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Vehicle Factors Affecting Tether Use and Misuse

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ABSTRACT

Objective: Field studies show that top tethers go unused in half of forward-facing child restraint installations in the United States, despite the presence of tether anchors in passenger vehicles for more than a decade. In the current study, parent volunteers with experience installing child safety seats were asked to use the Lower Anchors and Tethers for Children (LATCH) hardware to install forward-facing child restraints in several vehicles to identify tether anchor characteristics that are associated with tether use.

Methods: Tether anchor characteristics were documented in 57 popular 2012-13 vehicles. These features were used to select 16 vehicles with a range of tether anchor characteristics for volunteer testing. Thirty-seven volunteers were assigned to four groups; each group tested four vehicles and two forward-facing child restraints (one with a single tether strap and one with a v-shaped tether) in a split-plot experimental design. Volunteers were given verbal instruction on LATCH halfway through their trials. Mixed-effects logistic regression models were used to identify predictors of tether use, correct tether attachment, and correct and acceptable tether routing and head restraint position. Tether routing and head restraint position were evaluated independently of correct tether attachment.

Results: Subjects used the tether in 89 percent of the 294 forward-facing child restraint installations and attached the tether correctly in 57 percent of the installations. Tethers were more likely to be used when the tether anchor was located on the rear deck typically found in sedans, which had a use rate of 95 percent, compared with when the anchor was located on the floor, roof, or seatback of other vehicles, which had use rates ranging from 79 to 89 percent. Tethers were less likely to be attached correctly when there was potentially confusing hardware present (OR: 0.21, 95% CI: 0.10-0.44). In addition, tether anchors located on the rear deck or mid seatback had higher rates of correct attachment, 60 and 69 percent, respectively, than those on the floor, roof, or lower seatback, which all had correct attachment rates lower than 50 percent. Subjects had the greatest difficulty in a pickup truck that has a tether anchor constructed of webbing and located on the top of the seatback of an adjacent seating position, requiring the use of a router. The tether was attached correctly in only 11 percent of pickup installations. No vehicle tether hardware characteristics or vehicle manual directions were associated specifically with correct tether routing and head restraint position. Installations involving the

single tether strap were 10 times as likely to have the tether attached correctly and 1.7 times as likely to be routed correctly and have the head restraint positioned correctly, compared with installations with the v-shaped tether.

Conclusions: Tether use rates were higher than seen in the field, but parents did not use the top tether for every installation even after being instructed to do so. Tether anchors located on the rear deck of sedans were associated with increases in tether use and correct tether attachment. Among tether anchor locations that may be found in other vehicle types, tethers were more likely to be attached correctly when the tether anchor was located in the middle of the seatback compared with the floor or lower seatback. The presence of potentially confusing hardware was associated with reduced likelihood of tether use and correct tether attachment, although this finding may reflect the high tether use rates in sedans, which are least likely to have confusing hardware. Child restraint installations using a v-shaped tether were less likely to be attached correctly and less likely to be routed according to vehicle manual instructions, in part because few manuals provide instructions for v-shaped tethers.

INTRODUCTION

Lower Anchors and Tethers for Children, known as LATCH, is a child restraint securement system intended to make it easier for parents to install child restraints correctly in their vehicles. The vehicle part of the system consists of two lower anchors located near the seat bight and a top tether anchor generally located rearward of the seatback, mounted to the rear deck, floor, roof, or seatback. On the child restraint, the LATCH system consists of lower connectors linked to the child restraint either with webbing or rigid connections. LATCH has been required in passenger vehicles since model year 2003 and on child restraints manufactured beginning in 2002.

LATCH was intended to simplify child restraint installation by using the LATCH connectors as the main attachment to the vehicle, thus eliminating the need to use the vehicle seatbelt. For forward-facing installations using either LATCH lower anchors or the vehicle seat belt, using the top tether also provides safety benefits by reducing head excursion in a crash. However, most studies of child restraint installations with LATCH indicate that instead of eliminating misuse, new forms of misuse have been introduced (Decina and Lococo 2007, Jermakian and Wells 2011, Stewart et al. 2011). An important misuse is failure to use the tether, with several studies documenting that fewer than half of caregivers with tether hardware available use it with forward-facing child restraints (Decina and Lococo 2007, Jermakian and Wells 2011). In the most recent study, tethers were used in 56 percent of forward-facing child restraint installations (Eichelberger et al. 2013). When those who had not used the tether were asked the main reason for not using it, the most common response was lack of awareness of tethers or how to use them (Eichelberger et al. 2013).

Installing child restraints with LATCH may be easy in some vehicles, but the vehicle anchors may be difficult to access and use in other vehicles. In several studies examining factors contributing to child restraint installation errors, subjects used the tether correctly in 30 percent of installations (Klinich et al. 2011a, 2011b, 2013c). Tethers were used more frequently in sedans (with anchor locations on the rear deck behind the head restraint) than in vehicles with the tether anchor located on the seatback. However, when the tether was used, it was routed correctly more often in vehicles with the tether anchor on the seatback.

In a subsequent study focusing on vehicle factors affecting LATCH usability, parent volunteers used the lower anchors correctly in 60 percent of LATCH installations, compared with using the seat belt correctly in only 33 percent of safety belt installations (Klinich et al. 2012, 2013a, 2013b). Correct use of lower anchors was associated with a lower anchor clearance angle greater than 54 degrees, an attachment force of 40 pounds or less, and lower anchor depth within the bight of less than 2 cm. Installations with correct lower anchor use also had 3.3 times higher odds of tight installation compared with incorrect use. Tethers were used in 48 percent of forward-facing installations, with subjects using the tether more frequently during LATCH installations (54 percent) compared with seatbelt installations (33 percent). For installations using tethers, the tether was used correctly in 46 percent of trials. The most common errors were incorrect routing with respect to the head restraint (44 percent), loose tethers (26 percent), attachment to incorrect hardware (22 percent), and incorrect orientation of the tether hook (22 percent). Tether anchor characteristics including location, wrap distance, marking, and visibility were all examined, but no specific vehicle factors predicted the use or correct use of tethers.

