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SUBJECT EVALUATION OF DEVICES INTENDED TO REDUCE RISK OF SEATBELT ENTANGLEMENT

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16. Abstract

Since 2000, there have been over 200 incidents reported where a rear seat occupant became entangled in the seatbelt when they inadvertently switched it from emergency locking mode (ELR) to automatic locking mode (ALR). While a method is needed to lock the seatbelt when using it for child restraint system (CRS) installation, the National Highway Traffic Safety Administration (NHTSA) commissioned tool, inc. to develop prototype devices that could reduce the risk of seatbelt entanglement resulting from the lockability requirement. The purpose of this study is to perform testing with volunteer subjects to evaluate these prototype devices in comparison to standard seatbelt system by assessing how different designs would be used to install CRS, the quality of the resulting installations, how users would disentangle a trapped child surrogate, as well as to identify volunteer experience when using the belts themselves.

Four prototype devices were evaluated in two phases of testing. In phase 1, D1, D2, and D3 were compared to standard seatbelt and LATCH using two forward-facing and two rear-facing CRS. In phase 2, D1 and D4 were compared to standard seatbelt using three forward-facing CRS. Phase 1 tested 16 subjects while Phase 2 tested 24. Subjects were recruited to include men and women of different ages with and without previous CRS installation experience; phase 1 also included education level as a criteria, while phase 2 included subject size. After the first installation trial using each device, the subject was presented with a crash dummy entangled in same device belt system, and instructed to free the dummy. In phase 2, subjects also participated in "comfort" trials where they sat in the vehicle seat, donned the seatbelt, and performed a reaching task intended to trigger a nuisance locking scenario.

All four prototype devices had shorter disentanglement times than trials with the standard seatbelt, but there was not a statistically significant difference between the devices. There were no substantial differences in the quality of child restraint installation among the prototype devices. In phase 2, subjects viewed video instructions midway through the installation trials, which had a strong effect on reducing installation errors. In nuisance locking trials, subjects with higher BMI or taller stature were most likely to experience unintended seatbelt locking while performing a reach task.

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INTRODUCTION

Background

Regulations

Since 1993, FMVSS No. 208 has required that seatbelt assemblies include a means to lock the belt to allow secure installation of a child restraint system (CRS). The difficulties experienced by caregivers when securing CRSs with seatbelts led to the development of FMVSS No. 225, Child Restraint Anchorage Systems, which was published in 1999. This regulation requires motor vehicle manufacturers to install Lower Anchors and Tethers for Children (LATCH) systems. FMVSS No. 213, Child Restraint Systems, was simultaneously amended to require CRS manufacturers to provide components that can secure the CRS to the LATCH system. At the same time, the final rule also amended FMVSS No. 208 to rescind the lockability requirement for each rear designated seating position (DSP) equipped with LATCH and set the sunset of the requirement for September 1, 2012.

However, in 2011, FMVSS No. 208 was amended to retain the belt lockability requirement for LATCH-equipped DSPs and the plan to eliminate belt lockability requirements was reversed. This action occurred because many caregivers continued to install CRSs with seatbelts, even in seating positions equipped with LATCH. On February 27, 2014 NHTSA issued a final rule (NHTSA-2011-0176) that includes new labeling requirements to indicate that the LATCH system should only be used until the combined weight of the CRS and child reaches 65 pounds. When this weight limit is exceeded, the CRS should be secured using the seatbelt assembly.

The two methods commonly used to meet the seatbelt lockability requirements are 1) a locking latch plate (buckle tongue), which clamps the webbing, or 2) a device that switches the retractor from an emergency locking mode (ELR) to an automatic locking mode (ALR). The latter is more common, and is typically accomplished through the use of a mechanism that locks the retractor when the seatbelt is completely pulled out of the retractor.

Entanglement

However, there have been over 200 reported cases where children and adults have accidentally switched seatbelt modes from ELR to ALR and have become entangled in the seatbelt (Sidman & Liteplo, 2015). At least two fatalities have occurred from an occupant being strangled by the locked seatbelt (SafeRideNews 2009). Additionally, adult passengers may inadvertently engage the ALR mode when webbing is extracted from the retractor due to upper torso movement. This can occur more frequently with larger occupants. In most adult cases this results in a minor comfort or convenience issue; however, some individuals experience heightened anxiety due to the sensation of being entrapped by the seatbelt system. Current systems require the occupant to unbuckle the belt and allow the webbing to retract fully to switch the retractor locking mechanism back to ELR mode. Repeated issues with inadvertent activation of the ALR mode may cause some passengers to refrain from using the restraint system. In addition, some of the occupants who have become entangled in the seatbelt have had to cut the belt to be extracted.

