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Vehicle Characteristics Associated with LATCH Use and Correct Use in Real-World Child Restraint Installations

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Jessica B. Cicchino

Insurance Institute for Highway Safety

Jessica S. Jermakian

Insurance Institute for Highway Safety

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Abstract

Objective: To determine if vehicle features associated with LATCH ease-of-use in laboratory studies with volunteers predict LATCH use and misuse in real-world child restraint installations.

Method: Vehicle characteristics were extracted from prior surveys of more than 100 top-selling 2010-13 vehicles. Use and correct use of LATCH was determined from records of more than 14,000 child restraint installations in these vehicles that were inspected by child passenger safety technicians at Safe Kids car seat checkup events during 2010-12. Logistic regression was used to examine the association between vehicle features and use and correct use of lower anchors and top tethers, controlling for other relevant installation features.

Results: Lower anchors were more likely to be used and correctly used when the clearance angle around them was greater than 54°, the force required to attach them to the lower anchors was less than 178 N, and their depth within the seat bight was less than 4 cm. Restraints were more likely to be attached correctly when installed with the lower anchors than with the seat belt. After controlling for lower anchor use and other installation features, the likelihood of tether use and correct use in installations of forward-facing restraints were significantly higher when there was not hardware present that could potentially be confused with the tether anchor or when the tether anchor was located on the rear deck, which is typical in sedans.

Conclusions: There is converging evidence from laboratory studies with volunteers and real-world child restraint installations that vehicle features are associated with correct LATCH use.

Practical applications: Vehicle designs that improve the ease of installing child restraints with LATCH could improve LATCH use rates and reduce child restraint misuse.

Keywords: Child passenger safety, children, child restraints, LATCH

1. Introduction

Lower Anchors and Tethers for Children (LATCH) is a system designed to simplify the process of securing child restraints to vehicles. The LATCH system consists of two lower attachments on child restraints that secure to lower anchors located in the vehicle seat bight and replace the seat belt as the primary attachment to the vehicle, and a top tether on forward-facing child restraints that attaches to a tether anchor typically located on the rear deck, seatback, roof, floor, or back wall of the vehicle. In light of high rates of misuse when attaching child restraints to vehicles with the seat belt, LATCH was mandated in the United States for child restraints manufactured beginning in 2002 and passenger vehicles beginning in model year 2003. Most passenger vehicles are required to have two rear seating positions equipped with lower anchors and three rear seating positions equipped with tether anchors.

Although LATCH was intended to make it easier to install child restraints, the system is often not used. Fifty-eight percent of child restraints with lower attachments in vehicles equipped with lower anchors were attached with the lower anchors in a 2007 observational study (Decina & Lococo, 2007). Observational studies have found that the tether was used for 48-56% of forward-facing restraints in vehicles with tether anchors (Decina & Lococo, 2007; Eichelberger, Decina, Jermakian, & McCartt, 2014; Jermakian & Wells, 2011). In a national study of child safety seats inspected at Safe Kids checkup events during 2009-10, the tether was used with 28% of more than 15,000 forward-facing child restraints inspected (Safe Kids, 2011).

Laboratory studies with volunteers have identified vehicle features that make LATCH easier to use. Klinich, Manary, Flannagan, Malik, and Reed (2010) found that the force required to connect attachments to the lower anchors and the visibility of the lower anchors within the seat bight predicted correct lower anchor use when volunteers installed child restraints in seven vehicles. In a more recent study, volunteers instructed to install child restraints in 12 passenger vehicles with the lower anchors used them correctly 60% of the time (Klinich et al., 2013). When instructed to use the seat belt to install the child restraints, it was used correctly in 33% of installations. Incorrect lower anchor installations involved errors such as improperly oriented connectors, twisted LATCH strap webbing, connectors attached to incorrect vehicle hardware, and installations without full engagement. Three vehicle factors were associated with increased odds of using the lower anchors correctly: the depth of the lower anchors

relative to the seat bight, the clearance angle around the lower anchors (i.e., lack of obstruction around the anchors allowing them to be approached from shallow to steeply inclined angles), and the force required to attach the connectors on the child restraint to the lower anchors. Lower anchor depths of less than 2 cm, clearance angles of greater than 54°, and attachment forces of less than 178 N were each associated with correct lower anchor use rates above 50%. Correct lower anchor use was 19 times higher in vehicles meeting all three criteria than in vehicles meeting none of the criteria.

Klinich et al. (2010) also assessed vehicle features related to tether usability when installing forward-facing restraints. The tether was used more often when the tether anchor was located on the rear deck, where it typically is in sedans, than when it was located on the seatback, as is more typical in minivans and SUVs. However, when the tether was used, it was attached correctly more often when the tether anchor was on the seatback. In a subsequent volunteer study involving 16 vehicles with a larger variety of tether anchor locations, the tether was used significantly more often when the tether anchor was located on the rear deck than on the middle or bottom of the seatback, floor, or roof (Jermakian et al., 2014). Tether anchor location on the rear deck was also associated with significantly higher odds of attaching the tether correctly compared with the bottom of the seatback, roof, or floor, and location on the middle of the seatback was associated with higher odds of correct tether attachment than the bottom of the seatback or floor. The tether was less likely to be used and attached correctly if there was other hardware in the vehicle that potentially could be confused with the tether anchor, such as cargo tie-downs near the tether anchor.

The 12 vehicles in Klinich et al.'s (2013) volunteer study were selected to represent a variety of vehicle features, based on measurements of 98 top-selling 2010-11 vehicle models. The goal of the current study was to assess if vehicle features related to LATCH usability in laboratory studies with volunteers also predict real-world use and correct use of LATCH, using data collected during Safe Kids child seat checkup events during 2010-12 on child restraints that were installed in the passenger vehicle models surveyed by Klinich et al. (2013) and Jermakian et al. (2014). Specifically, this study examined if lower anchors were more likely to be used and correctly used when they were not located deep within the seat bight, they could be approached from inclined angles, and a low force was required to attach the connectors on the child restraint to them. The study also examined if tethers were more likely to be used

and correctly used in installations of forward-facing restraints when the tether anchor was located on the rear deck and when there was no other hardware present near the tether anchor that could be confused with it.

