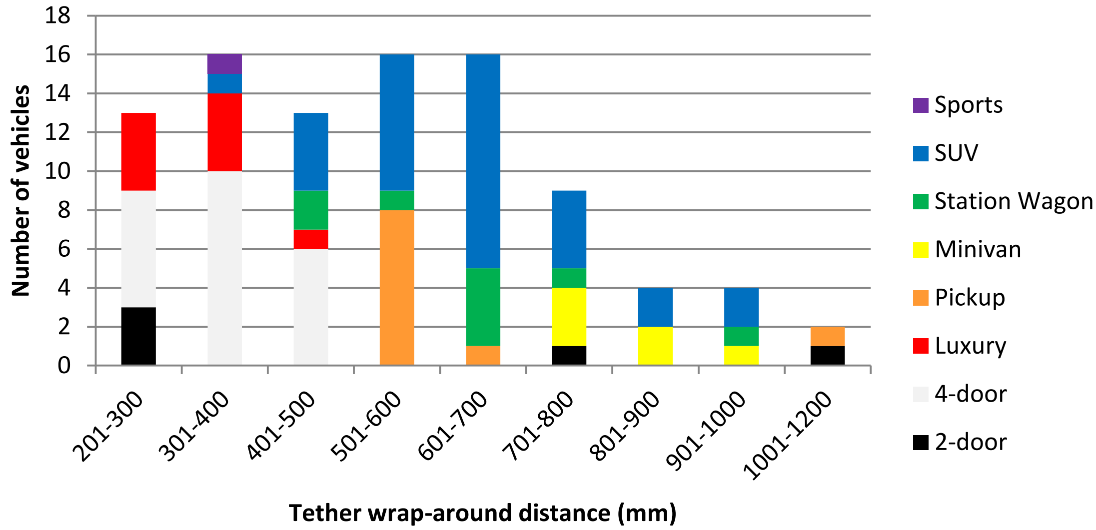

Figure 29. Distribution of tether wrap distance by vehicle type.

Twenty-two vehicles employed a tether routing device that directs the tether in a non-straight line path to the tether anchor, when needed. Examples are illustrated in Figure 30. In two Chevrolet Pickups and two Ford pickups, the tool for checking clearance was unable to pass through the tether routing device.

Figure 30. Examples of tether routing devices.

Twenty-one vehicles positioned the tether anchor for the 2L seating position so it is offset laterally from the centerline of the vehicle seating position. Some of these vehicles use a tether routing device to reroute the tether, while the rest attach the tether so it takes a diagonal path to the anchor within the range allowed by FMVSS 225. For the vehicles with an offset tether anchor in this position, the mean lateral offset from seat centerline value was 137 mm but ranged from 10 to 450 mm. Appendix L shows illustrations of all of the vehicle positions with offset tether anchors.

The tether anchor, or a clearly marked door covering the tether anchor, was visible in 87 vehicles. Sixty-eight of the tether anchors were marked with the ISO tether symbol. With regard to what covers the tether anchor, 42 had no cover, 48 are located behind a door, 5 are under a flap, 2 in a cargo compartment, 1 in a slit, and 1 behind a panel.

The ISO vehicle rating system assesses whether there is hardware that could be potentially confused with a tether anchor. Four of the vehicles (BMW MiniCooper, Honda Pilot, Honda CRV, Porsche Cayenne) have other hooks near the tether anchor shown in Figure 31. The Honda Ridgeline, shown in Figure 32, has the tether anchor for the center seating position located between the two lower LATCH anchors. For the outboard seating positions, the tether anchors are located on the sides of the vehicle seats near the floor. The Toyota Tacoma (Figure 33) uses a tether routing device to redirect the tether for the 2L seating position to an anchor located inboard of the seating position.

Figure 31. Confusing tether hardware in the BMW Minicooper, Honda Pilot, Honda CRV, and Porsche Cayennne.

Figure 32. Honda Ridgeline tether anchor locations for center seating position (left) and outboard seating positions (right, yellow tape indicating path of tether to anchor).

Figure 33. Toyota Tacoma tether anchor configuration for 2L position. The yellow tape traces the intended tether path.

7. Vehicle Manual Specifications

Ninety-five vehicle owner's manuals were reviewed considering a variety of topics. Manuals for the VW Routan, Mitsubishi Eclipse, and Audi A4 Quattro were not available online or from the dealer. The number of pages dedicated to child restraints ranges from 2 to 29 with a mean value of 15. All of the manuals contain separate sections for performing installations with LATCH or the seatbelt. Seventy-one mention that the tether should also be used with forward-facing seatbelt installations.

Most manuals use the term LATCH. However, Lexus and Mazda indicate that LATCH is sometimes referred to as ISOFIX, the Toyota Camry/Corolla use the term LATCH/ISOFIX, and the Dodge Ram, Honda Ridgeline, Toyota RAV4, and Toyota Tundra use the term ISOFIX.

Only one manufacturer, Ford, includes occupant weight limits for LATCH use in the manual. The table shown in Figure 34 is included in most Ford manuals to describe alternative methods for installing child restraints. Ford specifies a lower anchor limit of 48 lb with LATCH, but allows use above 48 pounds of LATCH and seatbelt together or the seatbelt and top tether together.

Recommendations for attaching child safety restraints for children

Restraint Type	Child Weight	Use any attachment method as indicated below by "X"				
		LATCH (lower anchors and top tether anchor)	LATCH (lower anchors only)	Safety belt and top tether anchor	Safety belt and LATCH (lower anchors and top tether anchor)	Safety belt only
Rear facing child seat	Up to 48 lb (21 kg)		X			X
Forward facing child seat	Up to 48 lb (21 kg)	X		X	X	
Forward facing child seat	Over 48 lb (21 kg)			X	X	

Figure 34. Typical table included in Ford manuals describing weight limits for LATCH use.

The ISO vehicle assessment protocol evaluates the clarity of the manual instructions in describing the locations of the lower and tether anchors. To obtain a good rating, instructions must include a graphical depiction of anchor locations that can be understood without text. Instructions without graphics receive a poor rating, while average ratings are given to graphics that need text to be understood. Seventy-nine manuals were rated "good", 11 were average, and 4 were poor in their depiction of lower anchors. For tether anchors, the respective numbers were 74, 14, and 6.

The description of how to route the tether was unclear for four vehicles; this is another item rated by ISO. The manuals were reviewed for directions about positioning the head restraint and routing the tether. The most common specification, found in 59 manuals, is to route the tether under the head restraint, but the up/down position of the head restraint is never specified. It is unclear whether the head restraint is to be raised to route the tether underneath and remain in the upright position, or returned to its lowest position. The remaining combinations of directions regarding head restraint position and tether routing are shown in Figure 35.

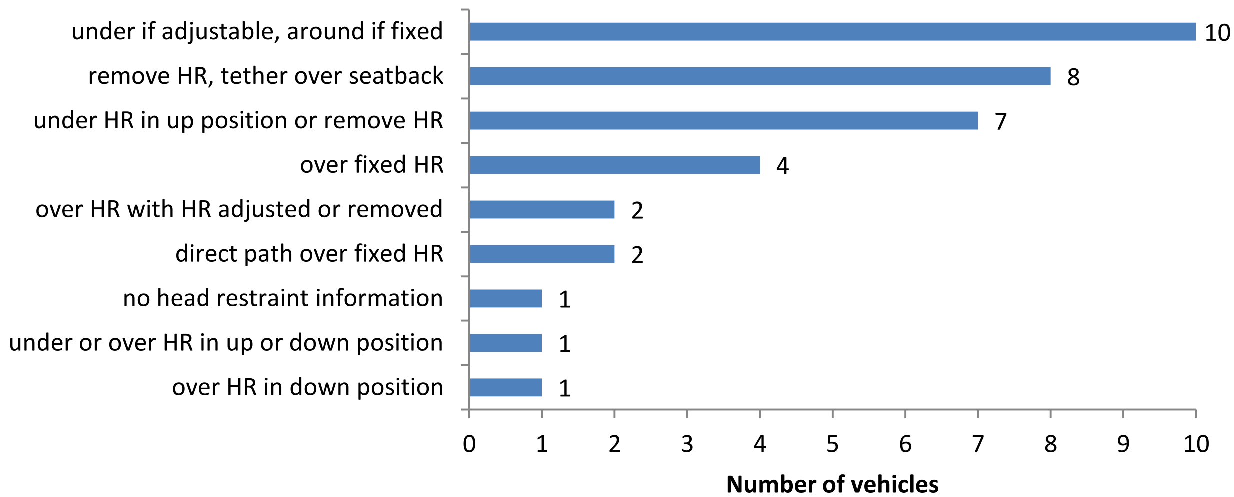

Figure 35. Directions regarding head restraint position and tether routing.

None of the manuals explain how to tether a rear-facing child restraint, although four manufacturers mention that some rear-facing child restraints have tethers. Some manufacturers explain that products with single tethers are routed differently from products with V-shaped tethers, but do so inconsistently across makes from a particular manufacturer.

Fifty-four vehicle manuals do not specify the position of the seatback when installing a child restraint. Nine specify that the seatback should be adjusted to a certain position, such as two notches back from most upright. Twenty-nine vehicles specify that child restraints should be installed with the seatback in an upright position.

B. Usability Assessments

1. Vehicle Ratings

The distribution of the overall ISO ratings is shown in Figure 36. The mean rating was 58% (out of a possible 100%), with a range from 41% to 78%. Figure 37 shows the distribution of each factor that is considered in the overall percentage by the number of vehicles rated good, average, or poor.

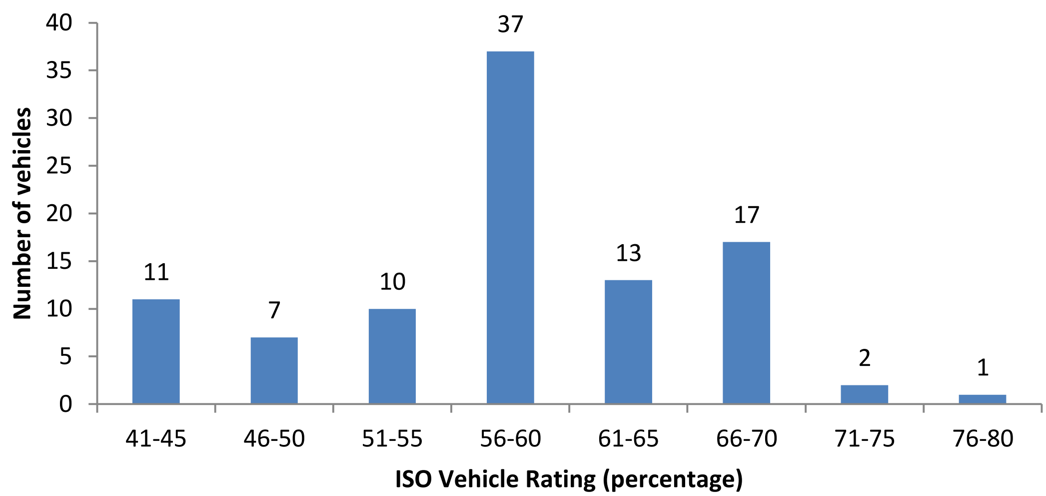

Figure 36. Distribution of ISO vehicle rating factors.

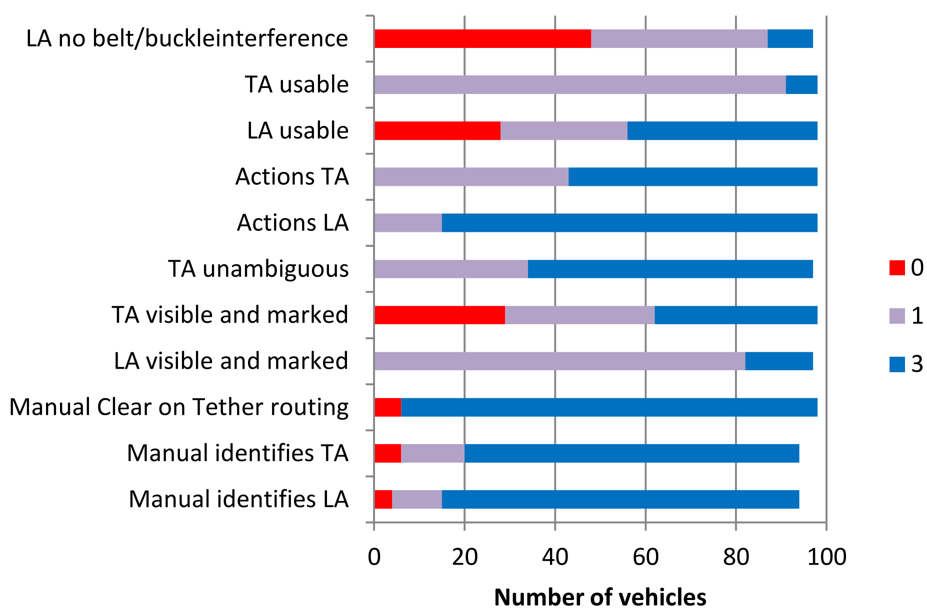

Figure 37. Distribution of vehicles according to score for each component of ISO rating (LA=lower anchor, TA=tether anchor; 0=poor, 1=average, 3=good.)

The distribution of vehicles by the overall grade derived from the SAE scores is shown in Figure 38. Note that the overall SAE grading scheme was developed as part of this study, rather than by SAE. The mean score is 68% (out of 100%), with a range from 20% to 100%. Only one vehicle met all of the SAE draft recommended practices. Four vehicles only met two or three. Figure 39 shows the distribution of how many vehicles met each SAE recommended practice. The majority met the collinearity requirement, had less than 5 degrees of fixture lateral angle, and did not have any rigid structure near the lower anchor. Only two vehicles had the recommended clearance around the lower anchor of 75 degrees. The Z-point depth and pitch angle could not be measured on the vehicles in which the fixture could not be installed.

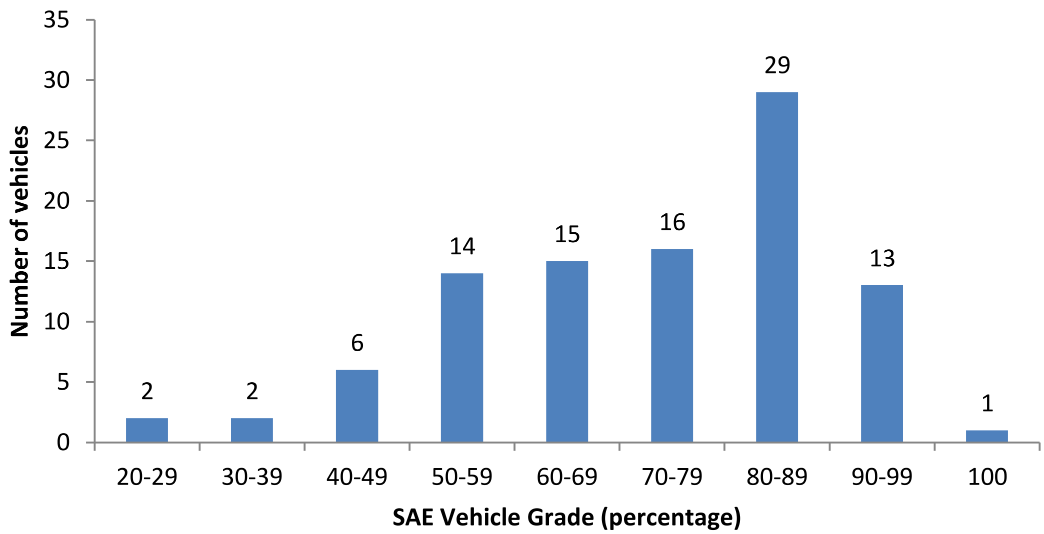

Figure 38. Distribution of vehicles by SAE grade.

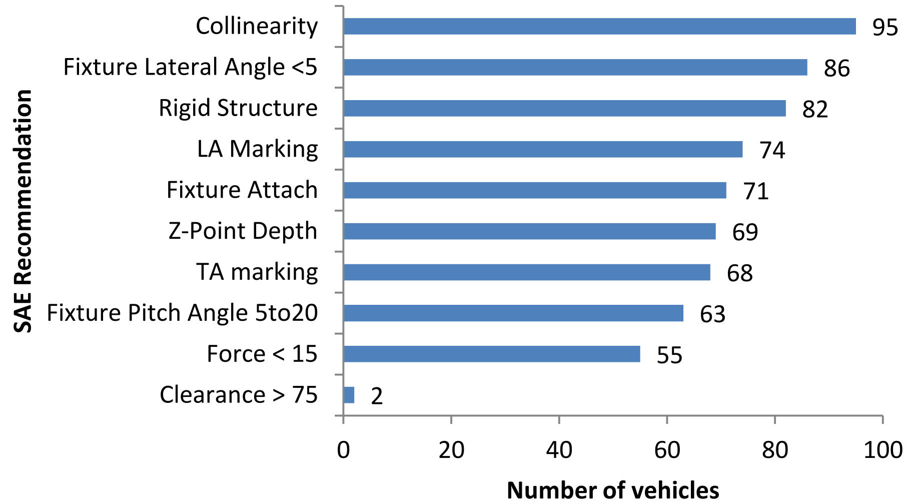

Figure 39. Distribution of vehicles according to how many met each SAE recommendation. (LA=lower anchor, CRF= child restraint fixture).

Figure 40 plots the derived SAE grades and the ISO ratings. The plot uses different symbols for different vehicle types, with most vehicle types spanning the range of scores. Disregarding vehicle type, there is a slight association between ISO ratings and the SAE grade derived in this study, but the relationship is not strong (R^2=.016) These results do not confirm the hypothesis that vehicles meeting the SAE recommendations would achieve higher scores using the ISO rating system. Figure 41 shows the range of ISO and SAE scores for each vehicle type. The range of derived SAE scores is wider than the range of ISO scores for all vehicle types. The ISO scores fall within the range of SAE grades for all vehicle types except pickup trucks and station wagons, where the ISO scores span a lower range than the SAE grades. Thus the relationship between ISO scores and derived SAE grades differs across vehicle type.

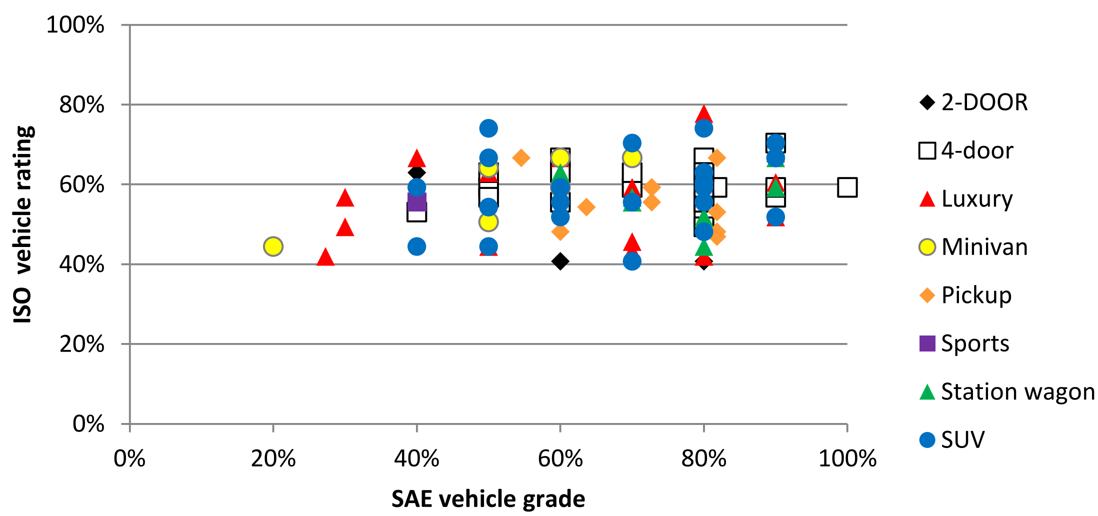

Figure 40. SAE grade vs. ISO vehicle rating.

