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

April 2014

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Abstract

Objective: The purpose of this research was 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.

Methods: 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 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.

Results: Overall, the lower anchors were used in 78% of the 14,360 installations using either the lower anchors or seat belt alone, and were used correctly in 49%. Controlling for other relevant installation features, the odds of using the lower anchors and of using them correctly were higher when the clearance angle around the lower anchors was greater than 54°, the force required to attach the child restraint to the lower anchors was less than 178 N, and the depth of the lower anchors within the seat bight was less than 4 cm. When child restraints were installed in seating positions with lower anchors meeting all three criteria, the lower anchor use rate was 80% and the correct use rate was 53%; when none of these criteria was met, the lower anchor use rate was 65% and the correct use rate was 41%. Restraints were more likely to be attached correctly when installed with the lower anchors (63%) rather than with the seat belt (34%). The tether was used in 49% of the 2,880 installations of forward-facing restraints, and was used correctly in 38%. If there was not hardware present that could potentially be confused with the tether anchor, the tether use rate was 50% and the correct use rate was 39%; if there was confusing hardware present, the tether use rate was 46% and the correct use rate was 34%. The tether was more likely to be used when the child restraint was attached with lower anchors alone or in combination with the seat belt (62%) than with the seat belt alone (29%). After controlling for lower anchor use and other installation features, the odds of tether use and correct use were higher when there was not confusing hardware present 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. Vehicle designs that improve the ease of installing child restraints with LATCH could increase LATCH use rates and reduce child restraint misuse.

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, 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 in child restraints installed in a larger variety of vehicles. Using data collected during Safe Kids child seat checkup events during 2010-12, information on the use and correct use of LATCH in child restraints that were installed in the passenger vehicle models surveyed by Klinich et al. (2013) and Jermakian et al. (2014) was used to determine if the lower anchor depth, clearance angle around lower anchors, and force required to connect attachments to lower anchors predict real-world lower anchor use and correct use. The relationship of tether anchor

location and the presence of confusing tether hardware to real-world use and correct use of tethers in forward-facing restraints was also assessed.

2. Methods

2.1. 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). 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 in both surveys were collected on all lower anchors in each vehicle. The larger force and depth within the seat bight and smaller clearance angle measurement of the two lower anchors in a seating position was used in the current analyses.

The tether anchor-related characteristics included the presence of other vehicle hardware that could be confused with the tether anchor (e.g., cargo tie-downs near the tether anchor), and the general location of the tether anchor (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 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.

2.2. 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); if the lower anchors, seat belt, and/or tether were used correctly upon arrival; and if the child restraint system was in the correct direction 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. The child restraint system was considered to be facing the wrong direction if it was forward-facing when the child was younger than 1 or less than 20 pounds.

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, which could be a Toyota Sienna or Honda Odyssey), the vehicle make was changed to match the vehicle model (i.e., Toyota Odyssey changed to Honda Odyssey).

2.3. Analyses

Logistic regression was used to examine the effect of vehicle features on use and correct attachment of lower anchors and tethers. Binary values of clearance angle (greater than 54° and 54° or less) and attachment force (less than 178 N and 178 N or more) associated with correct lower anchor use rates above and below 50% in Klinich et al. (2013) were used in lower anchor models. Lower anchor depths of 0-2 cm and 2-4 cm were compared with depths of 4 cm or more.

Separate 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 (use of lower anchors instead of the seat belt, correct

attachment of lower anchors when they were used, and correct attachment of the lower anchors among installations using the lower anchors or seat belt) in installations of rear-facing infant seats or bases, rear-facing convertible restraints, and forward-facing child restraints. Installations of rear-facing infant seats without bases were excluded. As in Klinich et al. (2013), models were also fit using depth and force together as predictors; clearance angle was correlated with both other lower anchor-related vehicle features and was not considered together with other features. All lower anchor models controlled for child restraint type, if the child restraint had previously been checked, and if the child restraint was facing the correct direction.