Vehicles in the previous volunteer study of LATCH (Klinich et al. 2013a) were selected based on various vehicle seat and LATCH characteristics but had limited variability in tether anchor characteristics that may affect tether use. The limited variability in tether anchor characteristics, combined with low tether use rates, limited the ability to identify tether anchor characteristics associated with tether use. The current study focused on identifying characteristics of vehicle tether anchors that increase the use and correct use of tethers. The protocol was designed to provide a larger number of trials with tether use than in the previous study, and vehicles were selected primarily based on their tether anchor characteristics.

METHODS

The study included a survey of new passenger vehicles to document relevant tether anchor characteristics, followed by volunteer testing to assess the relationship between specific tether anchor characteristics and tether use and correct tether use.

Vehicle Selection and Preparation

Fifty-seven popular 2012-13 model year vehicles were surveyed at dealerships to document the following tether anchor characteristics: general location, construction, packaging, distance to the head

restraint, and tether routing instructions with respect to the head restraint. The construction of the tether anchor was classified as wire, stamped parallel (anchor parallel to tether hook), stamped perpendicular (anchor perpendicular to tether hook), or webbing; examples of each type are shown in Figure 1.

Packaging was described as covered recess, open recess, open, or slit in carpet, as shown in Figure 2.

The type of head restraint also was documented as fixed, medium, large, or large hinged.

Each vehicle was evaluated for the presence of potentially confusing hardware. Vehicles were considered to have confusing hardware if there was other plausible attachment hardware such as cargo tie-downs or webbing loops (Figure 3) near the tether anchor or in a location a parent might expect to find a tether anchor.

The vehicles were classified into categories based on the tether anchor location (rear deck, roof, floor, mid seatback, or lower seatback), tether anchor distance to head restraint (>165 or <165 mm), and instruction for tether routing with respect to the head restraint (over, under, remove, around, inboard, outboard or some combination of these). Vehicles were assigned to four groups of four vehicles each (Table 1) such that each group contained four different vehicle manufacturers, three or four styles of head restraints, three or four different tether anchor locations, and two vehicles where instructions called for the tether to be routed under the head restraint. The three vehicles with less than 165 mm distance between the tether anchor and head restraint were placed into different groups. Appendix A summarizes the tether anchor characteristics of each vehicle.

Prior to volunteer testing, certified child passenger safety technicians installed each child restraint in the second row, left seating position (behind driver), to confirm that it was possible to do so without extraordinary effort. For vehicles that allowed more than one option for positioning the head restraint or routing the tether with respect to the head restraint, the condition that led to the most secure installation was used. In the Chrysler 200, the second row, right seating position, was used because it was difficult to install a child restraint in the left seating position due to some obstruction of the lower anchors.

To prepare for volunteer testing, head restraints were set in the highest position. Adjustable seatbacks were placed near the design seatback angle, unless otherwise directed in the vehicle owner's manual. The front seats were adjusted to the mid-track position with the seatback two notches rearward of full upright.

Volunteer Testing

Thirty-seven subjects participated in the volunteer testing. Subjects were eligible if they were transporting a child in either a harnessed child restraint or booster seat in their personal vehicle and had installed the seat themselves. Volunteers were compensated \$40 for their time. This study was approved by the Institutional Review Board at the University of Michigan.

Each subject was assigned to a vehicle study group of nine subjects. Efforts were made to include subjects with each combination of education level (some college or less, college graduate or more) and previous LATCH experience (none or some) in each group. An additional subject was tested in one group to allow inclusion of each combination of education and experience, because one of the original subjects' LATCH experience was misclassified during initial screening.

All subjects tested two forward-facing child restraints, one with a single tether strap (Evenflo Triumph, Figure 4A) and one with a v-shaped tether (Britax Marathon 70, Figure 4B). During the 2-hour test session, subjects installed each child restraint in four different vehicles, for a total of eight installations. One subject declined further participation after completing 6 installations. As instructed by the researchers, subjects performed all installations using the LATCH system.

The trial matrix used a split-plot experimental design, with all possible combinations of vehicles and child restraints tested across subjects. The design allows estimation of key main effects within subjects, and some interactions are assessed between subjects. The order of the study vehicles and the vehicle and child restraint combinations was varied for each volunteer to minimize learning effects.

For trials 1-4, subjects were directed to do their best to install a child restraint using LATCH. Child restraints were configured for the forward-facing orientation, and subjects were told they could use the child restraint and vehicle manuals. If subjects asked questions, the experimenter told them to refer to the manuals and do their best. After the subject completed an installation, a certified child passenger safety technician evaluated the quality of the installation. Because the focus was installing the child restraint in the vehicle, factors related to securing a child in the restraint were not assessed.

As noted above, a previous study showed that volunteers used tethers in less than half of the installations (Klinich et al. 2013b). Because the current study's focus was tether use and misuse, subjects received the following LATCH instruction after trial 4 to increase the likelihood they would use

the tether for the remaining trials: “The LATCH system lets you install the child restraint with two connectors on the child restraint that attach to bars located in the vehicle seat, plus a top tether on the child restraint [*show it to them*] that connects to a tether anchor in the vehicle. You can find out information about the vehicle anchors in the owner’s manual.”

After each of the last four trials, subjects filled out a questionnaire regarding elements of the installation. This questionnaire was not administered after trials 1-4 to avoid providing inadvertent education regarding LATCH. After completing all eight trials, subjects filled out another questionnaire that collected details regarding their previous LATCH and child restraint installation experience, as well as a race/ethnicity form. They also answered questions about which tether anchors were easiest to use and, if applicable, why they did not use the tether. Further details regarding the protocol, evaluation criteria, and forms are reported by Klinich et al. (2013c).