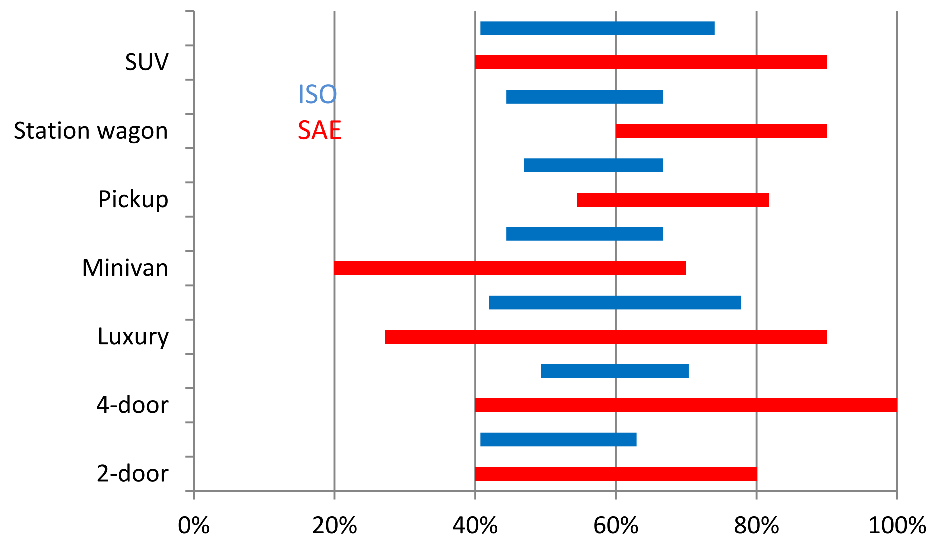

Figure 41. Ranges of SAE grades and ISO vehicle rating across vehicle types.

Figure 10 lists the ISO vehicle ratings and derived SAE grades for the 20 vehicles that were used in the ISO assessment vehicle/child restraint usability. The table is sorted from low to high overall derived SAE grades. The vehicle selection strategy used (based on clearance angle, tether wrap around distance, and H-point to bight angle) resulted in a rather even distribution of SAE grades ranging from 40% to 100%. The ISO ratings were more limited in range from 48% to 78%.

Table 10. Vehicles, types, ISO ratings, and SAE grades.

CODE	Make	Model	IIHS Size	IIHS Class	ISO Rating	SAE Grade
V022	Ford	Explorer	Mid-size	SUV	63%	40%
V023	Ford	F 150	Large	Pickup	59%	45%
V010	Dodge	Grand Caravan	Very Large	Minivan	62%	50%
V044	Chevrolet	Silverado	Large	Pickup	56%	50%
V099	Toyota	Sienna	Very Large	Minivan	64%	50%
V041	Chevrolet	Impala	Large	4 Door	56%	60%
V047	Chevrolet	Tahoe	Large	SUV	59%	60%
V058	Honda	Odyssey	Very Large	Minivan	63%	60%
V014	Jeep	Liberty	Mid-size	SUV	70%	70%
V027	Ford	Focus	Small	2 Door	56%	70%
V064	Hyundai	Sonata	Mid-size	4 Door	56%	70%
V080	Nissan	Versa	Small	4 Door	63%	70%
V030	Ford	Taurus	Large	4 Door	67%	80%
V052	Honda	Accord	Mid-size	2 Door	59%	80%
V070	Mazda	3	Small	4 Door	59%	80%
V085	Subaru	Outback	Mid-size	Station Wagon	48%	80%
V098	Toyota	RAV4	Small	SUV	56%	80%
V059	Honda	Pilot	Mid-size	SUV	67%	90%
V067	Kia	Soul	Small	Station Wagon	78%	90%
V075	Mitsubishi	Lancer	Small	4 Door	59%	100%

2. Child Restraint/Vehicle Interaction

Table 11 summarizes the ISO ratings for each child restraint, vehicle, and child restraint/vehicle interaction, as well as the derived SAE vehicle grade. ISO child restraint ratings range from 36% to 91%, ISO vehicle ratings range from 48% to 78%, derived SAE vehicle ratings range from 40% to 100%, and ISO vehicle/child restraint interaction ratings range from 14% to 86%. If the Clek booster seat, the one seat with rigid LATCH, is not included, the lowest interaction rating is 33%. For all vehicles, the KeyFit30 had the best interaction rating, while the worst interaction rating for each vehicle is highlighted in bold for each vehicle. For 11 of the 20 vehicles, the worst interaction occurred with the Alpha Omega installed rear-facing. However, the forward-facing Truefit, Frontier, and Maestro had the worst interaction score in 1 to 3 vehicles. The two infant restraints, the forward-facing Alpha Omega, and the rear-facing TrueFit never had the worst interaction score in a vehicle. Among the rear-facing restraints, the interaction rating decreased with child restraint rating fairly consistently in almost all vehicles.

However, for the forward-facing restraints, there was no pattern between interaction rating and child restraint rating.

Table 11. Summary of ISO child restraint, vehicle, and vehicle/child restraint interaction ratings.

Vehicle Scores			Child restraint scores								
			91%	84%	40%	36%	65%	60%	54%	50%	92%
	ISO Vehicle Rating	SAE Grade	Key Fit 30	Snugride	RF True Fit	RF Alpha Omega	Frontier	FF Alpha Omega	Maestro	FF TrueFit	Clek booster
2011 Ford Explorer	63%	40%	86%	74%	69%	**43%**	69%	69%	48%	52%	71%
2011 Ford F150 SuperCab	59%	45%	86%	74%	52%	58%	54%	50%	**49%**	67%	71%
2011 Chevrolet Silverado	56%	50%	86%	74%	59%	58%	58%	57%	56%	**52%**	71%
2011 Dodge Grand Caravan	62%	50%	86%	74%	71%	**58%**	62%	69%	69%	67%	71%
2011 Toyota Sienna	64%	50%	68%	63%	59%	47%	48%	57%	**43%**	52%	14%
2011 Chevrolet Impala	56%	60%	75%	63%	59%	**33%**	52%	59%	57%	52%	29%
2011 Chevrolet Tahoe	59%	60%	86%	74%	71%	**63%**	69%	69%	67%	77%	71%
2011 Honda Odyssey	63%	60%	86%	74%	64%	58%	58%	59%	59%	**52%**	71%
2011 Ford Focus	56%	70%	86%	74%	69%	**43%**	69%	67%	67%	52%	71%
2011 Hyundai Sonata	56%	70%	86%	74%	69%	**48%**	62%	71%	67%	52%	71%
2011 Jeep Liberty	70%	70%	86%	70%	71%	63%	**59%**	69%	66%	67%	71%
2011 Nissan Versa	63%	70%	86%	74%	58%	**43%**	58%	56%	56%	67%	71%
2011 Ford Taurus	67%	80%	79%	67%	62%	**33%**	51%	59%	62%	42%	43%
2011 Honda Accord 2 dr	59%	80%	86%	74%	71%	63%	61%	69%	69%	**52%**	71%
2011 Mazda 3	59%	80%	79%	63%	54%	**33%**	56%	62%	53%	42%	71%
2011 Subaru Outback	48%	80%	86%	74%	69%	**43%**	69%	67%	67%	52%	71%
2011 Toyota Rav4	56%	80%	86%	74%	41%	58%	48%	51%	**38%**	67%	71%
2011 Honda Pilot	67%	90%	75%	60%	52%	48%	49%	53%	57%	**37%**	43%
2011 Kia Soul	78%	90%	79%	67%	64%	**53%**	54%	61%	57%	57%	43%
2011 Mitsubishi Lancer	59%	100	86%	73%	69%	**48%**	69%	69%	69%	52%	71%

FF=forward-facing, RF=rear-facing

3. NHTSA proposed Vehicle/Child Restraint Fit ratings

Based on the NHTSA proposed vehicle/child restraint fit criteria, the KeyFit passed in all vehicles. The Graco Snugride failed only in the Kia Soul because the buckle interfered with the seatbelt installation and prevented a tight installation.

For the forward-facing installations, there were only four failures. In the Kia Soul, the seatbelt latch plate interfered with installing the forward-facing TrueFit using the seatbelt, which also prevented achieving a tight installation with the belt, causing two failures of the NHTSA criteria for this child restraint/vehicle combination. The tether could not be adequately tightened in two situations: the Frontier in the F150 and the Maestro in the Mazda 3. The Clek booster with rigid lower connectors passed the evaluation criteria in all vehicles except the Ford Taurus. In this vehicle, the lower anchors are offset towards the center from the seatbelts, which would not allow use of the belt when the booster is attached to the lower anchors. The booster allows the option of inserting the lower connectors unattached into the bight if they cannot be connected to the anchors, but this was not possible in the Taurus. None of the other products failed the criteria when evaluated in booster seat mode.

At least one failure occurred in all but one of the vehicle/seat combinations when convertible seats were installed rear-facing. Table 12 summarizes the factors contributing to the failures. The only vehicle/seat combination that passed was the TrueFit in the Kia Soul. The TrueFit could not be installed at the correct angle in half the vehicles, and the Alpha Omega could not be installed at the correct angle in any vehicle, because the proposed NHTSA procedure prohibits use of pool noodles or towels.

Table 12. Causes of failure with rear-facing convertibles in each vehicle (A=Alpha Omega, T=TrueFit).

	# Failures	Angle Correct	Operate harness	Tight install	Front seat as directed	Latch plate interfere	Buckle interfere	Tighten LATCH belt	Attach LATCH belt
Dodge Caravan	2	AT							
Hyundai Sonata	2	A	T						
Mitsubishi Lancer	2	AT							
Nissan Versa	2	A				T			
Kia Soul	3	A				A	A		
Mazda 3	3	A	T			T			
Ford Taurus	4	A	T			T	T		
Toyota Sienna	4	AT			T	T			
Chevrolet Tahoe	5	AT	T	A				A	
Chevrolet Impala	6	A	T	A		T	T		A
Ford F150	6	AT	T	T	T	T			
Ford Explorer	7	AT	T	T	T	T	T		

C. Volunteer Testing

1. Lower Anchor Use

Subjects used lower anchors correctly during 59% of the 212 LATCH installations performed. Table 13 summarizes the rates of correct use for each vehicle. Overall, pickup trucks and SUVs had the highest rates, 4-doors the lowest, and minivans and station wagons were in between.

Table 13. Rates of correct lower anchor use for each vehicle.

Vehicle	Rate
Ford Taurus	17%
Chevrolet Impala	28%
Hyundai Sonata	29%
Toyota Sienna	47%
Ford Explorer	59%
Mazda 3	61%
Kia Soul	67%
Nissan Versa	67%
Mitsubishi Lancer	71%
Dodge Grand Caravan	83%
Ford F150	89%
Chevrolet Tahoe	100%

If the lower anchors were visible, 69% of subjects used them correctly vs. 51% if the anchors were not visible ($p=0.001$). The presence of a lower anchor marking did not improve correct use, with 52% of marked lower anchors used correctly compared to 75% of unmarked anchors.

Based on preliminary univariate analysis, Figure 42 shows that correct lower anchor use is strongly related with the amount of clearance around the lower anchors ($p<0.0001$). Lower anchor attachment force, shown in Figure 43, is also strongly associated with correct lower anchor use ($p<0.0001$), in that the vehicles with the highest attachment forces have the lowest rates of correct lower anchor use compared with the lower three quartiles. The depth of the lower anchor within the bight is also related to correct lower anchor use as shown in Figure 44, with correct use substantially higher in vehicles where the depth is less than 2 cm ($p<0.001$).

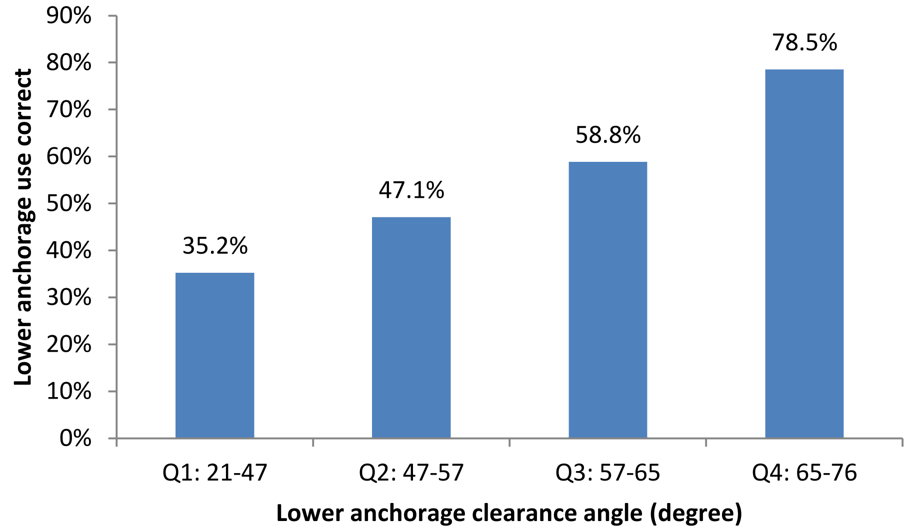

Figure 42. Lower anchor correct use vs. lower anchor clearance angle.

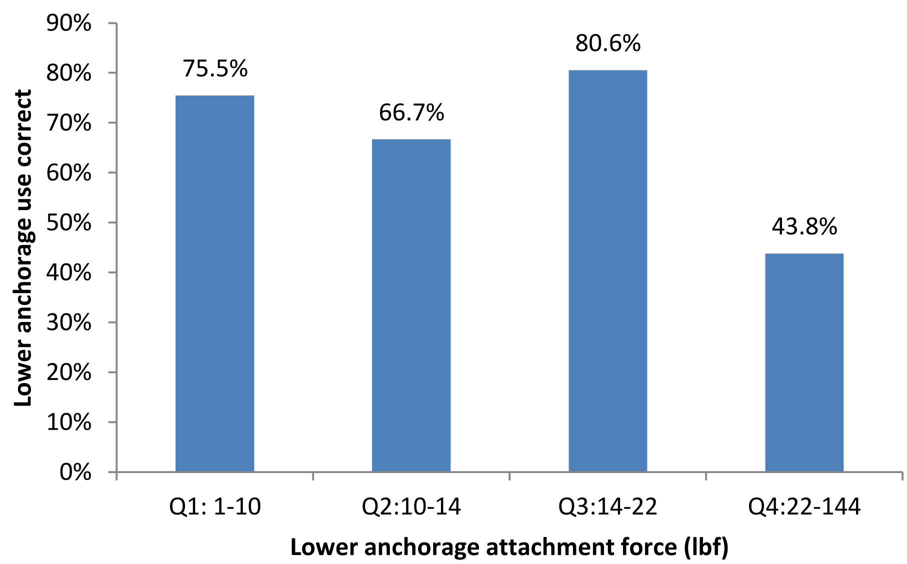

Figure 43. Lower anchor correct use vs. lower anchor attachment force.

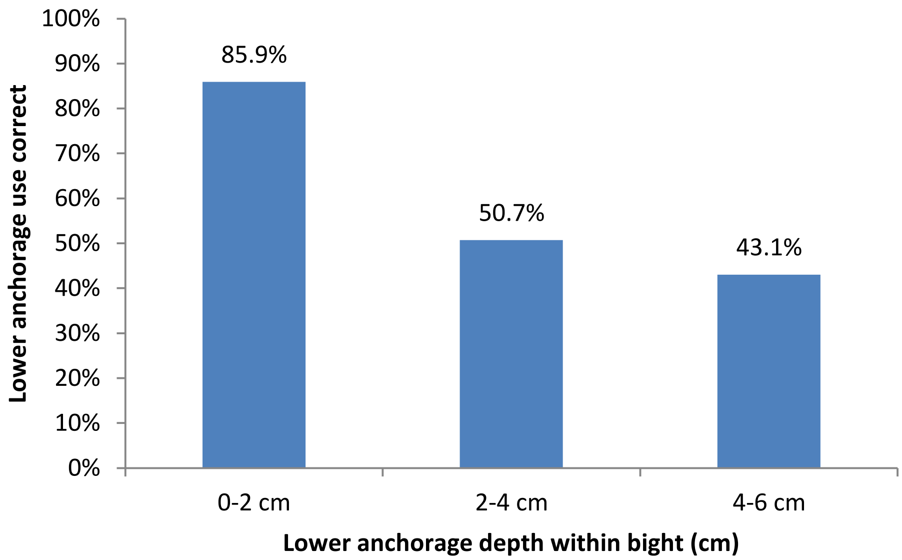

Figure 44. Lower anchor correct use vs. lower anchor attachment force.

Based on the significance of these factors in predicting correct lower anchor use, a series of mixed-models logistic regression models were used to identify specific vehicle LATCH features associated with correct LATCH use. There were strong relationships between the correct use of lower anchors and the clearance angle, attachment force, and depth within the bight. However, all three variables were correlated for this set of vehicles (Table 14). As a result, it was not possible to analyze attachment force and clearance angle in the same model. Correlations with depth were moderate, so we did attempt to model depth with the other variables, as described below.

Table 14. Correlations among key predictors of LATCH correct use

	Clearance Angle (deg)	Attachment Force (N)
Depth (in)	-0.70	0.35
Clearance Angle (deg)		-0.71

When depth level was used as the feature measure, no demographic variables were significant, but depth level was a highly significant predictor of correct use of lower anchors [F(2, 61.55)=9.09, p=0.0003]. When force was used as the primary predictor, no demographic variables were significant and force was a highly significant predictor of correct lower anchor use [F(1, 20.91)=9.49, p=0.0057]. When depth was added to the force model, force became marginally significant [F(1,31.04)=3.50, p=0.0710], while depth level remained highly significant. This result does not guarantee a causal relationships between depth and correct installations, but it does indicate that depth is a somewhat better predictor of correct installations than force (using the logistic model).

Finally, using clearance angle as the primary predictor of correct lower-anchor use, education was marginally significant [F(2,35.24)=2.81, p=0.0735] and clearance angle was highly significant [F(1,202)=16.61, p <.0001]. When both clearance and depth level were included in the same model, both became marginally significant. Here, to the extent there is unique variance attributable to depth and clearance separately, they are about equally predictive of correct installation.

In general, the combinations of these variables indicate that all three are individual important, but the correlations make it impossible to truly identify separate contributions to prediction of correct installation. Unfortunately, the correlation among these variables is not guaranteed to hold true in future vehicle designs. Thus, the inability to statistically identify the separate contribution of each means that a rating system for vehicle design should promote good design by considering all of these measures.

To ascertain appropriate thresholds for attachment force and the clearance angle, the measured values for these variables for the 12 study vehicles were compared to the rates of correct lower anchor use, as shown in Figure 45 and Figure 46. For the attachment force, the blue zone and red zones correspond to correct attachment rates above and below 50%, respectively. A threshold force to distinguish between the two zones was determined to be 40 lb based on interpolation between the two points closest to the 50% threshold.

A similar process was used for the clearance angle, with the threshold cutoff of 54° based on the two points closest to the 50% mark. One vehicle does not fall within either zone. However, when considering vehicles with clearance angles of 43° and 44°, their rates of correct use are 67% and 17%, placing the average correct use for vehicles with this range of clearance angles below 50%. .

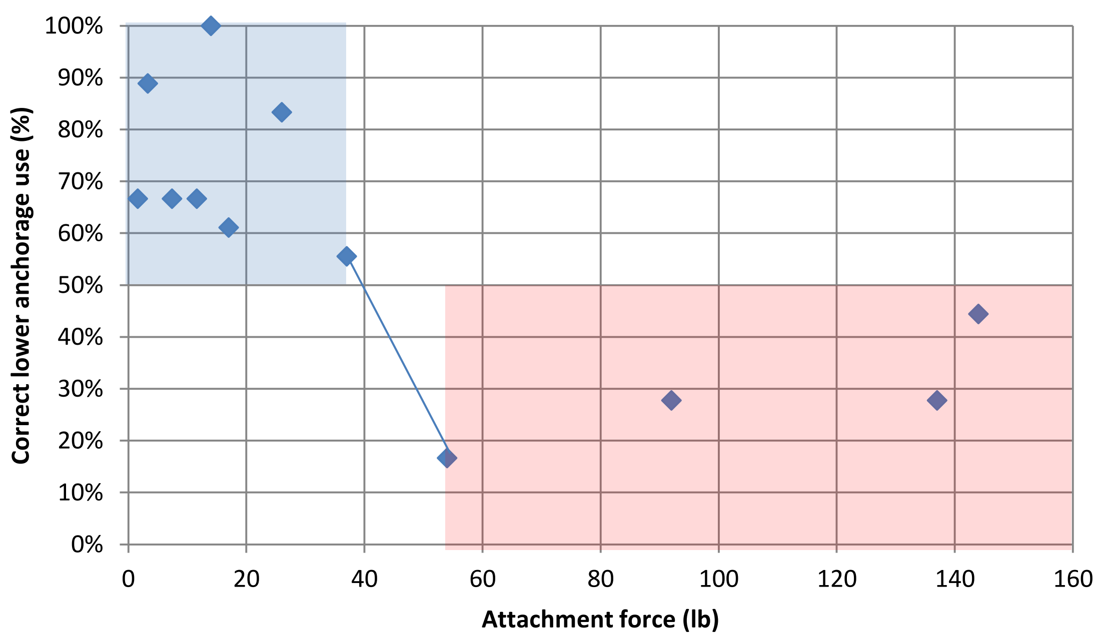

Figure 45. Rate of correct lower anchor use vs. attachment force for each vehicle.

