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Evaluation of Correct Child Restraint System Installation

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16. Abstract This research project used an experimental design, called an “incomplete factorial” type, with a convenience sample of 75 novice and 75 experienced child restraint system (CRS) users to test whether user experience, child’s age/weight/height, vehicle characteristics, and CRS characteristics are associated with installation errors. This study identified conditions related to correct and incorrect CRS use to inform programming and education with the goal of increasing correct use. The results help frame the target population for programming and education as not only novice users, but also experienced users, as the study did not find a significant difference in errors by experience.		

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Executive Summary

This study examined factors associated with accurately selecting and properly installing child restraint systems (CRSs) and securing the child in the CRS for both novice and experienced users. The study team used an experimental design called an "incomplete factorial" design with a convenience sample of 75 novice and 75 experienced CRS users to test whether user experience, child's age/weight/height, vehicle characteristics, and CRS characteristics are associated with installation errors.

Each of the 150 participants completed four CRS installation trials. For each trial, the participant was assigned one child-size doll (infant, 16-month-old, 3-year-old, or 6-year-old) and one vehicle type (sedan, SUV, minivan, or pickup truck). Participants were told the age, height, and weight of the doll and asked to select and install the CRS in the assigned vehicle and secure the doll in the appropriate CRS. By the end of the four trials, each participant worked with all four dolls and all four vehicle types.

The study team categorized specific makes and models of CRSs and vehicles as easier or more challenging to install to examine the effect that CRS and vehicle features have on the installation process. The team randomized the presentation order across trials for the vehicle type, the easy/more challenging CRSs and vehicles, and the child-sized dolls to control for sequence, learning, and fatigue effects. The study team documented participant problems, errors, CRS acceptance, and confidence in installation.

Selecting the CRS

Overall, participants selected an inappropriate CRS (rear-facing-only, convertible, or booster) in only 10 percent of the trials, and there was no statistically significant difference between novice and experienced participants (13% versus 8%). Among the 62 selection errors, 25 involved premature graduation of the 3-year old to the booster seat, and 24 involved selection of the rear-facing-only seat for the 16-month old. None of the participants selected a wrong CRS for the infant.

Installing the CRS

Participants made installation errors in 68 percent of trials. Participants made the highest percentage of errors in trials when using rear-facing-only CRSs (83%) followed by convertible CRSs (77%). Participants were more likely to obtain secure fits in the minivans (49%), and participants were only able to achieve secure fits between the CRS and the vehicles in 25 percent of pickup truck trials. Participants made a greater percentage of errors when installing the CRS in the center seating position (74%) relative to the outboard seating position (62%). Errors associated with using the lower anchor system accounted for almost all this difference. When using the lower anchors and tether system to install the CRS in the center seating position, most participants incorrectly used the outboard lower anchors (80%).

There was not a statistically significant difference between the percentage of installation errors for novice and experienced users (71% versus 65%), but novice participants were more prone to making certain types of installation errors than experienced ones. Novice participants were more likely to have loose fits between the CRS and the vehicles (76% versus 60%), make errors related to using the seat belt retractors (65% versus 44%), and use both the seat belts and the lower anchor systems to install the CRS in the vehicles (35% versus 18%).

Securing the Doll

Overall, participants made errors when securing the doll in the CRS in 71 percent of trials, but there was no significant difference between novice and experienced participants (73% versus 69%). However, analysis of the specific errors related to securing the dolls in the CRS indicated that novice participants were more likely to make errors with respect to working with the chest clip than experienced participants (54% versus 38%). These issues included fastening the chest clips properly (7% versus 1%) and positioning the chest clips at the correct height (52% versus 37%).

Participants made the fewest securement errors in trials when working with the 6-year-old dolls (34%) compared to the other doll sizes (81% - 88%). Most participants selected the booster seat for the 6-year-old, which involves fewer steps to secure the doll. Participants made a greater percentage of errors when working with the convertible compared to the rear-facing-only CRS for positioning the harness height (25% versus 10%), crotch buckle (24% versus 8%), and using the infant insert (34% versus 11%). The convertible CRS was selected most often when working with larger sized dolls, which required the participant to make adjustments to these features from its standardized setting, and errors could occur if participants did not make the adjustments or made them incorrectly. Conversely, participants made more errors related to securing the doll snugly in the CRS when working with the rear-facing-only compared to the convertible CRS (68% versus 50%). The factors that were the strongest predictors of a securement error were child size, lack of use of the vehicle manual, CRS type, and CRS ease of use.

Perceived Confidence and Performance

Compared to their actual performance, most participants were overconfident in their ability to install the CRS or secure the doll. While participants made installation errors in 68 percent of trials, they lacked confidence in their work for only 21 percent of trials. Similarly, participants made securement errors in 71 percent of trials, but indicated they did not secure the child properly for only 7 percent of the trials. These findings suggest a gap between perceived and actual performance.

Perceived Ease of Use

Overall, participants tended to report that the booster seat was the easiest to use and the convertible was the most difficult. However, there was no relationship between a participant reporting that a feature was easy to use and the likelihood of making an error. Sixty to 80 percent of participants reported that the feature was easy to use, but still made errors related to its use. Experienced participants were more likely than novice participants to be "overconfident."

Conclusion

This study identified conditions related to correct and incorrect CRS use to inform programming and education with the goal of increasing correct use. The results help frame the target population as not only novice users, but also experienced users, as the study did not find a significant difference in errors by user experience.

1 Introduction

1.1 Background

Motor vehicle crashes are the primary cause of accidental death and injury among children between the ages of 5 and 14 years old in the United States (CDC, 2018). In 2017 an estimated 1,147 children under age 14 were fatally injured in motor vehicle traffic crashes, an 8-percent decrease from 1,244 in 2016. Of the 1,147 child fatalities, 794 were passenger vehicle occupants and 267 of the 794 were known to have been unrestrained (NHTSA, 2019).

NHTSA recommends that all children 12 and younger sit in the rear seats of moving vehicles and use child restraint systems (CRS) of appropriate height and weight. Research has shown that placing a child in the back row of the vehicle reduces the risk of injury by 64 percent for newborns to 8-year-olds and reduces the risk by 31 percent for children 9 to 12 years old (Durbin et al., 2015). In addition, an age- and size-appropriate CRS that is installed correctly provides the best protection in a crash until the child is large enough for an adult seat belt to fit properly. When compared to unrestrained child passengers, harness-based child restraints reduce fatal injuries by 71 percent for infants and 54 percent for 1- to 4-year-olds (Hertz, 1996; NHTSA, 2016). Children ages 2 to 6 in child restraints and belt-positioning booster seats are about 28 percent less likely to be fatally injured than those using safety belts alone. Finally, children 4 to 8 using belt-positioning boosters are 45 percent less likely to be injured than their cohorts in seat belts alone (Elliot et al., 2006).

Currently, there are three broad types of child restraint systems designed for typically developing children: rear-facing-only (infant carrier), convertible, and belt-positioning booster seats. Each system is designed to protect a child within a given height and weight category in the event of a crash. Rear-facing-only and convertible seats are secured to the vehicle seat using the vehicle's seat belt system or the vehicle's lower anchors and tether system, and the child is secured to the seat using the CRS harness system. Conversely, a booster seat provides a transition from the child safety seat with its internal harness to the vehicle lap/shoulder belt by repositioning the child so that the vehicle's seat belt system safely holds both the child and the booster in place.

Additional seating recommendations are based on the child's age, height, and weight. Children should be rear-facing for as long as possible. From birth to 12 months, children should be restrained rear-facing, and children 1- to 3 years old should be restrained in rear-facing car seats until they reach the height and weight limit of the CRS (NHTSA, 2020). Due to developmental conditions, children under age 2 are at greater risk of injury from sudden, jerky motions that occur during crashes (Jakobsson et al., 2005, McMurry et al, 2018). Rear-facing-only and rear-facing convertible seats are designed to protect the child from neck and cervical spine injuries during a crash. These rear-facing seats act as a "catcher's mitt" supporting the child's head and neck in the event of a frontal crash. Once the child is at least 2 years old and has exceeded the height or weight limits of the rear-facing seat, the convertible seat can be installed in the forward-facing position so the child can sit more upright.

NHTSA recommends that children remain in forward-facing child restraints in the rear seats of vehicles for as long as possible (NHTSA, 2020). Some forward-facing seats have weight limits up to 40 pounds, while others have limits that go up to 65 and even 85 pounds. Finally, when children have outgrown forward-facing seats, they should use belt-positioning booster seats until adult seat belts fit properly. The belt-positioning boosters elevate children to improve the fit of vehicle three-point seat belts, which are designed for adults, and allow children to bend their knees to prevent submarining, since many vehicle seats are also designed to fit adults.

While child restraint use has increased over the years (reaching 90% in 2017), children are still fatally injured in motor vehicles crashes. Possible factors include a child riding unrestrained in a vehicle, improperly secured in a CRS, or prematurely transitioned to a restraint system that is not appropriate (Li & Pickrell, 2018; Duchossois & Nance, 2008). In a NHTSA survey of child restraint misuse, one or more installation errors were identified in 73 percent of all CRSs observed (Decina & Lococo, 2003). The level of misuse was greatest for CRSs designed for infants and toddlers, where misuse was identified in approximately 82 percent of the cases. In addition, the 2011 *National Child Restraint Use Special Study* identified the most prevalent errors using nationally representative observations and interviews. The errors included incorrect harness routing slot used, improper harness positioning, loose CRS installation, loose harness straps, and improper lap belt placement (Greenwall, 2015).

Many factors contribute to errors made when selecting, installing, or securing a child in a child safety seat. For example, there are thousands of CRS makes and models, each with its own installation procedures and manual. Caregivers may not understand the terminology, have barriers to reading instructions, or be overwhelmed by wording or images. There is a never-ending flow of new caregivers who are unfamiliar with child passenger safety. Finally, despite their inexperience, a new parent may overestimate accuracy in selecting a CRS, installing a CRS to the vehicle, and securing the child in a CRS.

A study by Mirman et al. (2014) asked experienced caregivers to install a forward-facing child restraint seat in a vehicle and explored the relationship between CRS installation accuracy, security, caregiver confidence, and caregiver's perceptions of ease of use. Once the installation was complete, participants were asked to rate ease of use and confidence with the installation. They were also asked to estimate the likelihood of a crash and injury, and identify if they consulted any CRS information. The results suggest that the caregivers overestimated the accuracy and security of their installations. Eighty-nine percent of the participants installed the CRS inaccurately and/or insecurely. Of those participants with installation errors, 30 percent reported being confident that the CRS was installed correctly (Mirman, 2014).

The present study explored why selection, installation, and securement errors occur and what factors (e.g., CRS and vehicle features, user familiarity) contribute to the errors. Overall this study analyzed experienced and novice CRS user installation performance and confidence to determine what factors contributed to the number and type of errors.

1.2 Study Objectives

This study provides insight into the types of errors related to selecting, installing, and securing a child in a CRS and identifies causal factors that contribute to these errors for both novice and experienced users. Based on previous research, the study team identified and tested potential factors including child age/height/weight, features of the CRS and the vehicle, and seating position (center or outboard). Overall, the study addresses four objectives.

1. Identify user errors related to:

   – Selecting a CRS based on a child's height/weight/age;
   – Installing the CRS in various vehicles; and
   – Securing the child in the CRS.

2. Analyze the roles of the experimental factors (child age/height/weight, features of the CRS and vehicle, seating position and CRS familiarity) in predicting errors.

3. Examine the relationship between the caregivers' levels of perceived risk and inaccurate CRS installations.

4. Examine the relationship between the caregivers' level of confidence and inaccurate CRS installations.

2 Study Design

2.1 Overall Study Design

The study team used an "incomplete factorial" experimental design with a convenience sample of novice and experienced CRS users to test whether user experience, child's age/weight/height, vehicle characteristics, and CRS characteristics are associated with installation errors.

2.1.1 User: Experienced Versus Novice

The study examined how familiarity with installing CRS systems and securing children in them may influence the number and types of errors a user makes during the process. That is, an inexperienced (novice) user may be unfamiliar with the features used to secure a CRS to a vehicle seat and may be more likely to have difficulties locating it or may not know how to use it properly when compared to an experienced user.

When recruiting participants for the study, researchers used the following criteria to classify someone as a novice or experienced CRS user. A **novice** user met all criteria of

- Transporting a child (4 or younger) in a passenger vehicle less than two times a week (including never);
- Securing a child passenger (4 or younger) in a CRS fewer than 13 times in the past 6 months; and
- Having not installed a CRS in a passenger vehicle in the past year.

An **experienced** user met all criteria of

- Regularly transporting a child (4 or younger) at least twice a week;
- Securing a child passenger (4 or younger) in a CRS at least 25 times during the past 6 months; and
- Installing a CRS in a vehicle 3 or more times in the past year.

2.1.2 Child's Age, Height, and Weight

Recommendations for CRS use, user knowledge, and adherence to the recommendations vary based on the child's age and size. The study design included representation of children in four different age/height/weight categories. The study team used four Huggable Images safety training dolls to simulate the children.

- Infant (19 inches tall and 7 pounds)
- 16 months (31 inches tall and 22 pounds)
- 3 years (38 inches tall and 30 pounds)
- 6 years (48 inches tall and 46 pounds)

Each doll represented a child who could use either a rear-facing-only, convertible CRS (in the rear-facing or forward-facing mode), and/or a high back booster given the age, height, and weight. Table 2-1 identifies the recommended CRS type for each of these children.

Table 2-1. CRS Type by Child's Age

Child's Age	CRS Type			
	Rear-Facing-Only	**Convertible Rear-Facing**	**Convertible Forward-Facing**	**High back Booster**
Infant	X	X		
16 months		X	X	
3 years			X	
6 years			X	X

Note. The X indicates which seats would be correct based on manufacturer specifications. The participants were considered correct if they selected a seat that was not best practice (e.g., 16-month-old in a forward-facing convertible) but fit the child based on available information from the seat manual and labels.

2.1.3 CRS Characteristics

The design and location of some CRS features might make it more difficult for the user to install the CRS and increase the likelihood of errors. For example, the location and configuration of the belt path, the presence and design of the lock-off, location of the tether strap, and the design of the lower anchor connectors, may affect the type and number of errors a user makes during the installation. Some CRS models are incompatible with some vehicle seats, making it nearly impossible for a user to get a secure fit. The following sections outline some of the CRS characteristics and features that may affect perceived ease of use and correct installation.

2.1.3.1 Features of Rear-Facing-Only and Convertible Seats

Rear-facing-only (infant carrier) CRSs are primarily designed and recommended for children from birth to around 25 lbs. These CRSs are typically two pieces, a base and a carrier piece. The base can be installed in the vehicle; the carrier locks to the base and is used to secure the child. The carrier can also be secured to the vehicle seat without using the base, and rear-facing child restraints are not required to have tethers.

The convertible CRS is designed for a child from birth to around 70 lbs. In the rear-facing position, it can be used until the child is at least 2 years old, and many convertible seats are being designed to accommodate older children who weigh more (up to 40 lbs.) and are taller than the average 2-year-old. In the forward-facing position, some models can be used for children up to 70 lbs., accommodating children to approximately 7 years old.

Belt Path Location and Design

Users sometimes find it difficult to identify the proper belt path, but this problem is more likely on a convertible CRS because it has separate belt paths for both forward and rear-facing positions. While the belt paths are often labelled, manufacturers use different approaches when identifying these locations. Some manufacturers use simple labels with a single color to identify the different belt path; others use different colors with detailed information on each label to distinguish the two belt paths (forward-facing versus rear-facing). Figure 2-1 provides examples of different labelling methods for CRS belt paths.

Figure 2-1. Belt Path Labels

The width and direction of the belt path might also contribute to the number and type of errors. In addition, while most CRSs have simple and direct belt paths, others may require a serpentine method with more complex belt routing that may contribute to errors.

Lock-Off Location and Design

A lock-off is used with the lap and shoulder belt to clamp the tightened seat belt together and hold the CRS securely in place. When used properly, the seat belt is locked in pre-crash mode. Without lock-offs, most CRSs will require the seat belt retractors or locking clips to achieve secure fit. Most CRSs have lock-offs on both sides of the CRS or in the centers (base of rear-facing-only CRS or seat pan of a convertible CRS). When the lock-off is located on the side of the CRS, the user must identify which side should be used to secure the CRS and if the lap belt alone or both lap and shoulder belt should be threaded through the lock-off. Some CRS models allow users to open doors or levers on the CRSs, feed the seat belts across, buckle the seat belts, remove any excess slack, and close the doors, which eliminates the need to tighten the seat belts.

While other manufactures have similar designs, the feature only serves as a belt tensioner, and the user is required to use the retractor mechanism to lock the belt place. The locations and mechanisms also vary based on manufacturer. Figure 2-2 shows examples of different lock-off designs.

Figure 2-2. Belt Lock-off Examples

Lower Anchors and Tether Straps and Connectors

The lower anchors and tether system on a CRS has two parts: the lower anchor straps/connectors and the tether strap/connector. When used properly, lower anchors secure the CRS to the vehicle when the combined weight of the child and CRS is less than 65 lbs. The tether strap is often used only when the seat is in forward-facing position. There is a great deal of variability in how the CRS lower anchor and tether connectors are designed, stored, and used. The design of the anchor connectors varies by manufacturer (i.e., standard lower anchors and tether clips, quick connectors, rigid connectors, "sure" lower anchors and tether, etc.). The procedures for tightening the lower anchor straps can also differ. In addition, there are variations in the storage location and methods across CRSs. Figure 2-3 depicts different types of connectors and lower anchors and tether systems. The images on the top depict a system with a single-pull dual-tightening system that equally tightens both anchors and a push-button lower connector. The images on the bottom show a one-sided tightening system with a standard lower anchors and tether connector, which resembles a metal hook.