Data Analyses

The following outcome variables were considered:

- Tether use: Tether on the child restraint was attached to some part of the vehicle.
- Correct attachment to tether anchor: Tether was attached to the correct vehicle hardware in the correct orientation, and webbing was flat and tightened so that there was 10 mm or less of slack (measured by pinching the slack and measuring the height of the loop).
- Correct tether routing: Tether was routed and the head restraint was positioned as directed by the vehicle manual.
- Acceptable tether routing: Tether was routed and the head restraint was positioned in a manner deemed acceptable by child passenger safety technicians because it resulted in a tight, stable installation, even if it did not follow the vehicle manual directions.

Although not used as primary outcome variables, the following installation outcomes also were documented:

- Correct use of lower anchors: Child restraint connectors were fully engaged with the correct vehicle hardware in the correct orientation, and the LATCH strap webbing was flat.

- Tight installation: Restraint did not move more than 1 inch laterally or fore/aft when tested with a moderate pull/push applied at the restraint belt path.
- Child restraint installation completely correct: Correct use of lower anchors, correct attachment to tether anchor, correct tether routing, and tight installation.
- Child restraint installation acceptable: Correct use of lower anchors, correct attachment to tether anchor, acceptable tether routing, and tight installation.

Mixed-models logistic regression was used to identify predictors of tether use, correct tether attachment, and correct and acceptable tether routing. Univariate chi-squared analyses were conducted to identify key variables for consideration in the logistic regression models. Potential predictor variables included the following:

- Subject variables: Gender, age (20-29, 30-39, 40-49, 50-70 years), education (some college or less, college graduate or more), child restraint installation experience (rear-facing only, rear- and forward-facing, forward-facing only, forward-facing and booster, all), lower anchor experience (none/some), tether anchor experience (none/some).
- Experimental variables: Child restraint model, vehicle make and model, vehicle type, vehicle group, trial number, instruction (none in trials 1-4, yes in trials 5-8).
- Tether anchor characteristics: location (rear deck, roof, floor, mid seatback, or lower seatback), construction (wire, stamped parallel, stamped perpendicular, webbing), packaging (covered recess, open recess, open, slit in carpet), labeling (yes/no), distance from tether anchor to head restraint (continuous), distance from tether anchor to head restraint (>165 or <165 mm), presence of confusing hardware (yes/no), tether hook can be attached in the incorrect orientation (yes/no), tether anchor is visible without further action (yes/no).
- Behavioral variables (all yes/no): Used child restraint manual, used vehicle manual, correct use of lower anchors, obtained tight installation. Positioned head restraint as directed and routed tether as directed were used as potential predictor variables in the analyses of tether use and correct tether attachment only.

The regression models were conducted using SAS 9.3 PROC GLIMMIX. Models were used to predict the probability of tether use, correct tether attachment, correct tether routing and head restraint

position, and acceptable tether routing and head restraint position; random effects were used to account for the within-subject elements of the experimental design. For each outcome, the initial model was built in a backward stepwise manner by entering all candidate variables and removing variables that were not significant at $p=0.05$. For consistency, subsequent models for each outcome used all non-vehicle predictors identified as significant in the initial model.

RESULTS

The 37 subjects completed a total of 294 forward-facing child restraint installations, with an average of 18 installations per vehicle. Subjects ranged in age from 21 to 68 years, and 38 percent were male. More than half (62 percent) were college graduates, and 70 and 62 percent had previous experience with lower anchors and tethers, respectively.

Table 2 summarizes for each vehicle rates of tether use including correct attachment plus correct and acceptable routing, correct use of the lower anchors, and tight child restraint installation. Subjects used the tether in 89 percent of the 294 installations and attached the tether correctly in 57 percent of the installations. When reviewing the errors, 11 percent of installations involved tethers attached to incorrect hardware, 8 percent involved incorrect orientation of the tether hook, 22 percent involved twisted tether webbing, and 20 percent involved loose tethers. In 32 percent of installations, subjects routed the tether and positioned the head restraint according to the vehicle owner's manual. The tether was routed and the head restraint was positioned in a manner deemed acceptable by child passenger safety technicians in 45 percent of installations.

Overall, subjects used the lower anchors correctly in 79 percent of all trials and obtained an acceptably tight installation of the child restraint in 63 percent (Table 2). Subjects installed the child restraints completely correct, including correct use of lower anchors, correct attachment and routing of the top tether, and tight installation in 20 percent of trials. When less strict requirements for tether routing were considered, parents achieved an acceptable installation in 32 percent of trials.

Table 3 shows the rates of tether use and correct tether attachment by several tether anchor characteristics. Tether anchor characteristics with the highest tether use rates were not necessarily the characteristics with the highest rates of correct tether attachment. For example, the tether anchor

construction with the highest use rate, 94 percent for webbing, had the lowest rate of correct attachment, with only 11 percent of tethers correctly attached.

Table 4 lists the rates of tether use, correct tether attachment, correct tether routing, and acceptable tether routing for each tether style (single or v-shape) for the first four trials (before LATCH instruction) and the last four trials. Subjects had higher rates of tether use and correct tether attachment (attachment to the correct vehicle hardware in the correct orientation, flat webbing, and tight tether) after receiving LATCH instruction. The rate of tether use rose from 84 percent in the first four trials to 95 percent in the last four trials, while the rate of correct attachment went from 53 to 61 percent. Child restraints with single tethers had higher rates of correct attachment compared with those with v-shaped tethers (71 vs. 42 percent), as well as higher rates of correct routing (48 vs. 16 percent). A higher proportion of installations with v-shaped tethers had twisted tether webbing (33 percent) and loose tethers (27 percent) than those with the single tether (10 percent with twisted webbing and 13 percent with loose tether). Providing instruction after trial 4 led to improvements in correct use and routing for the single-strap tether but not the v-shaped tether.