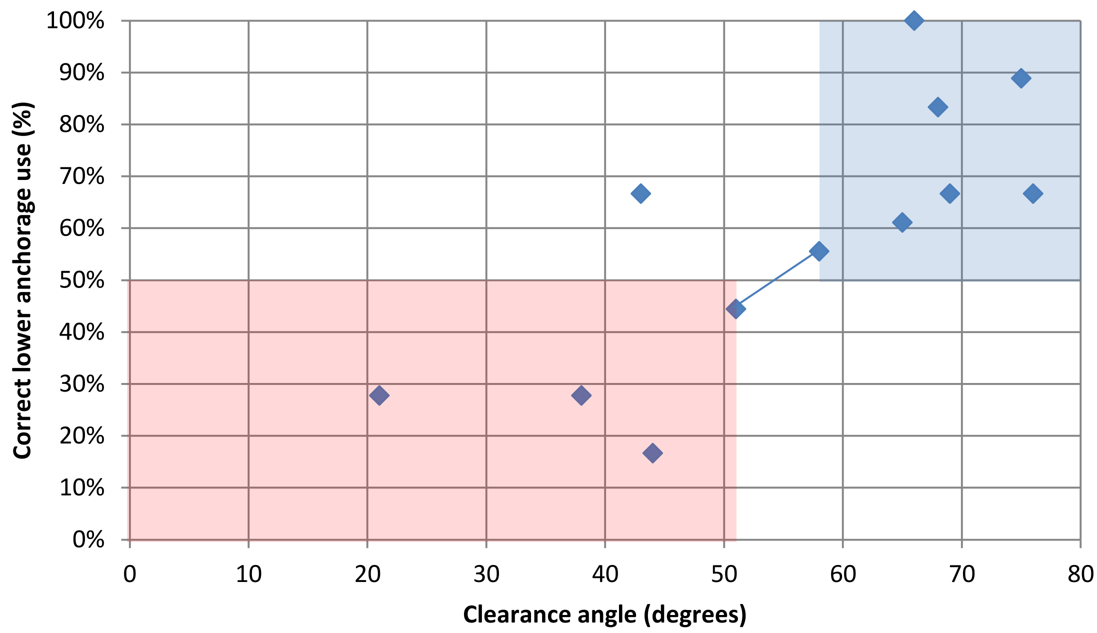

Figure 46. Rate of correct lower anchor use vs. clearance angle for each vehicle.

Figure 47 shows the percentage of subjects achieving correct lower anchor use for the ISO vehicle rating, ISO vehicle/child restraint interaction rating, and the derived SAE grade corresponding to each test condition. None of the existing composite rating systems of LATCH usability appear to be associated with the rates of correct lower anchor use. However, two of the components of the derived SAE grade (clearance angle and force measured) are associated with correct lower anchor use as mentioned above, but not at the threshold levels suggested by the recommended practice. The SAE recommended practice suggests a force of 16.9 lbf and a clearance angle of 75° as the target values.

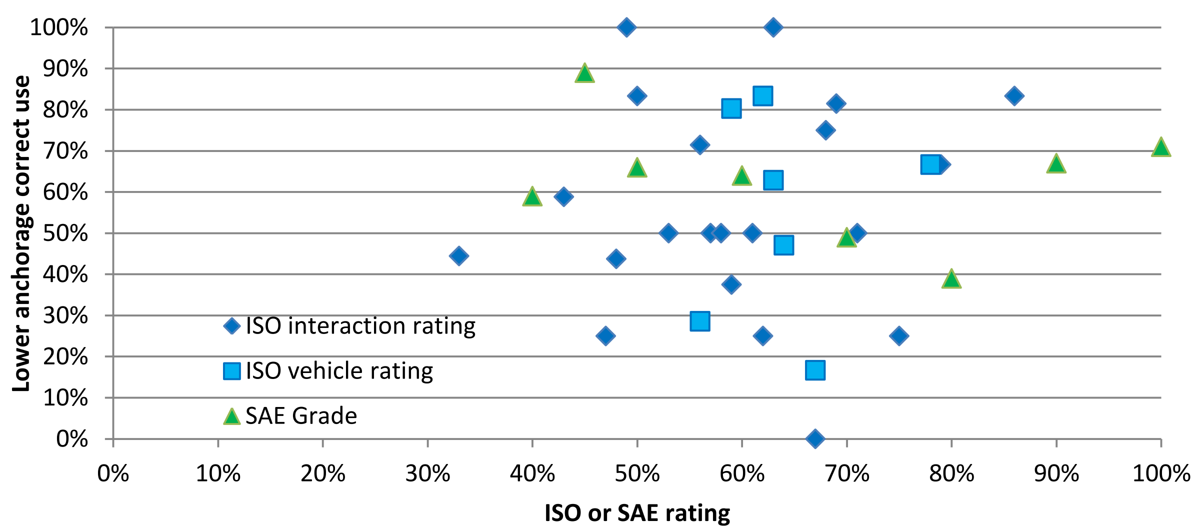

Figure 47. Lower anchor correct use vs. lower anchor attachment force.

When reviewing the 85 instances of incorrect lower anchor use by the subjects, 74% did not have the connectors properly oriented, 57% did not have the LATCH belt webbing flat, 35% attached the connectors to incorrect vehicle hardware, and 31% did not have full engagement.

2. Tether Anchor Use

Overall, subjects used the tether in 48% of the forward-facing installations, considering both installations with lower anchors and with the seatbelt. Subjects used the tether in 54% of installations using the lower LATCH anchors and 33% installations using the seatbelt (p=0.080). Seventy-six percent of subjects who consulted the vehicle owner's manual used the tether, compared to 36% of subjects who did not consult the manual (p<0.0001). Use of the child restraint manual also increased rates of tether use (61% vs. 41%, p=0.028). Fifty-seven percent of subjects with previous LATCH experience used the tether, compared to 41% who had not previously used LATCH (p=0.061).

Table 15 shows the rates of tether use for each vehicle. The rates of correct tether use, given that it was used, are shown in 0 (p=0.048). In the italicized seven vehicles, correct use rates are based on only 2-4 trials.

Table 15. Rates of tether use for each vehicle.

Vehicle	Rate
Nissan Versa	18%
Dodge Grand Caravan	25%
Ford Explorer	25%
Hyundai Sonata	25%
Kia Soul	33%
Mitsubishi Lancer	33%
Toyota Sienna	33%
Ford Taurus	50%
Chevrolet Impala	67%
Ford F150	75%
Chevrolet Tahoe	92%
Mazda 3	92%

Table 16. Rates of correct tether use for each vehicle (when used).

Vehicle	Rate
Mitsubishi Lancer	0%
Ford F150	11%
Ford Explorer	33%
Ford Taurus	33%
Hyundai Sonata	33%
Chevrolet Tahoe	36%
Nissan Versa	50%
Toyota Sienna	50%
Mazda 3	55%
Kia Soul	75%
Chevrolet Impala	88%
Dodge Grand Caravan	100%

Italics indicates percentage based on only 2-4 trials.

The use rate by tether anchor location is shown in Figure 48 (P=0.068). The rate of correct use was 11% when the tether anchor was located on the back wall, and 51% for the three remaining locations (p=0.026). The pickup truck with the anchor on the back wall was the only vehicle with a tether routing guide, which apparently was challenging for subjects to figure out how to use. To compare the relative visibility of each tether anchor, Table 17 shows what the tether hardware looks like in each vehicle. Above each picture are the vehicle name, vehicle identification code, and rate of tether use in forward-facing configurations. The hardware configuration of one of the most-often used anchors (Tahoe) is most similar to the least-often used anchor (Versa). Subjects testing vehicles DEF had the lowest rates of tether use (13%), while those testing vehicles JKL had the highest rates of tether use (43%).

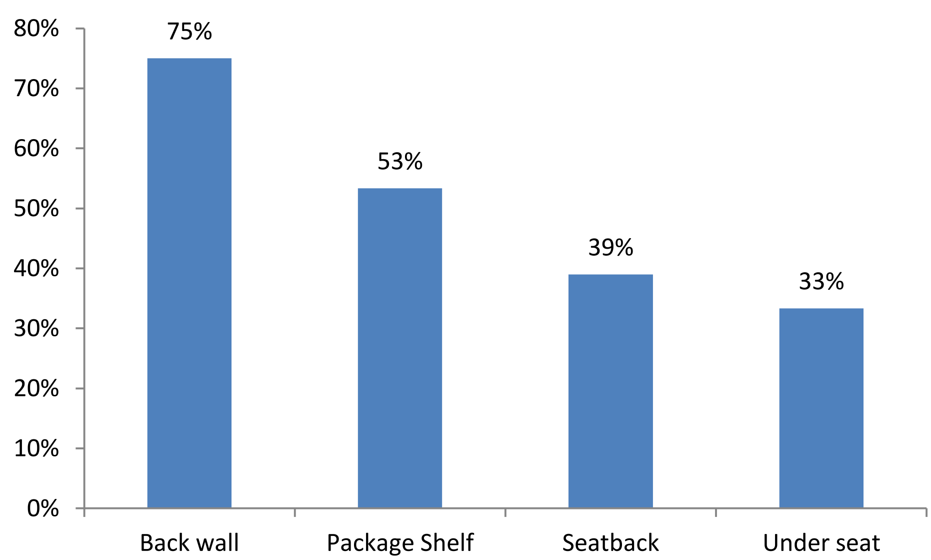

Figure 48. Rate of tether use in forward-facing installations by tether anchor location.

Table 17. Illustrations of tether anchors in each vehicle, plus rate of tether use in forward-facing installations.

Tahoe: K 92% 	Mazda 3: J 92% 	F150: L 75% 
Impala H : 67% 	Taurus: C 50% 	Lancer: I 33% 
Soul: F 33% 	Sienna: A 33% 	Sonata: B 25% 
Caravan: D 25% 	Explorer: G 25% 	Versa: E 18% 

The angle of the head restraint relative to the H-point (using quartile categories) was correlated with tether use. Vehicles with flatter head restraints had lower use rates than those that protruded more, based on the angle difference between the head restraint base and head restraint tangent measured relative to the estimated H-point (p=.001). However, the total range of head restraint angles was relatively small, spanning from 4.7° to 10.4° among the 12 vehicles. Table 18 shows pictures of the head restraints in each vehicle. Overall, there was minimal variation in head restraint design. It was hypothesized that the size of the head restraint might block visibility of tether anchors located on package shelves and contribute to lower use rates, but the Sonata has one of the smaller head restraints and one of the lowest rates of tether use.

Fifty-three percent of vehicles where the tether anchor was marked had correct tether usage, compared to 36% when the tether anchor was not marked (p=0.171). This may be related to the location of the tether anchor, because those on the package shelf were more likely to be marked than those on the seatback. Unlike lower anchors, tether anchors are not required to be marked or visible by FMVSS 225.

Table 18. Head restraints in each test vehicle.

<table>
<tr>
<td>Tahoe: K 92%
</td>
<td>Mazda 3: J 92%
</td>
<td>F150: L 75%
</td>
</tr>
<tr>
<td>Impala H : 67%
</td>
<td>Taurus: C 50%
</td>
<td>Lancer: I 33%
</td>
</tr>
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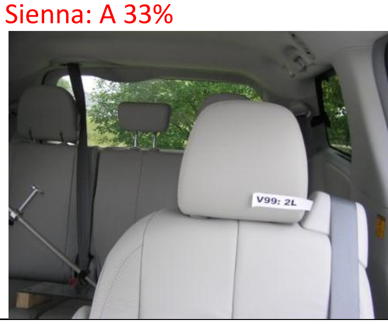
<td>Soul: F 33%
</td>
<td>Sienna: A 33%
</td>
<td>Sonata: B 25%
</td>
</tr>
<tr>
<td>Caravan: D 25%
</td>
<td>Explorer: G 25%
</td>
<td>Versa: E 18%
</td>
</tr>
</table>

Among the tethers that were used incorrectly in at least one respect, 22% were attached to incorrect hardware, 22% had hooks had been oriented incorrectly, 26% were not completely tight, and 44% were not correctly routed relative to the head restraint. Figure 49 shows the percentage of subjects correctly routing the tether as a function of the routing direction relative to the head restraint. The tether was most often correctly routed when it was routed over the head restraint. None of the subjects who were directed by the vehicle to remove the head restraint did so.

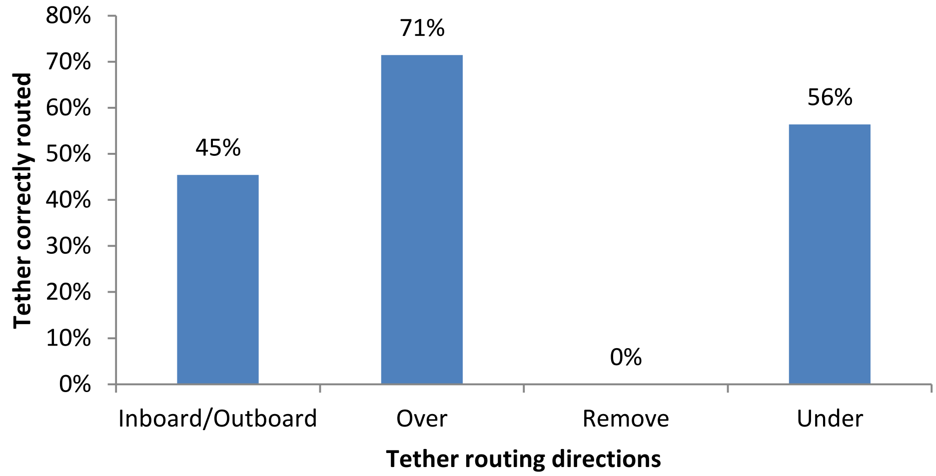


Figure 49. Rate of correct tether routing based on routing direction.

3. Installation Tightness

Overall, subjects obtained an acceptably tight fit of the child restraint in 31% of all trials, based on the 1" test for tightness. Figure 50 shows the rate of tight installation for each vehicle using either the lower anchors or seatbelt for the installation. Most vehicles had similar rates of tightness for both methods of installation. However, the Kia Soul, Ford Taurus, and Ford Explorer had substantially higher rates of tight installation with the seatbelt compared to LATCH, while the Hyundai Sonata had no tight installations with the seatbelt compared to 25% of those with LATCH.

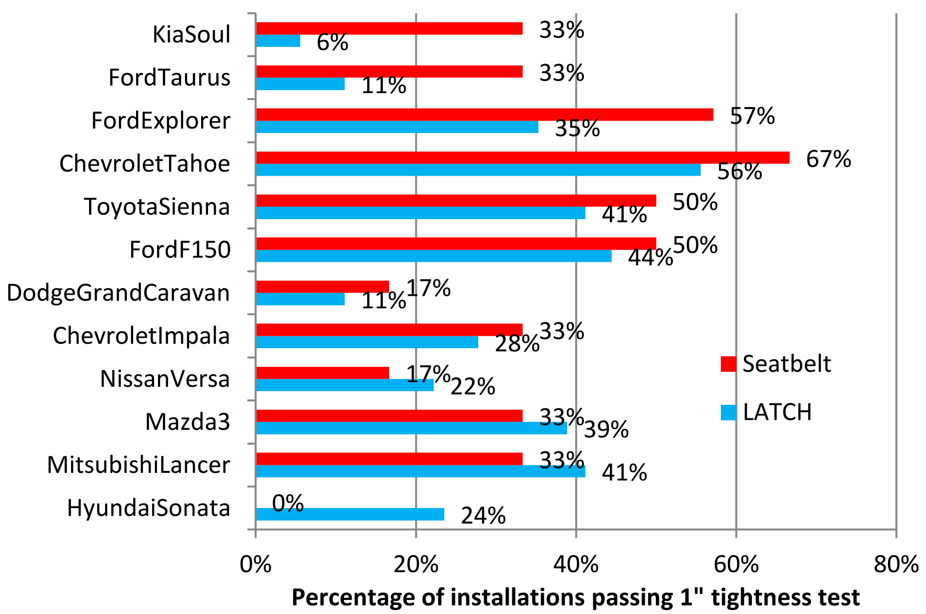


Figure 50. Percentage of trials with tight installation for each vehicle by method of installation.

Subjects achieved a tight fit in 30% of installations with lower anchors and 36% of installations with the seatbelt (p=0.642). In trials where the lower anchors were correctly used, 37% of subjects achieved a tight fit compared to 19% of trials where the lower anchors were not correctly used (p=0.015). For the seatbelt installations, tight fit was achieved in 63% of trials where the seatbelt was used correctly compared to 18% of those where the seatbelt was incorrectly used (p<0.0001). Tether use in forward-facing trials improved the rate of tight installation (38% vs. 20%, p=0.044), but correct tether use was not correlated with tight fit in forward-facing installations.

Thirty-nine percent of men and 25% of women achieved tight fit in their installations (p=0.011). Of those with previous LATCH experience, 52% obtained a tight fit compared to 19% without LATCH experience (p<0.0001). Forty-two percent of subjects who used the vehicle manual passed the 1” test for tightness compared to 27% of those who did not use it(p=0.017); no difference was found when considering use of the child restraint manual.

Using multi-variate regression, the two significant predictors of tight installation across all conditions were correct use of hardware and previous LATCH experience. Subjects who correctly used either the lower anchor hardware or seatbelt had 2.4 higher odds of achieving tight installation compared to those who made errors in using the hardware [F(1,253)=5.25, p=0.0227]. For subjects who had LATCH experience, the odds of tight installation were 7 times the odds for subjects without LATCH experience [F(1, 29.64)=10.24, p=0.0033].

Overall, only 13% of installs were completely correct, in that they correctly used the lower anchors or seatbelt, obtained a tight fit, obtained the correct angle, and used the tether as directed. (Note that these factors only address installation of the child restraint, not securing the occupant). Table 19 shows rates of correctly performing key installation tasks across vehicles. For vehicle and child restraint combinations that passed the proposed NHTSA fit criteria, 16% were correctly installed compared to 4% of those that did not meet the proposed NHTSA fit criteria (p=0.006). Correct installation rates did not vary with method (p=0.779) or direction (p=0.732), but the rear-facing infant seat had higher than expected rates of correct installation (29%) and the rear-facing convertible had lower than expected rates of correct installation (1%) (p=<0.001).

Table 19. Rates of correct use for each vehicle.