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. Models that examined use of the lower anchors instead of the seat belt included all installations using either attachment method alone, and models that examined the correct attachment of lower anchors when they were used excluded installations where lower anchors were used but it was unknown if they were correctly attached. Models that examined 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.

To examine predictors of tether use and correct use, separate models were fit for each combination of tether-related vehicle predictor (presence of confusing hardware and location of tether anchor) and outcome (tether use and correct tether use in all installations) in installations of forward-facing restraints in seating positions for which tether anchor characteristics had been assessed. Models examining correct tether use excluded installations where the tether was used but correct use was unknown. 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 seat had been checked previously. The correct direction of the seat was considered as a covariate but was not significant at the 0.05 level in initial models, and was excluded in final models. As in Jermakian et al.

(2014), the presence of confusing hardware and tether location were correlated and were not included together in models.

Results were considered statistically significant at the 0.05 level, and p-values of less than 0.10 are also reported.

3. Results

3.1. Lower anchor use and correct use

On arrival to child seat checkup events, there were 16,506 child restraints installed in study vehicles with any attachment method in seating positions that had lower anchors. Characteristics of these installations and of the lower anchors at the seating positions in which they were installed are summarized in Table 1. More than half of installations were of rear-facing infant seats, in SUVs, or in the right seating position in the second row of the vehicle. Child restraints were attached most often using the lower anchors alone (68%), followed by the seat belt alone (19%), both the lower anchors and seat belt (9%), and an unknown attachment method (4%).

Of the 14,360 installations where child restraints were attached with either the lower anchors alone or seat belt alone, the lower anchors were used in 78% and the seat belt was used in 22%. The child restraints were attached correctly to the vehicle in 57% (49% by correctly used lower anchors, and 8% by correctly used seat belts), were attached incorrectly in 38% (26% by misused lower anchors, and 12% by misused seat belts), and correct attachment was unknown in 5%. Among the installations where child restraints were attached with the lower anchors alone, the lower anchors were used correctly in 63% of installations, misused in 33% of installations, and correct use was unknown in 4% of installations. When child restraints were attached with the seat belt alone, the seat belt was less likely to be used correctly (34%); it was misused in 57% of installations and correct use was unknown in 9% of installations. In a logistic regression model controlling for child restraint type, prior child restraint check, and correct direction of the child restraint and including installations using either attachment method alone where correct use was known, child restraints were significantly more likely to be attached correctly when the lower anchors were used than when the seat belt was used (OR = 3.07, 95% CI = 2.81-3.36).

Tables 2-4 describe the results of a series of logistic regression models examining the relationships between lower anchor depth, clearance angle, and force to lower anchor use, correct

attachment of the lower anchors when they were used, and correct attachment of the lower anchor in installations using the lower anchors or seat belt alone, controlling for child restraint type, prior child restraint check, and correct direction of the child restraint. Each column in the tables presents the results of a different model, with odds ratios listed for the covariates included. 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, and attachment forces of less than 178 N were associated with significantly higher odds of lower anchor use compared with greater attachment forces (Table 2, columns 1 and 3). In the model examining both of these features (column 4), both features were independently associated with lower anchor use. The odds of lower anchor use were higher with clearance angles greater than 54° compared with 54° or less (column 2), but this was not statistically significant.

Among installations where the lower anchors were used to attach the child restraint, anchor depths of 2-4 cm compared with larger depths and clearance angles greater than 54° were associated with significantly higher odds of correct lower anchor attachment (Table 3). 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. 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 lists the results of models examining the same set of covariates on the odds of correct lower anchor attachment among installations using either the lower anchors alone or seat belt alone. Lower anchor depths less than 4 cm, clearance angles greater than 54°, and attachment forces less than 178 N all significantly predicted correct lower anchor use when analyzed separately, and lower anchor depth and attachment force independently were associated with correct lower anchor use when analyzed together.