Tether Anchor Characteristics Associated with Tether Use and Correct Tether Attachment

A series of mixed-effects logistic regression models identified specific vehicle tether anchor features associated with tether use, as shown in Table 5. In addition to vehicle and subject predictor variables, the models included random effect variables that accounted for the partially within-subject design. Many predictor variables in these analyses were highly correlated, such as a subject's previous lower anchor experience, tether experience, child restraint installation experience, and use of the child restraint manual. To avoid including highly correlated variables in the regression models simultaneously, the final models considered the following potential predictors: child restraint model, instruction, age, previous tether experience, education, gender, and vehicle manual use. Tether anchor variables are also highly correlated. Consequently, the following tether anchor variables were considered in the models one at a time: location, marking, construction, packaging, whether visible, and presence of confusing hardware.

Tether use was highest for vehicles with tether anchors located on the rear deck (Table 5, model I), with the odds of using the tether reduced by 89 to 97 percent when the anchor was located on the

seatback, floor, or roof. The presence of potentially confusing tether anchor hardware was negatively associated with tether use (Table 5, model II), with the odds of using the tether reduced by 88 percent in vehicles with confusing hardware present. No other vehicle factors were associated with tether use once the other significant subject and experimental predictors were included. Subjects 40 years and older were less likely to use tethers, as were those without previous tether experience. In both models, subjects also were more likely to use the tether after receiving LATCH instruction prior to trial 5.

The results in Table 5 indicate that tether use was highest when the anchor was located on the rear deck compared with other locations. Table 6 shows additional pairwise comparisons conducted for each combination of tether anchor location, with statistically significant differences indicated in bold. For tether use, no other locations had statistically different rates of use except for the rear deck.

Tethers were attached correctly in 57 percent of installations, but the rate of correct attachment was very low (11 percent) for the Ford F-150 pickup truck, despite a high tether use rate of 94 percent. The Ford F-150 has an unusual tether anchor set-up. The anchor is on the top of the seatback of an adjacent seating position, is constructed of webbing, and requires the use of a router. Because of the low rate of correct attachment and the unusual tether anchor configuration, the installations in the Ford F-150 were excluded from the regression models exploring tether anchor characteristics associated with correct tether attachment.

Correct tether attachment was associated with tether anchors located on the rear deck (Table 7, model I), with the odds of attaching the tether correctly reduced by 79 to 86 percent when the tether anchor was located on the bottom of the seatback, roof, or floor compared with the rear deck. The presence of potentially confusing tether anchor hardware was negatively associated with attaching the tether correctly (Table 7, model II), with the odds of correct attachment in vehicles with confusing hardware reduced by 79 percent. Subjects 50 years and older were less likely to attach tethers correctly. In both models, subjects were more likely to attach the tethers correctly after receiving LATCH instruction prior to trial 5, yet they were less likely to attach tethers correctly if they used the vehicle owner's manual. Child restraint model was the strongest predictor of correct use, with the odds of correctly attaching the tether 10 times as likely for installations with the child restraint model equipped with the single tether.

Table 8 shows pairwise comparisons of tether anchor location and its effect on correct tether attachment. Subjects were least likely to attach the tether correctly when the tether anchor was located on the floor, followed by the roof and then bottom of the seatback. Subjects were most likely to attach the tether correctly when the anchor was on the rear deck followed by the middle of the seatback. Some differences between specific tether anchor locations were not statistically significant.

Tether Routing and Head Restraint Position

All vehicle owner's manuals provided direction on how to route the tether with respect to the head restraint (i.e., over, under, outboard) and how to position the head restraint (i.e., up, down, remove). However, only one manual provided routing instructions specific to child restraints with a v-shaped tether. With some combinations of the study vehicles and the child restraints, using a tether routing or head restraint position that was contrary to the vehicle manual directions resulted in a good, or possibly better, child restraint installation. Such cases were not considered to be routed correctly but were considered acceptable, despite not adhering to the vehicle manual directions. Table 9 shows the combinations of vehicle manual directions for tether routing and head restraint position and the rate of correct and acceptable tether routing and head restraint placement in the installations.

Adjustable head restraints initially were placed in the highest position, and subjects left them in this position in 138 of 163 installations using the tether (85 percent). For adjustable head restraints, the head restraint position was correct in 67 percent of the installations, including 90 percent of the installations with the head restraint in the highest position. Irrespective of correct head restraint position, tethers were routed in accordance with the vehicle manual instructions in 58 percent of installations using the tether, and 70 and 46 percent of installations with the single tether and v-shaped tether, respectively. The most common routing paths were under or over the head restraints, accounting for 43 and 24 percent of installations with the tether, respectively. The remaining routing paths were to one side, both sides, or some combination of all of the above. Tethers were routed in a manner deemed acceptable in 78 and 76 percent of installations with the single tether and v-shaped tether, respectively.

In the regression models, no vehicle tether hardware characteristics or vehicle manual directions were associated with correct tether routing and head restraint position. The only significant predictor was child restraint model, with the odds of correctly routing the tether and positioning the head restraint with

installations involving the child restraint with the single tether 1.7 times the odds for the child restraint with the v-shaped tether ($F(1,220)=4.06$, $p=0.0451$). Child restraint model was not significant when considering acceptable tether routing and head restraint position.