Figure 2-3. Lower Anchors and Tether Systems

Harness: Adjustments and Re-Thread

Most conventional harnesses are a 5-point system with straps coming over the child's shoulders, pelvis, and between the legs. All come together at a common buckle located at the child's crotch. A retainer clip (also called chest clip) is located on the shoulder straps and when used properly will hold the straps together over the child's chest at armpit level. While all of these components act in unison to secure the child in the CRS, each component introduces opportunity for error.

The height of the harness straps needs to be adjusted as the child grows. Some CRSs include a no re-thread harness system meaning the harness height can be adjusted by pressing a lever and raising the harness. Others require the user to re-thread the harness straps by removing them from the slots and routing them through a set of slots at a higher level in the back of the CRS. Re-threading can introduce errors such as twisting straps or not re-securing the harness straps properly. Alternatively, the mechanism for raising the harness straps may not be clearly labelled. Figure 2-4 shows examples of a no re-thread harness system (left) and a re-thread harness system (right).

Some seats have multiple crotch buckle locations to accommodate smaller and larger children. Adjusting the crotch buckle can vary, some seats require the user to re-thread the straps and others simply need the user to slide it into the next position.

Figure 2-4. Examples of No Re-Thread and Re-Thread Harness Systems

2.1.3.2 High back Booster Seats

Booster seats provide the transition from child seats with internal harnesses to vehicle seat belts. To transition to a booster seat, children should meet the minimum and maximum booster seat recommended weight range. Compared to the other CRSs, booster seats do not restrain the child; they position the child so that the vehicle seat belt fits properly over the stronger parts of the child's body and allows the child's knees to bend comfortably while the child is riding in the vehicle, which greatly reduces the tendency to slouch.

There are two types of booster seats, a backless booster and high back booster. High back boosters, as well as some backless boosters, have shoulder belt guides that route the shoulder belts toward children and makes their angles more vertical so the belts cross the center of children's chests. Both types of booster seats use arm rests to guide the lap belts so they lie low and flat cross the upper thighs. Only high back booster seats were included in this study.

Belt Path and Labelling

The overall design and labelling of the shoulder belt guide differ among different booster seats. Additionally, booster seats may have specific requirements about the placement of the shoulder belts with respect to built-in arm rests. For example, some booster seats require that the shoulder belts be routed under the armrests nearest to the vehicle buckles, while others do not have such restrictions.

Positioning of Head Restraint

When using the high back booster seat, the ease with which a user can adjust the head restraint height can vary. Proper use of the high back booster requires the booster's head restraint be at a certain height with respect to the crown of the child's head, and sometimes the manual provides guidance about placement with respect to the child's ears. As with other CRS features, the labelling and mechanisms used to accomplish this positioning can differ depending on the manufacturer. For example, some boosters have handles located at the tops of the seats that allow users to raise and lower the head restraints (left-side image in Figure 2-5). Others require two hands to perform the tasks and have additional levers on the back sides of the seats (right-side image in Figure 2-5).

Figure 2-5. Examples of Head Restraint Adjustment Mechanisms

2.1.4 Protocol for Selecting Representative Child Restraint Systems

Using a two-stage method, the study team selected six CRS makes/models for the study. In the first stage, the team analyzed sales trends for rear-facing-only seats, convertible car seats, and high back booster seats. The team created a list of top-selling CRSs for each type based upon sales at several different nationally representative stores, including Amazon, Wal-Mart, Target, and Babies-R-Us.

In the second stage, the team worked with certified child passenger safety technicians (CPSTs), a national expert in child passenger safety, and NHTSA representatives to identify CRS features that may make the CRS easier or more challenging to install. The team reviewed the 2016 Safe Ride News lower anchors and tether manual and several websites, including NHTSA Ease of Use Ratings, IIHS Booster Evaluations, the Car Seat Lady, and Consumer Reports to inform the classification. Features and characteristics considered when rating the CRSs are presented in Table 2-2. The team rated each feature of each seat type as easy, average, or difficult with respect to how they may affect the installation.

Table 2-2 . Rear-Facing-Only and Convertible CRS Features and Booster Seats

Rear-Facing-Only and Convertible CRS Features That May Affect Ease of Installation and Securement	
Seat Dimensions	• Width and height • Center of gravity • Weight of CRS

Lower Anchors and Tether Installation	• Belt path labelling
	• Lower anchor design
	    o Standard lower anchor clips versus quick connectors versus rigid connectors
	    o One-sided versus two-sided tightening
	• Tether location on CRS

Seat Belt Installation	• Installation procedures with a seat belt • Belt path labelling • Width of belt path • Presence of a lock-off o Lock-off location and design

Harness System	• Chest clip configuration
	• Crotch buckle configuration
	• Harness design
	• Harness adjustment
	    o Re-thread versus no re-thread
	    o Splitter plate design
	    o Width of adjustment slots (in the plastic of the seat)

Recline Adjustment	• Recline adjustment process • Method for determining if CRS is level o Bubble indicator versus color indicator versus line
CRS Labelling	• Overall content and clarify of CRS labels
CRS Manual	• Content and clarity of information related to CRS installations • Overall organization
High back Booster Seat Features That May Affect Ease of Installation and Securement	
Seat Dimensions	• Width and height • Arm rest height

Seat Belt Installation	• Procedure for routing the seat belt
	    o Shoulder belt guide
	    o Lap belt
	• Use of colors to differentiate belt routes

Height Adjustment	• Procedures for adjusting the head restraint
Lower Anchors	• Presence of lower anchors for attachment purposes
CRS Labelling	• Overall content and clarity of CRS labels
CRS Manual	• Content and clarity of information related to CRS installations • Overall organization

The process guided the selection of six seats for the study, including one easy and one more challenging CRS for each seat type (i.e., rear-facing, convertible, and booster).

2.1.5 Vehicle Characteristics

Similar to the CRS, certain vehicle features may affect how easy or challenging it is to install a CRS and the number and types of errors made by the user. The vehicle seat pan width, depth, contour, angle, and slope can all influence how securely a CRS can be installed in a vehicle. In addition, the location and number of lower anchors and tether systems, and the design and geometry of the seat belt and buckle, can all influence CRS installation. Some vehicle restraint systems and seats may be incompatible with some models of CRSs. The following sections outline some of the vehicle characteristics that may affect CRS installation.

Lower Anchors and Tether System

Lower anchors and tether systems consist of built-in straps and hooks on the CRS and anchor hardware in the vehicle. When in use, the lower anchors and attachments take the place of seat belts. However, not all vehicle lower anchor and tether systems are the same. In some vehicles, the lower anchor hardware is more easily identifiable because it protrudes from the seat bight. Alternatively, anchors in other vehicles are recessed into the seat bight, making it difficult to find. The number of anchor positions available in the vehicles vary as well. Some vehicles have anchors in two seating positions (the outboard seats), and other vehicles have anchors in all three rear seating positions (See Figure 2-6).

The location of the tether anchor also varies across vehicles. The tether anchor is on the shelf behind the second row of seats in most sedans. However, in hatchbacks, minivans, crossovers, and SUVs, the tethers are often located on the backs of the seats (top or bottom) or sometimes on the ceilings of the vehicles. Alternatively, some vehicle types have more complex procedures for attaching the tethers. Most pickup trucks require additional steps including routing the straps through the fabric routing loop and hooking the CRS straps to the tether anchors above the seats adjacent to the seating position where the CRSs are installed. Figure 2-7 depicts examples of tether locations in different vehicle types and different installation requirements.

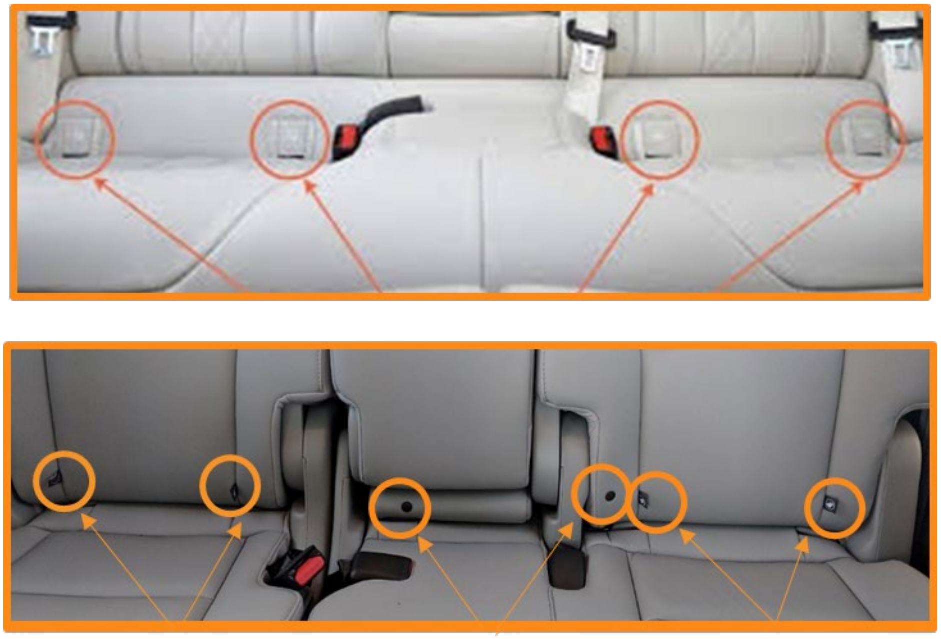


Figure 2-6. Examples of Different Anchor Configurations

Figure 2-7. Examples of Tether Locations and Install Requirements

Seat Belt and Buckle

When using a seat belt to secure the CRS to the vehicle, the length, width, and position of the buckle may affect installation. A long buckle stalk may make it difficult to tightly secure the CRS to the seat. In addition, the position of the buckle may also affect the user's ability to secure the seat. Sometimes the buckle is recessed into the seat cushion, which makes it challenging for the user to locate it and lock the belt. Others are raised out of the seats and tilted forward.

Finally, the location of the shoulder belt can also vary depending on the vehicle make and model. For example the shoulder belt may originate from the C-pillar, the back of the seat, or the ceiling of the vehicle. Vehicles that have the shoulder belts originating from the ceiling require extra attachment at the vehicle seats to function properly. Figure 2-8 shows examples of different seat belt origination points.

Figure 2-8 Seat Belt Origination Point Examples

Vehicle Seat Dimensions

When the CRS has a wide base and the vehicle seat is narrow or raised, as is the case with some center seating positions in the second row, the CRS may not fit properly on the vehicle seat. In addition, some CRS manufacturers have specific requirements for how much of the CRS rests on the vehicle seat. If the depth of the vehicle seat is shallow, meeting that requirement may be impossible. Additionally, a seat with a very steep slope or no slope at all can make it challenging to achieve a correct installation angle that meets the CRS manufacturer requirements.

2.1.6 Protocol for Selecting Representative Vehicle Features

The study team selected eight vehicles for inclusion using a two-stage process. In the first stage, the team reviewed 2015 and 2016 vehicle sales to select top-selling vehicles across vehicle types (i.e., minivans, SUVs, sedans, and pickup trucks). The team selected top-selling vehicles in an effort to make the research findings applicable to what parents and caregivers are currently exposed to when trying to install CRSs in vehicles.

In the second stage, the team conducted closer inspection of the top-selling vehicles to determine if they possess features that make it easier or more challenging for users to install CRSs (See Table 2-3). The team classified features by "ease of use" in consultation with subject matter experts, CPSTs, NHTSA representatives, and a thorough review of the Insurance Institute for Highway Safety (IIHS) lower anchors and tether system for children (LATCH) ratings (IIHS, 2016). Certified CPSTs confirmed each classification by examining 2016 and 2017 vehicle models.

Table 2-3. Vehicle Features

Vehicle Features That May Affect Ease of Installation	

Vehicle Seat	• Contour of the vehicle seat
	  ○ Bucket versus bench
	  ○ Presence of a hump for the center seat
	• Width and depth
	• Angle or slope
	• Angle of seat back
	• Presence of arm rests that protrude from seat back

Lower Anchors and Tether for Child Restraints System	• Clarity of labelling of the lower anchor and tether system
	• Number of lower anchors
	• Position of lower anchors in the seat bight
	  ○ Recessed versus protruding
	  ○ Clearance around the anchor
	• Number of tether anchors
	• Position of tether anchors

Seat Belt	• Length of the buckle stalk
	• Position of the buckle stalk
	  ○ Recessed into seat versus tilted forward
	• Seat belt design origination
	  ○ From seat back, door, or ceiling of vehicle
	• Seat belt design
	  ○ Lap/shoulder belt
	  ○ Automatic locking retractor (ALR)
	  ○ Emergency locking retractor (ELR)
	  ○ Locking lower anchor plate

Vehicle Manual	• Content and clarity of information related to CRS installations • Overall organization
Vehicle Interior	• Overall interior size of the vehicle • Space between the front row of seats and second row of seats

2.2 Overview of Session Protocol

Participants were asked to complete four CRS installation trials, one for each of the child-size dolls (infant, 16 month-old, 3 year-old, and 6 year-old). The participants were assigned a different vehicle and doll for each trial. The study team randomized the order of installation to control for sequence, learning, and fatigue effects across trials. Statisticians randomly assigned the 150 participants across 600 trials to a vehicle, seating position, and CRS type with respect to ease of use to achieve balance for every level of these variables. For each trial, the experimenter handed the participant the assigned doll with a label to identify the age, weight, and height of the doll. The experimenter then escorted the participant to the assigned vehicle. Next, the experimenter instructed the participant to select the CRS they felt was most appropriate out of the three available (infant, convertible, and booster). Participants could also choose to use the seat belt if they thought that was appropriate. The study team provided each participant with the manuals for each vehicle and CRS. Participants were asked to complete each installation by securing the CRS to the vehicle and securing the assigned doll in the CRS. The team repopulated the CRS selection pool after each trial, allowing participants to use the same CRS for more than one trial.

After each installation, the team administered a post-installation questionnaire to ask participants about ease of installation and challenges related to the CRS, the vehicle, and the manuals. The study team also completed an observational checklist after the participants left the lab to record the errors across trials and measurements of lateral and forward CRS movement to assess CRS installation.

3 Study Participants

3.1 Recruitment

3.1.1 Participant Recruitment

The research team recruited participants from the greater Washington, DC, area and conducted the study in Rockville, Maryland. The team recruited participants through advertisements in local papers, websites such as Craigslist, social media sites, and various parenting group websites. The team also posted flyers at businesses frequented by drivers transporting children, including local stores that sell CRSs, community and recreational centers, daycare centers, and pediatric offices.

The study team screened potential participants for eligibility as either a "novice" or "experienced" CRS users when they called in response to the advertisement. The screener instrument also collected information on age, sex, race, driving practices, and CRS experience.

3.2 Participant Demographics

The study team screened 358 people and enrolled 150 as participants in the study. The team classified 75 participants as novice CRS users (43 females and 32 males) and 75 as experienced CRS users (54 females and 21 males).

All experienced users indicated that they met the minimum criteria, and in the past year, 55 of the 75 experienced participants had each installed a CRS in a passenger vehicle more than 6 times. Twenty other participants had each installed a CRS between 3 to 5 times. The average age of experienced users was 38 years old.

For novice users, 74 reported that they never transported children 4 or younger. One indicated that he/she had transported a child but did so less than two times a week. In addition, this participant indicated that he/she secured the child in the CRS fewer than five times in the last six months. None of the novice users installed a CRS in a passenger vehicle within the past year. The average age of the novice participants was 42 years old.

Participant responses to the screener questions show a clear distinction between the participant types, with experienced users having more familiarity with installing CRSs and securing children in them. While some novice users indicated that they had each installed a CRS in the past, none had done so within the past year, and only one novice participant had secured a child in a CRS within the past six months. Table 3-1 shows a breakdown of the participants' experiences.