	Installs with lower Anchors (LA)			Installs with seatbelt (SB)			Forward-facing installs			All installations		
	N	% LA correct	% Tight	N	% SB correct	% Tight	N	Tether used	Tether correct, if used	N	Angle Correct	All Correct
Chevrolet Impala	18	28%	28%	6	0%	33%	12	67%	88%	24	71%	4%
Chevrolet Tahoe	18	100%	56%	6	67%	67%	12	92%	36%	24	79%	29%
Dodge Grand Caravan	18	83%	11%	6	33%	17%	12	25%	100%	24	75%	4%
Ford Explorer	17	59%	35%	7	43%	57%	12	25%	33%	24	71%	17%
Ford F150	18	89%	44%	6	67%	50%	12	75%	11%	24	75%	13%
Ford Taurus	18	17%	11%	6	33%	33%	12	50%	33%	24	75%	4%
Hyundai Sonata	17	29%	24%	6	0%	0%	12	25%	33%	23	74%	0%
Kia Soul	18	67%	6%	6	33%	33%	12	33%	75%	24	71%	13%
Mazda 3	18	61%	39%	6	50%	33%	12	92%	55%	24	79%	25%
Mitsubishi Lancer	17	71%	41%	6	17%	33%	12	33%	0%	23	74%	9%
Nissan Versa	18	67%	22%	6	33%	17%	11	18%	50%	24	75%	0%
Toyota Sienna	17	47%	41%	6	17%	50%	12	33%	50%	23	74%	13%
Overall	212	60%	30%	73	33%	36%	143	48%	46%	285	74%	13%

4. Subject Factors

In the first three groups of 9 subjects, 2 or 3 in each group had previous LATCH experience, compared to 6 in the fourth group ($p<0.0001$). In groups ABC and GHI, 30% of subjects were college graduates, compared to 70% in groups DEF and JKL ($p<0.0001$). Group JKL used the vehicle manual 41% of the time compared to 17%-28% for the other groups ($P=0.008$), but there was no difference according to the rate of child restraint manual use ($p=0.578$) Of the 37 completely correct installations, 4 subjects performed 16 of them and two of these subjects were in group JKL.

The only subject factor contributing to correct lower anchor use was education, with subjects' rate of correct lower anchor use increasing with higher education level. Correct use of lower anchors was also associated with subject group described by the vehicles that each tested ($p<0.0001$) because education levels were not evenly distributed across vehicle groups. However, previous LATCH experience was not a predictor. Subject education predicted whether or not they used the tether in forward-facing installations ($p=0.001$). The group with the highest education also had higher rates of correct tether use given that the tether was used.

IV. Discussion

A. Vehicle Survey

The survey of LATCH hardware in vehicles revealed very few innovations in installations. Only 7 vehicles provided three sets of LATCH anchors in the second row, and only one vehicle provided an extra lower anchor to allow use of the center seating position using LATCH. Even more disappointing is the scarcity of LATCH hardware in the third rows of vehicles with third rows. Consumers are likely purchasing vehicles with third rows so they can transport more children, so providing multiple seating positions with LATCH in the third row would allow them more choices in how to transport family members. A problem with the proposed usability rating systems is that they offer no incentive for providing additional seating positions equipped with LATCH.

The problem of hardware that could be confused with the lower or tether anchors that has been noted in earlier LATCH installations (SafeRideNews) no longer seems to be prevalent. There was no notable hardware that could be confused with the lower anchors, and only six vehicles with confusing tether hardware. In addition, tether anchors that required folding forward of the seatback for access are no longer manufactured.

This study focused on 2011 vehicles because they are required to implement the updated FMVSS 202 head restraint regulations. This has primarily led to larger, flat head restraint designs. Because the backset requirement for front seat occupants is not required for the back seat, there was less interference between child restraints and vehicle head restraints than expected.

The primary causes of interference between the child restraint fixture and vehicle seats was either stiffness around the lower anchors that prevented attachment of the rigid lower connectors, or the shape of the vehicle seatback. The child restraint fixture could not be installed in 27 vehicles. While the fixture is used by FMVSS 225 to define the location of the lower anchors relative to the seat contour, the regulation does not require that the fixture can be physically installed in a production seat. Because of the high rates of interference, we suspect that many manufacturers simply use a virtual version of the seat to define the lower anchor geometry. If the fixture was actually installed as recommended by SAE, it would help identify potential real-world conflicts with seat trim and other components.

A limitation of the vehicle measurement survey is the use of an estimated H-point as an origin rather than an actual H-point, which was required because of time and budget constraints. The accuracy of the H-point estimate depends primarily on the cushion stiffness. However, the deflection of a vehicle seat cushion by a child restraint is likely to be less than the deflection of a seat cushion by the 165 lb H-point manikin. Thus use of an estimated H-point with the tool may offer a better comparison across vehicles relative to the child restraint installation issues of interest in this project. Using the dimensions of the tool, it would be possible for a vehicle manufacturer to translate the measurements taken relative to the estimated H-point to a new origin using the actual H-point.

The data presented in the current report focus on measurements in the 2L seating position. Comparison of the results from this seating position to the second-row right seating position provided an estimate of repeatability. The measurement tools and procedures developed for the study show good repeatability in the two seating positions.

We measured vehicles as they were available at the dealership. No effort was made to control for the vehicle seat cover type, so the data are based on both leather and fabric seats. In some cases, the seams from leather seats seemed to pose more of a problem than those from fabric. Rating systems should consider listing the type of seat cover used for evaluation.

The procedure to measure depth of the lower anchor within the bight was developed for this study and was predictive of lower anchor usability during volunteer testing. If this procedure is used for assessing vehicles, it should be clear that the color of the tape should be visible without any deflection of the seatback or seat cushion.

B. Usability Assessments

Overall, the SAE grade developed from the recommended practices seemed to characterize the range of hardware features found in the vehicle fleet better than the ISO vehicle rating. The SAE grades were not strong predictors of ISO vehicle ratings.

A limitation of the ISO rating system is that there it does not combine ratings for a particular child restraint, vehicle, and child/restraint vehicle interaction. In addition, there is no direction on evaluating multiple seating positions within a vehicle, and what to do if different seating positions have different results. In addition, some of the evaluations of the usability of lower anchors or tether anchors are rather qualitative, as are some of the evaluations of whether the seatbelt buckle interfere with installations. For both these factors, there are numerous other options that could provide more quantitative assessments. For example, the ISO procedure gives a poor rating of lower anchor usability if "it takes extreme effort", while we applied a quantitative assessment that any lower anchors with attachment forces greater than 50 lb would receive a poor rating. For seatbelt buckle potential interference, we gave anchors with at least 70 mm clearance from seatbelt hardware a score of good and at least 35 mm a score of average to correspond with the ISO qualitative descriptions of "no possible interference" and "possible interference".

The proposed NHTSA fit evaluations only used the second-row left position for comparison to results from volunteer tests conducted during this study. It would likely be more difficult to meet the criteria in the center second- row and third-row seating positions. The most challenging requirement is achieving the correct angle with a rear-facing convertible seat without using any devices such as towels or pool noodles. If multiple child restraints fail this criterion in most vehicles, it indicates a problem with the requirement or a systematic incompatibility between vehicle seats and child restraint design. On the other hand, if only one product has an issue in many vehicles (i.e., TrueFit harness inoperable in seven of 20 vehicles and latch plate interference in eight vehicles in the current study), this suggests an issue with the child restraint designs. In the current study, the proposed NHTSA criteria did not identify any single vehicle with a consistent problem across multiple child restraints, other than the rear-facing convertible angle requirement found in almost all vehicles.

When comparing results from the proposed NHTSA fit assessment to volunteer results, only 4% of installations were completely correct in the vehicles that failed the proposed NHTSA criteria compared to 16% of those that met the criteria. This suggests that child restraints identified as meeting the NHTSA criteria by vehicle manufacturers will still have a substantial number of installation errors, although the vehicles failing the NHTSA criteria are likely to have even more installation errors.

While the prime focus of the usability assessments in this study was vehicle features and vehicle/child restraint interactions, the child restraint form of the ISO LATCH usability procedure was used to classify child restraints by their ease-of-use. Table 20 summarizes findings. Because of the ISO emphasis on labeling and manuals, and similarities among US products, most US products receive similar scores. For volunteer testing, the child restraint model was never a significant predictor of key outcomes (tightness, correct lower anchor use, tether use) even though they received different ISO child restraint scores. The ISO child restraint ratings emphasize labels and manuals, but Klinich et al. (2010) performed volunteer tests showing that the effect of child restraint usability features is much stronger than any variations in labels or manuals. In addition, the ISO child restraint rating would give a higher score to poor graphics without text than good graphics with text because it does not define "good" graphics.

Table 20. Issues using ISO form to evaluate child restraint usability

Item	Description of ISO child restraint feature	Findings
1.1.1	Do child restraint labels show how to prepare/use/attach ISOFIX?	Most child restraints have labels only on one side, and include both text and pictures, so they usually score a 1. To get a 3, labels must be only pictures and on both sides.
	Does child restraint manual show how to prepare/use/attach ISOFIX?	Most child restraint manuals use both text and graphics, so they score a 1. To get a 3, manuals need to be graphical with text unnecessary.
1.1.2	Do child restraint labels show how to use anti-rotation devices (tethers)?	Most labels do not include diagrams showing the tether attachment. The few that do also include text. So most child restraints score a 1 or 0.
	Does manual show how to use anti-rotation devices (tethers)?	Most child restraint manuals use both text and graphics, so they score a 1. TO get a 3, manuals need to be graphical with text unnecessary.
1.1.3	Do labels show how to detach/remove ISOFIX attachments, base, and anti-rotation devices?	Most labels do not cover removal and score 0.
	Do labels show how to detach/remove ISOFIX attachments, base, and anti-rotation devices?	Most child restraint manuals use both text and graphics, so they score a 1. Some do not explicitly address removal and get a 0. TO get a 3, manuals need to be graphical with text unnecessary.
1.1.4	Do instructions and labels agree?	Most do, and score a 3.
1.2.1	Can child restraint be used without assembling?	Most can, and score a 3.
1.2.2	Are flexible attachments ready to use?	Most score a 1 or 0 because they are stored and require 2 steps to release, or 0 because the webbing needs to be routed.
	Is top tether ready to use?	Most score a 1 because you can't get a 3 if tether webbing is wrapped in rubber band.
1.2.3	Can lower flexible attachments be correctly routed through CRS, without risk of misrouting or interference with child restraint harness?	For convertibles, many require rerouting of the LATCH belt through different paths, so they score a 0 because of potential for choosing the wrong path. A child restraint could only score a 3 if there is only one belt routing path, which does not have potential for interference with the harnesses.
1.2.4	Can tether be adjusted with a one-hand operation?	Almost all US products use a tilt-lock or button-release tether adjuster, which can be tightened with one hand and thus scores a 3.

The ISO child restraint scores for the models used in this study are shown in Table 21. For convertibles, each mode is rated. The child restraints were selected to provide a variety of sizes and interactions with vehicles, but they also provide a range of child restraint ease-of-use ratings. However, the ratings within each product type are similar, varying from 4% to 10% percentage point differences for each pair of products. For US child restraints, the ISO child restraint rating almost seems to reflect that some types of child restraints are easier to install than others, rather than usability differences within types. In the volunteer tests, the rear-facing infant restraint (score 91%) had higher than expected rates of correct installation, while the rear-facing convertible (score 36%) had lower than expected rates of correct installation. The forward-facing convertible (score 60%) and forward-facing combination (54%) had rates of correct installation that were expected statistically.

Table 21. ISO ease-of-use ratings for child restraints used in testing

Child restraint	Type	ISO rating
Clek	Booster with rigid lower connectors	92%
Frontier	Forward-facing	65%
Maestro	Forward-facing	54%
AlphaOmega FF	Forward-facing convertible	60%
TrueFitFF	Forward-facing convertible	50%
AlphaOmega RF	Rear-facing convertible	36%
TrueFitRF	Rear-facing convertible	40%
KeyFit	RF Infant	91%
Snugride	RF Infant	84%

C. Volunteer Testing

The vehicles selected for subject testing were sorted into groups to provide a range of SAE grades, vehicle types, and manufacturers for each test session. However, since the SAE grades were not correlated with subject installation performance, some sets of vehicles produced results that suggest some sets were more difficult than other sets. Regardless, there were very few vehicles that had high rates of both correct lower anchor use and correct tether use. For example, the Lancer had the fourth highest rate of correct lower anchor use and the worst rate of correct tether use, while the Impala had the second lowest rate of correct lower anchor use and second highest rate of correct tether use. The vehicles selected for volunteer testing based on a wide variety of LATCH hardware implementations also provided a wide range of installation performance by the subjects.

The only subject recruitment criterion was currently transporting a child in a child restraint and were randomly assigned to test one of four groups of vehicles. While the average age and gender distribution for each subject group was similar, the fourth group had 6 subjects with previous LATCH experience compared to 2 or 3 subjects in the other three groups. This appeared to have led to much higher rates of tether use with forward-facing installations for vehicle set JKL of 86% compared to 36% percent average across the other three vehicle groups. This made it difficult to define vehicle features contributing to tether ease-of-use, because some vehicles had only 2 or 3 trials with tether use. One subject in the fourth group accounted for 7 of the 37 error-free installations. Analyses of vehicle factors associated with installation error were performed with and without this subject's data, but conclusions did not change (although percentages shifted slightly) so they were included in the dataset. For future studies of LATCH usability, subjects without child restraint experience may offer an advantage. If a countermeasure to increase tether use or improve usability is effective for them, it should also be effective for experienced child restraint users.

The rate of achieving a tight fit was double when the lower anchors were used completely correctly compared to trials when they were not (38% vs. 19%). Thus measures to improve the usability of lower anchors may also improve the rate of achieving a tight installation.

The current study did not identify any significant vehicle seat characteristics that contributed to the quality of installation. In Klinich et al. (2010), the presence of a bightline waterfall seemed to improve installation tightness, although it did not affect correct lower anchor use. The earlier study only evaluated forward-facing installations. The earlier study and the current study also used different child restraints with different profiles; in the earlier study the child restraints were selected to be easy-to-use, while in the current study used child restraint with a range of usabilities was chosen. The variations in child restraint shapes make it difficult to identify particular vehicle seat characteristics that result in better compatibility across all child restraints.

Tether anchors located on the package shelves were all marked with the ISO symbol, compared to only one of those located on the seatback. This may have contributed to the higher rate of tether use when it is located on a package shelf. More research is needed to identify whether different styles of tether hardware (made a shaped bar or stamped from metal plate)are easier to use. There was also insufficient data to determine whether tether anchors located at different locations on the seatback (middle, base, or under) are easiest to use.

The current study suggests that if there were more allowable options in tether routing relative to the head restraint in a particular vehicle, as well as additional allowable positions for the head restraint, the rate of correct tether use would increase. Of the 143 forward-facing installations, only 31 had the tether completely correct. If tether routing errors are ignored, the number would increase to 44, raising correct tether use rates from 22% to 31%. There has not been published research indicating that a particular tether routing option (over, under, around the head restraint or remove the head restraint) is better than the others at reducing occupant head excursion, the main purpose of a tether. Different manufacturers recommend different routings. If a particular routing performs better dynamically, it should be recommended across vehicles. If they all work equally well, any should be considered suitable for use.

V. Recommendations

A. Tether

One of the biggest challenges of increasing proper restraint use, including proper LATCH use, appears to be getting people to use the tether. The current results are consistent with the recent tether use survey by Jermakian and Wells (2011), as well as the earlier IIHS survey (2003). The main issue is use, not usability. No subjects tried to use the tether and could not; they either used it or did not even try. Tether use was higher in installations with lower anchors compared to seatbelt installations. Some possible remedies for the problem:

1) Public education campaign using a video showing reduced head excursion with tether use.
2) Improvements in vehicle manuals
    a. Emphasize using tether with seatbelt
    b. Provide directions for single and V-shaped tethers
    c. Provide directions for rear-facing tethering
    d. Provide flexibility in routing options (see below)
    e. Use of the term LATCH rather than ISOFIX.
3) Requiring permanent tether anchor labeling.
4) Adding a highly visible "tether tag" to each tether anchor in new vehicles that requires scissors to remove. The tag could include text such as "Keep your child safer. When using a forward-facing child seat, attach the tether to this anchor. See vehicle manual for more information." The tag would identify the hardware for current users of child seats, and possibly increase awareness of the tether anchor presence for future parents. A version could be developed for the used vehicle market as well.
5) Alter the message about LATCH to emphasize the lower anchors separately from the tether.

In the current study, more subjects used the tether correctly when the tether anchor was marked (53% vs. 36%) although the results were not significantly different. However, since there appeared to be no disbenefit from marking the tether location, we believe that the SAE and ISO recommendations to mark the tether permanently should be considered when assessing LATCH usability.

Several subjects used the tether correctly except for routing the tether as directed around the head restraint. The directions for tether routing vary considerably, with the most common route under the head restraint. The easiest way to minimize the misuse of incorrect tether routing is to allow multiple options for tether routing unless there is a demonstrated safety problem for a particular method. Thus allowing the tether to be used with the head restraint removed, or under, over, or around the head restraint in either the lower or upper position may be desirable and provide better choices for different styles of tether straps (single vs. V-strap). Another option would be to identify the tether routing that provides the best performance results in terms of reducing head excursion of child occupants and encourage manufacturers to specify this routing uniformly across the fleet. The research to support this option has not yet been done.

A common problem when attaching the tether to an anchor on a package shelf is that the anchor is too close to the head restraint to allow sufficient room to accommodate the length of the tether hook and adjustment hardware. Reviewing these lengths of tether hardware on 21 child restraints made by 11 different manufacturers indicates that hardware lengths range from 102 to 184 mm, with 15 child restraints having lengths between 140 mm and 165 mm. A common-sense approach to the space issues, illustrated in Figure 51, suggests that having tether anchors on a package shelf at least 165 mm rearward of the back of the head restraint could likely provide adequate clearance for installing the tether. For those located on the seatback, the distance below the head restraint should be at least 165 mm. Based on a review of tether wrap around distances and pictures from the vehicle survey, approximately 70 of the 98 vehicles would meet this requirement.

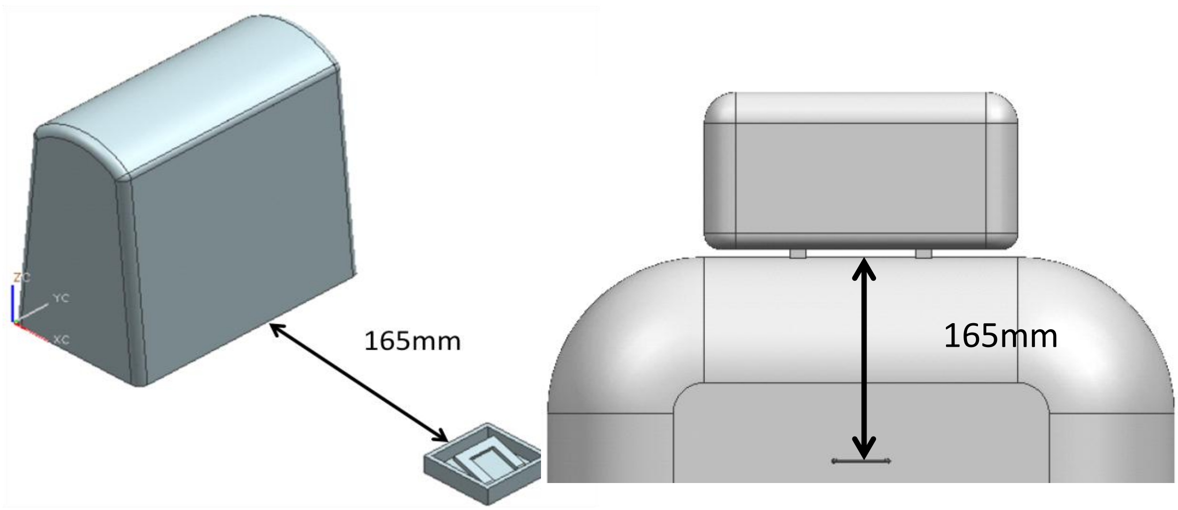


Figure 51. Illustration of proposed recommendation to have the tether anchors located at least 165 mm rearward or below the head restraint.

B. Lower Anchors

A number of factors were evaluated to identify the vehicle hardware characteristics that lead to correct use of lower anchors. As shown in the table below, three items regarding lower anchor hardware had a significant effect on the rate of correct lower anchor use by volunteer subjects. The results presented are shown for overall correct use of lower anchors, but each of these factors also predicts correct hardware choice, proper orientation, full engagement, and LATCH webbing being flat that go into assessment of overall correct use.

Table 22. Factors predicting correct lower anchor use among subjects.