DISCUSSION

Despite the presence of tether anchors in passenger vehicles since 2002, field studies indicate that about half of forward-facing child restraint installations in the United States do not use the top tether. In the current study, parent volunteers with experience installing child safety seats were asked to use LATCH to install forward-facing child restraints in several vehicles to identify tether anchor characteristics associated with tether use. Volunteers used the top tether in 89 percent of trials, which is a larger proportion than previous volunteer studies (Klinich et al. 2012a, 2012b, 2013a) and much higher than use rates observed in the field (Decina and Lococo 2007, Eichelberger et al. 2013; Jermakian and Wells 2011). Tether use rates improved from 83 to 95 percent after parents received verbal instruction on LATCH halfway through their trials but still did not reach 100 percent.

Tethers were more likely to be used when the tether anchor was located on the rear deck behind the head restraint in sedans, which had a use rate of 95 percent, with the odds that parents use the tether reduced by 89 to 97 percent when the tether anchor was located on the seatback, floor, or roof. Pairwise comparisons suggest that anchors on the middle of the seatback may result in higher tether use rates than those on the bottom of the seatback, floor, or roof, but the differences were not statistically significant. The presence of potentially confusing hardware decreased tether use, with the odds of using the tether reduced by 88 percent when potentially confusing hardware was present. However, because sedans with tether anchors located on the rear deck are also least likely to have confusing hardware, the significance of confusing hardware variable may just reflect the highest use rate of the tethers located on rear decks. Other vehicle factors such as tether anchor markings, construction, and packaging were not associated with increased tether use when other subject and study design factors were included in the statistical models.

Subjects were more likely to attach the tether correctly when the tether anchor was located on the rear deck or middle of the seatback, which had correct attachment rates of 60 to 69 percent, with the odds of attaching the tether correctly for these locations more than 4 times the odds for locations on the

floor, roof, or lower seatback. Minivans and SUVs typically do not have rear decks, but locating tether anchors on the middle of the seatback instead of other typical locations in these vehicles may increase the likelihood that parents will attach the tether correctly. Tethers attached to anchors in vehicles with confusing hardware also were less likely to be attached correctly. Cargo tie-downs or other potentially confusing hardware may be desirable or necessary features in many minivans and SUVs, and therefore minimizing or removing them may not always be an option; providing clear labels on tether anchors or other attachment points may alleviate confusion when parents are installing child restraints, although tether anchor marking was not predictive of tether use or correct attachment. Subjects had the greatest difficulty in the pickup truck; the tether was attached correctly in only 11 percent of installations and, therefore, pickups were excluded from these analyses.

Vehicle factors were not as influential as child restraint model in predicting correct tether attachment. Subjects were 10 times as likely to correctly attach the tether, including attaching it to the correct hardware in the correct orientation and keeping the webbing flat and tight, when installing the child restraint with the single-strap tether. Subjects installing the restraint with v-shaped tether had particular difficulty with getting the tether strap tight and having it remain untwisted. The difficulty with getting the tether tight may be due, in part, to the location of the adjustor hardware, which is located a fixed distance (145 mm) from the back of the child restraint. This always places the adjustor hardware in the vicinity of the head restraint regardless of tether anchor location and may make it more difficult to tighten. With the single-strap tether, the adjustor hardware is near the tether hook so that the adjustor hardware is more accessible when the tether anchor is located farther from the child restraint, such as on the seatback, floor, or roof. Moving the adjustor hardware for v-shaped tethers farther from the back of the child restraint may make them easier to tighten sufficiently. V-shaped tethers are used by a small number of child restraint manufacturers who maintain that tethers with two connection points on the child restraint provide more stability, distribute loads over a greater area, and have a longer length that allows for more energy absorption. However, if caregivers have more trouble adequately tightening this type of tether, then any safety benefits of the v-shaped tether may be diminished.

Routing of the tether and head restraint position were evaluated independently of correct tether attachment in part because incorrect tether routing was the most common tether misuse in a previous

volunteer study of LATCH (Klinich et al. 2012a). A review of relevant literature did not identify any studies indicating that a particular tether routing option is better at reducing occupant head excursion, the main purpose of a tether. All vehicles provided direction on tether routing and head restraint position, but following the directions was not always possible and did not always result in the best child restraint installation, based on an assessment by certified child passenger safety technicians. When the manuals for two vehicles directed subjects to route the tether under the head restraint but place the head restraint in the down position, not a single subject followed this direction. Problems also were encountered when the installation involved the v-shaped tether strap, in part because only one vehicle provided specific directions for routing a v-shaped tether, resulting in the need for improvised routings. In most cases, the v-shaped tether was best routed on either side of the head restraint, but vehicle manuals usually instructed the user to route the tether over or under the head restraint. This was often difficult because the spacing between the two tether connection points on the child restraint is wider than the head restraint or its mounting posts. When volunteers did route the tether over the head restraint, the placement of the straps near the edge of the head restraint was often precarious and could slip off during normal use, leading to slack in the tether. When the tether routing and head restraint positioning was evaluated as acceptable by a child passenger safety technician, despite not following the vehicle manual instructions, the rates of installations with either correct or acceptable routing were equivalent between the two child restraint models. This suggests that secure routings are possible with the v-shaped tether, but the most stable routing path may differ from the vehicle manual instructions. Although v-shaped tethers are present on a small percentage of child restraint models, the models are popular and may represent a meaningful portion of the child restraint market. As a result, it is important for vehicle manufacturers to consider v-shaped tethers when providing instruction on tether routing.

Several subject and experimental factors were associated with tether use, including LATCH instruction, previous tether experience, and subject age. In a survey of drivers who had installed child restraints in their vehicles, the main reason for not using the tether was lack of awareness of tethers or how to use them, with fewer than half of tether non-users having heard of the term “top tether” or being able to identify the tether anchor (Eichelberger et al. 2013). Developing novel ways to educate parents about tethers may increase their use. Current LATCH education efforts incorporate messages about both

lower and tether anchors. More emphasis solely on tethers, because of the demonstrated safety benefit, may be warranted.