Table 3-1. Participant CRS Experience

			Transported a child under 5 years old at least <u>twice a week</u>			Secured a child under 5 years old in a CRS in the past <u>6 months</u>				Installed CRS in a vehicle		Installed a CRS in the past year		
			Never	**No**	**Yes**	**5 or less times**	**6 – 12 times**	**25 – 53 times**	**54 or more times**	**Yes**	**No**	**None**	**3 – 5 times**	**6 or more times**
Experienced	Male	21	-	-	21	-	-	1	20	21	-	-	5	16
	Female	54	-	-	54	-	-	1	53	54	-	-	15	39
Novice	Male	32	31	1	-	1	-	-	-	17	15	32	-	-
	Female	43	43	-	-	-	-	-	-	26	17	43	-	-

4 Study Procedures

4.1 Experimenter Training

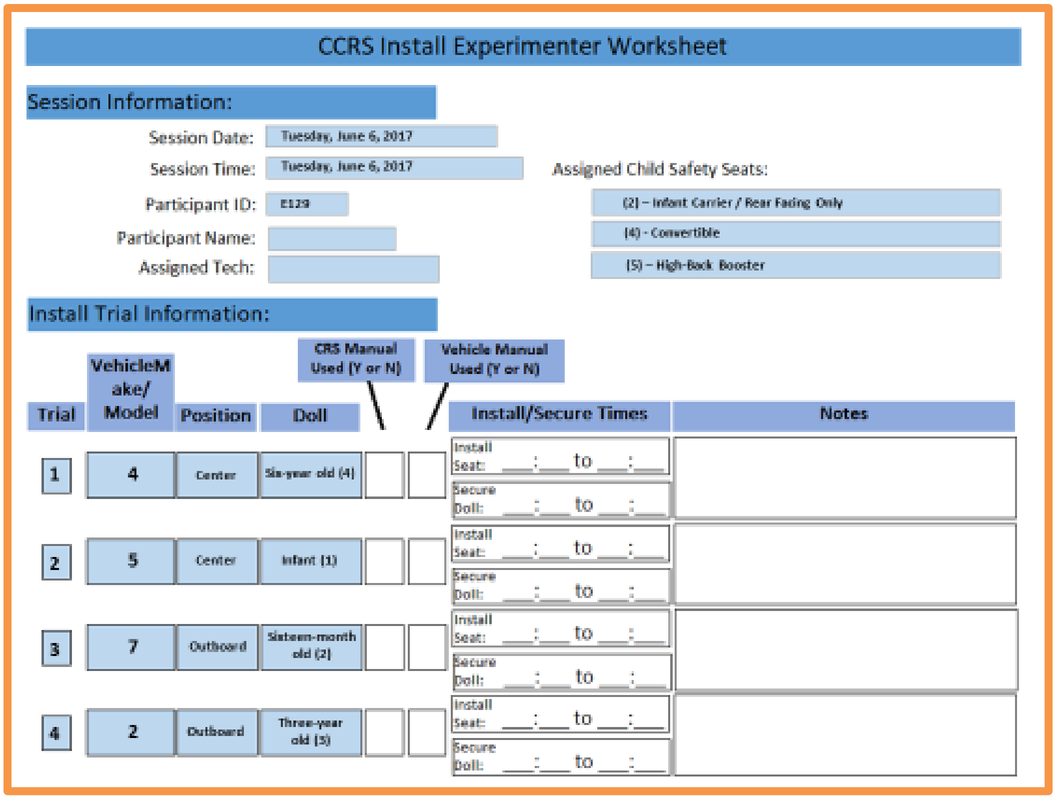
The study team trained six CPSTs to be experimenters for this study. All experimenters were active CPSTs or instructors, had recent experience with all types of CRSs and lower anchors and tether systems, and were capable of meeting the physical demands of the study.

Experimenters attended a one-day training session with lectures, hands-on practice, and role-playing. The training provided a brief overview of how CRSs should be installed in each vehicle and highlighted key features for each CRS and vehicle in the study. It included the location of the lower anchors and tether system, how to adjust the CRS harness straps, angle of installation, crotch buckle position, and use of lock-offs. The training also emphasized unique CRS manufacturer installation requirements and likely installation errors.

In addition to the one-day training, experimenters each participated in two supervised data collection sessions before they directed data collection sessions independently. During the first supervised session, a trainer was responsible for walking the participant through the session. The experimenter shadowed the trainer and observed how the participant was guided through the session, interactions between the participant and trainer, and finally how the trainer recorded key data elements during and after CRS installation. It included documenting how the participant installed the CRS and secured the child; errors made by the participant; any observations that might help to explain the data; and any comments made by the participant indicating confusion, frustration, or assuredness. During the second session, the experimenter was responsible for running the session while the trainer observed and answered questions.

4.2 Preparing the Lab

The experimenter prepared the lab prior to participant arrival. The experimenter reviewed the random sequence of vehicle type, CRS type, and doll size assignments for each scheduled participant. The experimenter used a worksheet to identify the dolls, vehicles, vehicle seating positions (second row center versus second row driver side outboard), and CRSs the participant would be working with for each trial (see Figure 4-1). The experimenter ensured the vehicle manual and the CRS manual were available for participants to reference if they elected. Next, the experimenter placed the dolls in the order they would be installed across trials. Last, the experimenter confirmed the assigned CRSs were set out for selection and in their “out-of-the-box” standardized conditions (all CRS features at factory settings).



CCRS Install Experimenter Worksheet

Session Information:

Session Date: Tuesday, June 6, 2017

Session Time: Tuesday, June 6, 2017

Participant ID: E129

Participant Name:

Assigned Tech:

Assigned Child Safety Seats:

(2) – Infant Carrier / Rear Facing Only

(4) - Convertible

(5) – High-Back Booster

Install Trial Information:

Trial	VehicleMake/Model	Position	Doll	CRS Manual Used (Y or N)	Vehicle Manual Used (Y or N)	Install/Secure Times	Notes
1	4	Center	Six-year old (4)			Install Seat: __:__ to __:__ Secure Doll: __:__ to __:__	
2	5	Center	Infant (1)			Install Seat: __:__ to __:__ Secure Doll: __:__ to __:__	
3	7	Outboard	Sixteen-month old (2)			Install Seat: __:__ to __:__ Secure Doll: __:__ to __:__	
4	2	Outboard	Three-year old (3)			Install Seat: __:__ to __:__ Secure Doll: __:__ to __:__	

Figure 4-1. Example Experimenter Worksheet

4.3 Consent and Risk Appraisal Questionnaire

Each participant read and signed a consent form. The consent form provided a complete overview of the study, outlined any risks associated with participation, and explained that the participant was free to withdraw from the study at any time. Each participant completed a pre-install questionnaire that asked about risk appraisal specific to motor vehicle crash and injury risks, and driving habits involving children. The participant completed the questionnaire prior to the trials to minimize the influence of installing CRSs on responses. All forms and procedures were approved by the Institutional Review Board at Westat, Inc., and this information collection was approved by the Office of Management and Budget under control number 2127-0721.

4.4 CRS Installation Trials

Following the pre-install questionnaire, each participant was given the first doll and asked to think of this doll as a real child to make proper installation a more important factor than time. Every doll had a laminated card indicating its age, height, and weight (see Figure 4-2). The experimenter read the age, height, and weight for the doll and guided the participant over to the CRS selection station. The experimenters asked participants to select the CRS they found most appropriate to safely transport the assigned dolls. Participants could select any of the CRSs made available to them or could use the seat belts alone if they found that most applicable.

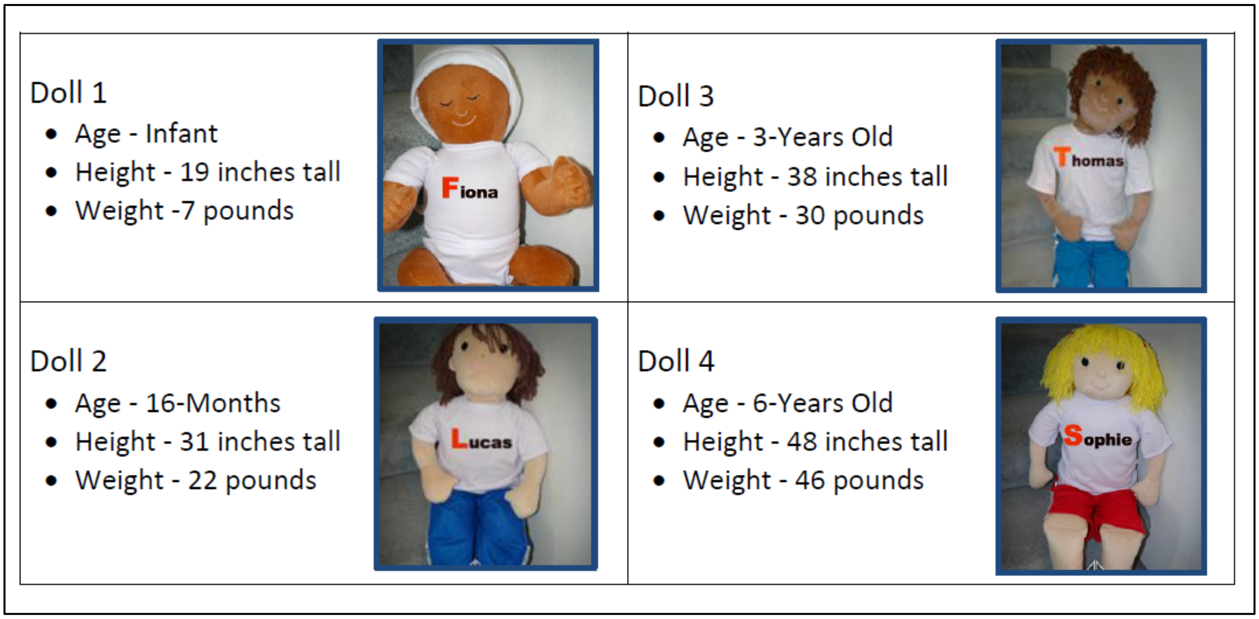


Figure 4-2. Doll Height and Weight Cards

The experimenter informed participants that the vehicle and CRS manuals were available for their use. However, the experimenter did not provide verbal instructions on how to use the different CRS features or vehicle features. Experimenters followed a written script to help ensure uniformity.

After the participants selected the restraint type (i.e., CRS or seat belt), the experimenter asked them to install the CRS in the assigned vehicle and seating position, and secure the doll in the selected CRS. Participants were given 30 minutes to install the CRS and secure the doll.

When installing the CRS, participants could select the installation method they found most appropriate (e.g., lower anchors and tether or seat belt). During each trial, the experimenter documented observations of interest using a tablet computer. The experimenter encouraged participants to think aloud and made every effort to record when a participant found something easy or when they expressed confusion or frustration with the various CRS and vehicle features.

After the participant completed each trial, the experimenter administered a post-installation questionnaire using a tablet. The questionnaire adapted to each participant's experimental conditions using skip patterns to ask questions relevant to the CRS type selected, the direction of the installation (rear-facing versus forward-facing), the method of installation (lower anchors and/or tether versus seat belt and/or tether), the vehicle, and the seating position.

The post-installation questionnaire collected participant opinions and perceptions regarding their experiences during each trial using a series of ratings. Specifically, the questionnaire captured acceptance of the CRS, confidence in installation, challenges with installation, and usability of the CRS and vehicle manuals.

Prior to beginning each new trial, the experimenter replenished the CRS selection pool with a duplicate seat. The experimenter reminded the participant that if he/she found it appropriate, he/she could select the same seat used in the previous trial. The experimenter used the identical procedure for all four trials.

Once the session was over and the participant left the facility, the experimenter completed a close inspection of all four installed CRSs. The experimenter took pictures and completed the Observation Checklist to document the circumstances of each installation and any errors. The experimenter took measurements of lateral and forward movements and documented installation fit.

Experimenters looked for specific types of installation errors with respect to each type of CRS, vehicle type, and child size. Tables 4-1 and 4-2 identify and define all possible errors documented for each trial and included in subsequent analysis. Note, a participant often made more than one error for any of the steps related to installing the CRS and securing the doll. There was one possible selection error, which was selecting the incorrect CRS with respect to the assigned doll's age, height, weight, and the CRS manufacturer requirements.

Table 4-1. Possible installation errors

Installation error name	Definition
Unable to Complete Installation	Participant was unable to complete the installation of the CRS.
Incorrect Direction of Install	Participant installed the CRS in the incorrect direction based on the assigned doll's weight, and height and CRS manufacturer requirements.
Lower Anchors <u>and</u> Seat Belt Used to Install CRS	Participant chose to install the CRS using both the vehicle seat belt and the CRS lower anchor system, and the use of both was not allowed per the CRS manufacturer and vehicle requirements.
CRS Not Securely Attached	The CRS was not securely attached to the vehicle. There was either lateral and/or forward movement of more than 1 inch at the belt path.
Seat Belt Routed Incorrectly	The seat belt is not routed properly through the CRS belt path per the CRS manufacturer requirements.
Seat Belt Twisted	The seat belt was twisted during the CRS installation.
Retractor Error	A seat belt retractor error can be made in several ways: (1) The participant failed to lock the retractor and a lock-off was not present or not used on the CRS. (2) The participant locked the retractor and also used the lock-off on the CRS (if one was present).
CRS Lock-Off Error	A CRS lock-off error can be made in several ways: (1) The participant did not use the retractor for the seat belt and did not use the lock-off on the CRS. (2) The participant used both the lock-off and the seat belt retractor. (3) The lock-off was used incorrectly per the CRS manufacturer requirements (e.g., not shut or locked, wrong side with respect to the location of the seat belt buckle). Note: Only two of the chosen CRSs had lock-offs.
Lower Connectors Attached to Incorrect Seating Position	Participant attached lower connectors to the vehicle anchors in the wrong seating position.
Lower Connectors Attached Incorrectly	A lower connector can be attached incorrectly in several ways, these include: (1) the bulky side of the lower anchor connector is not

Installation error name	Definition
	oriented properly (on top), (2) The hook portion of the clip is not facing downward. (3) The lower anchor connector is not actually attached to the lower anchor in the vehicle (e.g., just placed in the seat bight), or (4) the lower anchor connector is attached to something other than the lower anchor in the vehicle (e.g., attached to the seat belt buckle).
Lower Connectors Routed Through Incorrect Belt Path	This error is made when: (1) a participant installs a CRS in the rear-facing direction and uses the forward-facing belt path; or (2) a participant installs a CRS in the forward-facing direction and uses the rear-facing belt path. Note: Only the convertible CRS had multiple belt paths.
Weight of Doll Over Lower Anchor Limit	Participant chose to install a convertible CRS using the lower anchors for the 6-year-old doll. Most vehicle manufacturers have a 65 lbs. lower anchor weight limit. The 65 lbs. limit is the combined weight of the seat and the CRS. If the CRS weighs 25 lbs. (which was the case for the two convertible seats selected) the maximum weight for an allowed doll would be 40 lbs.
Tether Is Attached to Incorrect Vehicle Anchorage Point	This error can occur if the participant either: (1) Secured the tether to an anchorage in a different seating position than specified by the vehicle manual. (2) Secured the tether to a different anchorage not intended for a tether, for example a cargo net anchor.
Tether Attached Incorrectly	Participant did not secure the tether properly with respect to the hook (e.g., hook side was facing up instead of down).
Tether Routed Incorrectly	Participant routed the tether harness improperly with respect to the head restraint as specified in the vehicle and CRS manuals.
Tether Not Tight	Participant connected the tether and the CPS technician was able to identify slack in the tether webbing. Slack was defined as the ability to pinch the tether webbing together.
CRS Touching Front Seat	The installed CRS is touching the front seat and the CRS manufacturer manual indicates this is not allowed.
Recline Angle Incorrect	Most CRS have level lines or bubble indicators to identify proper recline angle. This error occurred when the angle of the installed CRS does not adhere to the manufacturer specifications listed in the manual.
Recline Foot Not Attached	Participant installed the CRS in the rear-facing direction without attaching or improperly attaching the recline foot. Note: Only one of the selected CRSs required that a recline foot be attached when installed in the rear-facing direction.
Incorrect Carrier Handle Position	The CRS was installed and the handle was not placed in one of the allowed positions. Note: Certain rear-facing-only seats require that the carrier handle be in a specific or in one of several specific positions.

Note. The sum of all installation errors, seat belt install errors, lower anchor install errors, tether install errors, and rear-facing install errors were also calculated and used in analyses.

Table 4-2. Possible securement errors

Securement error name	Definition
Unable to Secure Doll	Participant was unable to secure the doll in the CRS.
Crotch Buckle Incorrect Location	Participant did not have the crotch buckle in the correct location based upon the assigned doll's size. Note: Both rear-facing-only and convertible seats selected had multiple locations for the crotch strap, based upon the size of the doll.
Crotch Buckle Not Fastened	Participant failed to fasten the harness straps into the crotch buckle.
Harness Straps Twisted	Participant introduced twists or folds into the harness straps when securing the doll.
Harness Height Incorrect	Harness straps were routed (through the back of the seat) at the wrong height with respect to the doll's size and the direction of installation.
Harness Straps Threaded Incorrectly	Participant failed to thread the harness straps through the proper slots (matching slots in the plastic and the seat fabric).
Harness Straps Not Snug	Harness straps were too loose on the doll and the CPS technician was able to pinch and hold the webbing of the harness in the pinched position.
Harness Not Adjustable	Harness straps were routed improperly through the CRS and could not easily be adjusted. During an installation, it is possible for the user to twist the harness, or catch portions of the harness on parts of the CRS or wedge portions of the harness webbing between the CRS and the vehicle seat. In cases such as these, the straps would not be able to be adjusted (tightened or loosened) easily when securing the doll.
Harness Not Anchored	Harness strap anchors are not locked or anchored to the back of the CRS properly and can be pulled through. This type of error typically occurs when a re-thread is necessary.
Chest Clip Fastened Incorrectly	Chest clip is not fastened at all or improperly fastened (out of alignment).
Chest Clip Not at Armpit Level	Chest clip was not at armpit level.
Chest Clip Threaded Incorrectly	Participant introduced twists into the webbing of the chest clip prior to buckling.
Legs Don't Bend Over Edge of Seat in Booster	The doll’s legs did not bend properly over the edge of the seat. Proper booster fit requires that the child's legs are able to bend naturally over the edge of the booster seat without the child slouching.
Shoulder Belt Not Over Center of Chest in Booster	Shoulder belt did not cross the center of the chest. Proper booster fit requires that the shoulder belt should cross over the center of the child's chest.
Lap Belt Not Low On Hips in Booster	Lap belt was positioned too high on the dolls abdomen. Proper booster fit requires that the lap belt should lie low across the child's hips (across the anterior superior iliac spine [ASIS]).