2. Methods

Logistic regression was used to evaluate the relationship between characteristics of lower anchors and tether anchors and the use and correct use of LATCH with child restraints. Information on use and correct use of lower anchors and tethers was obtained from car seat checkup events. Characteristics of lower anchors and tether anchors were assessed on over 100 top-selling passenger vehicle models. Details on the data sources and analytical methods used follow below.

2.1. Child restraint system use data

Data on child restraint system use in the study vehicles were collected at car seat checkup events conducted by Safe Kids at locations across the United States during 2010-12. Parents and caregivers voluntarily attend these events and receive assistance from a certified child passenger safety (CPS) technician in installing a child restraint or booster seat or checking to see if the child restraint system is installed correctly. The CPS technician documents information on the child, vehicle, child restraint system, and installation characteristics upon arrival to and departure from the event on a standardized checklist for each child and child restraint device in the vehicle.

Information that was used in this study included the vehicle make, model, and model year; seating position of the child restraint system; general child restraint type; if the child restraint had been checked at a previous similar car seat checkup event; how the child restraint was attached upon arrival (using the lower anchors, seat belt, and/or tether); and if the lower anchors, seat belt, and/or tether were used correctly upon arrival. Correct lower anchor and seat belt use included tight attachment to the vehicle such that the child restraint did not move more than 1 inch side-to-side or front-to-back when pushed with moderate force at the belt path.

All checklist data used in this study were multiple choice except vehicle make, model, and year, which were recorded in write-in fields. Checklists were scanned into the database using optical mark recognition for multiple choice entries and optical character recognition for write-in data. Vehicle make

and model data were reviewed and cleaned to achieve a uniform and analyzable data set. Obvious misspellings or errors in translation, such as substitution of numbers for similar letters, were corrected. In the event of make and model mismatch (e.g., a minivan listed as a Toyota Odyssey), the make was changed to match the model (i.e., Toyota Odyssey changed to Honda Odyssey). Make and model mismatch was rare (<1% of study vehicles).

2.2. Vehicle data

Data on characteristics of relevant vehicle features were obtained from surveys of 98 top-selling model year 2010-11 passenger vehicles conducted by Klinich et al. (2013; see also Klinich, Manary, Flannagan, & Moore, 2012), and of 16 top-selling model year 2012-13 passenger vehicles conducted by Jermakian et al. (2014). Lower anchor characteristics that were assessed included:

- Depth of the lower anchors within the seat bight was measured by connecting a hook to each lower anchor, demarcated in colored 2-cm increments, and evaluating if markings for 0-2 cm, 2-4 cm, or 4 cm or more were visible when viewed from above (Figure 1a).
- Clearance angle represented the angle of approach possible when attaching the connectors on a child restraint to the lower anchors given the seat structure and stiffness. It was measured according to procedures drafted by the Society for Automotive Engineers (SAE, 2009) Child Restraint Systems Subcommittee. A tool developed by SAE was attached to each lower anchor (Figure 1b), and the angle of the tool was measured after a vertical load of 67 N was applied.
- Attachment force was determined based on a modification of SAE (2009) draft procedures in which the force required to attach the tool to each lower anchor was measured as the SAE-developed force tool was attached at the angle that provided the least resistance (Figure 1c).

Detailed descriptions of how the measurements of lower anchor depth, clearance angle, and attachment force were obtained are found in Klinich et al. (2012). Measurements were taken three times at each lower anchor using the same approach angle as the original measurement, and the three force measurements at each anchor were averaged. The larger depth within the seat bight, the larger mean force, and the smaller clearance angle measurement of the two lower anchors in a seating position were used in this study. Clearance angle and attachment force were measured continuously and then were converted into binary wide ($>54^\circ$) and narrow ($\leq 54^\circ$) angle and greater (≥ 178 N) and lesser (<178 N)

force categories for analyses. Clearance angle values greater than 54° and attachment forces less than 178 N were associated with correct lower anchor use rates of greater than 50% in Klinich et al.'s (2013) volunteer study.

Tether anchor characteristics that were assessed included:

- Presence of other vehicle hardware that could be confused with the tether anchor, such as cargo tie-downs or other plausible attachment hardware near the tether anchor, and
- General location of the tether anchor, which included the rear deck, roof, floor, seatback, or back wall/other.

Webbing loops on the seatback were not classified as potentially confusing hardware by Klinich et al. (2013), but were by Jermakian et al. (2014). Unusual tether anchor configurations such as those located in the seat bight or on the side of the rear seat were grouped with the back wall because both usually occurred in pickup trucks. The seatback was not divided into the middle and bottom of the seatback, as it was by Jermakian et al. (2014), because position on the seatback was not specified in the data for vehicles surveyed by Klinich et al. (2013).

Study vehicles included the range of model years for which the design was unchanged from the model(s) assessed in the vehicle surveys. For example, Klinich et al. (2013) measured the 2011 Nissan Altima, which underwent major design changes in the 2007 and 2013 model years; thus, study vehicles included model year 2007-12 Nissan Altima models. Multiple vehicles of certain vehicle models that varied in body style, trim level, and/or model year within the same generation were measured in the vehicle surveys, which for 10 vehicle models produced different measurements for lower anchor characteristics. In these cases differences in measurements for a vehicle model may have occurred for a variety of reasons, for example, variations in seat configurations, seat coverings, and manufacturing tolerances, or issues with measurement repeatability. In car seat checkup events, vehicle make, model and year are recorded but details of body style, trim level, seat configurations, or seat coverings are not captured. In order to combine data from the vehicle surveys with the real-world data, all vehicles within a vehicle model were grouped and assigned the characteristics or measurements relating to lower anchors with the lowest predicted use rates or correct use rates of the lower anchors based on the Klinich et al. (2013) usability study. When lower anchor-related measurements were taken in two or more vehicles of

the same vehicle model, the largest depth within the seat bight, the largest mean force value, and the smallest clearance angle value among all lower anchors in each seating position (e.g., left and right lower anchors of the seating position in variation A and left and right lower anchors of the seating position in variation B) were used in analyses.