Similar to Klinich et al. (2013), a categorical variable was created based on how many of 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. The categorical

variable created by Klinich et al. (2013) considered if lower anchor depths were larger or smaller than 2 cm; because correct lower anchor use in these data was higher in seating positions with lower anchor depths of 2-4 cm than 0-2 cm, 4 cm was used as the threshold in this analysis. 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, 42% met one, 22% met two, and 32% met all three.

Use of lower anchors, correct attachment of the lower anchors when they were used, and correct attachment of the lower anchors in installations using the lower anchors or seat belt alone increased monotonically with the number of criteria met. Among installations using the lower anchors or seat belt alone in seating positions with lower anchors meeting zero, one, two, and three criteria, lower anchors were used in 65%, 78%, 78%, and 80%, respectively; lower anchors were attached correctly when they were used in 61%, 61%, 64%, and 65%, respectively; and the lower anchors were attached correctly in 41%, 49%, 51%, and 53%, respectively, of installations using either the lower anchors only or the seat belt only. 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. 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%, 61%, and 45%, respectively), compared with other vehicle types (75-82% use, 63-69% correct attachment when they were used, and 50-57% correct attachment among installations with either lower anchors or seat belts alone).

The models summarized in Table 5 examined the relationship of the number of lower anchor criteria met to the three outcome measures. Odds of lower anchor use and correct use among installations with lower anchors or seat belts alone increased with the number of lower anchor criteria met. Installations in seating positions with lower anchors meeting all three criteria were considerably more likely to use the lower anchors (OR = 2.10, 95% CI = 1.69-2.58) and to use the lower anchors correctly in installations using the lower anchors or seat belt alone (OR = 1.66, 95% CI = 1.36-2.03) 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 = 1.24, 95% CI = 0.96-1.59).

3.2. Tether use and correct use

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 in which they were installed are summarized in Table 6. The tether anchor was most often located on the seatback (55% of installations) or the rear deck (29%). Lower anchors were used alone or in combination with the seat belt in 63% 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 in 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 78% and misused in 19%; correct use was unknown in 3% of the installations. Overall, the tether was used correctly in 38% of the installations, was not used or was misused in 61%, and was used but correct use was unknown in 2%. Of the installations where the lower attachment type was known, tether use and correct use was much higher when the child restraint was attached using the lower anchors alone or in combination with the seat belt (62% use, 49% correct use) than with the seat belt alone (29% use, 21% correct use). Lower anchor use (either alone or in combination with the seat belt) was a covariate in the subsequent logistic regression models.

The tether was used in 46% of installations when hardware that could be confused with the tether anchor was present compared with 50% of installations where there was no confusing hardware. The tether was used correctly in 34% of installations with confusing hardware and 39% without confusing hardware. Table 7 shows the results of logistic regression models examining the relationship between the

presence of confusing hardware and use and the correct use of the tether, controlling for prior child restraint check and lower anchor use. The absence of confusing hardware was associated with higher odds of tether use (OR = 1.33, 95% CI = 1.09-1.64) and correct use (OR = 1.31, 95% CI = 1.06-1.61), both of which were statistically significant.

The tether was used and correctly used most often in installations where the tether anchor was located on the roof (57% and 44%, respectively), followed by the seatback (50% and 39%, respectively), rear deck (48% and 38%, respectively), floor (44% and 32%, respectively), and back wall/other (36% and 23%, respectively). However, the rear deck was associated with the highest odds of tether use and correct use in logistic regression models that controlled for lower anchor use and prior child restraint check (Table 8). 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 (Table 8). The odds of using the tether (OR = 1.24, 95% CI = 1.03-1.50) and the odds of using the tether correctly (OR = 1.22, 95% CI = 1.01-1.48) were significantly higher when the tether anchor was located on the rear deck than in other locations.