Securement error name	Definition
Legs Don't Bend Over Edge of Seat in Vehicle Seat	The doll's legs did not bend over the edge of the seat. Proper seat belt fit means, when sitting in the vehicle seat, the child's legs are able to bend naturally over the edge of the seat without the child slouching. Note: Based on current NHTSA recommendations, none of the dolls included in our study should be restrained in the vehicle seat and seat belt alone.
Shoulder Belt Not Over Center of Chest in Vehicle Seat	The shoulder belt did not cross the center of the chest. Proper seat belt fit requires that the shoulder belt should cross over the center of the child's chest. Note: Based on current NHTSA recommendations, none of the dolls included in our study should be restrained in the vehicle seat and seat belt alone.
Lap Belt Not Low On Hips in Vehicle Seat	The lap belt was positioned too high on the doll's abdomen. Proper seat belt fit requires that the lap belt should lay low across the child's hips (across the ASIS). Note: Based on current NHTSA recommendations, none of the dolls included in our study should be restrained in the vehicle seat and seat belt alone.
Infant Insert Error	Participant failed to remove the insert for any doll other than the infant doll or removed the insert when securing the infant doll. Note: Two of the seats had an infant insert, which are typically to be used up to a certain weight.

Note. The sum of all securement errors, crotch buckle answers, harness errors, chest clip errors, booster fit errors, and seat belt fit errors was also calculated and used in analyses.

5 Data Quality Control and Cleaning

5.1 Database Cleaning

The study team completed a series of data quality checks. First, all data was reviewed for accuracy and completeness by the experimenter prior to submitting data. Next, data forms were reviewed by project staff to identify data entry errors, outlier values, or any anomalies in the data collection process. When possible, any discrepancies or gaps in the data were resolved by reviewing experimenter notes and photographs of the different installations.

The team verified all files were properly merged by participant ID and trial number. The team also checked each trial against the assigned experimental settings. As part of study protocol, there were times when a participant was randomly assigned the middle seating position of the vehicle for installing a CRS. Most participants installed the CRS as instructed, in the middle seating position. However, four participants refused to install the CRS in that position because the middle seat lacked lower anchors. In one additional case, the participant mistakenly installed the CRS in the outboard seat rather than the middle seat. Otherwise, data collectors strictly adhered to the assigned experimental settings.

The team examined frequencies to check for any anomalies in distributions. The team reviewed values that appeared inconsistent with expected data and checked them against data collector notes and photos. For example, if a data collector noted that the chest clip was not fastened but recorded information about the chest clip height, photos were reviewed to resolve any conflicts. In all cases, the raw data was preserved, and clean data files were saved separately.

5.2 Preparing Analysis File

The study team prepared the data for analysis by recoding and deriving variables to create the analysis variables. The team renamed variables to shorten, simplify, and clarify meaning. The team recoded blank values or values of "NA" (not applicable) as appropriate missing codes.

The team also created indicator variables for errors by examining the response options for a variable and coding it as an error or not. For example, the team created an indicator variable for seat selection errors ("1" if an error was made, "0" if an appropriate seat was selected). The team also created grouped outcome variables. For example, the team created the grouped outcome variable, "Harness_Strap_Error," by combining "harness straps not snug" and "harness straps twisted." The team coded this variable as "1" if either error occurred, "missing" if the harness straps did not apply, and "0" otherwise. The team also created the grouped variable, "Secured_Error" by combining harness strap errors with other errors related to securing the doll in the CRS (e.g., chest clip not at armpits, crotch buckle not fastened). As shown in Figure 5-1, this regrouping method allowed the team to analyze CRS errors at three levels including a fine level (i.e., exact errors, such as "harness straps not snug"), an intermediate level (i.e., harness strap errors in general), and a high level (i.e., any errors related to securing the child in the seat).

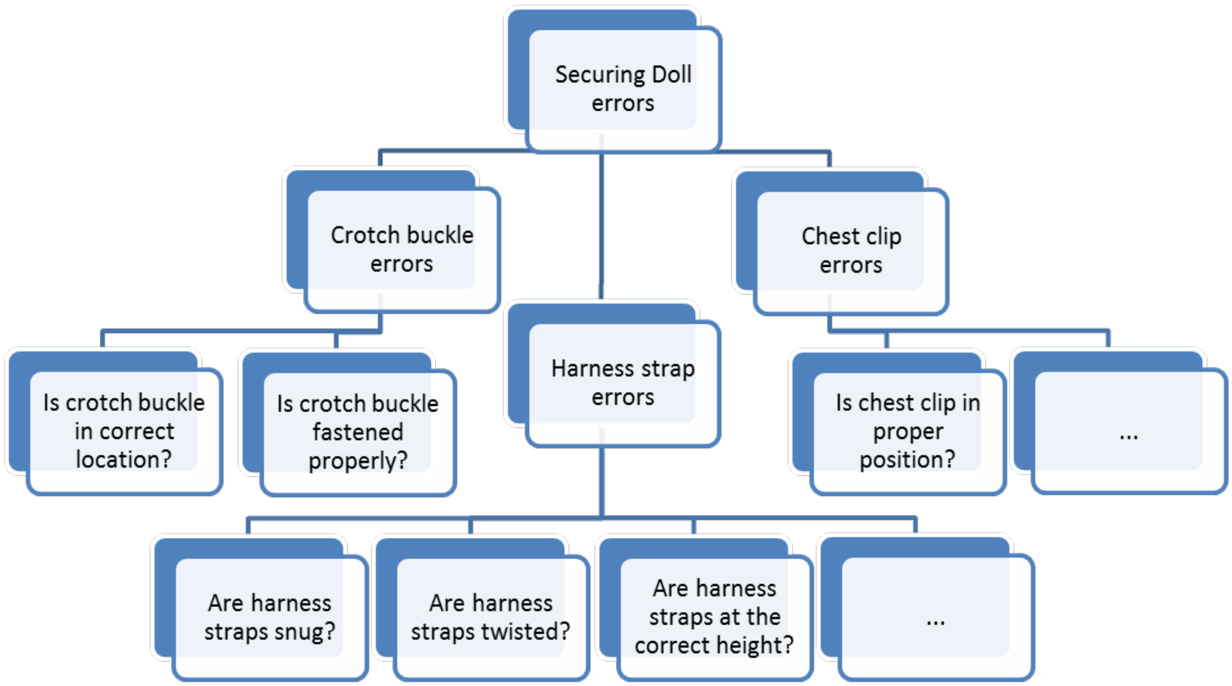


Figure 5-1. Example of Hierarchy of Possible Errors

6 Analytical Approach

6.1 Analysis Approach

The study team followed this analysis approach to gain a robust picture of the relationship between the factors of interest (participant experience, CRS type, vehicle type and vehicle seating position) and the types and frequency of installation and securement errors.

- Univariate information (basic means and proportions)
- Bivariate information (percentage of trials in which participants made one or more errors, by participant experience, CRS type, vehicle type, or seating position)
- Multivariate models (interactions between factors, predictive modeling to identify which factors best predict errors)

6.1.1 Univariate and Bivariate Analyses

First, the study team looked at the distribution of each analysis variable. Statistics included frequencies for all categorical or binary variables, including rates for each type of error variable, and basic descriptive statistics (minimum, mean, median, and maximum) for all continuous variables, such as number of minutes for installation. The team also confirmed counterbalancing among all experimental conditions.

The study team ran a basic cross-tabulation along with a chi-square test of association for each relevant combination[1] of experimental factor (participant experience, doll size, CRS type, vehicle type, or seating position) and error. The study team calculated all p-values using the Pearson chi-square test (the svychisq function in R's survey package), with a Rao-Scott second-order correction to adjust for clustering of trials within participants.[2]

Most analyses used a subset of the 600 trials. For example, participants did not complete the installation in 61 out of 600 trials (10.2%) because time ran out. So, when analyzing installation errors, the study team only included trials where the participants completed the installations.[3]

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[1] "Relevant combinations" means that we dropped cross-tabulations that resulted in a table with zero rows or only one row, since the chi-square test requires, at minimum, a 2x2 table. For example, looking at high-back booster errors by seat type results in a table with only one row, since such errors apply only to the high-back booster.

[2] Although the test statistic calculated is the Pearson chi-square with the Rao-Scott second-order correction applied, Thomas and Rao (1987) show that the asymptotic null distribution of this test statistic is best approximated by an adjusted version of the F distribution. Consequently, although the test itself is still considered a chi-square test, the critical value from the adjusted F distribution along with the necessary numerator and denominator degrees of freedom are provided along with the p-value.

[3] Note that the respondent reporting that they completed the installation does not mean that the installation was performed correctly. The installation was considered "complete" whenever the respondent told the data collector that they were finished with the trial. If a participant was close to completing the installation when the time for the trial expired, researchers were instructed to allow the participants to finish.

All error variables are listed in Tables 4-1 and 4-2. For analysis purposes, the study team classified the error variables into three main categories. Low-level errors are specific errors; for example, Seat Belt Twisted or Harness Straps Not Snug. Intermediate errors include multiple low-level errors, for example, Seat Belt Install Errors that include Seat Belt Routed Incorrectly, Seat Belt Twisted, Retractor Error, and CRS Lock-off Error. There are three high-level error variables: Selected Incorrect CRS, Installation Errors, and Securement Errors. The Installation and Securement errors include all installation-related and securement-related errors, respectively. The analysis looked at all intermediate and high-level errors both as simple indicators (0= no errors made, 1=one or more errors made) and as counts (total number of errors of that type made during a trial).

The study team used indicator variables to test how often errors were made and whether making the error was associated with any factors of interest; for example, testing whether there is a statistically significant association between participant's experience and making one or more errors when working with the harness. The analysis also used the lower-level error indicator variables in the same way. Unless specified otherwise, the term "error variable" refers to the indicator version of each error.

For each count variable, the study team performed F-tests to test whether the mean number of errors differed across factor levels, again accounting for the clustering of trials within participants. For factors with three or more levels, the team also performed pairwise t-tests to determine which, if any, levels of the factor were significantly different in terms of error counts.

Finally, the study team examined whether perception of success or reported ease of use was associated with error rates. Participants were asked to report their perception of success and ease of use on Likert-type 5-point scales. Due to small cell sizes, the study team frequently collapsed these variables into 3-point scales (negative/neutral/positive). Similar to the analysis performed for the indicator error variables, the team performed a series of crosstabs and chi-square tests to examine the associations between the participant's perception of success and reported ease of use and the types and frequency of errors.

6.1.2 Interaction Effects

Interactions between factors may play important roles in determining the number and types of errors made by participants. For example, certain CRS types may be more challenging for novice users than for experienced users. With this in mind, the study team examined the following interaction effects on the types and frequency of errors.

- Experience by CRS type, by doll size, by seating position, and by vehicle ease of use
- CRS type by CRS ease of use, by vehicle type, and by seating position
- Vehicle type by ease of use

The study team selected these interactions during the design stage of the study based on which interaction effects were most likely to be present and have large enough sample sizes to support analysis. For interactions involving CRS type, the study team excluded trials where participants selected the vehicle seat belts alone due to the small sample size in that group (11 total trials).

Loglinear models tested for the presence of interaction effects for each error. The study team excluded rare errors (defined as those that were made in less than 20 trials) from this analysis because it was unlikely that there would be enough power to detect any effect. A loglinear model for a three-way contingency table, as is the case for an error variable crossed with an interaction term, predicts the expected count in cell *ijk* as a function of the three variables in the table. Two separate models were fit for each combination of interaction term and error variable. First, the team fit a homogenous association model, which assumes that the odds of making the error depend only on the main effects of each factor and excludes any interaction effect between the factors:

$$\log u_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^E + \lambda_{ik}^{XE} + \lambda_{jk}^{YE}$$

In this formula, X stands for factor 1 with levels indexed by i, Y stands for factor 2 with levels indexed by j, and E stands for the error variable with levels (0 or 1) indexed by k. The log expected count in cell *ijk* ($\log u_{ijk}$) depends on some overall mean term (λ) plus additional terms that depend on the levels of each factor. Next, the team fit the saturated model:

$$\log u_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^E + \lambda_{ik}^{XE} + \lambda_{jk}^{YE} + \lambda_{ij}^{XY} + \lambda_{ijk}^{XYE}$$

This model includes additional terms accounting for any interaction effect between the two factors. The team then performed an F-test to determine whether adding the interaction effect improved model fit. If the p-value for the test is small, that means the interaction effect contributes information about the frequency of errors above and beyond that contributed by the main effects alone, so there is a significant interaction effect between the two factors. A large p-value means that the odds of making an error are adequately explained by the main effects of the factors alone, and the interaction effect does not contribute substantially.

6.1.3 Multivariate Modeling

The team conducted the univariate and bivariate analyses to examine a single error variable with one or two factors of interest at a time. The team also conducted multivariate modeling to determine which causal factors are the strongest predictors of CRS installation and securement errors by simultaneously considering all factors of interest.

The team fit three separate logistic regression models, using the three high-level error indicators as outcomes: selected correct CRS, installed CRS, secured doll. All models accounted for the clustering of trials within participant. The set of possible predictors included all factors of interest and all interactions between these factors, as well as participant age, gender, perception of risk, and both CRS manual and vehicle manual use.

As an example for the selecting CRS error outcome, let *Y* be the indicator for an error in selecting the correct CRS, where $Y_{ij} = 1$ if participant *i* selected an inappropriate CRS in trial j, and 0 otherwise. Then let $x_1, \dots, x_p$ be the *p* predictors of interest. For example, let x_1= assigned doll, x_2= vehicle number, etc. Some x_i might be interactions between other predictors. The general initial form of the model can be written as:

$$\Pr(Y_i = 1 | X_1 = x_1, \ldots, X_p = x_p) = \pi_i$$
$$logit(\pi_i) = \beta_0 + \beta_1 x_1 + \cdots + \beta_p x_p$$

This full model, including all possible interactions, would include far too many variables to interpret easily. Therefore, the team used lasso regression (Tibshirani, 1996) to identify the strongest predictors of each type of error and select a more parsimonious model. Lasso regression is a form of penalized regression, in which the parameter estimates are constrained by an upper bound λ:

$$\sum_{k=1}^{p} |\beta_k| < \lambda$$

This constraint has the effect of forcing some parameter estimates to 0, effectively dropping them from the model. Typically λ is set via cross-validation, fitting the model on a subset of data and then testing the model fit on the excluded validation data. This means that models selected via lasso regression tend to be models with good predictive power, rather than simply models that fit the particular dataset well. Lasso is also designed to deal with many correlated variables, reducing concerns about multicollinearity among the final set of predictors. Lasso was a well-suited method to meet the study objective of finding the best predictive factors.

Continuing the example from above, the final model for a given error will be:

$$\Pr(Y_i = 1 | X_1 = x_1, \ldots, X_r = x_r) = \pi_i$$
$$logit(\pi_i) = \beta_0 + \beta_1 x_1 + \cdots + \beta_r x_r$$

where *r,* the final number of variables in the model, will be a number much smaller than *p*, the number of variables considered in the initial model.

7 Results

7.1 Basic Frequencies

This report generally focuses on results with $p<0.05$ ("statistically significant" results). (Wasserstein & Lazar, 2016). All p-values controlled for clustering of trials within participants but did not incorporate an explicit adjustment for multiple comparisons.

Overall, for 538 (90%) of the 600 trials, participants selected the appropriate CRS (rear-facing-only, convertible, booster) for the doll's height and weight. The number of trials where a specific CRS type was used varied because participants were allowed to choose a CRS type from three available for each trial. Participants selected the convertible seat for 44 percent of the trials, followed by the infant seat (28%) and booster seat (26%) (see Table 7-1).

Table 7-1. Trials by CRS Type

CRS Type	Number of trials used	Percentage of trials
Infant seat	170	28%
Convertible	261	44%
Booster	158	26%
Vehicle seat belt only	11	2%
Total	600	100%

Participants installed the CRS in the vehicle for 560 of 600 (93%) and secured the doll for 549 (92%) of the trials. In 29 trials (5%) the participant was unable to complete either step in the time allotted—that is, the CRS was not installed or the doll was not secured.

Table 7-2 presents error rates for all installation-related errors examined by the study team. The table includes the total number of applicable trials. For example, the study team only looked at lower anchor errors for the 151 trials in which the participant attempted to use the lower anchor system to secure the CRS to the vehicle.

Participants made one or more installation errors in 68 percent of the trials in which they completed the installation. In 68 percent of the applicable trials, participants did not secure the CRS tightly to the vehicle seat.