A similar methodology was applied for vehicle models with conflicting tether anchor characteristics among the surveyed vehicles. Vehicle models included in both surveys were categorized as having confusing hardware if it was identified as such by Jermakian et al. (2014), who used an expanded definition of hardware that could be confused with the tether anchor. This characteristic did not vary among vehicles of the same model that were assessed in the same survey. Tether anchors were in different locations in seating positions of two vehicles surveyed because while the vehicles are the same base model, the body types were different. The left and right second-row seats on the Mazda 3 had tether anchors located on the rear deck of the sedan, but tether anchors were on the seatback in the hatchback; these tether anchors were categorized as located on the seatback. The tether anchor of the left second-row seat of the Chevrolet Silverado was located on the back wall for the crew cab or seatback for the extended cab, and was categorized as located on the back wall.

2.3. Analyses

Chi-square analyses were used to preliminarily assess the relationship between lower anchor characteristics and tether characteristics and correct use rates of lower anchors and tethers. The Mantel-Haenszel chi-square statistic was used to test for linear trends in lower anchor correct use rates by lower anchor depth, and the Pearson statistic was used in other chi-square analyses. Logistic regression was used to conduct a more rigorous examination of the effect of lower anchor characteristics and tether characteristics on use and correct use of lower anchors and tethers, respectively, after controlling for other installation features that may affect LATCH use.

Separate regression models were fit for each combination of lower anchor-related vehicle predictor (depth of lower anchors within seat bight, force required to attach connectors to lower anchors, and clearance angle around lower anchors) and outcome in installations of rear-facing infant seats or bases, rear-facing convertible restraints, and forward-facing child restraints. Outcomes for lower anchor use and correct use included:

- Use of the lower anchors instead of the seat belt,
- Correct attachment of the lower anchors when they were used, and
- Correct attachment of the lower anchors among installations using the lower anchors or seat belt.

Installations of rear-facing infant seats without bases were excluded. Models controlled for the type of child restraint and if the child restraint had previously been checked.

In the lower anchor measurement data set, clearance angle varied significantly by lower anchor depth ($\chi^2[1]=39.8, p<0.0001$) and attachment force ($\chi^2[2]=30.7, p<0.0001$), but lower anchor depth and attachment force were unrelated ($\chi^2[2]=1.5, p=0.47$). A model examining each outcome measure was constructed using both lower anchor depth and attachment force as predictors to examine their independent contributions to lower anchor use and correct use, and clearance angle was not included in any models with other predictors.

Separate regression models were also fit for each combination of tether-related vehicle predictor (presence of confusing hardware and location of tether anchor) and outcome in installations of forward-facing restraints in seating positions for which tether anchor characteristics had been assessed.

Outcomes for tether use and correct use included:

- Use of the tether in installations of forward-facing restraints, and
- Correct tether use among installations of forward-facing restraints.

Preliminary models indicated that the tether-related vehicle predictors were not significantly related to correct tether attachment when the tether was used, and these models are not presented. Tether models controlled for lower anchor use, which has been associated with tether use in prior observational and volunteer studies (Eichelberger et al., 2014; Klinich et al., 2010, 2013), and if the restraint had previously been checked. Tether anchor location and the presence of confusing hardware were closely related in the tether anchor measurement data set ($\chi^2[4]=24.7, p<0.0001$) and were not included together in models.

Analyses were based on known values. Among the 16,506 installations of included restraint types in seating positions of study vehicles with lower anchors, attachment type was unknown in 4% and previous restraint check was unknown in 6%. Correct use of the lower anchors or seat belt was unknown in 4% and 9% of installations using those attachment methods alone, respectively. Among the 2,880

installations of forward-facing restraints in seating positions where tether characteristics were assessed, attachment type was unknown in 7% and previous restraint check was unknown in 5%. Correct use of the tether was unknown in 3% of installations when it was used. Analyses examining correct attachment of the lower anchors in installations using the lower anchors alone and the seat belt alone excluded installations where the lower anchors were used but correct use was unknown, and analyses examining correct tether use excluded installations where the tether was used but correct use was unknown. Installations where both the lower anchors and seat belt were used to attach the child restraint were excluded from final lower anchor models, but results were similar if they were included and categorized as installations using the lower anchors.

3. Results

3.1. Lower anchor and installation characteristics

On arrival to child seat checkup events, there were 15,927 child restraints installed in study vehicles using the lower anchors alone (70%), the seat belt alone (20%), or both the lower anchors and seat belt (10%) in seating positions that had lower anchors. Installations using both the seat belt and lower anchors were excluded from subsequent analyses of lower anchor use and correct use. Characteristics of the 14,360 installations using the lower anchors alone or seat belt alone and characteristics of the lower anchors at those seating positions are summarized in Table 1. Rear-facing infant seats were the most common restraints installed, SUVs were the most common vehicles, and restraints were most commonly installed in the right seating position in the second row of the vehicle.

Child restraints were attached using the lower anchors in 78% of installations using the seat belt or lower anchors alone, and were attached with correctly used lower anchors in 52% of these installations. Lower anchors were used correctly in 66% of the installations when they were used. This rate of correct use was strikingly higher than the correct use rate of 38% for installations using the seat belt.

Table 2 describes correct lower anchor use rates by characteristics of the lower anchors and of the installation. Correct lower anchor use rates among installations using seat belts alone or lower anchors alone varied significantly by lower anchor depth, with the lowest rates when the lower anchors were 4 cm deep or more and the highest rates when the lower anchors were 2-4 cm deep. Lower anchors

were used correctly significantly more often when clearance angles were greater than 54° than when they were smaller, and when attachment forces were less than 178 N compared with higher forces. Correct lower anchor use rates varied significantly by child restraint type and if the child restraint had previously been checked.

The type of child restraint also varied by lower anchor depth and attachment force, and if the restraint had previously been checked varied by lower anchor depth (table not shown). Smaller proportions of the restraints installed in seating positions with lower anchor attachment forces of less than 178 N were forward-facing restraints (16% vs. 20%) or rear-facing convertible restraints (26% vs. 30%), and a larger proportion were rear-facing infant seats (54% vs. 46%), compared with installations in seating positions with greater lower anchor attachment forces. The opposite pattern was seen for lower anchor depth, where larger proportions of restraints installed in seating positions with lower anchor depths of less than 4 cm were forward-facing restraints (17-22% vs. 14%) or rear-facing convertible restraints (26-29% vs. 26%), and a smaller percentage were rear-facing infant seats (48-51% vs. 56%), compared with greater lower anchor depths. A greater proportion of restraints installed in seating positions with lower anchor depths of less than 4 cm had been previously checked compared with larger lower anchor depths (20-21% vs. 18%).