The current study had several limitations. While specific tether anchor locations were associated with tether use and correct attachment, it is unknown how tethers attached to different tether anchor locations perform dynamically and whether there are differences in preventing forward excursion in a crash. Also, all testing was performed with U.S. child restraints and vehicles; findings may not apply to systems designed to meet ISOFix requirements (International Standards Organization 2010).

Vehicle makes and models were chosen to represent a range of tether anchor characteristics and were not necessarily representative of the most common tether anchor configurations. The tether anchor configuration in the pickup truck was substantially different than in other vehicles and proved challenging for volunteers to use correctly. Since space for a tether anchor behind the rear seat is limited, tether anchors in pickup trucks often have unusual configurations that may result in decreased or improper tether use. Only one pickup truck was included in this study, and installations in it were removed from statistical models of incorrect tether attachment because its unique tether anchor configuration and significant misuse dominated the analyses. However, pickups are frequently used as family vehicles so vehicle manufacturers should reconsider current design options to improve usability.

All the volunteer subjects had some experience in installing child safety seats. An effort was made to recruit subjects with and without previous LATCH experience, but the initial screening questions were not always adequate for categorizing LATCH experience. To prevent educating potential study participants about LATCH, volunteers were asked how they installed child restraints in their own vehicle, rather than asking them if they had experience with the LATCH system. After they participated in the study (and received instruction about LATCH), volunteers filled out a more detailed questionnaire regarding their previous experience. Several subjects were misclassified during the initial screening, with some initially saying they used LATCH but later stating they had not once they learned more about it. Others had used LATCH before but not realized what it was called. To satisfy the experimental matrix of each subject group having at least one subject with each combination of education level and previous LATCH experience, an additional subject was recruited for one group because of the initial misclassifications.

In this study, rates of tether use and correct child restraint installations were much higher than in previous volunteer studies. More than half of study participants were college graduates, had experience with a wide range of child restraint types, and had previous experience with lower anchors and tethers. This may limit the applicability of results to the general U.S. population. Focusing recruitment to obtain different levels of education and previous LATCH experience also resulted in less diversity of subject ages. Only four subjects were in their 40s and only three were older than 50, with the four oldest subjects frequently making installation errors. As a result, age was a more significant predictor in several analyses compared with previous studies that had more distributed ranges of subject ages.

All of the subject variables related to experience were correlated: previous child restraint experience, prior lower anchor experience, and prior tether experience. In addition, use of the child restraint or vehicle manual was inversely related to subjects' experience, with subjects less likely to use the manual if they had previous LATCH experience. As a result, only one of these subject predictors, tether experience, was considered a potential predictor in regression analysis. The within-subject elements of the study design helped account for this limitation because subjects were compared with themselves across vehicles in which they were tested.

Despite these limitations, the current study provides information about factors associated with tether use, correct tether attachment, and correct and acceptable tether routing and head restraint position. In particular, tether anchors located on the rear deck of sedans were associated with increases in tether use and correct tether attachment. Among tether anchor locations that may be found on other vehicle types, subjects were more likely to attach tethers correctly when the tether anchor was located on the middle of the seatback compared with the floor or lower seatback. The presence of confusing hardware was associated with reduced likelihood of tether use and correct tether attachment. Child restraint installations using a v-shaped tether were less likely to be attached correctly and routed according to vehicle manual instructions compared with the single-strap tether.

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Table 1 Vehicle study groups

Group	Vehicle	Vehicle type
1	2013 Mazda 3 Touring	Small sedan
1	2012 Ford Taurus	Large sedan
1	2012 Nissan Rogue	Small SUV
1	2013 Toyota Highlander	Midsize SUV
2	2012 Toyota Camry	Midsize sedan
2	2012 Kia Sedona	Large Minivan
2	2013 Subaru Outback	Midsize sedan
2	2013 Ford Fiesta	Mini sedan
3	2013 Honda Odyssey	Large Minivan
3	2012 Chevrolet Malibu	Midsize sedan
3	2013 Ford F150 SuperCab	Large pickup
3	2013 Jeep Patriot	Small SUV
4	2013 Chrysler 200	Midsize sedan
4	2013 Volkswagen Jetta Sportwagen	Midsize sedan
4	2013 Honda CR-V	Midsize SUV
4	2013 GMC Acadia	Large SUV

Table 2 Rates of correct child restraint installation for volunteer study vehicles.

	N	Tether attachment and routing				Child restraint installation			
		Tether used	Correct tether attachment	Correct tether routing and head restraint position	Acceptable tether routing and head restraint position	Lower anchors correct	Tight	Installation completely correct	Installation acceptable
Mazda 3	18	100%	56%	33%	50%	78%	67%	28%	44%
Ford Taurus	18	100%	67%	28%	39%	78%	44%	6%	17%
Nissan Rogue	18	89%	50%	33%	44%	94%	78%	22%	33%
Toyota Highlander	18	89%	61%	0%	50%	78%	72%	0%	39%
Toyota Camry	19	95%	68%	53%	63%	84%	63%	37%	47%
Kia Sedona	20	80%	40%	0%	35%	90%	75%	0%	30%
Subaru Outback	19	79%	47%	21%	21%	79%	74%	21%	21%
Ford Fiesta	20	95%	70%	60%	60%	65%	60%	40%	40%
Honda Odyssey	18	78%	61%	44%	61%	89%	67%	33%	50%
Chevrolet Malibu	18	89%	78%	61%	61%	44%	61%	33%	33%
Ford F150 SuperCab	18	94%	11%	11%	11%	83%	44%	11%	11%
Jeep Patriot	18	78%	61%	33%	50%	67%	56%	17%	33%
Chrysler 200	18	94%	67%	11%	33%	83%	56%	6%	28%
Volkswagen Jetta Sportwagen	18	89%	39%	22%	33%	83%	56%	11%	22%
Honda CR-V	18	89%	50%	39%	39%	100%	61%	28%	28%
GMC Acadia	18	94%	83%	61%	61%	67%	72%	28%	28%
Overall	294	89%	57%	32%	45%	79%	63%	20%	32%

Table 3 Rates of tether use and correct tether attachment by tether anchor characteristics.