Table 7-2. Overall Error Rates for Installation-Related Errors

Error	Number of trials with one or more error	Total number of applicable trials	Error rate
Installation Error	**373**	**549**	**67.9%**
Incorrect Direction of Install	6	549	1.1%
Lower Anchors and Seat Belt Used to Install CRS	53	549	9.7%
CRS Not Securely Attached	264	391	67.5%

Error	Number of trials with one or more error	Total number of applicable trials	Error rate
Seat Belt Installation Errors	197	339	58.1%
Seat Belt Routed Incorrectly	84	339	24.8%
Seat Belt Twisted	86	337	25.5%
Retractor Error	100	181	55.2%
CRS Lock-off Error	15	61	24.6%
Lower Anchor Installation Errors	60	151	39.7%
Lower Connectors Attached to Anchor From Incorrect Seating Position	37	151	24.5%
Lower Connectors Attached Incorrectly	25	151	16.6%
Lower Connectors Routed Through Incorrect Belt Path	12	72	16.7%
Weight of Doll Over Lower Anchor Limit	7	151	4.6%
Tether Installation Errors	31	52	59.6%
Tether Attached to Incorrect Vehicle Anchorage Point	14	52	26.9%
Tether Attached Incorrectly	13	52	25.0%
Tether Routed Incorrectly	18	50	36.0%
Tether Not Tight	15	52	28.8%
***CRS-Specific Feature #1 Used Incorrectly**	46	108	42.6%
***CRS-Specific Feature #2 Used Incorrectly**	40	109	36.7%
Rear-facing Installation Errors	127	249	51.0%
CRS Touching Front Seat	58	242	24.0%
Recline Angle Incorrect	64	243	26.3%
CRS-Specific Feature #3 Used Incorrectly	4	34	11.8%
Incorrect Carrier Handle Position	47	163	28.8%

*Two study CRSs had unique installation features that were not present in any other CRSs. To avoid identifying the specific makes and models, we refer to these features only as CRS-specific features.

Table 7-3 presents error rates for all securement-related errors. For trials where the participant was able to secure the doll, only 157 (29%) were completed with the doll properly restrained in the CRS. Overall, participants made one or more errors when securing the doll in the CRS in 71 percent of the trials in which they completed the securement.

Table 7-3. Overall Error Rates for Securement-Related Errors

Error	Number of trials with one or more error	Total number of applicable trials	Error rate
Securement Errors	**387**	**544**	**71.1%**
Crotch Buckle Errors	72	379	19.0%
Crotch Buckle Incorrect Location	64	376	17.0%
Crotch Buckle Not Fastened	9	379	2.4%
Harness Errors	257	380	67.6%
Harness Straps Twisted	35	367	9.5%
Harness Height Incorrect	67	363	18.5%
Harness Straps Threaded Incorrectly	4	379	1.1%
Harness Straps Not Snug	3	379	0.8%
Harness Not Adjustable	216	376	57.4%
Harness Not Anchored	19	378	5.0%
Chest Clip Errors	171	379	45.1%
Chest Clip Fastened Incorrectly	15	379	4.0%
Chest Clip Not at Armpit Level	165	378	43.7%
Chest Clip Threaded Incorrectly	18	378	4.8%
Booster Fit Errors	60	153	39.2%
Legs Don't Bend Over Edge of Seat in Booster	16	152	10.5%
Shoulder Belt Not Over Center of Chest in Booster	45	153	29.4%
Lap Belt Not Low on Hips in Booster	13	150	8.7%
Seat Belt Fit Errors	8	11	72.7%
Legs Don't Bend Over Edge of Seat in Vehicle Seat	6	11	54.5%
Shoulder Belt Not Over Center of Chest in Vehicle Seat	4	11	36.4%
Lap Belt Not Low on Hips in Vehicle Seat	5	11	45.5%
Infant Insert Error	47	196	24.0%

Looking at average number of errors per trial, participants made an average of 1.36 installation errors and 1.38 securement errors per trial (See Table 7-4).

Table 7-4. Descriptive Statistics, Errors per Trial by Error Type

Error Type	Median	Mean	Std Err	Max.	N
Installation Error	1	1.36	0.06	6	549
Seat Belt Install Errors	1	0.84	0.05	4	339
Lower Anchor Install Errors	0	0.54	0.06	3	151
Tether Install Errors	1	1.15	0.16	4	52
Rear-Facing Install Errors	1	0.69	0.06	3	249
Securement Error	1	1.38	0.06	8	544
Crotch Buckle Errors	0	0.19	0.02	2	379
Harness Errors	1	0.91	0.05	5	380
Chest Clip Errors	0	0.52	0.05	3	379
Booster Fit Errors	0	0.48	0.06	3	153
Seat Belt Fit Errors	2	1.36	0.30	3	11

On average, participants took the most time to install the convertible CRS (average of 16 minutes), followed by the rear-facing-only CRS (12 minutes) and booster seat (6 minutes). Participants spent an average of 2 to 4 minutes securing the dolls. The most time was spent securing the 16-month-old and the infant dolls (average of 4 minutes each), and the least spent when securing the 6-year-old (2 minutes).

Participants took more time in trials when they made one or more errors (14 minutes for both installation and securement errors) and less when they did not make an error (12 minutes for no installation errors, and 11 minutes for no securement errors).

Table 7-5. Average time spent installing the CRS and securing the doll (in minutes)

	Installation Time (minutes)	Securement Time (minutes)	Total Time (minutes)	N
Overall	11.57	2.96	13.17	538
CRS Type				
Rear-facing-only	12.16	3.73	14.37	161
Convertible	15.54	2.97	17.01	208
Booster	6.31	2.24	7.56	158
Vehicle seat belt	-	3.64	3.64	11
Doll size				
Infant	12.18	3.56	14.15	142
16-month-old	14.89	3.20	16.59	127
3-year-old	13.39	2.69	14.81	119
6-year-old	6.73	2.41	8.06	150
Errors made				
At least one installation error	12.76	3.18	14.27	353
No installation errors	9.66	2.59	11.55	174
At least one securement error	12.63	3.07	14.24	379
No securement errors	9.03	2.70	10.63	154

When interpreting results, it is important to account for the association between CRS type and doll ($F(5.4, 806) = 151.78$, $p<0.0001$). Ninety-seven percent of participants selected the rear-facing-only seat for the infant doll, while 87 percent of participants selected the high back booster for the 6-year-old doll. Participants most commonly chose the convertible seat for both the 16-month-old doll (83%) and the 3-year-old doll (83%).

Table 7-6. CRS Type Chosen by Doll Assigned

CRS type	Doll				Number of trials
	Infant	16 month	3 years	6 years	
Rear-facing-only	146 97.33%	24 16.00%	0 0.00%	0 0.00%	**170**
Convertible	4 2.67%	124 82.67%	125 83.33%	*8* *5.33%*	**261**
Booster	0 0.00%	*2* *1.33%*	*25* *16.67%*	131 87.33%	**158**
Vehicle seat belt	0 0.00%	0 0.00%	0 0.00%	11 7.33%	**11**
Total	**150** **100%**	**150** **100%**	**150** **100%**	**150** **100%**	**600**

*Chosen CRS types in italics are incorrect.

7.2 User Experience

The study team examined differences in CRS selection, installation, and child securement errors by level of experience. The analyses included both count (number of errors) and indicator (presence of one or more errors) outcomes. When comparing experienced and novice participants on the count outcome variables, there were significant differences in the average number of errors for installations where the participant used the seat belt to attach the CRS to the vehicle and for using the chest clip properly when securing the doll in the CRS. On average, novice users made more errors than experienced when using the seat belt to attach the CRS and with the chest clip. There was no statistically significant difference at the $p<0.05$ level in average number of errors made by experienced and novice participants for the remaining count outcome error types.

Table 7-7. Average number of errors made by experienced and novice participants

Type of errors	Average errors per trial experienced participant	Average errors per trial novice participant	p-value for F-test
Installation Errors	1.26	1.46	0.1150
Securement Errors	1.30	1.46	0.2091
Seat Belt Installation Errors	0.73	0.95	0.0407
Chest Clip Errors	0.40	0.66	0.0038

Participants typically selected the appropriate CRS for the doll's height and weight (experienced: 92% [277 of 300 trials]; novice: 87% [261 of 300 trials]). The association between experience and selecting the incorrect CRS is not statistically significant at the $p<0.05$ level ($F[1, 149)$[4]= 3.66, N=600, p=0.0575).

Experienced participants failed to complete the installation in 15 out of 300 trials (5%), while novices failed in 25 out of 300 (8.3%) ($F[1, 149) = 2.48$, N=600, p=0.1172).[5] The analysis did not find a significant difference at the $p<0.05$ level between the two user groups in trials with one or more installation-related errors (experienced: 65% [185 of 284 trials]; novice: 71% [188 of 265 trials]) ($F[1, 149] = 1.87$, N= 549, p = 0.1730).

While both experienced and novice participants had difficulty attaching the CRS tightly to the vehicle seat, there was lateral and/or forward movement (greater than one inch) in a larger percentage of trials completed by the novice participants (experienced: 60% [121 of 202 trials]; novice: 76% [143 of 189 trials]) ($F[1, 149] = 6.80$, N= 391, p=0.0100).[6]

The only specific seat belt-related error that resulted in a significant difference between the two user groups was the use of the retractor. Retractors gather and store extra seat belt webbing in the vehicle. The seat belt retractor is typically located on the pillars, ceiling, or in the vehicle seat. Correct installation of a CRS using a seat belt requires that the retractor be switched to locking mode if a CRS does not have a lock-off or the lock-off is not used.

When installing the CRS with the seat belt, novice participants were significantly more likely to forget to switch the retractor into locking mode when appropriate or to incorrectly use the retractor in combination with the CRS lock-off (experienced: 44% [37 of 84 trials]; novice: 65% [63 of 97 trials]) ($F[1, 149] = 6.16$, N=181, p=0.0142).

The lower anchor and tether connections in the vehicle are made of two lower anchor bars located in the seat bight and one tether anchor. Participants used the lower anchors and tether system in approximately 35 percent of the trials. Experienced participants elected to use the lower anchor system to install the CRS more often than the novice participants. Experienced participants chose the lower connectors in 122 out of 217 possible trials (56%), and novice users selected it in 94 out of 214 possible trials (44%) (F[1, 149]]= 4.60, N=431, p=0.03).

When novice participants opted to use the lower anchors and tether system, they were more likely to incorrectly use both the seat belt and the lower anchor system to install the CRS (35% of all trials in which lower anchors and tether system was used, versus 18% for experienced trials, $F[1, 112]= 5.21$, N= 210, p=0.0243). These cases were excluded from the lower anchors and tether error analyses because the participant already made a major error by using lower

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[4] The p-value for the second-order Rao-Scott correction to the Pearson chi-square test uses an approximation based on the F distribution.

[5] Since installations were not complete for these 40 trials, the study team removed them from all analyses of installation errors.

[6] Booster seat trials were excluded from this analysis because booster seats do not need to be fastened to the vehicle seat. Trials using only the vehicle's seat belt without a CRS were also excluded.

anchors and tether in combination with the seat belt. The lower anchors and tether error analyses only included trials where the participant elected to use the lower anchors or both lower anchors and tether.

Securing the doll in the CRS involves working with the CRS crotch buckle, harness straps, and chest clip. Each of these steps introduces the opportunity for the participant to make errors. Only 29 percent (175 trials) of the 544 completed installations were completed with the dolls securely restrained in the vehicle (experienced: 87 out of 283 trials [31%]; novice: 70 out of 261 trials [27%]).

Overall, when examining the likelihood of making securement errors, there appears to be no significant difference between the two user groups at the $p<0.05$ level (experienced: 69% [196 of 283 trials]; novice: 73% [191 of 261 trials]) ($F[1, 149]= 10.35$, $N=544$, $p= 0.3106$). Participants made chest clip-related errors in approximately 45 percent of trials in which a chest clip was used. In addition, novice participants made these errors in a greater percentage of trials than experienced participants (experienced: 38% [76 of 202 trials]; novice: 54% [95 of 177 trials)) ($F[1, 149]= 5.89$, $N= 379$, $p=0.0164$).

When fastening the chest clip, novice users made errors in about 7 percent of trials (13 out of 177 trials) compared to 1 percent of trials (2 out of 202 trials) for experienced users. Although the difference is statistically significant ($F[1, 149]= 5.24$, $N=379$, $p=0.0235$), this error was rare in both groups (only 15 trials).

When the harness straps are secured and the chest clip is fastened, the clip should be positioned so that it is in the center of the child's chest at armpit level. novice participants positioned the chest clip in the wrong location in about 52 percent of trials (91 out of 176 trials) compared to 37 percent of trials (74 out of 202 trials) for experienced users. This difference is statistically significant ($F[1, 149]= 5.22$, $N=378$, $p=0.0237$).

Overall, experienced participants made one or more errors specific to the booster seat in 41 percent of the trials, and novice participants made one or more errors in 37 percent of the trials. However, this difference was not statistically significant ($F[1, 149]= 0.28$, $N= 153$, $p= 0.5945$).

7.3 Doll Size

The study team looked at errors across the different doll sizes. There were significant differences in the average number of overall installation errors when comparing the different doll sizes as well as the average numbers of installation errors pertaining to use of the seat belt and the lower connectors. There were significant differences across the dolls with respect to rear-facing errors. There were also significant differences in the average number of overall securement errors by doll size as well as the average numbers of securement errors related to the harness and to the crotch buckle.

Table 7-8. Average number of errors per trial for each doll size[7]

Types of error	Average errors per trial infant	Average errors per trial 16-month-old	Average errors per trial 3-year-old	Average errors per trial 6-year-old	p-value for F-test
Installation Errors	1.68	1.56	1.62	0.58	<0.0001
Securement Errors	1.41	2.21	1.57	0.43	<0.0001
Seat Belt Installation Errors	1.29	1.08	0.92	0.46	<0.0001
Lower Connector Installation Errors	0.28	0.67	0.57	2.33	0.0010
Crotch Buckle Errors	0.05	0.35	0.21	0.00	<0.0001
Harness Errors	0.91	1.02	0.75	0.88	0.0281
Rear-Facing Installation Errors	0.78	0.64	0.30	-	0.0031
Booster Seat Errors	-	2.50	1.28	0.29	<0.0001

When participants were working with the infant sized doll, they always selected an appropriate CRS. Participants chose an inappropriate CRS for 17 percent of the trials (26 out of 150 trials) when working with the 16-month-old doll and the 3-year-old doll. Most of the 16-month-old errors (24 out of the 26 trials) were due to the participant selecting the rear-facing-only CRS. Two (1%) of the 16-month-old and 25 (17%) of 3-year-old trails were incorrectly put in the booster. All errors participants made when selecting a CRS for the 6-year-old were related to the participant using only the vehicle seat belt with no CRS or booster seat.

The majority of participants made one or more errors on trials when installing the CRS for the infant (80%), 16-month-old (84%), and 3-year old (63%) dolls. Conversely, participants were least likely to make errors on trials when installing the CRS for the 6-year-old (45%).

Table 7-9. Likelihood of making one or more installation errors by doll size

Doll size	Correct	Error	Total	P-value
Infant	29 20.00%	116 80.00%	145 100%	
16-month-old	22 16.30%	113 83.70%	135 100%	
3-year-old	48 36.92%	82 63.08%	130 100%	
6-year-old	77 55.40%	62 44.60%	139 100%	
Total	176 32.06%	373 67.94%	549 100.00%	p <0.0001

Note. Counts are provided for each column with percentage of total trials for that row presented underneath each count.

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[7] A value of "-"indicates that that error did not apply to any dolls of that size.

Participants made the lowest proportion of securement errors for trials involving the 6-year-old doll (34%) compared to the other dolls (t[148]= -9.32, p<0.0001 versus infant, t[147]= -11.46, p<0.0001 versus 16-month-old, and t[148]= -10.29, p<0.0001 versus 3-year-old). For all other size dolls, the participants made securement errors in 81 to 88 percent of the trials.

Table 7-10. Likelihood of making one or more securement errors by doll size

Doll size	Correct	Error	Total	P-value
Infant	28 19.44%	116 80.56%	144 100%	
16-month-old	16 12.21%	115 87.79%	131 100%	
3-year-old	18 14.52%	106 85.48%	124 100%	
6-year-old	95 65.52%	50 34.48%	145 100%	
Total	157 28.86%	387 71.14%	544 100.00%	p <0.0001

Note. Counts are provided for each column with percentage of total trials for that row presented underneath each count.

Overall, participants did not set the harness height correctly in 28 percent of the trials (34 out of 123 trials) when working with the 16-month-old and 21 percent of the trials (19 out of 92 trials) when working with the 3-year-old. [8] When working with infants, participants selected an incorrect harness height in 9 percent of the trials (12 out of 140 trials).

There was a statistically significant relationship at the p<0.05 level between doll size and not securing the harness straps snugly (p=0.0005). Participants were most likely to leave the infant doll (70%, 99 of 142 trials) loosely secured in the CRS relative to the 16-month-old (53%, 69 of 129 trials, t[144]=3.00, p=0.0032) and 3-year-old (46%, 45 of 97 trials, t[144]=4.13, p<0.0001).

When working with the 16-month-old doll, 34 percent (44 of 128 trials) had least one error related to the crotch buckle relative to 21 percent (21 of 99 trials) when working with the 3-year-old and 5 percent (7 of 144 trials) when working with the infant.

Participants positioned the crotch buckle in the wrong slot when working with the 16-month-old in 33 percent of the trials (42 of 127 trials), relative to 18 percent of the trials (17 of 97 trials) when working with the 3-year-old and 3 percent (5 of 144 trials) when working with the infant.

Some CRSs have an insert to better position the child in the CRS if the child is below a given weight. The insert should be removed after the child exceeds the weight limit for the insert. This insert was present in two of the selected seats - the easier rear-facing-only CRS and the easier convertible CRS.

[8] The 6-year-old group has small sample sizes for all harness-related errors because only 8 participants selected a seat with a harness (the convertible seat) for the 6-year-old doll. Most participants (142 out of 150) put the 6-year-old doll in the high-back booster or in the vehicle seat alone.