3.2. Logistic regression predicting lower anchor use and correct use from lower anchor characteristics

Tables 3-5 describe the results of a series of logistic regression models examining the relationships between lower anchor characteristics and lower anchor use and correct use, controlling for child restraint type and prior child restraint check. Of installations using the lower anchors alone or seat belt alone, anchor depths of 0-2 cm and 2-4 cm were associated with significantly higher odds of lower anchor use compared with larger anchor depth values (Table 3, model 1), and attachment forces of less than 178 N were associated with significantly higher odds of lower anchor use compared with greater attachment forces (Table 3, model 3). In a model examining both of these features, both features were independently associated with lower anchor use (Table 3, model 4). The odds of lower anchor use were higher with clearance angles greater than 54° compared with 54° or less, but this was not statistically significant (Table 3, model 2).

Among installations where the lower anchors were used to attach the child restraint, anchor depths of 2-4 cm compared with larger depths (Table 4, model 1) and clearance angles greater than 54° (Table 4, model 2) were associated with significantly higher odds of correct lower anchor attachment, controlling for child restraint type and prior child restraint check. Lower anchor depths of 0-2 cm were associated with higher odds of correct lower anchor attachment than depths of 4 cm or more, but not significantly so. Attachment force was unrelated to correct attachment when considered singly (Table 4, model 3). When attachment force and lower anchor depth were analyzed in the same model, the odds of correct lower anchor use were marginally higher when attachment forces were less than 178 N, and lower anchor depths of 2-4 cm were again significantly associated with higher odds of correct lower anchor use than larger lower anchor depths (Table 4, model 4).

Table 5 lists the results of models examining the odds of correct lower anchor attachment associated with lower anchor characteristics among installations using either the lower anchors alone or seat belt alone when controlling for the same factors as previous models. Lower anchor depths less than 4 cm (Table 5, model 1), clearance angles greater than 54° (Table 5, model 2), and attachment forces less than 178 N all significantly predicted correct lower anchor use when analyzed separately (Table 5, model 3), and lower anchor depth and attachment force independently were associated with correct lower anchor use when included in the same model (Table 5, model 4).

3.3. Logistic regression predicting lower anchor use and correct use from number of lower anchor criteria met

A categorical variable was created based on if the following criteria were met in seating positions with lower anchors in study vehicles: anchor depth less than 4 cm, clearance angle greater than 54°, and attachment force less than 178 N. Of the 13,868 installations using the lower anchors or the seat belt alone where data were available on the anchor depth, clearance angle, and force, 4% of installations were in seating positions with lower anchors that met none of the criteria and 32% met all three.

A notably smaller percentage of installations in cars (7%) were in seating positions with lower anchors that met all three criteria, compared with 44-50% for other vehicle types (table not shown). Lower anchors alone were also least often used, attached correctly when they were used, and attached correctly in installations using either lower anchors or seat belts alone in cars (72%, 63%, and 47%, respectively),

compared with other vehicle types (75-82% use, 66-71% correct attachment when they were used, and 51-58% correct attachment among installations with either lower anchors or seat belts alone) (table not shown).

Correct lower anchor use rates in installations using the lower anchors or seat belt alone were significantly higher when the lower anchors met all three criteria than when they met none (58% vs. 42%, $\chi^2[1]=28.28, p<0.0001$). Logistic regression models examined the relationship of whether the lower anchors met none or all of the three criteria to lower anchor use and correct use among installations meeting all or no criteria and controlling for restraint type and prior restraint check. Among installations using the lower anchors or seat belt alone, installations in seating positions with lower anchors meeting all three criteria were considerably more likely to use the lower anchors (OR = 2.06, 95% CI = 1.67-2.54, $p<0.0001$) and to use the lower anchors correctly (OR = 1.64, 95% CI = 1.34-2.00, $p<0.0001$) than in seating positions with lower anchors meeting none of the criteria. Among installations using the lower anchors, the lower anchors were also more likely to be attached correctly when they were used in seating positions with lower anchors meeting all three criteria than those meeting none of the criteria, but this finding did not reach statistical significance (OR = 1.22, 95% CI = 0.95-1.57, $p=0.12$).

3.4. Characteristics of tether anchors and forward-facing restraint installations

On arrival at child seat checkup events, there were 2,880 forward-facing child restraints installed in seating positions where tether anchor characteristics were assessed in the study vehicles. Characteristics of these installations and of the tether anchors at the seating positions with the installations are summarized in Table 6. The tether anchor was most often located on the seatback (56% of installations) or the rear deck (30%). Lower anchors were used alone or in combination with the seat belt in 69% of installations.

Among cars, tether anchors most often were located on the rear deck (81%), followed by the seatback (9%), roof (6%), floor (3%), and back wall/other (1%); in minivans, anchors all were located on the seatback; in SUVs, anchors most often were located on the seatback (75%) followed by the roof (10%), rear deck (9%), and floor (5%); and in pickup trucks, anchors most often were located on the back wall/other (88%) followed by the seatback (12%)(table not shown). Hardware that could be confused with

the tether anchor was present in a larger percentage of installations in pickup trucks (50%) compared with minivans (35%), SUVs (21%), and cars (6%)(table not shown).

The tether was used in 49% of installations. Among the installations where the tether was used, it was used correctly in 80%, and overall the tether was used correctly in 39% of installations. Table 7 describes correct tether use rates by tether anchor and installation characteristics. Tether use and correct use rates were much higher when child restraints were attached using the lower anchors alone or in combination with the seat belt compared with when they were attached with the seat belt alone (use: 62% vs. 29%, correct use: 50% vs. 21%), and were also higher when child restraints had previously been checked. Lower anchor use and prior restraint check further differed by tether anchor characteristics (table not shown). The lower anchors were used alone or in combination with the seat belt more often when there was hardware present that could be confused with the tether anchor (76% vs. 67%), and lower anchor use varied by tether anchor location, ranging from 56% use when the tether anchor was on the rear deck or floor to 78% use when the tether anchor was on the roof. Prior restraint check varied by tether anchor location, with restraints previously checked least often when the tether anchor was located on the back panel/other (15%) and most often when it was located on the roof (31%).