Lower anchor use was strongly associated with tether use and correct use in all models. Discrepancies between the raw percentages of tether use by tether anchor location and results of logistic regression models are due to variability in lower anchor use by vehicle type; lower anchors were used least often in cars, which typically have tether anchors located on the rear deck. Tether use and correct use was highest in minivans (52% and 43%, respectively), followed by SUVs (50% and 38%, respectively), cars (47% and 38%, respectively), and pickup trucks (36% and 21%, respectively).

4. Discussion

LATCH was designed to simplify the process of installing child restraints, 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 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 increased with the number of these criteria the lower anchors met.

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 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. It also may explain why tether use was slightly lower in cars than in minivans and SUVs in this study and in some field observations (Jermakian & Wells, 2011), when easier-to-use tether anchors (i.e., located on the rear deck and without hardware that could be confused for the tether anchor) are present in a larger proportion of cars.

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. 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 that tightness was evaluated separately from correct use of lower anchors in the volunteer studies.

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. For example, they may be more knowledgeable about child seat checkup services or attend such events because they are more interested in vehicle safety than other parents, or because they found it difficult to install their child restraint. 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). 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.

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.

ACKNOWLEDGEMENTS

The authors thank Safe Kids Worldwide for allowing the use of its child safety seat checkup event data and providing a data set to us. We also thank IIHS colleagues Nate Oesch for assistance in cleaning

the data, and Anne McCartt for suggestions that improved this study. This work was supported by the Insurance Institute for Highway Safety.

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Table 1
Characteristics of 16,506 child restraint installations and of lower anchors in seating positions where child restraints were installed in study vehicles assessed for lower anchor use

	Percent
Child restraint installation characteristics	
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	26
Base only	4
Seating position	
First row right	<1
Second row left	28
Second row right	59
Second row center	12
Third row, any seat	1
Child restraint checked before	
Yes	17
No	77
Unknown	6
Child restraint in correct direction	
Yes	94
No	4
Unknown	2
Attachment method	
Lower anchors alone	68
Seat belt alone	19
Lower anchors and seat belt	9
Unknown	4
Lower anchor characteristics	
Lower anchor depth	
0-2 cm	24
2-4 cm	26
4 cm or more	48
Unknown	1
Clearance angle	
54° or less	50
Greater than 54°	48
Unknown	2
Attachment force	
Less than 178 N	85
178 N or more	15
Unknown	<1

Table 2
Logistic regression models of characteristics predicting lower anchor use in installations using seat belt or lower anchors alone

	Odds ratio (95% confidence interval)			
Predictors	Model 1	Model 2	Model 3	Model 4
Anchor depth				
0-2 cm	1.39*			1.42*
	(1.25, 1.54)			(1.28, 1.58)
2-4 cm	1.41*			1.53*
	(1.27, 1.56)			(1.37, 1.71)
4 cm or more	1			1
Clearance angle				
54° or less		1		
Greater than 54°		1.07		
		(0.98, 1.16)		
Attachment force				
178 N or more			1	1
Less than 178 N			1.22*	1.39*
			(1.09, 1.37)	(1.21, 1.53)
Child restraint checked before				
No	1	1	1	1
Yes	1.37*	1.37*	1.37*	1.36*
	(1.22, 1.53)	(1.22, 1.54)	(1.22, 1.53)	(1.21, 1.53)
Child restraint type				
Forward-facing with harness	1	1	1	1
Rear-facing infant seat with base	2.21*	2.10*	2.11*	2.20*
	(1.99, 2.47)	(1.89, 2.34)	(1.90, 2.35)	(1.97, 2.45)
Rear-facing convertible	2.30*	2.24*	2.24*	2.31*
	(2.04, 2.61)	(1.98, 2.53)	(1.98, 2.53)	(2.04, 2.62)
Base only	3.09*	2.96*	2.90*	3.10*
	(2.37, 4.03)	(2.27, 3.878)	(2.23, 3.78)	(2.37, 4.05)
Child restraint correct direction				
No	1	1	1	1
Yes	1.45*	1.46*	1.45*	1.45*
	(1.18, 1.77)	(1.19, 1.78)	(1.18, 1.77)	(1.19, 1.78)