Usability criteria	Suggested threshold	Correct lower anchor use	
		Vehicles meeting criteria	Vehicles not meeting criteria
Lower anchor clearance angle	>54°	75%	37%
Lower anchor force	<40 lb	74%	29%
Lower anchor depth within bight	<2 cm	85%	46%

Figure 52 shows the rate of correct lower anchor use for each vehicle ordered from lowest to highest, and whether each vehicle meets the proposed usability thresholds. The three vehicles with the highest rates of correct lower anchor use meet all three criteria, while the vehicles with the three lowest rates of correct lower anchor use meet none of the criteria.

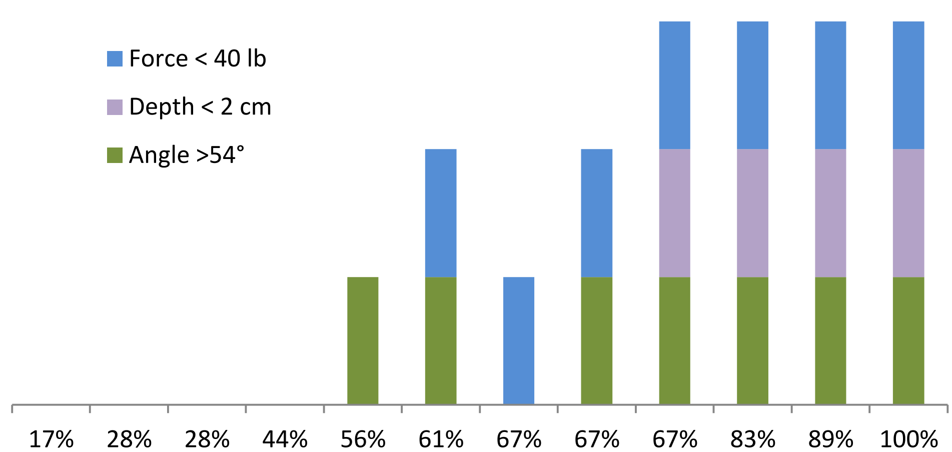


Figure 52. Distribution of subject-tested vehicles by rate of correct lower anchor use and number of usability criteria they meet.

When these criteria are applied to the entire set of 98 vehicles measured in the survey, the distribution of scores is shown in Table 23. There are a variety of manufacturers in each category. Of the 98 vehicles surveyed, 21 met all three requirements and 9 met none.

Table 23. Distribution of 98 vehicles according to lower anchor usability criteria.

	Total	Depth	Clearance	Force
Meet no requirements	9			
Meet one requirement	31	2	0	29
Meet two requirements	37	5	33	36
Meet all three requirements	21	21	21	21

C. LATCH Positions

A weakness of current LATCH usability rating systems is that they do not address multiple seating positions with LATCH. Any evaluation of LATCH usability should be designed to encourage installation of LATCH hardware in seating positions beyond those required by FMVSS 225. In particular, LATCH hardware should be as prevalent in the third row as it is in the second row, because families purchase vehicles with third rows because they want to transport children there. The availability of LATCH seating positions should also consider whether the vehicle manufacturer allows an “improvised” LATCH seating position in the center of a row by using the inboard lower anchors from the outboard seating positions and the available tether anchor.

VI. References

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VII. ACKNOWLEDGEMENTS

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Appendix A: Targeted Vehicle List

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CODE	Year	Make	Model	Version	IIHS Size	IIHS Class
V001	2011	BMW	328xi	Sedan	Mid-size	Luxury
V002	2011	BMW	528i	Sedan	Large	Luxury
V004	2011	Mini	Cooper Clubman	Z	Mini	2 Door
V005	2010	Chrysler	Three hundred 300C	S	Large	4 Door
V006	2010	Chrysler	Town & Country	Touring	Very Large	Minivan
V007	2010	Dodge	Avenger	Express	Mid-size	4 Door
V008	2011	Dodge	Caliber	Mainstreet	Small	Station Wagon
V009	2010	Dodge	Charger	SE	Large	4 Door
V010	2011	Dodge	Grand Caravan	Minivan	Very Large	Minivan
V011	2011	Dodge	Ram 1500	Crew Cab 4WD	Large	Pickup
V013	2011	Jeep	Grand Cherokee	Laredo	Mid-size	SUV
V014	2011	Jeep	Liberty	Sport 4WD	Mid-size	SUV
V015	2011	Jeep	Wrangler	Unlimited Sahara 4WD	Mid-size	SUV
V016	2011	Mercedes	C300	Sport	Mid-size	Luxury
V017	2011	Mercedes	E350	Sport	Large	Luxury
V018	2011	Mercedes	GL450	Sport Utility	Large	Luxury SUV
V019	2011	Mercedes	ML350	Sport Utility	Mid-size	Luxury SUV
V020	2011	Ford	Edge	SEL	Mid-size	SUV
V021	2011	Ford	Escape	XLT	Small	SUV
V022	2011	Ford	Explorer	XLT 4WD	Mid-size	SUV
V023	2011	Ford	F-150	XL Super Crew	Large	Pickup
V024	2011	Ford	F -150	XL Super Cab	Large	Pickup
V026	2011	Ford	Flex	SEL AWD	Mid-size	SUV
V027	2011	Ford	Focus	SE	Small	4 Door
V028	2011	Ford	Fusion	SE	Mid-size	4 Door

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CODE	Year	Make	Model	Version	IIHS Size	IIHS Class
V029	2011	Ford	Mustang	V6	Mid-size	Sports
V030	2011	Ford	Taurus	SE	Large	4 Door
V031	2011	Volvo	S40	T5	Mid-size	4 Door
V032	2011	Volvo	S60	T6	Mid-size	Luxury
V033	2011	Volvo	XC-90	AWD	Mid-size	Luxury SUV
V034	2011	Buick	Enclave	CX FWD	Large	SUV
V035	2011	Cadillac	CTS	Sport	Large	Luxury
V036	2011	Cadillac	Escalade	AWD	Large	Luxury SUV
V039	2011	Chevrolet	Equinox	LT	Mid-size	SUV
V040	2011	Chevrolet	HHR	LT	Small	Station Wagon
V041	2011	Chevrolet	Impala	LT Flex fuel	Large	4 Door
V042	2011	Chevrolet	Malibu	LS	Mid-size	4 Door
V043	2011	Chevrolet	Silverado	1500 Crew Cab	Large	Pickup
V044	2011	Chevrolet	Silverado	1500 LT Extended Cab	Large	Pickup
V045	2011	Chevrolet	Suburban	LT Half-ton	Very Large	SUV
V047	2011	Chevrolet	Tahoe	LS 4WD	Large	SUV
V048	2011	GMC	Acadia	SL	Large	SUV
V049	2011	GMC	Sierra	1500 Crew Cab	Large	Pickup
V050	2011	GMC	Sierra	1500 Extended Cab	Large	Pickup
V051	2011	Acura	MDX	Tech	Mid-size	Luxury SUV
V052	2011	Honda	Accord	LX-S	Mid-size	2 Door
V053	2011	Honda	Accord	SE	Mid-size	4 Door
V054	2011	Honda	Civic	Coupe	Small	2 Door
V055	2011	Honda	Civic	LX	Small	4 Door
V056	2011	Honda	CR-V	LX 4WD	Small	SUV
V057	2010	Honda	Fit	Sport	Mini	Station Wagon

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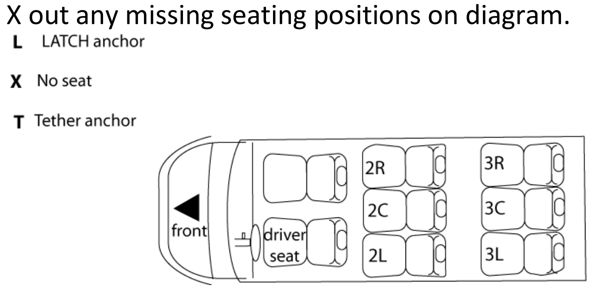
CODE	Year	Make	Model	Version	IIHS Size	IIHS Class
V058	2011	Honda	Odyssey	EX	Very Large	Minivan
V059	2011	Honda	Pilot	EX-L	Mid-size	SUV
V060	2011	Honda	Ridgeline	RTL	Large	Pickup
V061	2011	Hyundai	Azera	Limited	Large	4 Door
V063	2011	Hyundai	Santa Fe	GLS AWD	Mid-size	SUV
V064	2011	Hyundai	Sonata	Limited	Mid-size	4 Door
V065	2011	Hyundai	Veracruz	Limited AWD	Mid-size	SUV
V066	2011	Kia	Sedona	LX	Very Large	Minivan
V067	2011	Kia	Soul	Exclaim	Small	Station Wagon
V068	2011	Kia	Sportage	EX FWD	Small	SUV
V069	2011	Mazda	CX-9	Sport AWD	Mid-size	SUV
V070	2011	Mazda	Three 3	Sport	Small	4 Door
V071	2011	Mazda	Three 3	Sport	Small	Station Wagon
V073	2011	Mazda	Six 6	I Touring	Mid-size	4 Door
V074	2011	Mitsubishi	Eclipse	GS	Mid-size	2 Door
V075	2011	Mitsubishi	Lancer	ES	Small	4 Door
V076	2011	Nissan	Altima	SL 2.5	Mid-size	4 Door
V077	2011	Nissan	Murano	S AWD	Mid-size	SUV
V078	2011	Nissan	Rogue	SL AWD	Small	SUV
V079	2011	Nissan	Sentra	SR 2.0	Small	4 Door
V080	2011	Nissan	Versa	SHB 1.8	Small	4 Door
V081	2011	Porsche	Cayenne	Turbo Tiptronc	Large	Luxury SUV
V082	2011	Subaru	Forester	2.5X Premium	Small	SUV
V083	2011	Subaru	Impreza	2.5i	Small	Station Wagon
V084	2011	Subaru	Legacy	2.5i Limited	Mid-size	4 Door

Appendix A: Targeted Vehicle List

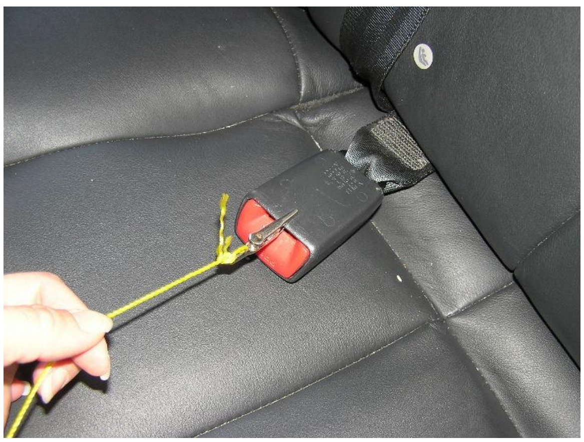
CODE	Year	Make	Model	Version	IIHS Size	IIHS Class
V085	2011	Subaru	Outback	2.5i	Mid-size	Station Wagon
V086	2010	Subaru	Tribeca	Limited	Mid-size	SUV
V087	2010	Suzuki	Grand Vitara	X Sport 4WD	Small	SUV
V088	2010	Suzuki	SX4	Crossover AWD	Small	Station Wagon
V089	2011	Jaguar	XF	Premium	Large	Luxury
V090	2011	Landrover	Range Rover	Sport Supercharged	Large	Luxury SUV
V091	2011	Lexus	ES-350	Sedan	Mid-size	Luxury
V092	2011	Lexus	RX 350	Sport Utility	Mid-size	Luxury SUV
V093	2011	Toyota	Camry	LE	Mid-size	4 Door
V094	2010	Toyota	Corolla	Sport	Small	4 Door
V095	2011	Toyota	Highlander	4WD	Mid-size	SUV
V096	2010	Toyota	Matrix	Hatchback	Small	Station Wagon
V097	2010	Toyota	Prius	Hybrid	Small	4 Door
V098	2011	Toyota	RAV4	SUV	Small	SUV
V099	2011	Toyota	Sienna	XLE	Very Large	Minivan
V100	2011	Toyota	Tacoma	Access Cab	Small	Pickup
V101	2011	Toyota	Tundra	4WD	Large	Pickup
V102	2011	Toyota	Venza	FWD	Mid-size	SUV
V104	2011	Audi	A4	Quattro	Mid-size	Luxury
V105	2011	Volkswagen	Jetta	SE 2.5	Mid-size	4 Door
V106	2010	Volkswagen	Routan	SE	Very Large	Minivan
V107	2011	Chevrolet	Cruze	LS	Small	4 Door

Appendix B: Vehicle Measurement Protocol

LATCH Usability Vehicle Survey Test Procedure

Step	Task	Record
1a	Identify test vehicle Photo: ¾ view of vehicle	VIN Manufacturer Make Model Edition
1b	Document vehicle configuration	Number of doors Number of rows Number of rear seating positions
1c	Document LATCH systems available in vehicle. • X out any missing seating positions on diagram.  • Place a T at each tether location. • Place an L at each lower anchor location. • Use 1R, 2L, 2C, 2R, 3L, 3C, 3R to document locations • If using a pair of lower anchors blocks use of the seatbelt in adjacent seating position, label position as 2LC, 2RC, 3LC, or 2RC • If a tether can be used by two adjacent seating locations, label position as 2LC, 2RC, 3LC, or 2RC	Locations of tether anchors Locations of lower anchors
1d	Place head restraints in highest position Place armrests in upright/stowed position Move front row seats forward Apply labels about 4 inches above bight between centerline and LA to indicate vehicle code and seating position	

<table>
<tr><td>2a</td><td>Install reference fixture
Attach hooks to each lower anchor

Attach clip strings to each buckle tab

Where belt webbing contacts vehicle seat cushion, pinch webbing in half and attach clip strings to center of webbing.

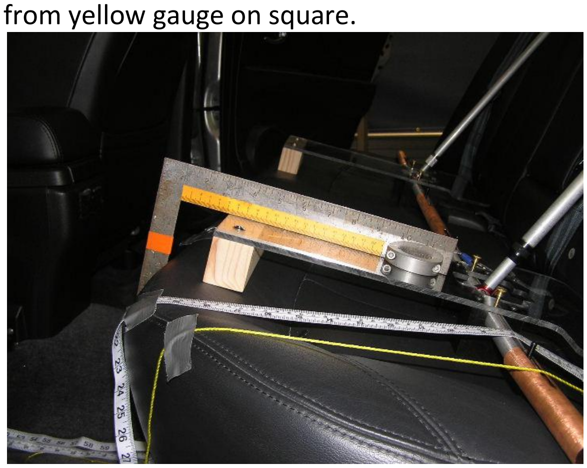
Center each assembly on centerline of seating position, indicated by head restraint centerline
Position fixture centerline at centerline of center</td><td></td></tr>
</table>

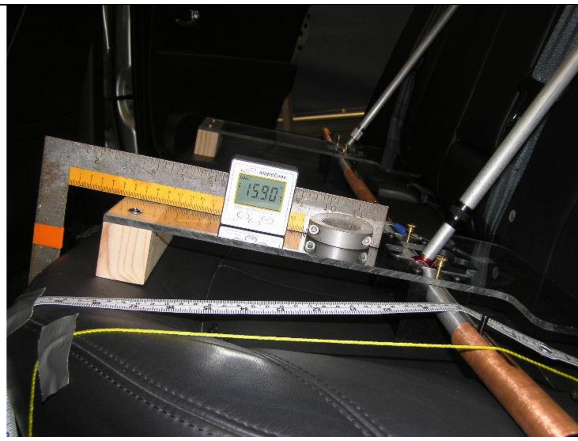
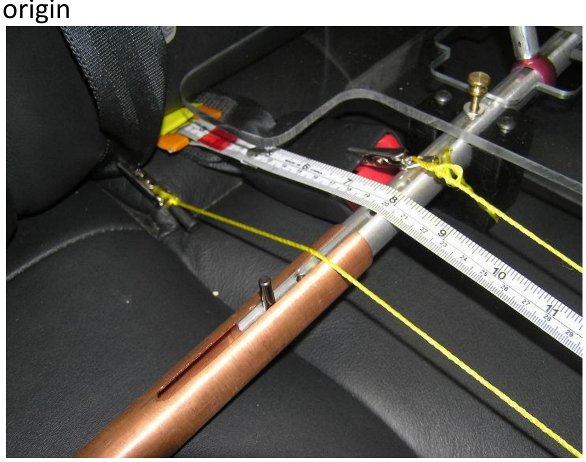
	seating position or center of vehicle  • Push each assembly against seatback with a force of 10 lb applied horizontally • Tighten thumbscrews on center bar • Attach outboard segments if needed as a reference for measuring belt webbing and tighten thumbscrews 	
2b	If seatbacks are adjustable • Attach standoff to vertical post at a point 300 mm above the origin	

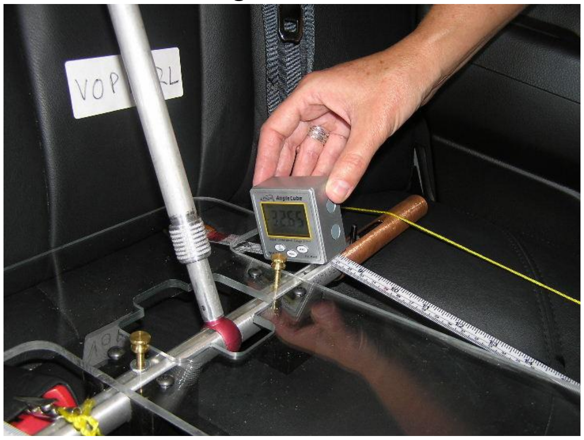
<table>
<tr><td></td><td>

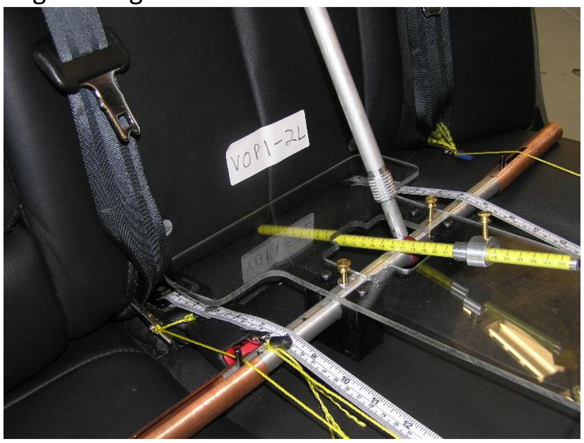
Adjust seatback angle to a locked position so the vertical post is closest to an angle of 25.5 degrees from vertical
Reinstall assembly and check that fixture centerlines are still aligned
Push each assembly against seatback with a force of 10 lb
</td><td></td></tr>
<tr><td>2c</td><td>If height of reference assembly falls at level of bight, attach rear plate to assemblies and repeat installation (newly discovered issue: need to build rear plate)
Example of reference assembly that falls at level of bight because of waterfall bightline
</td><td></td></tr>
<tr><td>2d</td><td>Continue installation of reference fixture

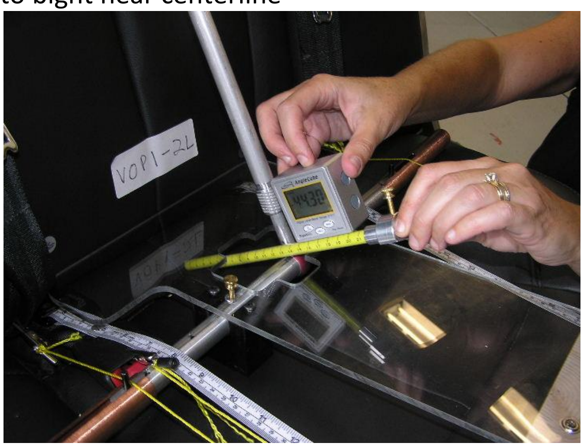
Route each hook from the LA to origin, and secure with tape to front of seat so measuring tape is perpendicular to origin bar
</td><td></td></tr>
</table>