3.5. Logistic regression predicting tether use and correct use from for tether anchor characteristics

The tether was used correctly in 35% of installations when hardware that could be confused with the tether anchor was present compared with 39% of installations where there was no confusing hardware (Table 7). Table 8 shows the results of logistic regression models examining the relationship between the presence of confusing hardware and the use and correct use of the tether, controlling for prior child restraint check and lower anchor use (alone or in combination with the seat belt). The absence of confusing hardware was associated with significantly higher odds of tether use (Table 8, model 1) and correct use (Table 8, model 2).

The tether was used correctly most often in installations where the tether anchor was located on the roof and least often when the tether anchor was located on the back wall/other (Table 7); correct use rates fell in the middle when the tether anchor was on the rear deck. However, the rear deck was associated with the highest odds of tether use (Table 9, model 1) and correct use (Table 9, model 2) in logistic regression models that controlled for lower anchor use and prior child restraint check. Odds of

tether use were significantly higher when the tether anchor was located on the rear deck than on the seatback or back wall/other, and odds of correct tether use were significantly higher when the tether anchor was located on the rear deck than on the back wall/other and marginally higher compared with the seatback.

Sample sizes were small and confidence intervals were wide in analyses examining use and correct use of tethers when tether anchors were located on the roof and floor. The same analyses were performed comparing the rear deck with other tether anchor locations as a binary variable. The odds of using the tether (Table 9, model 3) and the odds of using the tether correctly (Table 9, model 4) were significantly higher when the tether anchor was located on the rear deck than in other locations.

4. Discussion

LATCH was designed to make installing child restraints less difficult, but laboratory studies with volunteers have indicated that LATCH is easier to use in some vehicles than others. This study confirms that the associations of specific vehicle features with use and correct use of LATCH in usability studies with volunteers also are present in a large sample of real-world child restraint installations in a variety of vehicle models. As identified by Klinich et al. (2013), forces less than 178 N required to attach a child restraint to the lower anchors and clearance angles around the lower anchors greater than 54° were associated with significantly higher rates of correct lower anchor use. The depth of the lower anchors within the seat bight was also associated with higher lower anchor correct use rates, although at the threshold of less than 4 cm rather than the threshold of less than 2 cm determined by Klinich et al. (2013). The odds of installing child restraints using the lower anchors instead of the seat belt and of using the lower anchors correctly were considerably higher when the lower anchors met all three of these criteria compared with when they met none.

Child restraints installed in seating positions with lower anchors that have low attachment forces were more likely to be installed using the lower anchors than the seat belt, but attachment force was not significantly related to correct attachment of the child restraint to the lower anchors when they were used. Conversely, larger clearance angles significantly predicted correct attachment of the lower anchors when they were used, but were not significantly associated with using the lower anchors instead of the seat belt. These findings suggest that various features of the lower anchors may affect usability more at

different points during child restraint installation. If a large amount of force is required to attach a child restraint to the lower anchors, parents may be discouraged from using them at all, whereas a narrow clearance angle may not discourage use of the lower anchors as much as make correct attachment difficult.

Child restraints were more likely to be attached correctly when the lower anchors were used than when attached with the seat belt. This is consistent with evidence demonstrating that parents correctly use the lower anchors more often than the seat belt when instructed to use one or the other in the laboratory (Klinich et al., 2013) and further suggests that improving the usability of LATCH will lead to less child restraint misuse. However, it should be noted that other factors in addition to ease-of-use likely contributed to higher correct use of the lower anchors than the seat belt. For instance, the same parent characteristics may correlate with both choosing to use LATCH and installing child restraints correctly. Alternatively, the correct lower anchor use rate could have been inflated by parents who did not use LATCH because the lower anchors in their vehicles were difficult to use.

Similar to the findings of the laboratory study by Jermakian et al. (2014), tether anchors located on the rear deck and unaccompanied by potentially confusing hardware were associated with higher tether use and correct use rates after controlling for other installation characteristics. Prior usability studies had generally excluded pickup trucks with tether anchors on the back wall or in other unusual configurations, and in this study those tether anchor locations were associated with particularly low tether use and correct use rates. This finding is consistent with the field observations of tether use in forward-facing restraints conducted by Jermakian and Wells (2011), where tether use rates were considerably lower in pickup trucks than in other types of passenger vehicles, although Eichelberger et al. (2014) did not observe differences in tether use by vehicle type.

Tether use was much higher when forward-facing restraints were installed using the lower anchors than with the seat belt, which has also been the case in field observations (Eichelberger et al., 2014) and in usability studies when volunteers were asked to install child restraints with the lower anchors and seat belt in alternate trials (Klinich et al., 2010, 2013). The marked difference in tether use between installations with lower anchors and seat belts explains why correct tether use rates did not stand out for tether anchors located on the rear deck when raw percentages were examined, but were significantly

better for the rear deck when controlling for lower anchor use; lower anchors were used less often in cars, which typically have tether anchors located on the rear deck, than in other types of passenger vehicles.

Public education about LATCH has included information on the top tether together with information on lower anchors, and caregivers that consult their vehicle manual when installing a child restraint with the lower anchors may be more likely to read about the top tether and use it. Because a substantial proportion of child restraints in LATCH-equipped vehicles are installed using the seat belt, and LATCH-equipped vehicles typically have at least one rear seating position with a tether anchor but without lower anchors, it could be beneficial to increase the education of caregivers on the need to use the top tether with forward-facing restraints regardless of the attachment method. This is especially important given the potential for top tethers to reduce injuries in crashes. Top tethers have been demonstrated to reduce child crash test dummy head excursion in sled tests, even with instances of lower anchor and seat belt misuse in attaching the child restraint (Brown et al., 1995; Legault, Gardner, & Vincent, 1997; Lowne, Roy, & Paton, 1997; Lumley, 1997; Menon & Ghati, 2007).