*$p<0.05$

Table 3
Logistic regression models of characteristics predicting correct lower anchor use in installations using lower anchors alone

	Odds ratio (95% confidence interval)			
Predictors	Model 1	Model 2	Model 3	Model 4
Anchor depth				
0-2 cm	1.06			1.07
	(0.96, 1.18)			(0.96, 1.18)
2-4 cm	1.25*			1.29*
	(1.13, 1.39)			(1.16, 1.43)
4 cm or more	1			
Clearance angle				
54° or less		1		
Greater than 54°		1.13*		
		(1.04, 1.23)		
Attachment force				
178 N or more			1	1
Less than 178 N			1.02	1.11**
			(0.90, 1.15)	(0.98, 1.26)
Child restraint checked before				
No	1	1	1	1
Yes	1.90*	1.92*	1.92*	1.89*
	(1.69, 2.14)	(1.71, 2.16)	(1.71, 2.15)	(1.68, 2.13)
Child restraint type				
Forward-facing with harness	1.16*	1.17*	1.16*	1.17*
	(1.02, 1.31)	(1.03, 1.33)	(1.02, 1.32)	(1.03, 1.32)
Rear-facing infant seat with base	1	1	1	1
Rear-facing convertible	1.37*	1.38*	1.37*	1.38*
	(1.24, 1.52)	(1.25, 1.53)	(1.24, 1.52)	(1.24, 1.52)
Base only	1.09	1.07	1.09	1.10
	(0.88, 1.34)	(0.89, 1.37)	(0.88, 1.35)	(0.89, 1.36)
Child restraint correct direction				
No	1	1	1	1
Yes	1.55*	1.55*	1.54*	1.56*
	(1.23, 1.94)	(1.24, 1.95)	(1.23, 1.93)	(1.24, 1.96)

*$p<0.05$
**$p<0.10$

Table 4
Logistic regression models of characteristics predicting correct lower anchor use in installations using seat belt or lower anchors alone

	Odds ratio (95% confidence interval)			
Predictors	Model 1	Model 2	Model 3	Model 4
Anchor depth				
0-2 cm	1.20*			1.21*
	(1.10, 1.31)			(1.11, 1.33)
2-4 cm	1.35*			1.42*
	(1.24, 1.47)			(1.30, 1.56)
4 cm or more	1			1
Clearance angle				
54° or less		1		
Greater than 54°		1.13*		
		(1.05, 1.21)		
Attachment force				
178 N or more			1	1
Less than 178 N			1.12*	1.26*
			(1.02, 1.24)	(1.14, 1.39)
Child restraint checked before				
No	1	1	1	1
Yes	1.79*	1.80*	1.79*	1.78*
	(1.63, 1.96)	(1.64, 1.97)	(1.63, 1.97)	(1.62, 1.95)
Child restraint type				
Forward-facing with harness	1	1	1	1
Rear-facing infant seat with base	1.31*	1.27*	1.28*	1.29*
	(1.18, 1.44)	(1.15, 1.40)	(1.16, 1.41)	(1.17, 1.43)
Rear-facing convertible	1.70*	1.68*	1.68*	1.69*
	(1.52, 1.90)	(1.51, 1.87)	(1.51, 1.87)	(1.52, 1.89)
Base only	1.54*	1.53*	1.51*	1.55*
	(1.26, 1.89)	(1.25, 1.88)	(1.24, 1.85)	(1.27, 1.90)
Child restraint correct direction				
No	1	1	1	1
Yes	1.64*	1.65*	1.64*	1.66*
	(1.36, 1.99)	(1.36, 2.00)	(1.35, 1.98)	(1.37, 2.01)

*$p<0.05$

Table 5
Logistic regression models predicting lower anchor use in installations using seat belt or lower anchors alone, correct use of the lower anchors when they were used, and correct use of the lower anchors in installations using seat belt or lower anchors alone from number of lower anchor criteria met