	N	Tether used	Correct tether attachment
Anchor location			
Floor	36	89%	44%
Roof	19	79%	47%
Rear deck	129	95%	60%
Middle of seatback	54	87%	69%
Bottom of seatback	56	82%	50%
Packaging			
Covered recess	184	92%	60%
Open recess	54	87%	65%
Open	18	94%	11%
Slit in carpet	38	79%	50%
Construction			
Wire	128	87%	60%
Stamped parallel	93	90%	63%
Stamped perpendicular	55	93%	71%
Webbing	18	94%	11%
Anchor marked			
Yes	220	92%	61%
No	74	82%	43%
Anchor visible			
Yes	110	85%	51%
No	184	92%	60%
Confusing hardware present			
Yes	165	85%	47%
No	129	95%	70%

Table 4 Rates of tether use, correct tether attachment, and correct and acceptable routing by tether type and trials before and after LATCH instruction following trial 4.

	N	Tether attachment and routing			
		Tether used	Correct tether attachment	Correct tether routing and head restraint position	Acceptable tether routing*
Single tether					
Trials 1-4	73	85%	63%	42%	49%
Trials 5-8	74	97%	80%	53%	68%
Overall	147	91%	71%	48%	59%
V-shaped tether					
Trials 1-4	75	83%	43%	17%	32%
Trials 5-8	72	93%	42%	15%	29%
Overall	147	88%	42%	16%	31%
All installations					
Trials 1-4	148	84%	53%	30%	41%
Trials 5-8	146	95%	61%	34%	49%
Overall	294	89%	57%	32%	45%

Table 5 Mixed-effects logistic regression models predicting tether use. Statistically significant results indicated in **bold**.

Model	Predictors*	Odds ratio (95% confidence interval)	F-test
I	Tether location		
	Rear deck	Reference	F(4,79)=3.31, p=0.0146
	Floor	0.07 (0.01-0.58)	
	Roof	0.03 (0.003-0.35)	
	Middle of seatback	0.11 (0.02-0.64)	
	Bottom of seatback	0.06 (0.01-0.35)	
	Age		F(3,173)=3.15, p=0.0263
	50-70 years	0.01 (<0.001-0.25)	
	40-49 years	0.05 (0.003-0.76)	
	30-39 years	Reference	
	20-29 years	0.56 (0.04, 7.79)	
	Tether experience		F(1,173)=4.16, p=0.0430
	None	Reference	
	Some	9.00 (1.07-75.45)	
LATCH instruction		F(1,173)=11.99, p=0.0007	
No (trials 1-4)	Reference		
Yes (trials 5-8)	10.22 (2.72- 38.45)		
II	Confusing hardware		
	Yes	0.12 (0.19-0.823)	F(1,36)=5.0, p=0.0316
	No	Reference	
	Age		F(3,164)=1.99, p=0.1177
	50-70 years	0.01 (0.001-0.51)	
	40-49 years	0.05 (0.002-1.23)	
	30-39 years	Reference	
	20-29 years	0.82 (0.03-21.12)	
	Tether experience		F(1,164)=3.11, p=0.0798
	None	Reference	
	Some	7.14 (0.79-64.59)	
	LATCH instruction		F(1,164)=7.8, p=0.0058
	No (trials 1-4)	Reference	
	Yes (trials 5-8)	11.17 (2.03-61.63)	

*Potential covariates considered: child restraint model, instruction, age, previous tether experience, education, gender, and vehicle manual use.

Table 6. Pairwise comparisons of tether anchor locations in the mixed-effects logistic regression model predicting tether use* (F(4,79)=3.31, p=0.0146). Results shown are the odds ratio and 95% confidence interval of row title versus column title with statistically significant results in **bold**.

	Floor	Roof	Rear deck	Middle of seatback	Bottom of seatback
Floor	1	2.31 (0.19-28.59)	0.07 (0.01-0.58)	0.68 (0.11-4.33)	1.16 (0.18-7.64)
Roof	0.43 (0.04-5.38)	1	0.03 (0.003-0.35)	0.30 (0.03-3.18)	0.05 (0.06-4.14)
Rear deck	13.51 (1.72-111.11)	31.25 (2.87-333.33)	1	9.26 (2.86-52.63)	15.63 (2.86-83.33)
Middle of seatback	1.46 (0.23-9.26)	3.38 (0.31-35.71)	0.11 (0.02-0.64)	1	1.70 (0.33-8.77)
Bottom of seatback	0.86 (0.13-5.65)	1.99 (0.24-16.39)	0.06 (0.01-0.35)	0.59 (0.11-3.05)	1

*Other covariates in the model included instruction, age, and previous tether experience.

Table 7 Mixed-effects logistic regression models predicting correct tether attachment. Statistically significant results shown in **bold**.