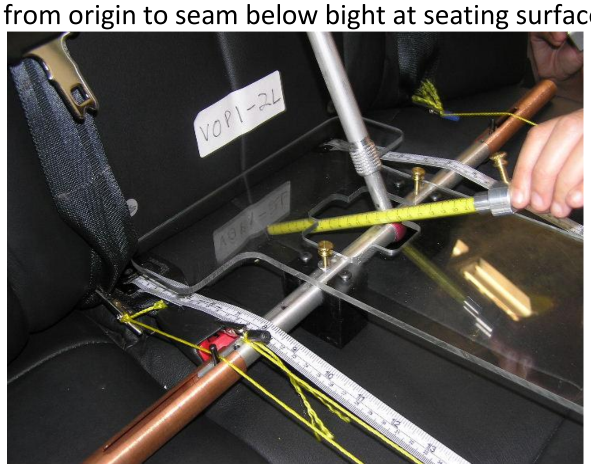
	 • Route each marking string to origin, and secure with tape to front of seat so string is perpendicular to origin bar • Adjust vertical rods to meet base of head restraint • Photo: front views of each seating position (cushion and seatback)	
3a	Measure cushion • Place square on T-plate and position against front of cushion • Record cushion length. Add 405 mm to value read from yellow gauge on square.  • Measure cushion angle relative to horizontal	Cushion length Floor height Cushion angle

	 • Measure floor height to inside corner of square, aligning tape to be parallel with square 	
3b	Measure lower anchor and seatbelt locations • Starting from left outboard, measure distance to the centerline of the reference fixture from the tape and string indicators where they cross the origin • For each lower anchor, record distance from LA to origin  • For each lower anchor, record angle of tape	LA1y, LA2y, LA3y, LA4y, LA5y, LA6y B1y, B2y, B3y, B4y, B5y, B6y LA1d, LA2d, LA3d, LA4d, LA5d, LA6d LA1a, LA2a, LA3a, LA4a, LA5a, LA6a

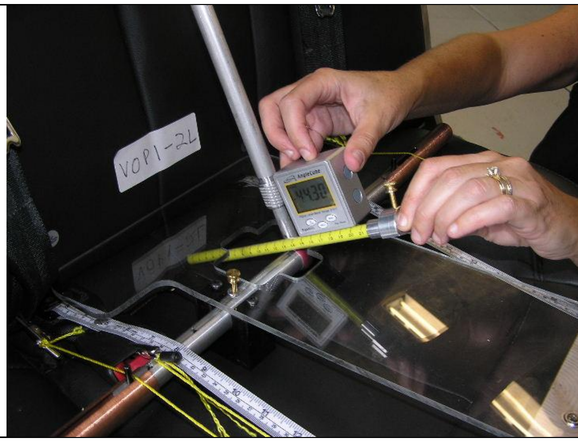
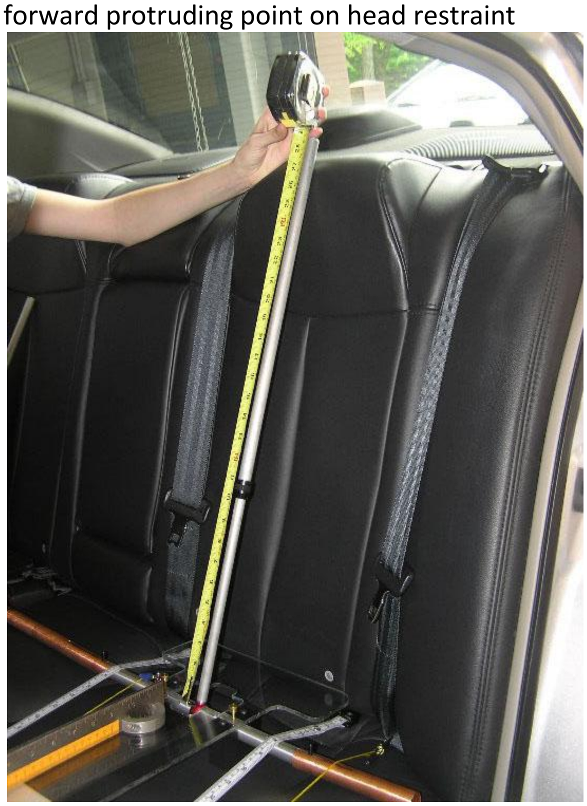
	between LA and origin  • Photos: front view close up of bight at each seating position	

<table>
<tr>
<td>3c</td>
<td>Document bight geometry
• For each seating position, record distance from origin to bight near centerline


• For each seating position, record angle from origin to bight near centerline


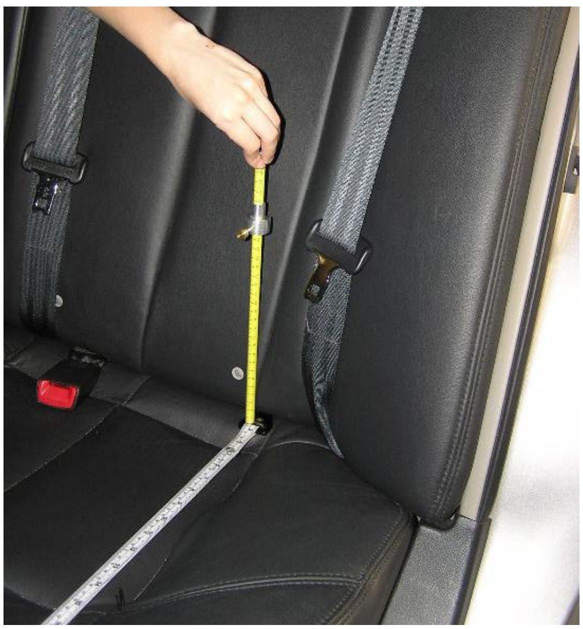
• If seat has a bightline waterfall, record distance from origin to seam below bight at seating surface


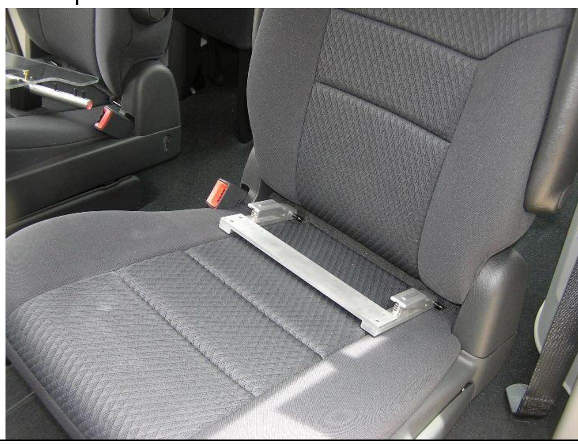
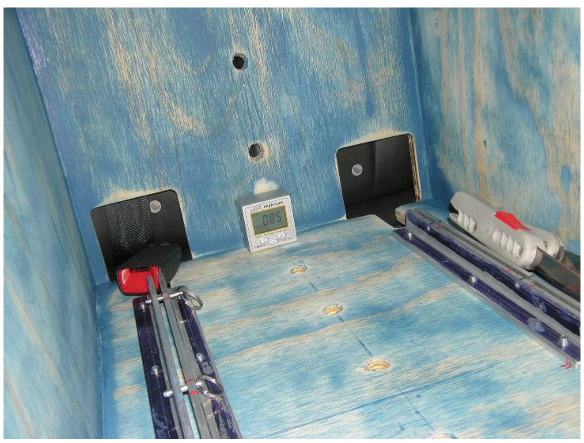
• If seat has a bightline waterfall, record angle from origin to seam below bight at seating surface</td>
<td>BightRd, BightCd, BightLd
BightRa, BightCa, BightLa
SurfRd, SurfCd, SurfLd
SurfRa, SurfCa, SurfLa</td>
</tr>
</table>

	 	
3d	Document head restraint position • Measure distance from origin to point on seatback below base of head restraint • Measure angle from origin to point on seatback below base of head restraint • Extend vertical rod so it extends beyond most forward protruding point on head restraint  • Measure distance from origin to head restraint tangent point • Measure angle from origin to head restraint tangent point	Head restraint base distance Head restraint base angle Head restraint tangent distance Head restraint tangent angle

		
3e	Lateral locations of tether anchors • Attach hooked tape to tether anchor. • Route the tape to the front of the seatback so it is parallel with vehicle centerline. • Measure lateral distance to tether anchor relative to the centerline of the vertical rod. 	TAy SBy
3f	Document distance to tether • Attach standoff to vertical rod • Adjust rod height to 563 mm above origin • Adjust standoff to be 300 mm above origin • Route the tape (already attached to tether hook) as directed by vehicle manufacturer. • Measure wrap around distance to tether.	TAd

	 Remove reference fixture	
3g	Photo: overall view of each row without measurement device, include head restraints and shoulder belt anchors	
4a	For rows with two pairs of outboard lower anchors, indicate whether a child restraint can be installed in the center position using the inboard lower anchors If yes, photo of center seating position at bight	Center seat use
4b	Document head restraint type: fixed, adjustable, removable Photo of each type of head restraint	Type of head restraint
4c	Document seatbelt characteristics Type of buckle stalk: webbing, plastic-covered webbing, fixed rigid, rotating rigid Type of latch plate: sliding or locking Detachable shoulder belt Y/N Switchable retractor: Y/N Shoulder belt guide: Y/N Adjustable shoulder belt height: Y/N Photo of each type of D-ring attachment Photo of each type of buckle	Buckle stalk type Latch plate type Detachable shoulder belt Switchable retractor Adjustable shoulder belt anchor
4d	Document seat characteristics Seatback type: fixed, adjustable, stowable Cushion stiffness: high, medium, low	Seatback adjustability Cushion stiffness
4e	Document buckle stalk length Measure length of buckle stalk from point where it contacts the seat cushion to where the buckle tab is inserted	Buckle stalk lengths
4f	Document LA marker location • Attach hooked tape to lower anchor. • Measure lateral position of LA marker relative to center of LA.	

	 • Document vertical position of LA marker relative to center of LA  • Photo: each pair of markers	
5a	Document seating position where LATCH components are being evaluated 1R, 2L, 2C, 2R, 3L, 3C, 3R If using lower anchors takes up two seating positions, document seating position as 2LC, 2RC, 3LC, or 3RC	Seating position
5b	Qualitative lower anchor assessment Indicate whether LA are visible If not visible, describe why: door, flap, buried, ?? Indicate type of LA markers: none, button, patch Indicate LA marker color: matching, contrasting Indicate LA maker symbol: circle, ISO symbol Indicate presence of confusing hardware.	Visible LA LA cover LA type LA color LA symbol Confusing LA hardware
5c	Qualitative tether anchor assessment Indicate TA location: package shelf, seatback, floor, roof, under seat	TA location Visible TA TA cover

	Indicate whether TA are visible If not visible, describe why: door, flap, carpet Indicate if tether router is present YN Indicate tether marker type: none, imprint, ?? Indicate symbol: anchor, anchor/CRS, text Indicate presence of confusing hardware How should tether be routed around head restraint? Over, under, remove HR, around	Tether router Tether marker Tether symbol Tether confusing hardware Tether head/restraint routing
6a	Check collinearity Apply collinearity fixture to the LA. Make up to three attempts. Record whether the tool can be attached. 	Collinear?
7a	Measure lateral angle • Retract anchors into CRS. • Place CRF on vehicle seat so access holes align with lower anchors.  • Record lateral angle.	Lateral angle
7b	Install CRF at LATCH position. Make up to three attempts.	CRF install

		
7c	Measure pitch angle • If CRF cannot be installed, retract anchors and place CRF on vehicle seat so access holes line up with lower anchors. • Measure pitch angle 	Pitch angle
7d	Record cushion and seatback contour • Using depth gage, record gap between base of CRF and cushion at each hole 	CG0, CG100, CG200, CG300, CG400, CG500 SG0, SG100, SG200, SG300, SG400, SG500

	 • Using depth gage, record gap between back of CRF and cushion at each hole 	
8	Measure attachment force for each lower anchor • At each LA, apply force tool and determine the easiest angle of approach • Record target angle • Apply force at target angle and record force and angle • Repeat twice	Target angle Force1, force2, force3 FAngle1, Fangle2, Fangle3
9a	Measure angle range for each lower anchor • At each LA, attach angle tool and position it near horizontal. • Apply 15 lb of force in the vertical direction. • Record angle of tool and force. • Repeat twice.	Angle1, Angle2, Angle3 Aforce 1, Aforce2, Aforce3
9b	Check for rigid interference • At each LA, attach angle tool and position it near horizontal. • Rotate angle tool upwards until it reaches a 75 degree angle. • Document any contact between the tool and a rigid component. • Document what the tool contacts.	Interference? Contact description

Appendix C: Summary of Proposed SAE Recommended Practice

1) Can the child restraint fixture attach to the lower anchors?

Both FMVSS 225 and CMVSS 210.2 use a child restraint fixture (CRF) (Figure 53) to help define seat geometry relative to locations of lower anchors. The fixture represents the nominal largest child restraint profile, combining both forward-facing and rearward-facing geometry, and has rigid lower connectors. The procedure specifies that the fixture should be attached at each seating position equipped with LATCH. This ensures that the vehicle lower anchors can be used with rigid lower connectors, and minimizes potential interference between the child restraint and vehicle seat, head restraint, or other vehicle structures. The sides of the fixture can be removed to allow easier placement into the vehicle rear seat.

Figure 53. CRF installed in vehicle and close-up of rigid connectors.

2) Is the force to attach lower anchors less than 75 N (16.9 lbf)?

SAE developed a tool (Figure 54) to measure the force required to attach a connector to the lower anchor. The tool represents the nominal shape of a generic lower connector and is used in conjunction with a force gauge to measure the attachment force when the tool is fully engaged with the lower anchor. SAE specifies that the tool should be engaged while holding it parallel to the vehicle seat cushion. The practice recommends an attachment force less than 75 N (16.9 lbf) for good usability.

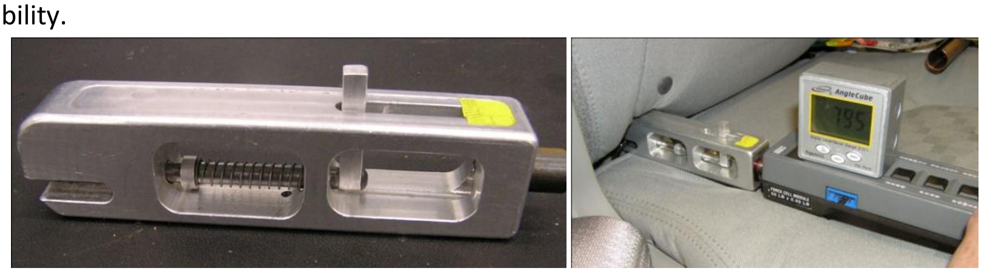


Figure 54. Tool used to measure lower anchor attachment force (left) and in use with force gauge (right).

The measurement of the attachment force could not be performed as specified in the draft recommended practice. The SAE document indicates that the tool should be attached to the lower anchor while sliding it along the surface of the vehicle seat cushion. However, on many vehicles, it was not possible to attach the tool from this angle, especially on vehicles with a bightline waterfall feature (which locates the bight some distance above the seating surface). When trying to attach the tool ignoring this specification, the measurement was not repeatable among different experimenters. In an effort to improve repeatability, the experimenter first determined the angle of approach for attachment that seemed to provide the least resistance. This angle was recorded, and then the force was measured three times while trying to maintain this angle.

3) Is the clearance angle around the lower anchors greater than 75 degrees?

   The seat structure and stiffness around the lower anchors should allow sufficient clearance to attach a child restraint connector and to allow that connector to align with the belt path when the child restraint is tightened. To measure the clearance, the tool shown in Figure 55 is attached to the lower anchor. As shown in Figure 56, a vertical force of 15 lbf is applied to the tool, and the angle of the tool under this applied force is measured. Recommended practice is to allow at least 75 degrees of clearance relative to horizontal.

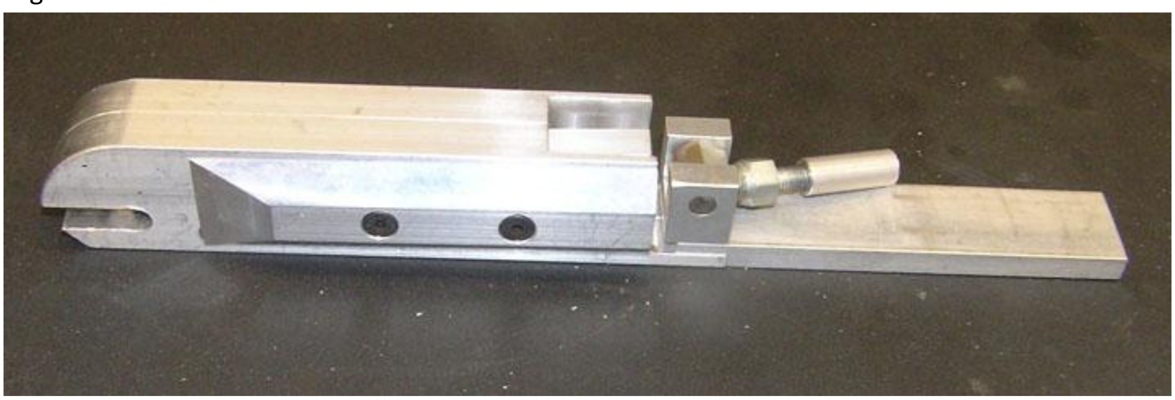


Figure 55. Tool used to measure lower anchor clearance.

Figure 56. Method of measuring lower anchor clearance.

4) When resting unattached on the vehicle seat, is the fixture lateral angle +/- 5 degrees?

When the fixture is placed on the seat the lateral angle should be +/- 5 degrees (Figure 5). The fixture is designed so its rigid connectors can be retracted so it is not attached to the vehicle. The intent of this test is to prevent the seat cushion contour from causing too much lateral tipping of the CRS.

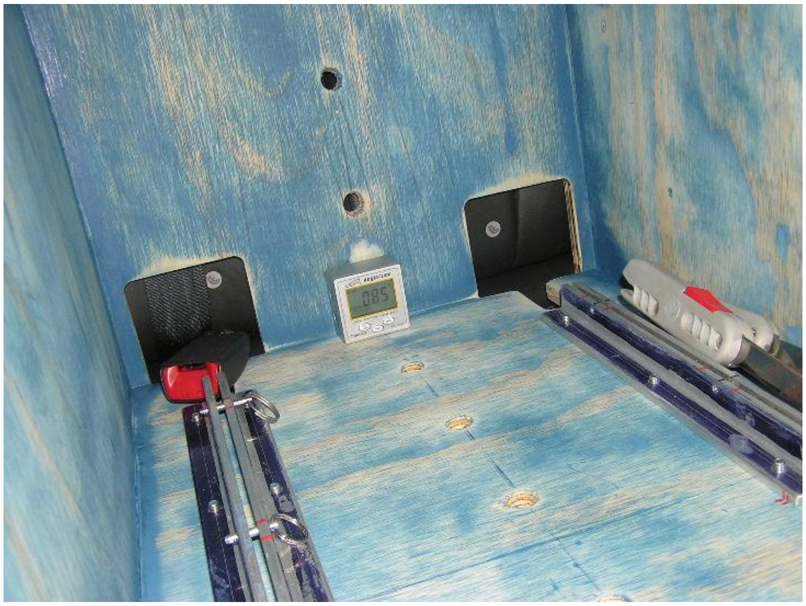


Figure 57. Measuring lateral angle of CRF resting on vehicle seat with rigid connectors removed.

5) When installed on the lower anchors, is the pitch angle of the fixture between 5° and 20°?

When the fixture is installed using the rigid connectors, the pitch angle about the vehicle y-axis of the bottom of the fixture must be 15° + 5°/-10°. This ensures that a child restraint installed with rigid connectors is at an appropriate angle.

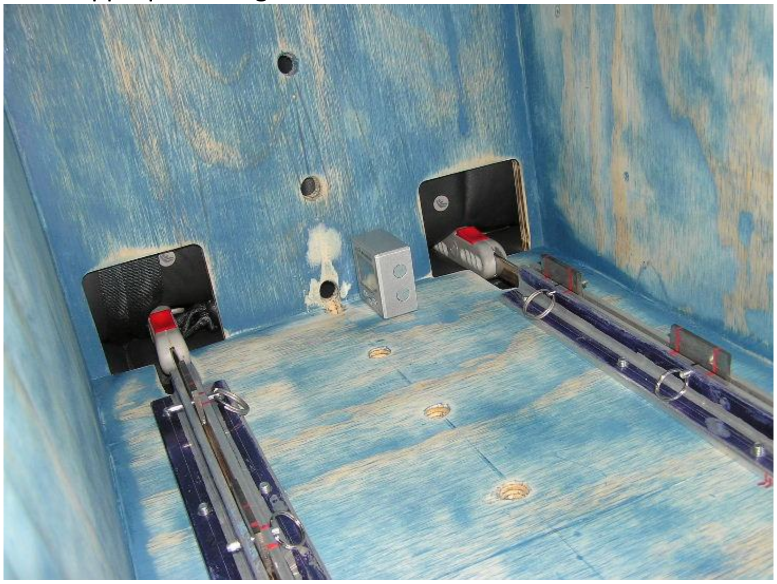


Figure 58. Measuring pitch angle of fixture when installed at a LATCH position.