Cars least often had lower anchors with easy-to-use characteristics but most often had tether anchors located in the most beneficial rear shelf location. Lower anchors in cars were especially likely to be located deep within the seat bight and have a narrow clearance angle; 81% of installations in cars assessed for lower anchor use were in seating positions with lower anchors that were 4 cm deep or greater, and for 64% the clearance angle around the lower anchors was 54° or less. The low usability of lower anchors in cars may be because the rear seats in cars are more often fixed directly to the unibody structure, as opposed to being an independent structure, and there is less flexibility in places to locate the anchors.

Some study limitations should be noted. Study-wide type I error possibility was not investigated. Data are collected at Safe Kids child safety seat checkup events by volunteers whose primary responsibility is to educate parents about correctly installing child safety seats. Guidelines on how to determine correct installation are provided but there is likely variability among CPS technicians in how installations are evaluated. In addition, the criteria for determining correct installation differ from those used in the volunteer studies by Klinich et al. (2013) and Jermakian et al. (2014). As one example, correct use of lower anchors in the checkup event data included an evaluation of tightness while tightness was

evaluated separately from correct use of lower anchors in the volunteer studies. Some criteria used to determine LATCH and seat belt misuse in volunteer studies, such as flipped connectors or twisted seat belts, were not specifically noted in the checkup event data. Vehicle characteristics examined in this study were limited to those that were related to LATCH misuse in prior laboratory studies. These laboratory studies also examined a number of other vehicle features and found them to be unrelated to LATCH misuse (Klinich et al. 2013; Jermakian et al. 2014), but it is possible that additional vehicle features would be related to LATCH use and misuse in this larger dataset with a greater diversity of vehicles. This study and laboratory studies focused on newer vehicles, and older models may have different issues affecting LATCH use and misuse.

Information on vehicle body type and trim level within a vehicle model were not available from the child restraint use database, but vehicle characteristics could vary among these factors. For example, vehicle trim levels for some models often indicate different seat coverings (fabric vs. leather), which may influence lower anchor measurements. Vehicle models available in sedan and hatchback body styles would likely have different tether anchor locations. For the instances where more than one vehicle within the same vehicle model was measured by Klinich et al. (2013) and Jermakian et al. (2014), LATCH-related vehicle characteristics were often but not always similar among the vehicles. In those cases, the LATCH characteristic expected to result in lower use or correct use rates were assumed for all study vehicles of a given model. This assumption may result in an underestimation of the effect of the given characteristic on use rates. Analyses reported in this paper were also conducted using the LATCH characteristics of the vehicle with the trim level or body type that was the most popular as determined by vehicle identification number counts, and results were similar.

Parents and other caregivers that attend child safety seat checkup events are self-selected and may not be typical of all parents. Although analyses controlled for a some factors that affected LATCH use and misuse, data were not available on other factors known to correlate with the quality of child restraint installations, such as characteristics of the child restraint (Jermakian et al., 2014; Klinich et al., 2014) or demographics of the driver or extent of driver experience with installing child restraints (Eichelberger et al., 2014; Klinich et al., 2013; Winston, Chen, Smith, & Elliot, 2006). It was not possible to separate effects of vehicle type from effects of LATCH characteristics because they were so closely

related, and the vehicles chosen by parents and caregivers likely vary by demographic characteristics that correlate with correct LATCH use. Given these limitations, it is affirming that the findings of the current study replicate those conducted in the laboratory, where many of the limitations inherent in the large, real-world data set in the current study were controlled.

Converging evidence from laboratory studies and real-world child restraint installations indicate that the force required to attach a child restraint to the lower anchors, clearance angle around the lower anchors, and depth of the lower anchors within the seat bight are associated with use and correct use of the lower anchors, and tether anchor location and the presence of confusing hardware near the tether anchor are associated with use and correct use of the top tether. Vehicle designs that make LATCH easier to use can help LATCH fully realize its purpose of simplifying the process of installing child restraint and achieving higher rates of correct child restraint installations.

REFERENCES

- Brown, J., Kelly, P., Griffiths, M., Tong, S., Pak, R., & Gibson, T. (1995). The performance of tethered and untethered forward facing child restraints. *Proceedings of the 1995 International IRCOBI Conference on the Biomechanics of Impact*. Bron, France: International Research Council on the Biomechanics of Impact, 61-74.
- Decina L.E., & Lococo, K.H. (2007). Observed LATCH use and misuse characteristics of child restraint systems in seven states. *Journal of Safety Research*, 38, 273-81.
- Eichelberger, A.H., Decina, L.E., Jermakian, J.S., & McCartt, A.T. (2014). Use of top tethers in forward-facing child restraints: observations and driver interviews. *Journal of Safety Research*, 48, 71-76.
- Jermakian, J.S., Klinich, K.D., Orton, N.R., Flannagan, C.A.C., Manary, M.A., Malik, L.A., & Narayanaswamy, P. (2014). Factors affecting tether use and correct use in child restraint installations. *Journal of Safety Research*, 51, 99-108.
- Jermakian, J.S., & Wells, J.K. (2011). Observed use of tethers in forward-facing child restraint systems. *Injury Prevention*, 17, 371-74.
- Klinich, K.D., Flannagan, C.A.C., Jermakian, J.S., McCartt, A.T., Manary, M.A., Moore, J.L., & Wells, J.K. (2013). Vehicle LATCH system features associated with correct child restraint installations. *Traffic Injury Prevention*, 13, 14-23.
- Klinich, K.D., Manary, M.A., Flannagan, C.A.C., Ebert, S.M., Malik, L.A., Green, P.A., & Reed, M.P. (2014). Effects of child restraint features on installation errors. *Applied Ergonomics*, 45, 270-7.
- Klinich, K.D., Manary, M.A., Flannagan, C.A.C., Malik, L.J., & Reed, M.P. (2010). *Effects of vehicle features on CRS installation errors*. Ann Arbor, MI: University of Michigan Transportation Research Institute. Report no. UM-2010-38.

Klinich, K.D., Manary, M.A., Flannagan, C.A.C., & Moore, J.L. (2012). *LATCH Usability in vehicles*. Ann Arbor, MI: University of Michigan Transportation Research Institute. Report no. UM-2012-7.