Participants used the infant insert correctly in all trials when working with the infant doll. Participants (incorrectly) did not remove the insert in 52 percent of the trials (36 of 69 trials) when working with the 16-month-old doll and 22 percent (11 of 49 trials) when working with the 3-year-old.

7.4 CRS Type

Overall, participants made the most installation errors per trial when using the rear-facing-only (1.74) and convertible seats (1.70), and the most securement-related errors when using the convertible seat (1.85). Average error counts for other count outcomes with statistically significant differences between CRS types are presented in the table below.

Table 7-11. Average number of errors by CRS type

Error type	Average errors per trial for rear-facing-only		Average errors per trial for convertible		Average errors per trial for high back booster		Average errors per trial for vehicle seat belt		p-value
	Mean	N	Mean	N	Mean	N	Mean	N	
Installation errors	1.74	165	1.70	226	0.46	158	-	-	<0.0001
Securement errors	1.60	163	1.85	217	0.48	153	1.36	11	<0.0001
Seat belt installation errors	1.33	82	1.04	99	0.46	158	-	-	<0.0001
Lower anchor installation errors	0.30	54	0.67	97	-	-	-	-	0.0033
Crotch buckle errors	0.09	163	0.27	216	-	-	-	-	0.0000
Rear-facing installation errors	0.77	165	0.55	84	-	-	-	-	0.0159

When participants chose the convertible seat as a CRS for the assigned doll, they were correct for 100 percent of the trials because the convertible seats used in the study could accommodate all of the doll sizes.

The team found an association between CRS type and selecting the wrong CRS, mostly driven by the convertible seat (100% of trials correct) and the vehicle seat belt only (error in 100% of trials). The p-values for all pairwise comparisons (t-tests) between convertible and all other seat types are <0.0001 as are the p-values for all pairwise comparisons with vehicle belt only. The p-value for the pairwise comparison between rear-facing-only and high back booster is 0.3862. Participants incorrectly selected the rear-facing-only CRS for the 16-month-old doll in 14 percent of the trials (24 of 170 trials) and the high back booster for the 16-month-old and 3-year-old dolls in 17 percent of the trials (27 of 158 trials).

The team found installation errors were associated with CRS type ($F[1.97, 293.52] = 40.82$, $N = 549$, $p < 0.0001$). Participants made one or more errors related to installing the CRS in approximately 83 percent of trials (137 out of 165 trials) when working with the rear-facing-only

CRS and 77 percent of trials (173 out of 226 trials) when installing the convertible CRS. The lowest percentage of installation error was made when the participant was working with the high back booster (40%, 63 of 158 trials).

Correct installation direction is based on the child's age, height, and weight as well as any specific manufacturer requirements. Participants always installed the convertible and high back booster in the correct direction for the assigned doll's age, height, and weight. Participants installed the rear-facing-only CRS in a forward-facing position in approximately 4 percent of the trials.

Participants installed the CRS with either the seat belt or the lower anchors in 90 percent of trials. Participants incorrectly used both the lower anchors and the seat belt to attach the CRS to the vehicle seat in 10 percent of the trials. Participants incorrectly used both for 18 percent of the trials (29 out of 165 trials) when working with the rear-facing-only CRS and 11 percent of the trials (24 out of 226 trials) when working with the convertible CRS.

The team found a significant relationship between the type of CRS and the number of seat belt errors for installation and securement ($F[1.99, 296.95] = 18.61$, $N = 339$, $p < 0.0001$). Participants made the fewest errors when working with the booster seats, making errors for 40 percent of the trials (63 out of 158 trials). Conversely, participants made seat belt-related errors for 80 percent of the trials (65 out of 82 trials) involving the rear-facing-only CRS and 70 percent of the trials (69 out of 99 trials) working with the convertible CRS.

Table 7-12. Percentage of trials with one of more seat belt related errors by CRS type

CRS type	Correct	Error	Total	p-value
Rear-Facing-Only	17 20.73%	65 79.27%	82 24.19%	
Convertible	30 30.30%	69 69.70%	99 29.20%	
High back Booster	95 60.13%	63 39.87%	158 46.61%	
Total	142 41.89%	197 58.11%	339 100.00%	p <0.0001

Note. Cells show counts on top and percentages of total trials on bottom.

Seat belt retractor and CRS lock-off errors do not apply to booster seat trials, so there were fewer opportunities for participants to make seat belt errors in such trials. Participants used the retractor incorrectly in 53 (64%) rear-facing-only trials and 47 (47%) trials where a convertible CRS was used.

Participants made belt twisting errors in 36 percent of the trials (35 out of 98 trials) involving the convertible CRS and 27 percent of the trials (22 out of 82 trials) using the rear-facing-only CRS ($F[1.98, 294.61] = 4.70$, $N = 337$, $p = 0.0100$). The lowest percentage of errors (18%) were made in trials (29 out of 157 trials) involving routing the seat belt through the high back booster belt guide.

Overall, participants made lower anchors and tether-related errors in a higher percentage of trials when using the convertible CRS (47%) compared to the rear-facing-only CRS (26%) (F[1.99, 296.70) = 3.14, N= 151, p=0.0447).

Table 7-13. Percentage of trials with one or more lower anchor errors by CRS type[9]

CRS type	Correct	Error	Total	p-value
Rear-Facing-Only	40 74.07%	14 25.93%	54 100%	
Convertible	51 52.58%	46 47.42%	97 100%	
Total	91 60.26%	60 39.74%	151 100.00%	p= 0.0447

Note. Cells show counts on top and percentages of all trials in that row on the bottom.

Overall, the analysis did not find a significant difference between the rear-facing-only and convertible CRSs with regards to the percentage of harness errors across trials (F[1.80, 268.00]= 1.75, N= 380, p=0.1797). However, the study team identified significant differences when examining the specific features or components of the harness.

Participants did not adjust the harness height correctly in 25 percent of the convertible CRS trials (51 out of 206 trials) where a harness was used but only 10 percent of the rear-facing-only CRS trials (16 out of 157 trials) resulted in this type of error (F[1, 149]= 10.44, N= 363, p= 0.0037).

Breaking the errors down by direction of CRS, most of the harness height errors occurred in rear-facing installations. Forty-eight of the 67 harness height errors occurred in rear-facing installations, while 19 occurred in forward-facing installations. For the convertible CRS in particular, even though only 81 installations (39%) were rear-facing, this resulted in 32 installations with incorrect harness height (39%). However, this may also be confounded with doll size, because participants were more likely to position the infant doll in the rear-facing position.

Participants did not secure the harness snugly around the doll in significantly more trials (68%, 109 of 161 trials) involving the rear-facing-only CRS compared to the convertible CRS trials (50%, 107 of 215) (F[1.86, 277.12]= 5.25, N= 376, p=0.0070). Again, this may be confounded with doll size as nearly all of the dolls used in the rear-facing-only CRS were the infant dolls (146 out of the 161 trials).

The analysis found a statistically significant relationship between the CRS type and errors related to the crotch buckle (F(2.00, 297.62]= 10.36, N=379, p<0.0001). Participants made at least one error related to the crotch buckle in 27 percent of the trials (58 out of 216 trials) involving convertible CRSs compared to 9 percent of the trials (14 out of 163 trials) when participants were working with the rear-facing-only CRS.

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[9] This analysis only examined trials where the participant used the lower anchors to install the CRS in the vehicle and includes installations where the both lower anchors and tether were used. Trials where a participant used both the seat belt and lower anchors or booster seats were excluded.

The analysis found a statistically significant difference in crotch buckle location errors by CRS type. The crotch buckle was positioned in the wrong location for 24 percent of the convertible CRS trials (52 out of 213 trials), relative to 8 percent of the trials (12 out of 163 trials) for the rear-facing-only CRS (F(2.00, 297.92]= 10.32, N= 376, p<0.0001).

The analysis found a statistically significant relationship at the p<0.05 level between infant insert error (a pad that is placed in a rear-facing seat when used with an infant below a certain weight) and CRS type (F[1.82, 271.39]= 6.06, N= 196, p=0.0036). Participants made this error in 11 percent of the rear-facing-only CRS trials (10 out of 88 trials) and 34 percent of the convertible CRS trials (37 out of 108 trials). These involved cases where the participant was installing a child sized doll that was too big for the insert. This involved cases where the participant selected the rear-facing-only for a larger doll, and the insert should have been removed.

7.5 CRS Ease of Use

The study team examined differences in the number and type of installation errors between the easier and more challenging models of each CRS type (i.e., rear-facing-only, convertible, and booster seat). Pairwise t-tests, adjusted for clustering of trials within participants, were used to compare the percentage of installation errors made when using the easier versus more challenging models. Overall, there was not a significant difference in the percentage of installation errors when participants were working with the easier versus more challenging booster seats (easier booster: 36%; more challenging booster: 44%) (t[139]= 0.94, N= 158, p=.3475). However, there were differences in securement errors comparing the easier and more challenging booster seats, (t[135]= 2.12, N= 153, p=0.0360).

When comparing the two rear-facing-only CRSs, participants made a significantly higher proportion of installation errors when using the more challenging rear-facing-only CRS (91%) compared to the easy rear-facing-only CRS (76%) (t[139]= 2.65, N= 165, p=0.0089). On average, participants made 2.01 errors per trial with the more challenging rear-facing-only CRS, compared to an average of 1.50 errors per trial with the easier one. More challenging rear-facing CRSs produced significantly more seat belt errors of all types than easier rear-facing CRSs as well. Securement errors were very uncommon and could not be compared reliably.

Likewise, for the two convertible CRSs, there was a significant difference in the percentage of installation errors made on trials where the participant was using the more challenging convertible (93%) compared to the trials using the easier convertible (61%) (t[131]= 5.90, N= 226, p<.0001). On average, participants made 1.03 errors per trial when working with the easier convertible CRS, and 2.39 errors per trial with the more challenging one. More challenging convertible CRSs produced significantly more seat belt errors (except seat belt routing errors) than easier convertible CRSs. Participants were more likely to make lower anchors and tether errors installing the more challenging convertible CRS (63%) when compared to the easier convertible CRS (40%) (t[70]= 2.12, N= 97, p=0.0374). On average, participants also made almost twice as many lower anchor-related errors per trial when using the more challenging convertible CRS (1.00) compared to the easier convertible CRS (0.52). Similar to rear-facing CRSs, securement errors were very uncommon and could not be compared reliably.

7.6 Vehicle Type

Generally, vehicle features should not influence the participant's ability to select a CRS or secure the doll in the CRS. Therefore, the following analysis only addressed errors that relate to installing a CRS to the vehicle and differences among the different vehicle types (sedan, SUV, minivan, and pickup truck).

The study team only found a statistically significant difference by vehicle type in the average number of tether-related errors per trial. Participants made far more errors in the pickup truck (2.38) than in the sedan (0.71), SUV (0.70), or minivan (0.83). There was no significant difference in the average number of errors by vehicle type for the other errors.

Table 7-14. Average number of errors per trial by vehicle type

	Sedan		SUV		Minivan		Pickup Truck		p-value
	Mean	N	Mean	N	Mean	N	Mean	N	
Installation errors	1.44	135	1.37	134	1.12	137	1.48	143	0.0595
Tether install errors	0.71	17	0.70	10	0.83	12	2.38	13	0.0004

The analysis found a statistically significant difference across vehicle types in having a tight CRS installation ($F(2.92, 435.24] = 6.46$, N= 391, $p=0.0003$). Overall, participants made errors in 75 percent of trials (84 out of 112) involving pickup trucks with similar rates for sedans and SUVs. However, participants did not achieve a secure fit of the CRS to the vehicle seat in 51 percent of trials (46 out of 90) involving the minivans.

Table 7-15. Likelihood of not securing the CRS tightly to the vehicle seat by vehicle type[10]

Vehicle type	Correct	Error	Total	p-value
Sedan	27 28.42%	68 71.58%	95 100%	
SUV	28 29.79%	66 70.21%	94 100%	
Minivan	44 48.89%	46 51.11%	90 100%	
Pickup Truck	28 25.00%	84 75.00%	112 100%	
Total	127 32.48%	264 67.52%	391 100.00%	p = 0.0003

[10] This analysis is limited to trials where the participant completed the installation and chose a rear-facing-only or convertible CRS. All the booster seat trials were excluded from this analysis because they do not need to be secured to the vehicle seat. Installations using only the vehicle's seat belt were also excluded.

Overall, the analysis did not find a significant difference in lower anchors and tether system installation errors between the different vehicle types (F(2.94, 438.58]= 0.85, N= 151, p = 0.4651). However, the team did identify significant differences for specific lower anchor and tether system components between the different vehicle types. The analysis found a statistically significant difference in lower connector installation errors between vehicle types (F[2.85, 424.92]=2.89, N=151, p=0.0376). Participants made the fewest errors when attaching the CRS to the minivans. Participants selected the wrong anchor position in only 10 percent of the trials (4 out of 40) when working with the minivan. When working in the SUVs, sedans, and pickup trucks, participants made this type of error in 37 percent, 32 percent, and 21 percent of the trials, respectively.

Table 7-16. Likelihood of attaching the lower connectors to the lower anchors in the wrong seating position by vehicle type

Vehicle type	Correct	Error	Total	p-value
Sedan	19 67.86%	9 32.14%	28 100%	
SUV	26 63.41%	15 36.59%	41 100%	
Minivan	36 90.00%	4 10.00%	40 100%	
Pickup Truck	33 78.57%	9 21.43%	42 100%	
Total	114 75.50%	37 24.50%	151 100.00%	p = 0.0376

Participants made errors related to identifying and/or securing the tether in 92 percent of the trials (12 of 13 trials) when working in the pickup trucks. While fewer errors were made in the sedan, SUV, and minivan trials, participants still made one or more errors in 40 to 59 percent of the trials (59%, 10 of 17 trials in the sedan; 40%, 4 of 10 trials in the SUV; 42%, 5 of 12 trials in the minivan). There were too few trials in which participants used the top to compare statistically.

7.7 Vehicle Ease of Use

Similarly, vehicle's ease of use should not influence the participant's ability to select a CRS or secure the doll in the CRS. Therefore, the following analysis only addressed errors that relate to installing a CRS to the vehicle.

The study team looked at differences in errors related to achieving a tight installation across easier and more challenging vehicle models of each type. The analysis only found a statistically significant difference in the percentage of tight installation errors across trials when comparing easier and more challenging sedans (t[93]= -2.67, N= 95, p=0.0085). These differences were sometimes in the unexpected direction. When working in the easier sedan, participants did not obtain a secure attachment between the CRS and the vehicle seat in 83 percent of trials. Conversely, when working in the more challenging sedan, participants made this error in 58 percent of trials.

When comparing the easier and more challenging pickup trucks, participants made a retractor error in 66 percent of the trials (21 of 32 trials) in the easier pickup compared to 35 percent of the trials (7 of 20 trials) in the more challenging pickup ($t[50]= -2.25$, $N= 52$, $p=0.0260$).

An analysis of the difference in errors between easy and more challenging vehicle types found that participants made a greater percentage of errors when using the lower anchors in the easier sedan (64%, 7 of 11 trials) relative to the more challenging sedan (18%, 3 of 17 trials) ($t[26]= -2.66$, $N=28$, $p=0.0131$).

Overall, the analysis did not find a significant difference in tether routing errors between vehicle types. However, the participant made more errors routing the tethers in the more challenging pickup truck (80%) and the easier pickup (25%), but the numbers were too small to examine statistical significance.

There was not a significant difference in the percentage of trials where the CRS was touching the front seat back when participants were working in the easier and more challenging sedans ($t[59]= -0.20$, $N= 61$, $p=0.8410$) or SUVs ($t[60]= -1.29$, $N=62$, $p=0.1999$). Only 1 error was made with the more challenging minivan and 8 errors were made with the easier minivan. Despite the raw difference in the opposite direction than expected, the numbers are too small to feel confident in statistical comparisons. However, when comparing the easier and more challenging pickup trucks ($t[62]= 2.54$, $N=64$, $p=0.0121$), there was a significant difference. For the pickup trucks, participants made this error for 12 percent of the trials (4 out of 33 trials) when working with the easier pickup truck compared to 39 percent of trials (12 out of 31 trials) when working with the more challenging pickup truck.

The analysis did not find a significant difference in CRS recline angle errors between the easier and more challenging sedans ($t[59]= 0.15$, $N= 61$, $p=0.8779$), SUVs ($t[60]= -0.15$, $N= 62$, $p=0.8788$), or pickup trucks ($t[63]= 0.35$, $N= 65$, $p=0.7258$). Participants made this error in 32 percent of the trials (10 out of 31 trials) when working in the more challenging minivan and in 4 percent of the trials (1 out of 24 trials) when working in the easier minivan.

7.8 Seating Position

The study team assigned the seating position (i.e., center versus outboard) condition independently for each trial. However, the same seating position (e.g., center seat in the sedan and center seat in the minivan) are not equivalent in each vehicle type, as there are different features (center humps, presence or absence of lower anchors, etc.) that may affect ease of installation and success. This is important to consider when interpreting this analysis.