6) Does the collinearity tool attach to the lower anchors?

While FMVSS 225 places a tolerance on the distance between each pair of lower anchors, it does not specify a tolerance on how the two anchors align. SAE recommends that the anchors should be collinear within +/- 5 degrees. The tool shown in Figure 59 cannot be installed on a pair of lower anchors if they exceed the specification. Figure 60 illustrates the tool installed in a vehicle.

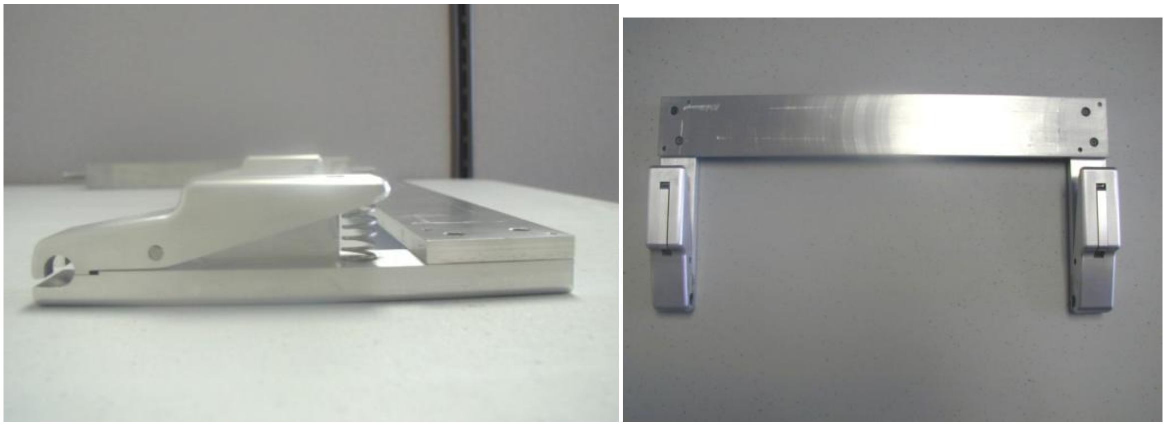


Figure 59. Side and top views of collinearity tool.

Figure 60. Collinearity tool installed in the vehicle.

7) Does the angle measurement tool contact any rigid structure around the lower anchors?

SAE recommendations specify that there is no rigid structure (from the seat or seatbelt hardware) near the lower anchor that might inadvertently engage the release button of a lower connector. An angle measurement tool (Figure 55) is attached to the lower anchor and rotated from the seat cushion to the seat back, and the vehicle would fail if the tool contacts any rigid structure.

8) When installed, is the distance from the Z-point on the fixture to the cushion less than 51 mm?

The draft recommended practice evaluates whether the seat contour may prevent good contact with the child restraint. To assess this, the fixture is attached to the lower anchors, and the gap between the seat cushion and the rearmost bottom point on the fixture centerline is measured. The gap should be less than 51 mm to ensure good contact between the vehicle seat and child restraint. An earlier version of the recommended practice suggested that the gap between the fixture and seat cushion also be measured and limited at a location 300-400 mm forward of the Z-point, but this was not included in the latest version.

9) Are tether anchors marked with ISO symbol?

The recommended practice suggests that the tether anchor be marked with one of the ISO symbols shown in Figure 61.

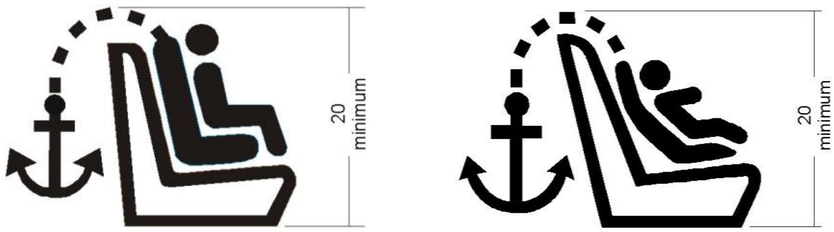


Figure 61. ISO tether anchor symbols.

10) Are lower anchors marked with ISO symbol?

The recommended practice suggests that each lower anchor be marked with the ISO symbols shown in Figure 62.

Figure 62. ISO lower anchor symbol.

11) If a tether router is present, does it accommodate the clearance tool?

Some vehicles use a tether routing device to redirect a tether towards an anchor that is offset from the centerline of the vehicle seating position. The SAE recommended practice uses a tool shown in Figure 63 to ensure that the tether routing device provides sufficient clearance to allow the tether hook and adjustment hardware to pass through it.

Figure 63. Using the tether router clearance tool (left=pass, right=fail).

Modifications to SAE Protocol

The SAE recommended practice did not address some aspects of the vehicle setup prior to measurement. The following settings were used:

- Setting adjustable seatbacks to approximately the design seatback angle
- Positioning head restraints in upright position
- Moving front seats out of the way, as necessary
- Allowing movement of seatbelt hardware, as needed, to attach CRF

The head restraint was positioned in the upright position in all vehicles, regardless of the manufacturer specification for head restraint position during child restraint installation, to provide more uniform measurements across vehicles that were expected to be most consistent with the location of fixed head restraints. In addition, positioning the head restraint in the most upright position would be expected to produce the least amount of interference when installing the fixture and larger child restraints.

Appendix D: Summary of Proposed ISO Protocol to Assess LATCH Usability

Child restraint assessment

For the child restraint assessment, the first section evaluates how well the child restraint labels and manuals convey how to prepare and use the lower anchors and tethers and how to remove LATCH. This section also assesses whether the information conveyed in the labels is consistent with the manual. The highest scores are awarded if the labels and manuals are primarily graphic and can be understood without text. The second part of the assessment evaluates whether the CRS, lower connectors, and tethers are ready to use.   It also examines the possibility of misrouting the LATCH belt and thereby interfering with the harness adjustment, and assesses whether the tether can be operated with one hand.

Vehicle assessment

The first section of the vehicle assessment evaluates whether the manual clearly indicates the locations of the lower and tether anchors, and whether the manual is clear regarding how the tether should be routed. The next section assesses whether the lower and tether anchors are visible and marked with the recommended ISO symbols. In addition, the vehicle is assessed to determine if the tether anchor hardware is unambiguous or whether there is potential for confusing it with other hardware.

The actions required to use the lower anchors and tether anchors are assessed. The type of any covering for the lower and tether anchors is noted because the ISO form records whether there are any steps needed to prepare to use the anchors, and some may require opening a door or panel to access the anchors.

The ISO form evaluates how usable the anchors are according to the following descriptions:

- Good: can attach on each anchor without additional actions?, sufficient clear space around the anchors
- Average: can attach on each anchor after single action, e.g. one-handed depression of seat cushion, or moving seat belt buckle or other feature such as head restraint out of the way
- Poor: cannot attach or not accessible without tools, physically modifying seat, or extreme effort.

For the current evaluation, data collected from some of the SAE procedures were used to quantify whether the anchors were usable according to the qualitative descriptions of the ISO rating system. Tether anchor usability was given a score of good unless there was a tether routing device that did not accommodate the SAE tool for checking clearance, which was given a score of poor.   Lower anchor usability was given a score of poor if the measured attachment force was 30 lb or greater, if the clearance angle was less than 40°, if the anchor depth within the bight was over 8 cm, or if the clearance angle tool could not be attached to the anchor. These factors were considered to be extreme effort. Lower anchor usability received an average score if the anchors were located 6-8 cm within the bight, because this depth would require depression of the seat cushion to access.   Other lower anchor conditions receive a good score.

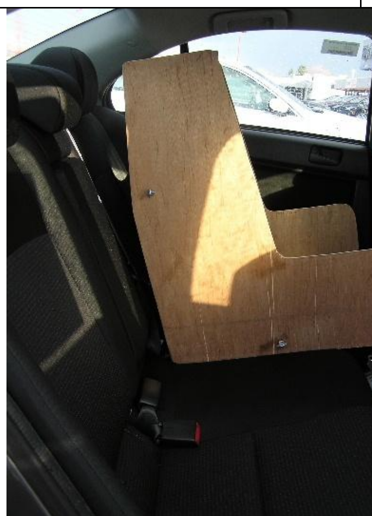
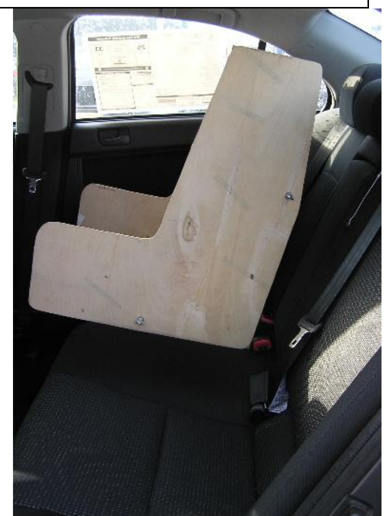
Finally, the potential for interference from seatbelt hardware with use of the lower anchors is assessed two ways. Vehicles receive a poor rating if the measurement notes indicate potential contact with a rigid structure. Lateral measurements described below were used to document the minimal distance between each lower anchor and the nearest belt webbing or hardware. Vehicles receive a poor score if the minimal distance for the 2L seating position is 0-35 mm, average if the distance is 36-70 mm, or good if the minimum distance is at least 71 mm.

Vehicle/Child restraint interaction

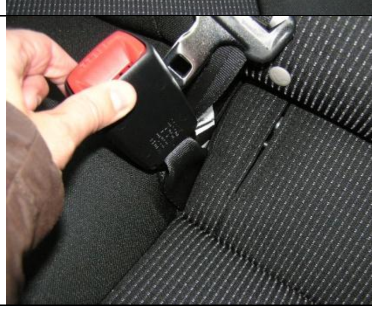
For the vehicle/child restraint interaction assessment, the procedure first examines whether the lower anchors are usable with this particular child restraint, whether they remain accessible during installation, and what type of feedback is available (visible/tactile/audible) to determine if the lower connectors are appropriately attached. The form is used to assess whether the LATCH belt can be tightened, although this refers to the ability to adjust the LATCH belt, not whether it can be tightened sufficiently. It also assesses whether the harness can be adjusted after installation and if there is potential for hidden slack in the LATCH belt. -The ISO evaluation also assesses the actions to attach the tether, whether it can be tightened, and what type of feedback is available to ensure correct attachment. If the child restraint has a separate base, the form is used to record whether the shell and base are ready for installation, the actions required to attach the shell to the base, feedback available on connection, and the number of actions to remove the shell from the base. Finally, the form is used to record the ease of releasing the tether and LATCH belt tension, the actions required to remove the LATCH belt, and the actions required to detach and store the tether. The form includes a few other assessments to address features relevant to design features found primarily on European child restraints, such as a support leg.

Appendix E: Sample vehicle picture set

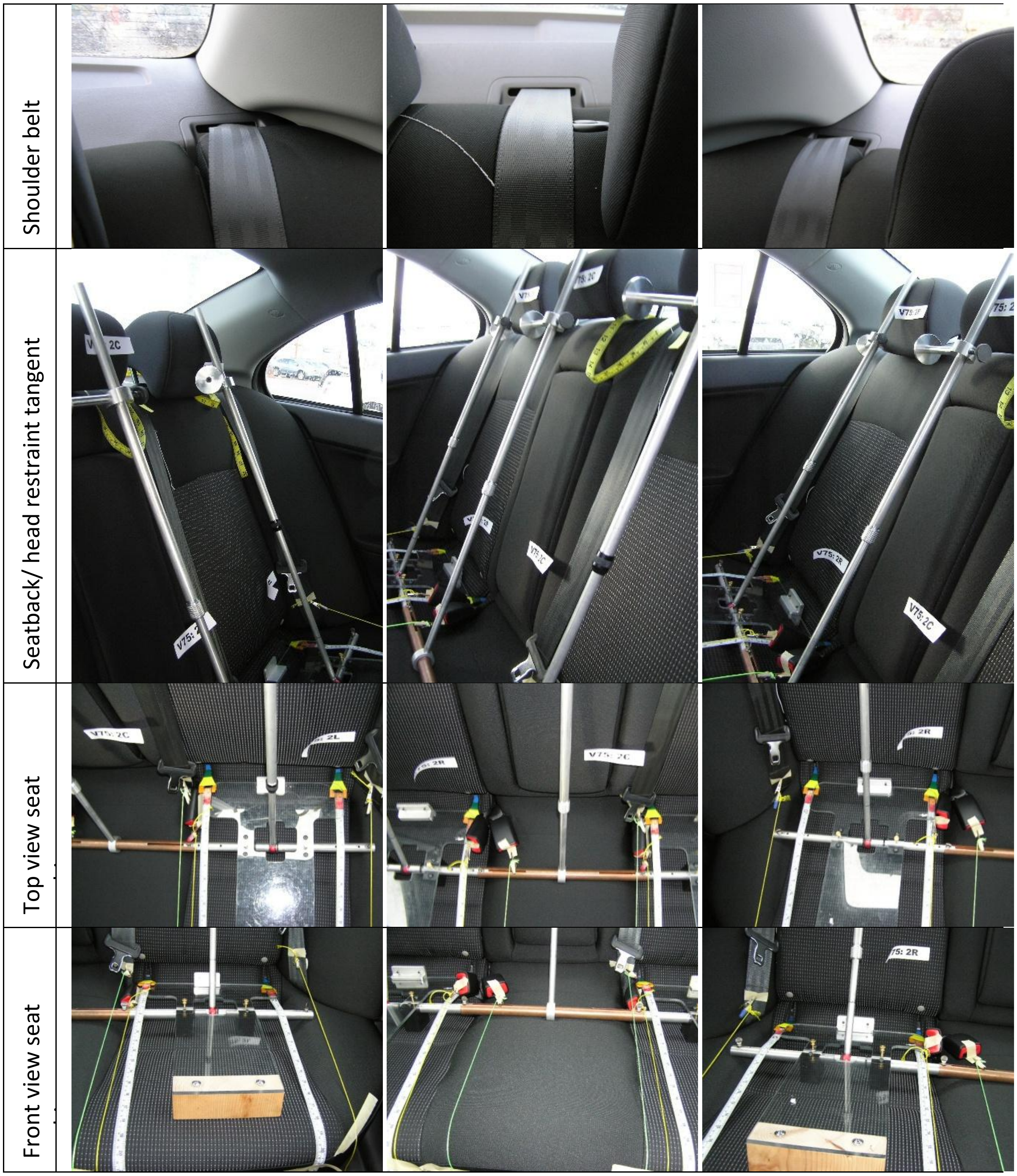
Appendix E: Sample vehicle picture set

Vehicle	Mitsubishi Lancer		
	2L	2C	2R
CRF installation			
Tether			
Tether (open)			
Tether close-up			

Appendix E: Sample vehicle picture set

Tether wrap			
Bightline waterfall			
Seat cushion contour			
Belt webbing			
Belt buckle			

Appendix E: Sample vehicle picture set



Appendix E: Sample vehicle picture set

Appendix F: Testing Script

Testing Script/Protocol

Thanks for coming in today. We're doing a study on how people install child seats. We are going to ask you to install different child seats in different vehicles today. You can use the instructions for the child seat and the vehicle. Let me know each time when you are done. When you are done, I will take some measurements, and you will answer some questions. Then we will go onto the next child seat and vehicle.

You might want to remove your jewelry. Please remember that most people make mistakes when installing child seats. We want you to do your best, but not get frustrated. We are testing the child seats and vehicles, not you.

This is a consent form for you to be in our study. Please look through it and let me know if you have any questions. I will give you a copy of the form to keep.

Give subject consent form to read and sign.

This cart has things you can use for installing the child seat. The instructions for the vehicle are stored in the glove compartment (or where they are), and the instructions for the child seat are here on the cart.

Pool noodle and child restraint and its unstored manual will be on test cart.

____

When installing infant seat:

Please install this seat rear-facing in the __________position of this vehicle. By rear-facing, I mean the child is facing the trunk. We want you to install the child seat using the SEATBELT/LATCH. For this child seat, we want you to place this baby dummy in it.

Tester will tell subject whether to use seatbelt or LATCH and the position chosen for installation. Use 6MO CRABI dummy. Base should be separate from the shell. Harnesses should be preadjusted to fit dummy. LATCH belt should be stored.

When installing convertible rear-facing:

Please install this seat rear-facing in the __________position of this vehicle. By rear-facing, I mean the child is facing the trunk. We want you to install the child seat using the SEATBELT/LATCH. For this child seat, we want you to place this toddler dummy in it.

Use 18MO CRABI dummy. Recline should be adjusted for rear-facing Harnesses should be preadjusted to fit dummy. LATCH belt should be routed for rear-facing, then stored. Tether should be stored.

When installing convertible forward-facing:

Please install this seat forward-facing in the __________position of this vehicle. By forward-facing, I mean the child is facing the same direction as the driver. We want you to install the child seat using the SEATBELT/LATCH. For this child seat, you don't need to use the dummy.

No dummy used in forward-facing installations. Recline should be adjusted for forward- facing. LATCH belt should be routed for forward-facing. LATCH belt and tether should be stored.

When installing forward-facing-only child seat:

Please install this seat forward-facing in the __________position of this vehicle. By forward-facing, I mean the child is facing the same direction as the driver. We want you to install the child seat using the SEATBELT/LATCH. For this child seat, you don't need to use the dummy.

No dummy used in forward-facing installations. Recline should be adjusted for forward- facing. LATCH belt and tether should be stored.

For seventh trial if subject has agreed:

This time, we would like you to install your child seat in the ________ position of this vehicle using LATCH.

If a rear-facing restraint, offer the use of the dummy so the subject can check the installation angle.

Record start time of installation:

If subject tries to install CRS in a different position, note it on check form and say

For today's study, we would like you to install the child seat in the xx position.

If subject can't find the instructions for the child seat or vehicle and asks for help, experimenter can show them where they are.

If the subject asks the experimenter questions, say **"I'm not allowed to help you, but you can find information about that in the manuals for the child seat and the vehicle."**

If subject asks if they have to use the instructions, say **"You don't have to, but they are here if you need them."**

If the subject asks the experimenter to assist with a particular task, say **"I'm sorry I'm not allowed to help you. Just do your best without hurting yourself or getting too frustrated."**

If subject says "I can't do this", state **"OK, please try and finish the installation except skip this part."**

Record end time of installation.

Give subject questionnaire and direct them to fill it out behind a screen so they can't view the experimenter checking installations.

Assess installation using check form. Prepare for next installation.

If you want to look at the vehicle or child seat to answer the questions, let me know.

If so, experimenter will pause assessment while subject reviews labels on installed child seat. Experimenter can answer questions about filling out the form, such as identifying CRS features (e.g. this is the tether).

Repeat installations until 8 installations are complete or less than 15 minutes left in the test session.

Thanks for being in our study today.

Please fill out this form so we can pay you.

If subject decides to drop out of the study, pay $12/hour rate for their participation so far.

If subject asks how they did, experimenter is allowed to provide a general assessment such as

"You did pretty good", "You improved between the first and last", or "There's a some areas that could be improved like tightness of the installation."

Here is some information about the things we are looking at, and here is information about how you can get your car seat checked at the UM hospital.

Provide subject with SafetyBeltSafe handout on "Quick Checklist for Safety Seat Misuse" and flier for Mott Buckle Up Hotline (fitting station at UM hospital.)

We would also like you to fill out this form. You can still participate if you do not want to fill out this form.

Ask subject to fill out subject questionnaire and race/ethnicity form.