Legault, F., Gardner, B., & Vincent, A. (1997). *The effect of top tether strap configurations on child restraint performance*. Warrendale, PA: Society of Automotive Engineers. SAE Technical Paper 973304.

Lowne, R., Roy, S., & Paton, I. (1997). *A comparison of the performance of dedicated child restraint attachment systems (ISOFIX)*. Warrendale, PA: Society of Automotive Engineers. SAE Technical Paper 973302.

Lumley, M. (1997). *Child restraint tether straps--a simple method of increasing safety for children*. Warrendale, PA: Society of Automotive Engineers International. SAE Technical Paper 973305.

Menon, R., & Ghati, Y. (2007). Misuse study of LATCH attachment: a series of frontal sled tests. *Annual Proceedings of the Association for the Advancement of Automotive Medicine*, 51, 129e54.

Society of Automotive Engineers. (2009). *Guidelines for implementation of the child restraint anchorage system or LATCH system in motor vehicles and child restraint systems*. Troy, MI: SAE International Child Restraints Systems Committee. Document No. J2893.

Safe Kids. (2011). *A look inside American family vehicles: national study of 79,000 car seats, 2009-2010*. Washington, DC.

Winston, F.K., Chen, I.G., Smith, R., & Elliot, M.R. (2006). Parent driver characteristics associated with sub-optimal restraint of child passengers. *Traffic Injury Prevention*, 7, 373-80.

Table 1

Characteristics of child restraint installations and of lower anchors in seating positions where child restraints were installed in study vehicles using lower anchors alone or seat belt alone

| | Percent |
|---|------------|
| <i>Child restraint installation characteristics</i> | (N=14,360) |
| Vehicle type | |
| Car | 33 |
| Minivan | 11 |
| SUV | 53 |
| Pickup truck | 3 |
| Child restraint type | |
| Forward-facing with harness | 17 |
| Rear-facing infant seat with base | 53 |
| Rear-facing convertible | 27 |
| Base only | 4 |
| Seating position | |
| First row right | <1 |
| Second row left | 28 |
| Second row right | 59 |
| Second row center | 13 |
| Third row, any seat | 1 |
| Child restraint checked before | (N=13,466) |
| Yes | 19 |
| No | 81 |
| <i>Lower anchor characteristics</i> | |
| Lower anchor depth | (N=14,151) |
| 0-2 cm | 24 |
| 2-4 cm | 26 |
| 4 cm or more | 49 |
| Clearance angle | (N=14,077) |
| 54° or less | 51 |
| Greater than 54° | 49 |
| Attachment force | (N=14,291) |
| Less than 178 N | 85 |
| 178 N or more | 15 |

Table 2

Correct lower anchor use rates in installations using seat belt or lower anchors alone where correct use was known, by lower anchor and installation characteristics.

| Characteristic | N | Lower anchors used correctly | Chi-square test |
|---|--------|------------------------------|-----------------------------------|
| <i>Lower anchor characteristics</i> | | | |
| Lower anchor depth | | | |
| 0-2 cm | 3360 | 53% | ² [1]=22.14, p<0.001 |
| 2-4 cm | 3631 | 57% | |
| 4 cm or more | 6751 | 49% | |
| Clearance angle | | | |
| 54° or less | 7011 | 51% | ² [1]=6.87, p=0.009 |
| Greater than 54° | 6656 | 53% | |
| Attachment force | | | |
| Less than 178 N | 11,792 | 52% | ² [1]=5.77, p=0.02 |
| 178 N or more | 2082 | 49% | |
| <i>Child restraint installation characteristics</i> | | | |
| Restraint type | | | |
| Forward-facing with harness | 2393 | 46% | ² [3]=115.67, p<0.0001 |
| Rear-facing infant seat with base | 7287 | 50% | |
| Rear-facing convertible | 3727 | 59% | |
| Base only | 533 | 55% | |
| Child restraint checked before | | | |
| Yes | 2496 | 64% | ² [1]=168.18, p<0.0001 |
| No | 10,590 | 49% | |
| Total | 13,940 | 52% | |

Note: Mantel-Haenszel chi-square statistic was used in analyses of lower anchor depth to examine linear trends; Pearson chi-square statistic was used in other analyses.

Table 3

Logistic regression models predicting lower anchor use in installations using seat belt or lower anchors alone from lower anchor characteristics, controlling for child restraint type and prior child restraint check.

| Model | Predictors | Odds ratio (95% confidence interval) ^a | p-value |
|-------|------------------|---|---------|
| 1 | Anchor depth | | |
| | 0-2 cm | 1.36 (1.23, 1.51) | <0.0001 |
| | 2-4 cm | 1.39 (1.26, 1.54) | <0.0001 |
| | 4 cm or more | 1 | |
| 2 | Clearance angle | | |
| | 54° or less | 1 | |
| | Greater than 54° | 1.06 (0.98, 1.15) | 0.17 |
| 3 | Attachment force | | |
| | 178 N or more | 1 | |
| | Less than 178 N | 1.23 (1.10, 1.38) | 0.0003 |
| 4 | Anchor depth | | |
| | 0-2 cm | 1.39 (1.25, 1.55) | <0.0001 |
| | 2-4 cm | 1.52 (1.36, 1.69) | <0.0001 |
| | 4 cm or more | 1 | |
| | Attachment force | | |
| | 178 N or more | 1 | |
| | Less than 178 N | 1.40 (1.24, 1.58) | <0.0001 |

^aAdjusted for child restraint type and prior child restraint check

Table 4

Logistic regression models predicting correct use of lower anchors when they were used from lower anchor characteristics, controlling for child restraint type and prior child restraint check.

| Model | Predictors | Odds ratio (95% confidence interval) ^a | p-value |
|-------|------------------|--|---------|
| 1 | Anchor depth | | |
| | 0-2 cm | 1.06 (0.96, 1.17) | 0.27 |
| | 2-4 cm | 1.25 (1.13, 1.39) | <0.0001 |
| | 4 cm or more | 1 | |
| 2 | Clearance angle | | |
| | 54° or less | 1 | |
| | Greater than 54° | 1.11 (1.04, 1.23) | 0.003 |
| 3 | Attachment force | | |
| | 178 N or more | 1 | |
| | Less than 178 N | 1.02 (0.90, 1.15) | 0.78 |
| 4 | Anchor depth | | |
| | 0-2 cm | 1.07 (0.96, 1.18) | 0.22 |
| | 2-4 cm | 1.29 (1.16, 1.43) | <0.0001 |
| | 4 cm or more | 1 | |
| | Attachment force | | |
| | Less than 178 N | 1.12 (0.99, 1.26) | 0.09 |