	Odds ratio (95% confidence interval)		
Predictors	Lower anchor use	Correct lower anchor use when they were used	Correct lower anchor use in installations using lower anchors or seat belt
Number of criteria met			
Zero	1	1	1
One	1.69*	1.05	1.35*
	(1.37, 2.08)	(0.82, 1.35)	(1.10, 1.64)
Two	1.78*	1.22	1.55*
	(1.43, 2.22)	(0.95, 1.58)	(1.26, 1.90)
Three	2.10*	1.24**	1.66*
	(1.69, 2.58)	(0.96, 1.59)	(1.36, 2.03)
Child restraint checked before			
No	1	1	1
Yes	1.37*	1.90*	1.79*
	(1.22, 1.54)	(1.69, 2.14)	(1.62, 1.96)
Child restraint type			
Forward-facing with harness	1	1.17*	1
		(1.03, 1.33)	
Rear-facing infant seat with base	2.11*	1	1.27*
	(1.89, 2.35)		(1.15, 1.40)
Rear-facing convertible	2.26*	1.39*	1.69*
	(2.00, 2.56)	(1.25, 1.54)	(1.51, 1.89)
Base only	3.04*	1.10	1.54*
	(2.32, 3.99)	(0.89, 1.37)	(1.26, 1.89)
Child restraint correct direction			
No	1	1	1
Yes	1.47*	1.60*	1.69*
	(1.20, 1.81)	(1.27, 2.01)	(1.39, 2.05)

*$p<0.05$
**$p<0.10$

Table 6
Characteristics of 2,880 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
Child restraint installation characteristics	
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
Child restraint checked before	
Yes	25
No	69
Unknown	5
Used lower anchors (alone or with seat belt)	
Yes	63
No	29
Unknown	7
Tether anchor characteristics	
Confusing hardware	
Yes	21
No	79
Tether anchor location	
Seatback	55
Rear deck	29
Roof	6
Back wall/other	4
Floor	3
Unknown	2

Table 7
Logistic regression models of characteristics predicting tether use and correct use from the presence of hardware that could be confused with the tether anchor

Predictors	Odds ratio (95% confidence interval)	
	Tether use	Correct tether use
Confusing hardware		
Yes	1	1
No	1.33*	1.31*
	(1.09, 1.64)	(1.06, 1.61)
Child restraint checked before		
No	1	1
Yes	1.47*	1.68*
	(1.22, 1.77)	(1.39, 2.02)
Used lower anchors		
No	1	1
Yes	3.85*	3.49*
	(3.21, 4.62)	(2.87, 4.24)

*p<0.05

Table 8
Logistic regression models of characteristics predicting tether use and correct use from location of the tether anchor

Predictors	Odds ratio (95% confidence interval)			
	Tether use		Correct tether use	
Location of tether anchor				
Rear deck	1		1	
Roof	0.96		0.96	
	(0.67, 1.38)		(0.67, 1.38)	
Floor	0.82		0.79	
	(0.51, 1.34)		(0.48, 1.30)	
Seatback	0.81*		0.83**	
	(0.67, 0.98)		(0.69, 1.01)	
Back wall/other	0.59*		0.48*	
	(0.38, 0.92)		(0.30, 0.79)	
Location of tether anchor				
Other		1		1
Rear deck		1.24*		1.22*
		(1.03, 1.50)		(1.01, 1.48)
Child restraint checked before				
No	1	1	1	1
Yes	1.43*	1.44*	1.63*	1.65*
	(1.18, 1.73)	(1.20, 1.75)	(1.35, 1.96)	(1.37, 1.99)
Used lower anchors				
No	1	1	1	1
Yes	3.88*	3.91*	3.48*	3.53*
	(3.22, 4.68)	(3.25, 4.71)	(2.85, 4.25)	(2.89, 4.30)

*p<0.05
**p<0.10