Appendix G: Experimenter Evaluation Form

Appendix G: Experimenter Evaluation Form

Subject ID: Installation number: 1 2 3 4 5 6 7 8

CRS: C1 C2 C3 C4 C5 **Method:** L SB Both

Installed position: 2L 2C 2R 3L 3C 3R **Vehicle:** A B C D E F G H I J K L

Start time: End time: Date: Evaluator:

MANUALS/ INSTRUCTIONS	**Yes**	**No**	**NA**	**Comment**
Did subject use vehicle manual?				
Did subject use child restraint manual?				
Installed as directed (LATCH or seatbelt)?				
Installed in directed position?				
Installed in directed orientation (RF/FF)?				
TIGHTNESS	**Yes**	**No**	**NA**	**Comment**
Does CRS pass 1” movement test?				
Tightness measurement				
LOWER ANCHORS	**Yes**	**No**	**NA**	**Comment**
Fully engaged				
Connectors oriented properly				
Attached to correct vehicle hardware				
LATCH belt flat?				
SEATBELT	**Yes**	**No**	**NA**	**Comment**
Routed correctly through				

belt path					
Seatbelt flat (not twisted)?					
Locked with	**Retractor**	**Locking latch plate**	**Locking Clip**	**CRS Lockoffs**	
Method recommended					
Method used by subject					
ANGLE	**Yes**	**No**	**NA**	**Comment**	
Angle correct?					
Pool noodles used?					
HEAD RESTRAINT POSITION	**Removed**	**Fixed**	**Up**	**Down**	**Mid**
Vehicle manual directions					
Position chosen by subject					
TETHER	**Yes**	**No**	**NA**	**Comment**	
Recommended?					
Used?					
Attached to correct vehicle hardware?					
Oriented correctly?					
Tightness measurement:					
Routing wrt head restraint	**Over**	**Under**	**Inboard**	**Outboard**	**Removed**
Vehicle manual directions					
Method used by subject					

Appendix H: Subject Evaluation Forms

Appendix H: Subject Evaluation Forms

Subject ID: Date:

Installation number: 1 2 3 4 5 6 7 8 **CRS:** C1 C2 C3 C4 C5

Method: L SB Both **Vehicle:** A B C D E F G H I J K L

Check one answer for each question

Do you agree with these statements?	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Don't know**	**NA**
I attached the child seat to the vehicle correctly.							
The vehicle manual is consistent with the child seat manual.							
This installation was harder than what I do at other times							
The vehicle headrest made it hard to install.							
The stiffness of the vehicle seat made it hard to install.							
The shape (or contour) of the vehicle seat made it hard to install.							
The seatbelt buckles got in the way of using LATCH.							

Appendix H: Subject Evaluation Forms

For seatbelt installations

How hard or easy was it to:	**Very Hard**	**Hard**	**Easy**	**Very Easy**	**Don't know**	**NA**
Understand the vehicle instruction manual about installing the child seat						
Figure out how to lock the seat belt						
Figure out where to route the vehicle belt						
Tighten the vehicle seat belt						
Figure out what angle the child seat should be						
Adjust the angle of the child seat						
Use the lock-offs on the child seat that pinch the vehicle belt						
Find the tether anchor in the vehicle						
Attach the tether strap on the top of the child seat to the vehicle						
Tighten the tether strap on the top of the child seat						
Store the LATCH belt						
Store the top tether (if not used)						

Appendix H: Subject Evaluation Forms

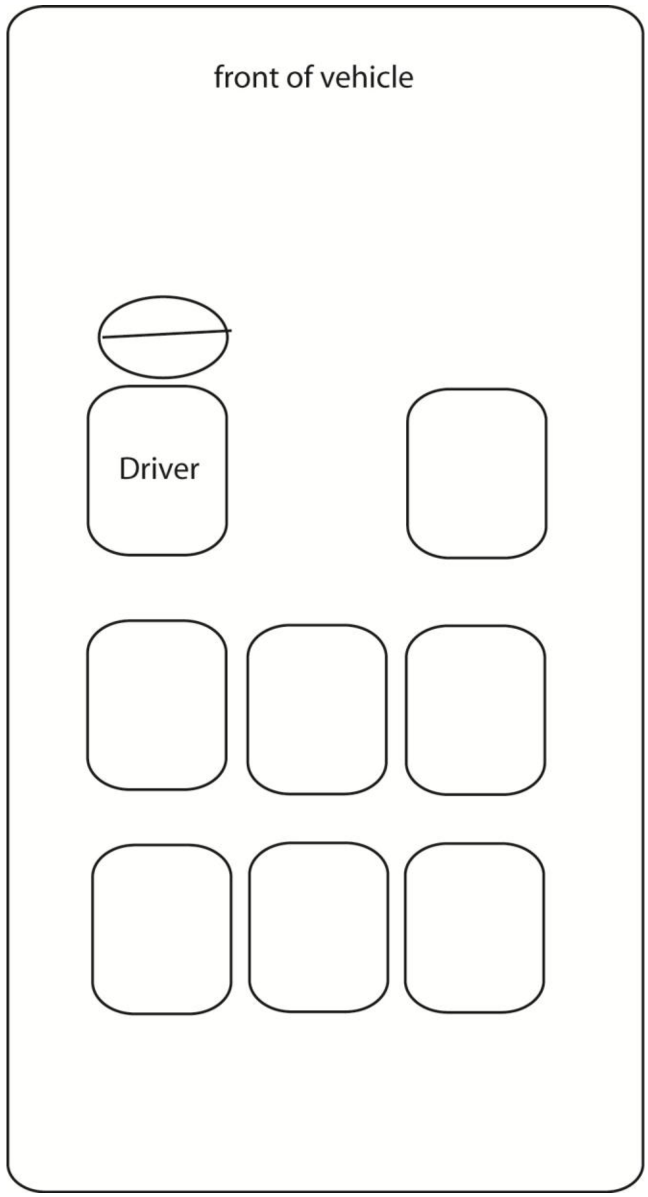
For LATCH installations

How hard or easy was it to:	Very Hard	Hard	Easy	Very Easy	Don't know	NA
Understand the vehicle instruction manual about installing the child seat						
Find the lower anchors in the vehicle						
Find the tether anchor in the vehicle						
Attach the LATCH belt connectors to the lower anchors						
Tighten the LATCH belt						
Figure out what angle the child seat should be						
Adjust the angle of the child seat						
Attach the tether strap on the top of the child seat to the vehicle						
Tighten the tether strap on the top of the child seat						
Store the tether (if not used)						

Put an S in all the positions where you could install a child seat using the seatbelt.

Put an L in all the positions where you could install a child seat using LATCH.

Put a T in all the positions where you can attach a top tether.



Appendix I: Post-session subject evaluation form

Appendix I: Post-session subject evaluation form

Subject ID: Date:

Which method did you like best for installing child seats rear-facing (circle one)

LATCH Seat belt

Which method did you like best for installing child seats forward-facing (circle one)

LATCH Seat belt

When thinking about installing child seats, please give each vehicle a rating about how much you liked it. 1 is worst, 10 is best.

Order	Name of Vehicle	Name of child seat	1	2	3	4	5	6	7	8	9	10
1												
2												
3												
4												
5												
6												
7												
8												

Do you have any suggestions or comments on the vehicles?

Appendix J: Summary of child restraint fixture attachment problems

Appendix J: Summary of child restraint fixture attachment problems

Vehicles in which child restraint fixture could not be attached in any position			
Vehicle code	***Vehicle name***	***Seating positions evaluated***	***Description of interference***
V001	BMW 328i	2L 2R	Outboard anchors were deep and high; stiff seat cushion and seatback; contour of outboard side of seat
V002	BMW 528i	2L 2R	Outboard anchors were deep and high; stiff seat cushion and seatback; contour of outboard side of seat
V005	Chrysler 300	2L 2C 2R	2L/2R: outboard side of roof is too short for CRF to fit. 2C: Anchors are deep and high; could not push up far enough at an angle to latch
V016	Mercedes C-Class	2L 2R	Anchors have small plastic covers on them that are buried in the seats. Could not get the outboard covers off of the lower anchors due to the stiff seatback and seat cushion
V028	Ford Fusion	2L 2R	Contour on outboard side of seatback will not allow you to push far enough rearward to attach
V029	Ford Mustang	2L 2R	CRF won't fit within the seat cushion area. Seat cushion width is approximately 33-cm, CRF is 40-cm
V034	Buick Enclave	2L 2R	Rigid-rotating buckles interfere; contour of bottom of seatback won't allow you to push CRD far enough rearward to attach
V035	Cadillac CTS	2L 2R	CRF won't fit in vehicle - the outboard side of the vehicle roof is too low
V048	GMC Acadia	2L 2R	You cannot get the rigid-rotating buckles out of the way; contour of seatback would not allow you to push CRF far enough rearward to lower anchors
V059	Honda Civic 2-dr	2L 2R	Can't get CRF in car even without the sides. The front seats will not fold down far enough and the door opening is too narrow
V069	Mazda CX-9	2L 2R	Could not push CRF far enough rearward to latch due to rigid seatback and seat contour
V073	Mazda 6	2L 2R	Bottom of outboard side of seatback is so rigid that you can't push CRF far enough rearward to latch
V074	Mitsubishi Eclipse	2L 2R	Roof was too low to fit CRF
V077	Nissan Murano	2L 2R	Could not push CRF far enough rearward to latch due to contour of seatback; top of CRF contacted head restraint
V079	Nissan Sentra	2L 2R	2L: Rigid seatbelt buckle interference; can't push far enough rearward due to the material

Vehicles in which child restraint fixture could not be attached in any position			
Vehicle code	***Vehicle name***	***Seating positions evaluated***	***Description of interference***
			behind the right anchor. 2R: Rigid-rotating seatbelt buckles interfere
V081	Porsche Cayenne	2L 2R	Dealership would not allow me to try and install CRF due to concerns of damage to the vehicle seats
V082	Subaru Forester	2L 2R	Could not push CRF far enough rearward due to outboard contour of seatback; inboard seatbelt buckles interfere
V089	Jaguar XF	2L 2R	Slits in rigid seatback leather are too small to get to anchors
V091	Lexus ES 350	2L 2R	Seatbelt buckle interference and anchors are too far rearward in seat to get CRF far enough rearward to attach. Stiff leather and hard structure in bottom of seatback
V092	Lexus RX 350	2L 2R	Could not safely get CRF in car because I could not get doors safely open all of the way due to the closeness of surrounding cars. (I think it would have attached)
V094	Toyota Corolla	2L 2R	Protruding contour of center seatback would not allow you to push CRF far enough rearward to attach; seatbelt buckle interference
V096	Toyota Matrix	2L 2R	Contour of seat and hard plastic trim on outboard side of seatback got in way of pushing CRF far enough rearward to latch; seatbelt buckle interference
V097	Toyota Prius	2L 2R	Protruding contour of center seatback would not allow you to push CRF far enough rearward; seatbelt buckle interference
V102	Toyota Venza	2L 2R	Contour of seat will not allow you to push CRF far enough rearward to latch; seatbelt buckle interference

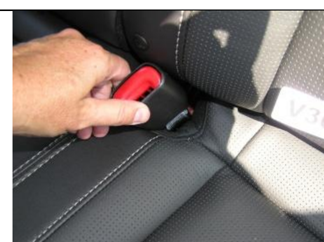
Vehicles in which fixture could be attached in at least one but not all positions			
Vehicle code	***Vehicle name***	***Seating positions where CRF could not be attached***	***Description of differences***
V009	Dodge Charger	2C	CRF was too long to fit in the center seat with the extending center console between the front seats
V018	Mercedes GL-450	3L 3R	Hard plastic surrounds latch anchors, therefore you cannot push up very far and at an angle needed to attach the CRF
V022	Ford Explorer	2L 2R	Hard plastic on bottom of inboard side of seatback will not allow you to push far enough rearward to latch; seatbelt buckle interference
V026	Ford Flex	2L	Could not get attached to right latch due to hard plastic on the bottom of the left center seatback
V033	Volvo XC90	2L	Battery dead in vehicle; could not move power-driver seat forward to fit CRF
V051	Honda Acura MDX	2C	Left anchor is positioned inside a small flap of leather; you could not get the CRF hook to fit inside the flap; seatbelt buckle interference
V063	Hyundai Santa Fe	2R	Could not push CRF far enough rearward to latch due to the outboard contour of the seatback; seatbelt buckle interference
V099	Toyota Sienna	2L 2R	Contour of seatback would not allow you to push far enough rearward to attach; anchors were high in bight and stiff material behind anchors
V100	Toyota Tacoma	1R	Contour of seatback would not allow you to push far enough rearward to attach
V106	Volkswagen Routan	2L 2R	Contour of seatback would not allow you to push far enough rearward to attach; stiff leather behind anchors

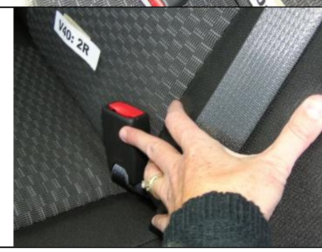
Appendix K: Description and illustration of potential interference with lower anchors

Appendix K: Description and illustration of potential interference with lower anchors

Instances of potential for rigid interference with lower anchors

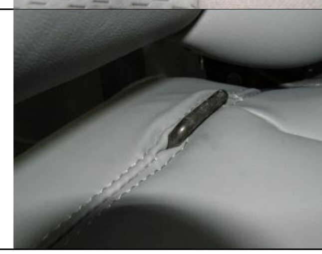
Vehicle code	***Vehicle Name***	***Seating Position***	***Anchor (L/R)***	***Description of interference***	***Picture of interference if available***
V001	BMW 328i	2L 2R	L R	Stiff seat cushion and seatback	
V001	BMW 328i	2R	L	2R seatbelt buckle	
V002	BMW 528i	2L 2R	L/R	Stiff seat cushion and seatback	
V004	Mini Cooper Clubman	2L 2R	L R	Hard plastic piece under latch anchor	
V005	Chrysler 300	2C	L/R	Bar on bottom of seatback; stiff seatback and cushion	

V005	Chrysler 300	2L 2R	L R	Bar on bottom of seatback; stiff seatback and cushion	
V006	Chrysler Town & Country	3LC	L	Cloth surrounding latch anchor is tight	
V018	Mercedes GL-450	2L 2R	L/R	Hard plastic surrounds latch anchors	
V018	Mercedes GL-450	3L 3R	L/R	Hard plastic surrounds latch anchors	
V019	Mercedes ML350	2L 2R	L/R	Hard plastic surrounds latch anchors	
V030	Ford Taurus	2L	R	Seatbelt buckle interference	
V030	Ford Taurus	2C	L	Seatbelt buckle interference	

V040	Chevrolet HHR	2L	R	Seatbelt buckle interference; had to pull seatback forward and push buckles into bight	
V040	Chevrolet HHR	2R	L	Seatbelt buckle interference 2R buckle; had to pull seatback forward and push buckles into bight	
V041	Chevrolet Impala	2L 2R	L/R	Shape of anchor makes it very hard to latch; very small area to hook	No photo
V052	Honda Accord 2-door	2L 2R	R L	Hard structure above right anchor in seatback Hard structure above left anchor in seatback	
V053	Honda Accord 4-door	2L 2R	R L	Hard structure above right anchor in seatback Hard structure above left anchor in seatback	
V058	Honda Odyssey	2L 2R	L/R	Hard structure above anchors in seatback	
V058	Honda Odyssey	2C	L/R	Anchor is small in width	

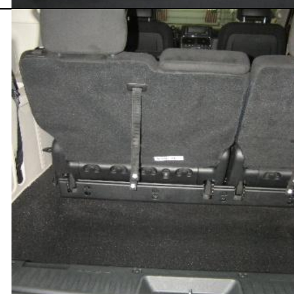
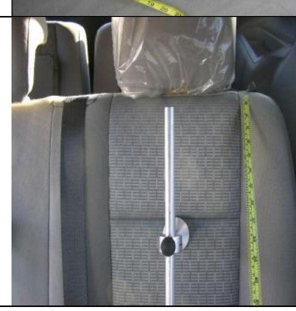
Appendix K: Description and illustration of potential interference with lower anchors

V063	Hyundai Santa Fe	2R	R	Bolt below the anchor		
V073	Mazda 6	2L	R	Hard structure/bar above the anchor		
V079	Nissan Sentra	2L	R	Material behind right anchor will not allow you to push far enough rearward		
V082	Subaru Forester	2L 2R	L/R	Too small of holes cut around anchors in seatback and foam material		
V089	Jaguar XF	2L 2R	L/R	Slits in rigid seatback leather are too small		
V091	Lexus ES 350	2L 2R	L/R	Stiff leather and hard structure in bottom of seatback		
V097	Toyota Prius	2L 2R	L/R	Stiff leather and deep anchors		

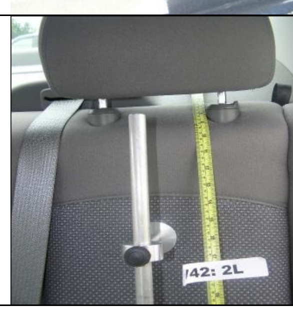
V099	Toyota Sienna	2L 2R	L/R	Stiff seat material in seat cushion behind the anchors won't allow you to push rearward	
V100	Toyota Tacoma	2L	L/R	Material surrounding anchor interferes	
V106	Volkswagen Routan	2L 2R	L/R	Stiff leather behind anchors	

Appendix L: Vehicles with offset tether implementations

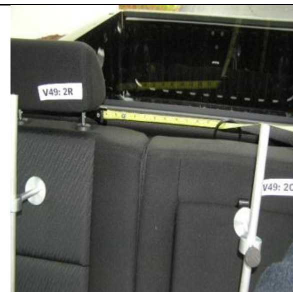
Appendix L: Vehicles with offset tether implementations

Code	Vehicle	Seating Positions	Distance tether to seat centerline	TA anchor Photo
V006		3C	85	
V010		3C	90	
V011		2L, 2C, 2R	450, 450, 450	
V020		2L, 2C, 2R	20, 25, 20	
V022		2L, 2R, 3R	145, 148, 140	

Appendix L: Vehicles with offset tether implementations

Code	Vehicle	Seating Positions	Distance tether to seat centerline	TA anchor Photo
V026		2L, 2R, 3R	130, 135, 135	
V027		2L, 2R	30, 30	
V028		2L, 2R	10, 10	
V040		2C	95	
V042		2L, 2C, 2R	40, 30, 40	

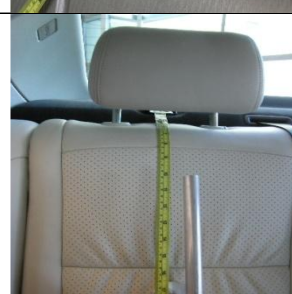
Appendix L: Vehicles with offset tether implementations

Code	Vehicle	Seating Positions	Distance tether to seat centerline	TA anchor Photo
V049		2L, 2C, 2R	445, 415, 410	
V050		2L, 2C, 2R	425, 425, 425	
V053		2L, 2R	32,32	
V059		3C	35	
V066		3C	35	

Appendix L: Vehicles with offset tether implementations

Code	Vehicle	Seating Positions	Distance tether to seat centerline	TA anchor Photo
V070		2L, 2R	35, 35	
V074		2L, 2R	240, 240	
V079		2L, 2R	105, 105	
V080		2L, 2R	34, 34	
V082		2L, 2C, 2R	100, 30, 100	

Appendix L: Vehicles with offset tether implementations

Code	Vehicle	Seating Positions	Distance tether to seat centerline	TA anchor Photo
				
V084		2L, 2R	32, 30	
V085		2L, 2R	50, 50	
V089		2L, 2R	30, 30	
V096		2C	140	

Appendix L: Vehicles with offset tether implementations

Code	Vehicle	Seating Positions	Distance tether to seat centerline	TA anchor Photo
V099		3C	102	
V100		1R	25	
V101		2L, 2C, 2R	440, 450, 420	
V104		2L, 2C, 2R	30, 30, 30	
V106		3L	155	

Appendix L: Vehicles with offset tether implementations

Code	Vehicle	Seating Positions	Distance tether to seat centerline	TA anchor Photo
V107		2L, 2C, 2R	35, 35, 32