Looking at average errors per trial, the study team only found statistically significant differences between seating positions for lower anchor errors ($N= 151$, $p<0.0001$) and errors related to rear-facing installations ($N= 249$, $p= 0.0284$). Participants made 1.17 errors per trial in the center seating position compared to 0.26 errors per trial in the outboard seating position when working with the lower anchors ($t[84]= 6.77$, $N=151$, $p < 0.001$). In addition, participants made 0.59 errors per trial when installing in the rear-facing direction in the center seating position compared to 0.79 errors per trial in the outboard seating position ($t[145]= -2.21$, $N= 249$, $p = 0.0284$).

Table 7-17. Average number of errors per trial, by seating position.

	Outboard		Center		p-value
	Mean	N	Mean	N	
Installation errors	1.27	283	1.45	266	0.1014
Securement errors	1.43	284	1.32	260	0.3520
Lower anchor install errors	0.26	105	1.17	46	<0.0001
Rear-facing install errors	0.79	133	0.59	116	0.0284

The majority of the participants made a greater percentage of errors on trials when installing the CRS in the second row center seating position (74%) compared to the second row outboard seating position (62%) ($F[1, 149]= 10.99$, $N= 549$, $p = 0.0012$).

Table 7-18. Percentage of trials where participant made one or more installation errors by seating position

Seating position	Correct	Error	Total	p-value
Outboard	108 38.16%	175 61.84%	283 100%	
Center	68 25.56%	198 74.44%	266 100%	
Total	176 32.06%	373 67.94%	549 100.00%	p = 0.0012

Overall, participants elected to use the lower connectors more often during trials when they were securing the CRS in the outboard seat position of the vehicle (105 trials out of 283 trials) compared to trials where they were working in the center seating position (46 trials out of 266 trials). When using the lower connectors to complete the installation, participants were more likely to make one or more errors related to the lower anchors in trials when they were working in the center seating position (80%) than they were in trials when they were working in the outboard seating position (22%).

In most vehicles, only the two outboard seating positions have lower anchors, and these lower anchors cannot be used to secure a CRS in the center seating position. Only one vehicle selected for this study (one of the minivans) had lower anchors in the center seating position. Therefore, if the participant elected to use the lower anchors to install the CRS in the center seating position for any of the other 7 vehicles, the study team recorded this as an error. In addition, if the participant attached the lower anchor connectors to something other than the lower anchor, the study team recorded it as an error.

When using lower anchors to install the CRS, participants attached the lower connectors to the incorrect location in 76 percent of trials (35 of 46 trials) when working in the center seating position compared to 2 percent of the trials (2 of 105 trials) when working in the outboard seating position ($F[1, 149) = 97.50$, $N=151$, $p<0.0001$). Note, all 11 trials where the participant successfully secured the CRS to the correct lower anchors in the center seat of the vehicle took place in the minivan that had lower anchors in the center seating position.

Additional analysis of the individual errors that contribute to the rear-facing error measure indicated that seating position may affect errors associated with the CRS touching the front seat. It is important to note that the study team set the front seats of the vehicle to a standardized setting prior to each trial. In 76 percent of the trials where the CRS was installed in the rear-facing mode, the CRS did not touch the front seat back. However, there was a strong relationship between this type of error and seating position. This particular error was made in a higher percentage of trials when the participant was working in the outboard seating position (32%, 41 of 129 trials) versus the center seat (15%, 17 of 113 trials) ($F[1, 149]= 11.39$, $N= 242$, $p = 0.0009$).

7.9 Bivariate Modeling

The study team also tested the following preplanned interactions between factors:

- Experience by CRS type, by doll size, by seating position, and by vehicle ease of use;
- CRS type by CRS ease of use, by vehicle type, and by seating position; and
- Vehicle type by ease of use.

A statistically significant interaction effect means that the two factors together result in error rates that are significantly different than the rates one would expect by simply adding up the main effects of the individual factors. For most errors tested, there was no significant affect of the interaction term on the frequency of errors.[11] Any statistically significant interactions are listed in the table below and explained in more detail following the table.

Table 7-19. Statistically significant interactions between factors of interest

Factor 1	Factor 2	Errors with significant interaction effects (p-value)
Experience	CRS type	None
Experience	Doll size	Seat Belt Installation Errors (p =0.0488)
Experience	Seating position	None
Experience	Vehicle ease of use	None
CRS type	CRS ease of use	Installation Errors (p=0.0071), Seat Belt Install Errors (p=0.0028), Seat Belt Routed Incorrectly (p=0.0067), Seat Belt Twisted (p=0.0245)
CRS type	Vehicle type	Seat Belt Twisted (p=0.0472)
CRS type	Seating position	Seat Belt Installation Errors (p=0.0304), Seat Belt Routed Incorrectly (p=0.0273)
Vehicle type	Vehicle ease of use	Retractor Error (p=0.0294), Lower Anchor Installation Errors (p=0.0384), CRS Touching Front Seat (p=0.0124)

[11] This may be partially due to small cell sizes for some errors; the power to detect an interaction effect decreases with smaller sample sizes, and any errors with two or more cells with zero counts were excluded from the analysis.

7.9.1 Experience

The percentage of trials with one or more seat belt related errors was roughly the same for both novice and experienced participants for the infant, 3-year-old, and 6-year-old dolls. However, novices were more likely than experienced participants to make errors in trials with the 16-month-old doll (90.6% versus 61.3%, N= 339, p=0.0488).

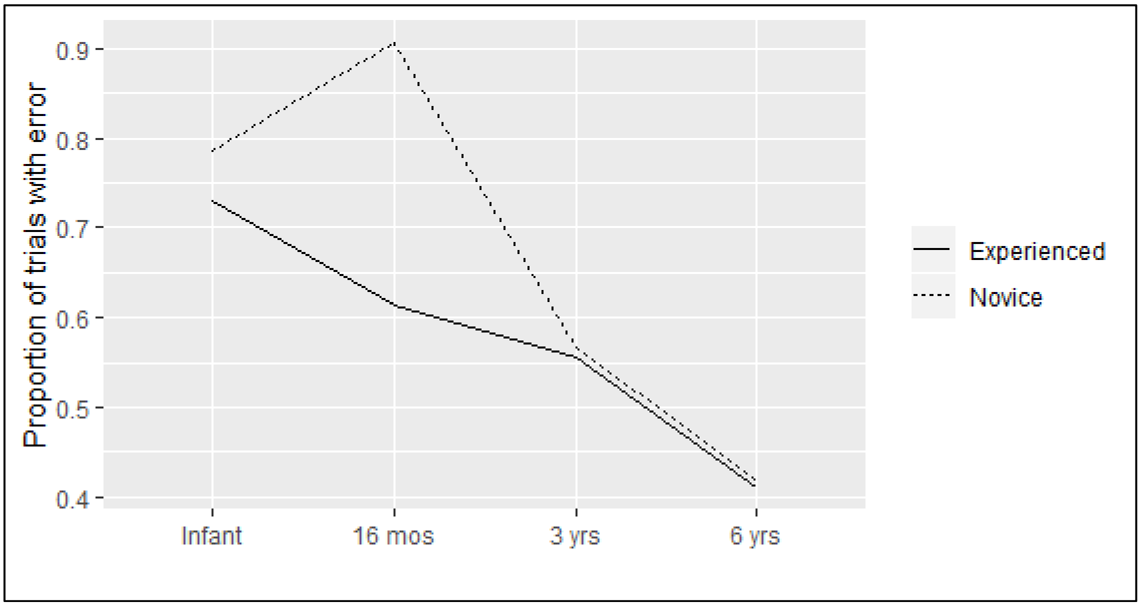

Figure 7-1. Interaction plot of seat-belt related errors by doll size, experienced versus novice

7.9.2 CRS Type

Analysis for the interaction between CRS type and CRS ease of use showed increases of approximately 50 percent in error rates between the easier and more challenging convertible CRSs for installation errors (N=549, p=0.0071), any seat belt related errors (N= 339, p= 0.0028), errors related to routing the seat belt (N= 339, p= 0.0067), and errors related to twisting the seat belt (N= 337, p= 0.0245). For example, participants made installment errors in 61 percent of trials when using the easier convertible but in 93 percent of trials when using the more challenging convertible CRS.

Table 7-20 shows the pattern of installment errors for all CRS types, and Figure 7-2 shows the interaction plot for installation errors. Roughly parallel lines would indicate no significant interaction effect. However, we see that the gap between the lines (difference in error rates) is smallest for the high back booster but much larger for the convertible.

Table 7-20. Installation errors by CRS type and ease of use

Easier			
	Rear-Facing-Only	**Convertible**	**Booster**
No Error	21	45	50
Error	67	70	28
% Errors	76.1%	60.9%	35.9%
More Challenging			
	Rear-Facing-Only	**Convertible**	**Booster**
No Error	7	8	45
Error	70	103	35
% Errors	90.9%	92.8%	43.8%

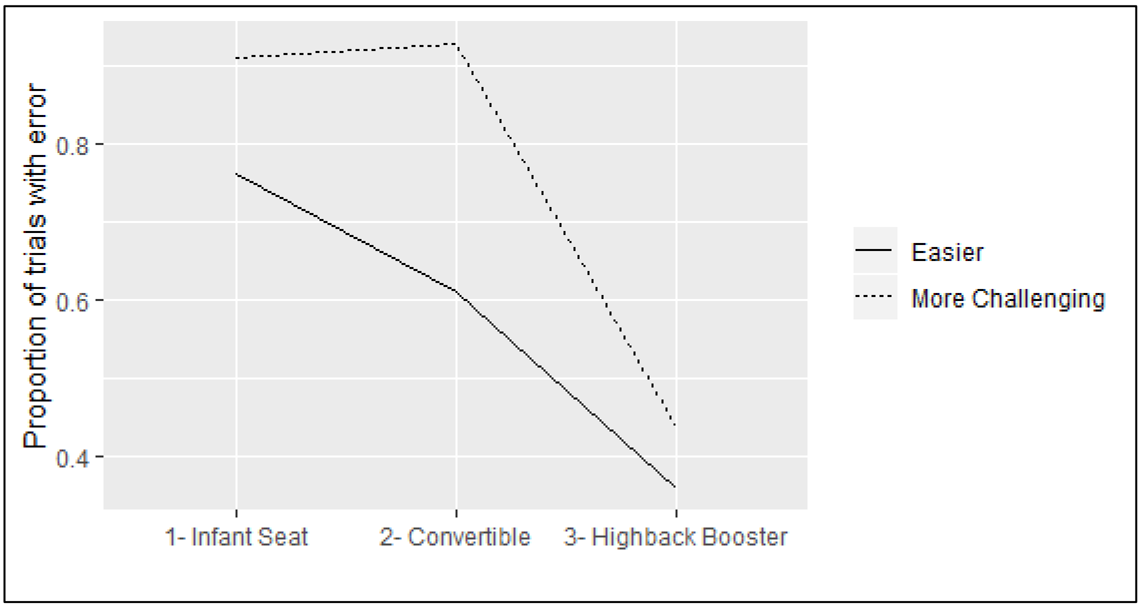

Figure 7-2. Interaction plot of installation errors by CRS type, by ease of use

For seat belt routing errors, however, participants had a much higher error percent when working with the more challenging rear-facing-only CRS (43.3% versus 19.2% for the easier CRS). Seat belt routing error rates were more similar between the ease of use groups for the convertible CRS and the booster seat.

Seat belt related errors were also influenced by the interaction between CRS type and seating position (N= 339, p=0.0304). Participants had higher seat belt related error rates when working in the outboard seating position with rear-facing-only and convertible CRSs, but the percent of errors was lower in trials where they were installing a booster seat in the outboard seating position.

There was also a statistically significant relationship between seat belt routing errors and the CRS type by seating position interaction (N= 339, p=0.0273). Participant error rates were higher when working in the outboard position for the rear-facing-only and lower for the booster seat, but the rates were similar in both seating positions in trials where they were working with a convertible CRS.

The statistically significant effects of the CRS type by vehicle type interaction was limited to seat belt twisting errors (N= 337, p=0.0472). Participants made roughly the same percentage of seat belt twisting errors across all CRSs for the SUV and pickup truck. However, when participants were working in the sedan, participants were about three times more likely to twist the seat belt when installing the convertible CRS (54.2% of trials) versus the rear-facing-only CRS (16.0%) or booster (15.0%). When in the minivan, participants were more likely to twist the seat belt when installing either the rear-facing-only (35.3% of trials) or convertible (39.1%) CRSs versus the booster (10.6%). Figure 7-3 shows that the SUV and the pickup truck show roughly the same rates while the rates for the sedan and the minivan differ.

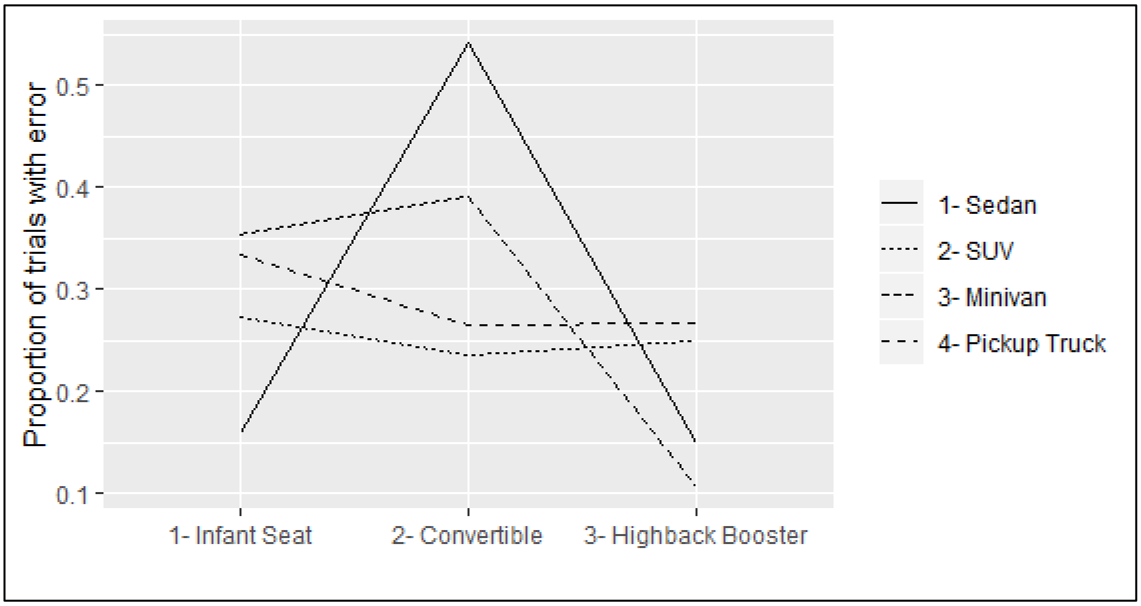

Figure 7-3. Interaction plot for seat belt twisting errors by CRS type, by vehicle type

Interactions with vehicle type had cells that were too small to allow statistical analyses.

7.10 Multivariate Analysis

Analyses of the univariate and bivariate effects of the factors of interest, while meaningful, are limited in that they examine the effect of only one or two factors at a time. To determine which causal factors are the strongest predictors of errors, it is important to simultaneously consider all factors of interest. As such, the study team fit three separate logistic regression models, one for each high-level error measure: Selected Incorrect CRS, Installation Errors, and Securement Errors.

7.10.1 Selecting CRS

While this study planned a logistic regression to analyze incorrect CRS selection, the relatively small proportion of failures (0.10) combined with the large proportion of variance explained by the doll size (no errors for infant) did not make such a model appropriate.

7.10.2 Installing CRS

When using the easier CRSs, participants were less likely to make installation errors in trials where the convertible CRS or booster seat was used compared to installing the rear-facing only CRS.

Overall, using the more challenging CRS rather than the easier CRS meant that participants were more likely to make an installation-related error (three time greater odds of making an error with challenging CRS versus easier). The interaction between ease of use and CRS type was not statistically significant when comparing the effect of ease of use with booster and convertible CRSs to the effect for rear-facing CRS.). Finally, participants were more likely to make errors when installing in the center seating position than in the outboard positions.

Table 7-21. Logistic regression model: CRS installation errors

Variable	Estimate	Odds Ratio	Std. error	t	p-value
(Intercept)	0.81	2.24	0.26	3.11	0.0023
CRS Type: Rear-Facing-Only (reference)	-	-	-	-	-
CRS Type: Convertible	-0.71	0.49	0.33	-2.18	0.0308
CRS Type: High back Booster	-1.85	0.16	0.36	-5.13	<.00001
CRS Ease of Use: More Challenging	1.20	3.33	0.47	2.56	0.0115
Seat Position: Center	0.81	2.25	0.20	4.08	0.0001
Convertible*More Challenging	0.92	2.51	0.69	1.33	0.1872
Booster * More Challenging	-0.82	0.44	0.59	-1.38	0.1685

Note. N participants, does not include trials where participants were unable to install the CRS or selected the vehicle seat belt.

7.10.3 Securing Doll

Participants were less likely to make errors in trials where they used the vehicle manual versus when they did not or were securing the 6-year-old doll versus the three other doll types. Participants also were more likely to make errors when using the more challenging versus the easier CRS.