Model	Predictors*	Odds ratio (95% confidence interval)	F-test
I	Tether location		
	Rear deck	Reference	F(4,79)=4.88, p=0.0014
	Floor	0.14 (0.04-0.46)	
	Roof	0.16 (0.37-0.72)	
	Middle of seatback	0.85 (0.31-2.38)	
	Bottom of seatback	0.21 (0.08-0.56)	
	Age		
	50-70 years	0.01 (0.001-0.18)	F(3,153)=3.88, p=0.0104
	40-49 years	0.21 (0.03-1.37)	
	30-39 years	Reference	
	20-29 years	0.83 (0.13-5.41)	
	Vehicle manual use		
	No	2.82 (1.02-7.78)	F(1,153)=4.09, p=0.0449
	Yes	Reference	
	LATCH instruction		
No (trials 1-4)	Reference	F(1,153)=5.12, p=0.0250	
Yes (trials 5-8)	2.28 (1.11-4.66)		
Child restraint			
With single tether	10.16 (4.57-22.59)	F(1,153)=32.83, p<0.0001	
With v-shaped tether	Reference		
II	Confusing hardware		
	Yes	0.21 (0.10-0.44)	F(1,235)=17.35, p<0.0001
	No	Reference	
	Age		
	50-70 years	0.02 (0.001-0.24)	F(3,235)=3.47, p=0.0170
	40-49 years	0.28 (0.03-1.54)	
	30-39 years	Reference	
	20-29 years	0.89 (0.13-5.97)	
	Vehicle manual use		
	No	2.58 (0.95-6.99)	F(1,235)=2.49, p=0.0631
	Yes	Reference	
	LATCH instruction		
	No (trials 1-4)	Reference	F(1,235)=4.68, p=0.0316
	Yes (trials 5-8)	2.17 (1.07-4.41)	
	Child restraint		
With single tether	9.91 (4.50-21.85)	F(1,255)=31.36, p<0.0001	
With v-shaped tether	Reference		

*Potential covariates considered for all models: child restraint model, instruction, age, previous tether experience, education, gender, and vehicle manual use.

Table 8 Pairwise comparisons of tether anchor locations in mixed-effects logistic regression model predicting correct tether attachment* (F(4,79)=4.88, p=0.0014). Results shown are the odds ratio and 95% confidence interval of row title versus column title with statistically significant results in **bold**.

	Floor	Roof	Rear deck	Middle of seatback	Bottom of seatback
Floor	1	0.87 (0.16-4.81)	0.14 (0.04-0.46)	0.17 (0.05-0.58)	0.70 (0.20-2.38)
Roof	1.15 (0.21-6.29)	1	0.16 (0.04-0.72)	0.19 (0.04-1.01)	0.80 (0.18-3.64)
Rear deck	7.01 (2.19-22.47)	6.13 (1.39-27.78)	1	1.18 (0.43-3.24)	4.88 (1.80-13.33)
Middle of seatback	5.96 (1.72-20.64)	5.21 (0.99-27.78)	0.85 (0.31-2.38)	1	4.15 (1.32-13.16)
Bottom of seatback	1.43 (0.42-4.88)	1.25 (0.27-5.71)	0.21 (0.08-0.56)	0.24 (0.08-0.76)	1

*Other covariates in the model included instruction, child restraint model, age, and vehicle manual use.

Table 9 Percent of installations using the tether with correct and acceptable tether routing and head restraint position by vehicle manual directions.

Directions for tether routing	Directions for head restraint position	Number of vehicles	Percent with correct routing and head restraint position	Percent with acceptable routing and head restraint position
Under	Up	5	45	55
Over	Fixed	3	48	61
Under	Down	2	0	50
Under or removed	Up or remove**	2	39	39
Outboard	Fixed	1	12	35
Over or around*	Fixed	1	48	61
Over or removed	Fixed or remove**	1	28	39
Removed	Remove	1	27	27

*Tether routing directions vary for single and v-shaped tethers.

**Head restraint may be removed if needed for good child restraint installation



Wire



Stamped parallel



Stamped perpendicular



Webbing

Figure 1 Examples of different tether anchor construction



Covered recess



Open recess



Open



Slit in carpet

Figure 2 Examples of different tether anchor packaging



Figure 3 Potentially confusing hardware includes cargo tie-down points (A and B) and webbing loops (C).



Figure 4 Evenflo Triumph child restraint with a single-strap tether (A) and Britax Marathon 70 child restraint with a v-shaped tether (B)

APPENDIX

Table A. Select tether anchor characteristics for study vehicles used in volunteer testing

Vehicle	Location	Construction	Packaging	Marking	Visible	Confusing hardware
2013 Mazda 3 Touring	Rear deck	Stamped parallel	Covered recess	Yes	No	No
2012 Ford Taurus	Rear deck	Wire	Covered recess	Yes	No	No
2012 Nissan Rogue	Floor	Stamped parallel	Covered recess	Yes	No	Yes
2013 Toyota Highlander	Middle of seatback	Wire	Covered recess	Yes	No	Yes
2012 Toyota Camry	Rear deck	Stamped perpendicular	Covered recess	Yes	No	No
2012 Kia Sedona	Bottom of seatback	Wire	Slit in carpet	No	Yes	Yes
2013 Subaru Outback	Roof	Stamped parallel	Covered recess	Yes	No	Yes
2013 Ford Fiesta	Rear deck	Stamped parallel	Covered recess	Yes	No	No
2013 Honda Odyssey	Bottom of seatback	Wire	Slit in carpet	No	Yes	Yes
2012 Chevrolet Malibu	Rear deck	Stamped perpendicular	Covered recess	Yes	No	No
2013 Ford F150 SuperCab	Back wall*	Webbing	Open	No	Yes	Yes
2013 Jeep Patriot	Middle of seatback	Wire	Open recess	No	Yes	Yes
2013 Chrysler 200	Rear deck	Stamped perpendicular	Covered recess	Yes	No	No
2013 Volkswagen Jetta Sportwagen	Floor	Stamped parallel	Covered recess	Yes	No	Yes
2013 Honda CR-V	Bottom of seatback	Wire	Open recess	Yes	Yes	Yes
2013 GMC Acadia	Middle of seatback	Wire	Open recess	Yes	Yes	No

*Tether anchor location for the Ford F150 was considered as rear deck for statistical analyses because its location is geographically similar to the rear deck locations.