^aAdjusted for child restraint type and prior child restraint check

Table 5

Logistic regression models predicting correct use of lower anchors in installations using seat belt or lower anchors alone from lower anchor characteristics, controlling for child restraint type and prior child restraint check.

| Model | Predictors | Odds ratio (95% confidence interval) ^a | p-value |
|-------|------------------|--|---------|
| 1 | Anchor depth | | |
| | 0-2 cm | 1.19 (1.09, 1.29) | 0.0001 |
| | 2-4 cm | 1.34 (1.23, 1.46) | <0.0001 |
| | 4 cm or more | 1 | |
| 2 | Clearance angle | | |
| | 54° or less | 1 | |
| | Greater than 54° | 1.12 (1.05, 1.21) | 0.001 |
| 3 | Attachment force | | |
| | 178 N or more | 1 | |
| | Less than 178 N | 1.12 (1.02, 1.24) | 0.02 |
| 4 | Anchor depth | | |
| | 0-2 cm | 1.20 (1.10, 1.31) | <0.0001 |
| | 2-4 cm | 1.42 (1.30, 1.55) | <0.0001 |
| | 4 cm or more | 1 | |
| | Attachment force | | |
| | Less than 178 N | 1.26 (1.14, 1.40) | <0.0001 |

^aAdjusted for child restraint type and prior child restraint check

Table 6

Characteristics of forward-facing child restraint installations and of tether anchors in seating positions where forward-facing child restraints were installed in study vehicles assessed for tether use.

| | Percent |
|--|----------|
| <i>Child restraint installation characteristic</i> | (N=2880) |
| Vehicle type | |
| Car | 31 |
| Minivan | 19 |
| SUV | 45 |
| Pickup truck | 4 |
| Seating position | |
| First row right | <1 |
| Second row left | 39 |
| Second row right | 52 |
| Second row center | 7 |
| Third row, any seat | 2 |
| Used lower anchors (alone or with seat belt) | (N=2666) |
| Yes | 69 |
| No | 31 |
| Child restraint checked before | (N=2723) |
| Yes | 27 |
| No | 73 |
| <i>Tether anchor characteristic</i> | |
| Confusing hardware | (N=2880) |
| Yes | 21 |
| No | 79 |
| Tether anchor location | (N=2823) |
| Seatback | 56 |
| Rear deck | 30 |
| Roof | 6 |
| Back wall/other | 4 |
| Floor | 3 |

Table 7

Correct tether use rates with forward-facing restraints where correct use was known, by tether anchor and installation characteristics.

| Characteristic | N | Tether used correctly | Chi-square test |
|---|------|-----------------------|-----------------------------------|
| <i>Tether anchor characteristics</i> | | | |
| Confusing hardware | | | |
| Yes | 585 | 35% | ² [1]=3.76, p=0.05 |
| No | 2250 | 39% | |
| Location of tether anchor | | | |
| Rear deck | 839 | 38% | ² [4]=15.96, p=0.003 |
| Roof | 179 | 45% | |
| Floor | 91 | 33% | |
| Seatback | 1552 | 40% | |
| Back wall/other | 118 | 24% | |
| <i>Child restraint installation characteristics</i> | | | |
| Used lower anchors (alone or with seat belt) | | | |
| Yes | 1795 | 50% | ² [1]=188.59, p<0.0001 |
| No | 832 | 21% | |
| Child restraint checked before | | | |
| Yes | 716 | 48% | ² [1]=34.70, p<0.0001 |
| No | 1964 | 36% | |
| Total | 2835 | 39% | |

Table 8

Logistic regression models predicting tether use and correct use from the presence of hardware that could be confused with the tether anchor, controlling for lower anchor use (alone or with the seatbelt) and prior child restraint check.

| Model | Outcome | Predictors | Odds ratio (95% confidence interval) ^a | p-value |
|-------|--------------------|--------------------|---|---------|
| 1 | Tether use | Confusing hardware | | |
| | | Yes | 1 | |
| 2 | Correct tether use | No | 1.33 (1.09, 1.64) | 0.006 |
| | | Confusing hardware | | |
| | | Yes | 1 | |
| | | No | 1.32 (1.07, 1.62) | 0.01 |

^aAdjusted for lower anchor use and prior child restraint check

Table 9

Logistic regression models predicting tether use and correct use from location of the tether anchor, controlling for lower anchor use (alone or with the seatbelt) and prior child restraint check

| Model | Outcome | Predictors | Odds ratio (95% confidence interval) ^a | p-value |
|-------|--------------------|---------------------------|--|---------|
| 1 | Tether use | Location of tether anchor | | |
| | | Rear deck | 1 | |
| | | Roof | 0.96 (0.67, 1.38) | 0.83 |
| | | Floor | 0.82 (0.51, 1.34) | 0.43 |
| | | Seatback | 0.81 (0.67, 0.98) | 0.03 |
| 2 | Correct tether use | Back wall/other | 0.59 (0.38, 0.92) | 0.02 |
| | | Location of tether anchor | | |
| | | Rear deck | 1 | |
| | | Roof | 0.96 (0.67, 1.38) | 0.84 |
| | | Floor | 0.79 (0.48, 1.30) | 0.35 |
| 3 | Tether use | Seatback | 0.83 (0.69, 1.01) | 0.07 |
| | | Back wall/other | 0.48 (0.30, 0.79) | 0.003 |
| | | Location of tether anchor | | |
| | | Other | 1 | |
| | | Rear deck | 1.24 (1.03, 1.50) | 0.02 |
| 4 | Correct tether use | Location of tether anchor | | |
| | | Other | 1 | |
| | | Rear deck | 1.22 (1.01, 1.48) | 0.04 |

^aAdjusted for lower anchor use and prior child restraint check



(a)



(b)



(c)

Figure 1. Tools used to measure (a) lower anchor depth, (b) clearance angle, and (c) attachment force.