Table 7-22. Logistic regression model: Secured doll error

Variable	Estimate	Odds Ratio	Std. error	t	p-value
(Intercept)	1.45	4.28	0.24	6.11	0.0000
Vehicle manual use	-0.70	0.50	0.28	-2.49	0.0138
Doll size: Infant (reference)	-	-	-	-	-
Doll size: 16-month-old	0.78	2.18	0.44	1.78	0.0766
Doll size: 3-year-old	0.72	2.05	0.50	1.44	0.1521
Doll size: 6-year-old	-1.51	0.22	0.63	-2.38	0.0187
CRS ease of use: More challenging	0.49	1.64	0.23	2.19	0.0304
CRS Type: Rear-Facing-Only (reference)	-	-	-	-	-
CRS Type: Convertible	-0.26	0.77	0.45	-0.58	0.5664
CRS_Type: High back Booster	-0.89	0.41	0.62	-1.44	0.1527

Note. N participants, does not include trials where participants failed to secure dolls.

7.11 Effect of User Perception

For most of the trials, participants were confident that they had properly attached the CRS to the vehicle. Participants indicated that they had installed the CRS properly for 77 percent of the trials. However, the study team recorded installation errors for 68 percent of trials. There is a statistically significant negative relationship (F[3.95, 588.45]= 5.54, N= 540, p=0.0002) between perception of success and making one or more installation-related errors (participants who were more confident were less likely to make errors). However, even among the participants who indicated that they installed the CRS properly, a majority (60 percent) still made one or more errors.

Similar trends were found when participants rated their success for securing the dolls. Participants felt that they were able to secure the doll properly for 92 percent of the trials, but they made securement errors in 71 percent of the trials. There was no significant relationship between perception of success and securement errors.

As expected, experienced participants were more confident than novice participants with their overall performance. When asked by the study team to rate their confidence in the CRS installation, experienced participants "somewhat agreed" or "strongly agreed" that they installed the CRS correctly in the vehicle for 80 percent of trials (234 of 289 trials) compared to novice participants who felt they installed the CRS properly for 184 of 272 trials (68%).

Similarly, experienced participants were more likely than novice participants to "Somewhat Agree" or "Strongly Agree" that they had secured the doll in the CRS properly (95%, 271 of 286 trials versus 86%, 238 of 277 trials). Additionally, more novice participants were likely to say that they "Somewhat Disagree" or "Strongly Disagree" that they secured the doll properly than experienced participants.[12]

Participants generally reported that the CRS and vehicle features were easy to use (see Table 7-67). Experienced participants were generally more likely to report that a feature was easy to use than novice participants. There was no statistically significant association between experience and reported ease of use for most of the 21 features tested. The eight features with a statistically significant association are listed in in Table 7-67, along with the percent of trials in which a participant reported the feature was "very easy" or "somewhat easy" to use, and the p-value from the Chi-square test of association.

While experienced users reported seven of the features, two of which related to the CRS manuals, easier to use than did the novices, the novices reported adjusting the recline angle of the CRS to be easier than did the experienced users.

Table 7-23. Participant interpretation of ease of use by experience

Feature	Percentage of trials reported "Somewhat Easy" or "Very Easy"		p-value
	Experienced	Novice	
Understanding the CRS manual install instructions	60.76%	48.13%	0.0010
Understanding the CRS manual securement instructions	73.96%	61.84%	0.0004
Understanding the labels on the CRS	68.61%	54.50%	0.0031
Tightening the harness	73.76%	64.53%	0.0166
Buckling the harness straps	91.63%	78.77%	0.0081
Adjusting the chest clip	90.43%	79.56%	0.0193
Finding the vehicle lower anchors	76.07%	68.48%	0.0393
Adjusting the recline angle of the CRS	61.29%	69.57%	0.0132

7.11.1 CRS Type

In general, participants tended to report that working with the different features on the booster seat was the easiest and the convertible features were the most difficult. For this analysis, the study team was only able to compare elements that were present on more than one seat type; for example, the team could not analyze booster-specific elements. There were significant associations between CRS type and reported ease of use for 7 of the 15 features tested; these features are listed in Table 7-24.

[12] Trials where the doll was not secured were excluded from the analysis

Table 7-24. Participant interpretation of ease of use by CRS type

Feature	Percentage of trials reported "Somewhat Easy" or "Very Easy"			p-value
	Rear-facing only seat	Convertible	Booster	
CRS manual install instructions	58.87%	38.82%	77.17%	<0.0001
CRS manual securement instructions	63.56%	57.47%	84.38%	<0.0001
Labels on the CRS	72.79%	49.78%	78.87%	<0.0001
Adjusting the harness height	51.72%	75.47%	N/A	0.0156
Routing the seat belt	67.59%	55.04%	89.17%	<0.0001
Tightening the seat belt	63.46%	53.85%	94.41%	<0.0001
Adjusting the recline angle of the CRS	80.00%	57.50%	N/A	<0.0001

7.11.2 Reported Ease of Use by Success Analysis

The study team also examined whether reported ease of use for individual CRS features was associated with success. If there was no association between reported ease of use and success, participants may not realize that they were using the feature incorrectly. The study team used Chi-square tests to examine the association between the reported ease of use for each feature and its associated error. A total of 25 tests were run with no explicit adjustment for multiple comparisons.

There was no statistically significant relationship ($p > 0.05$) between reported ease of use for a feature and its associated error variable for 19 of the 25 tests. In some cases, participants who made an error reported that the feature was easier to use. For example, participants reported that the harness was easy to tighten in about 75 percent of trials where the study team recorded the harness was not snugly fit around the doll. Conversely, participants reported that the harness was easy to tighten in 66 percent of trials where the study team recorded the harness was properly tightened around the doll. Even in trials where an error was made, 60 to 80 percent of participants generally reported that the element was easy to use, suggesting that they did not realize that they used the element incorrectly.

Table 7-25 lists the six tests with a statistically significant relationship between ease of use rating for a feature and its associated error variable. In all cases, participants who made an error associated with a feature where less likely to report the feature easy to use than those who did not make an error. In particular, participants who made a CRS installation or doll securement error were less likely to report the CRS manual was easy to understand than those who did not make such errors.

Table 7-25. Participant interpretation of ease of use by success

Feature	Associated error	Percentage of trials reported "Somewhat Easy" or "Very Easy"		p-value
		Correct	Error	
Understanding the labels on the CRS	CRS installation error	74.38%	62.09%	0.0046
Understanding the CRS manual install instructions	CRS installation error	73.51%	49.06%	<0.0001
Understanding the CRS manual securement instructions	Doll securement error	81.45%	65.15%	0.0075
Buckling the harness straps	Did not fasten crotch buckle properly	86.96%	71.43%	0.0004
Adjusting the chest clip	Chest clip not at armpit height	91.75%	78.86%	0.0254
Routing the seat belt	Did not route seat belt correctly	78.40%	57.83%	0.0035

The study team also examined the relationship between reported ease of use and number of errors made with a cluster analysis. The team calculated the average ease of use score for each trial, along with the total average number of errors made for each trial. After standardizing each variable, k-means clustering was used to identify four distinct groupings of trials: those with above-average reported ease of use and below-average errors (N=191), those with above-average reported ease of use but above-average errors (the "overconfident" group, N= 122), those with below-average reported ease of use and above-average errors (N=77), and those with below-average reported ease of use but below-average errors (the "underconfident" group, N=132). It is important to note that, on average, participants reported features to be very easy even when they made errors in a high percentage of trials, so even a below-average ease of use score does not mean that participants reported an feature is difficult to use. Consistent with the previous findings, the "overconfident" group of trials includes more trials in which the participant was attempting to install the convertible CRS and includes a higher percentage of experienced participants.

8 Discussion and Conclusions

Discussion

Selection Errors

Most participants selected an appropriate CRS for the assigned doll. The wrong CRS was selected in only 10 percent (62 of 600) of trials and never when working with the infant doll. Participants mistakenly chose the rear-facing-only CRS for the 16-month-old (24 trials, only incorrect because the rear-facing-only seat did not go up to the 16-month-old doll's weight), the booster seat for the 3-year-old (25 trials), or only used the vehicle seat belt for the 6-year-old (11 trials). Participants were less likely to choose the wrong CRS when working with the 6-year-old (7%) compared to either the 16-month-old (17%) or the 3-year-old (17%). These findings, in combination with the finding that participants always selected the correct CRS for the infant doll, support research suggesting that children from 1 to 4 years old are more likely to be improperly restrained (NHTSA, 2017; Decina & Lococo; 2004). In addition, participants were more likely to make premature graduation errors (38 trials) than the other direction of placing a doll in a CRS intended for a smaller child (24 trials). Contrary to the hypothesis, the error rate for novices was not statistically different from the rate for experienced participants.

Installation Errors

A majority of trials included an installation error (68% of trials), and previous experience with CRSs was not associated with a significant reduction in the percentage of installation or securement errors. It is possible that while experienced users have repeatedly installed a CRS, they may not be doing so properly, and with repeated exposure, the errors may be reinforced. In addition, although some of the participants regularly installed a CRS, the methods used when working with their own CRS and vehicle may not translate easily to other CRSs or vehicles. Although the basic method for installing a CRS and securing the child are similar across CRSs, the design of the features and specific steps differ. Overall, novice users were less likely to obtain a tight fit between the CRS and the vehicle seat than experienced users. Novice users were more likely to make errors related to the seat belt retractor, either by forgetting to switch it to locking mode or incorrectly using both the retractor and the CRS lock-off, than experienced users.

Compared to their performance, most participants were overconfident in their ability to install the CRS. While participants were confident that their installation was completed correctly in 79 percent of trials, only 32 percent of trials lacked installation errors. If parents and caregivers believe that they have installed the CRS correctly, they may be less likely to double-check the CRS manual or schedule an appointment with a CPST. In addition, despite the fact that there was no difference in the percentage of errors made by experienced and novice users, experienced participants were more confident in their performance than novices. Experienced participants may assume that all CRSs are similar with respect to how features are used and manufacturer's requirements and may be less likely to seek out additional information.

For most comparisons, there was no statistically significant relationship between reported ease of use for a specific CRS feature and making an installation error. In some cases, participants who felt a feature was easier to use were more likely to make an error than those who felt it was more difficult to use. For experienced users, this pattern may reflect differences in how seats are used that are not apparent to participants or repeated incorrect use with their own CRS that reinforces errors. For novice participants, this pattern likely reflects not being aware they made an error.

Overall, a greater proportion of participants made installation errors when working with the rear-facing-only CRS (83%) compared to the convertible CRS (77%). When comparing rear-facing-only to convertible CRSs, participants were more likely to make seat belt related errors (70% versus 80%) and use both the vehicle seat belt and the lower anchors and tether system (11% versus 18%). However, participants were less likely to make errors related to twisting the seat belt when routing through the belt path (27% versus 36%) and using the lower anchors and tether system (26% versus 47%). These findings may reflect the differences in the way rear-facing and convertible seats are designed and used. For instance, wanting to use the seat belt and lower anchors and tether is common with younger children because it is perceived to be safer even though it is not. This error may have been related to the rear-facing seat being commonly chosen for infants instead of a characteristic of the seat itself. Similarly, tethers are necessary to use the lower anchors and tether system fully, but tethers are typically only used with forward-facing seats.

It is important to note that differences in how CRS features are presented and used affect the number and types of installation errors. For example, the CRSs classified as more challenging lacked features such as clearly identified or visible belt paths or lower connectors, a no-re-thread harness, a recline level line indicator, and a seat belt lock-off. Participants made a significantly higher percentage of errors with respect to using the seat belt or lower anchors and tether to secure the CRS, working with the seat belt retractor, and errors associated with rear-facing installations when using the more challenging rear-facing and convertible CRSs. The percentage of errors related to lower anchors and tethers and the likelihood of the CRS touching the vehicle front seat back were strongly associated with the more challenging convertible CRS that had a more complex lower anchor routing system than the easier convertible CRS.

The percentage of trials with installation errors also varied by vehicle type. On average, the most installation errors per trial were made in the pickup trucks, and the fewest installation errors were made in the minivans. Minivans are marketed as family-friendly vehicles and perhaps manufacturers consider this when designing and positioning the specific features that are used for CRS installation. When working with the lower anchors, participants made the fewest errors in the minivans. This finding may be related to how clearly marked and visible the anchors were in the minivans relative to the other vehicles. When participants elected to use the tether, they experienced the most difficulty in the pickup trucks. Most pickup trucks require a complex routing method for the tether.

The vehicle seating position (center and outboard) also had an impact on the type and frequency of installation errors. Participants had more difficulty installing the CRS in the center seating position than in the outboard seating position. Errors associated with using the lower anchor system accounted for almost all of this difference across seating positions. When using the lower anchors and tether system to install the CRS in the center seating position, most participants used the outboard lower anchors. This error likely reflect the location of lower anchors, which look close enough to the center seat to be used with the center position. Additionally, recommendations have focused on younger children being in the center seat, such that caregivers will try to place children who are small enough to use lower anchors in the center seat. Without checking the vehicle manual, they may simply “borrow” the outboard seat anchors and not realize it is not safe.

Vehicle ease of use findings were sometimes opposite from the expected direction. Users made fewer errors with some elements of more challenging vehicles compared to easier vehicles. This finding may represent either not differentiating the seat on elements that were most important to installing a car seat. Conversely, the more difficult seat may have forced participants to look at manuals to figure out what was not working. Using the manuals was associated with fewer errors. Differences in vehicle ease of use were also found with some low-frequency installation steps, making it difficult to understand observed differences by vehicle ease of use. Future studies should note these unexpected findings and examine vehicle design carefully to determine what may be affecting CRS installation.

Securement Errors
A majority of trials included a securement error (71% of trials). Doll size affected the likelihood of securement errors. In general, participants made the greatest percentage of errors when securing the infant, 16-month-old, and 3-year-old. The fewest errors were made when working with the 6-year-old. This finding is not surprising as most participants selected the booster seat for the 6-year-old, which requires fewer steps to secure the doll and uses the vehicle seat belt.

Harness height errors, crotch buckle position errors, and infant insert errors were all strongly associated with doll size. Participants were more likely to make errors related to these features when working with the 16-month-old and 3-year-old compared to the infant. This finding is likely because the CRSs were presented to the participant in a standardized or “out-of-the-box” setting. That is, the harness straps were positioned in the lowest setting at purchase, the crotch buckle was positioned in the inner most slot, and the infant insert was left in the CRS. These positions are typically ideal for an infant, but as the child grows, all of these features need to be adjusted or removed from the “out-of-the-box” or standardized setting, allowing for the introduction of additional errors when working with the older dolls. On the other hand, participants were less likely to have the harness adjusted snugly around the infant when compared to the older dolls. This finding might be associated with participants’ difficulty tightening the straps and the smallest doll requiring the most tightening or the perception that the infant is the most fragile.

As with installation errors, CRS type was also associated with securement errors. Compared to the rear-facing-only CRS, a larger proportion of participants made errors related to positioning of the harness height, placing the crotch buckle in the correct location, and using the infant insert with the convertible CRS. This finding is possibly because the convertible CRS was used with larger sized dolls, which required the participant to make the adjustments mentioned above that could lead to errors. Conversely, participants made more errors related to securing the doll snugly in the CRS when working with the rear-facing-only CRS. Again, this finding could be associated with the infant doll requiring more tightening or being perceived as fragile. Participants were overly confident they had correctly secured the doll. They indicated that they secured the child properly in 93 percent of the trials despite avoiding errors in only 29 percent of trials.

The factors that were the strongest predictors of an error related to securing the doll were doll size, vehicle manual use, CRS type and CRS ease of use. Overall, participants were less likely to make securement errors when they used the vehicle owners' manual or when securing the 6-year-old doll. This finding suggests that participants who read the manuals are more informed and more likely to check that they have installed a seat correctly than those who do not. Reading the manual may be predictive of checking for changes needed to the "out-of-the-box" settings that were likely related to CRS type and CRS ease of use effects seen. The 6-year-old doll was also most often placed in the booster seat, which is easier to install and secure the doll.

Conclusions

While novice participants were more prone to certain types of errors, there was no significant difference in the number of errors made by experience level. One possible explanation is that experience may not transfer across different CRSs. Each CRS make and model has specific features and requirements related to their use. Based on study findings, experience with one CRS may not necessarily help a user install a different CRS correctly. Another possibility is that the experienced users may have been installing CRSs incorrectly in the past, reinforcing errors over time and making them prone to repeat such errors.

A limitation of the study was that participants were working in new and unfamiliar conditions, including the CRSs, vehicles, and laboratory environment. Future research could explore installation in familiar conditions involving participants' CRSs and vehicles. This manipulation may help isolate errors experienced users would make in their natural environment from those associated with an unfamiliar CRS and vehicle.

Most participants were overconfident in their ability to install the CRS or secure the doll, suggesting they were not aware that they were making mistakes. Programming could highlight this finding and bring awareness to novice and experienced users alike about the importance of having their CRS checked by a CPST, even when they think it is installed correctly.

One approach to potentially reduce CRS errors would be developing educational materials that specifically highlight and address the areas of misuse identified in this study. It may also be beneficial to work with CPSTs to ensure training and educational materials address common installation errors. For example, educating caregivers about only using the seat belt or the lower anchors may help reduce incidences of these two restraint systems being used in combination.

This study also found a relationship between CRS features that need to be adjusted as a child grows and errors pertaining to these features. Specifically, participants were more likely to make harness height, crotch buckle position, and infant insert errors when working with the 16-month-old and 3-year-old than when working with the infant. This finding suggests there may be a breakdown in correct CRS use as a child grows over time and the CRS settings require adjustment. Encouraging caregivers to have their CRS rechecked as their child reaches growth milestones would give opportunity to adjust features from "out-of-the-box" to size-appropriate settings and possibly reduce associated errors.

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