In previous Phase I research for this project, Tool, inc. (Tool) analyzed data from 216 reported incidents from 1998-2015 in a NHTSA-provided database to increase understanding of the circumstances

surrounding entanglement. The findings demonstrated that there are unintended consequences from NHTSA regulated equipment. Key findings include:

- The increase in entanglement incidents over time has resulted from increased vehicle exposure in the field and OEM preference for ALR mode retractors over locking latch plates.
- The majority of reported incidents involve children.
- Entanglement involves the inadvertent actuation of retractor's ALR mode often due to misuse of the seatbelt system.
- Children in child seats attached with the LATCH system have been entangled in seatbelts that were not in use.
- The cinching forces and regions entangled often leads parents and first responders to cut the seatbelt.

Countermeasures: Phase 1

As a result of the entanglement problem, the Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA) are seeking countermeasures that successfully address the competing needs of ensuring lockability of seatbelts and mitigating entrapment risk in misuse conditions. Tool, Inc. has designed and developed three prototype lockability devices for evaluation at the University of Michigan Transportation Research Institute (UMTRI). The three designs are: Buckle-controlled ALR, Buckle-knob, and Buckle-button.

The three prototype designs are shown in Figure 1. The Buckle-controlled ALR (left) is designed so ALR cannot be activated if the seatbelt is not buckled. Nearly 40% of reported entanglement incidents involved unbuckled seatbelts. The Buckle-knob concept (center) includes Buckle-controlled ALR, but also includes a knob that pops out on full payout of the webbing to attract attention. The user then turns the knob to engage ALR. The Buckle-button Concept includes Buckle-controlled ALR, but adds a button that requires manual activation of the locking mechanism (right).

Figure 1. Prototype designs: Buckle control (left), Buckle-knob(center), and Buckle-button (right).

Countermeasures: Phase 2

In phase 2 of the study, the buckle control system evaluated in phase 1 was assessed again. In addition, a new design, Buckle-switch (shown in Figure 2), was evaluated as well. With this system, the ALR cannot be activated unless the switch on the buckle is shifted from adult to CRS mode.

Figure 2. Buckle-switch prototype design.

Objectives

The first phase of this investigation tested the three prototype devices with volunteer subjects (in comparison to traditional seatbelt design and LATCH installation) to determine how the new belt designs would be used to install CRS, the quality of the resulting installations, and how users would disentangle a trapped child.

The second phase of this investigation tested two prototype devices with volunteer subjects, in comparison to traditional seatbelts, to determine how the new belt designs would be used to install CRS, the quality of the resulting installations, how users would disentangle a trapped child, as well as to identify volunteer experience when using the belts themselves.

METHODS: PHASE 1

The three prototype devices (D1, D2, D3) and one production seatbelt (SB) with switchable ELR/ALR retractors were received from Tool, Inc. The devices each have a different combination of functions added to the standard seatbelt. All seatbelts came from the second row of the 2015 Chevrolet Suburban platform. Devices D2 and D3 both require the user to affirm locking the retractor via a step that goes beyond pulling the seatbelt all of the way out of the retractor.

Buckle Control

The "Buckle Control" prototype device (D1) retractor locks the same way as a standard switchable retractor, via the shoulder belt webbing pulled all the way out of the retractor. However, there are two differences: 1) it only switches to ALR when the seatbelt is buckled and 2) the retractor goes from ALR to ELR when the buckle is released, so the belt does not need to be fed all the way back into the retractor to disengage the ALR (Figure 3).

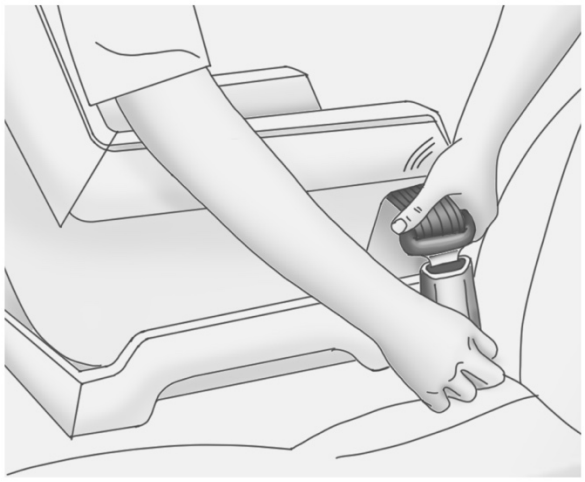


Figure 3. "Buckle Control" locks when the shoulder belt is pulled all the way out of the retractor if the seatbelt is buckled. The retractor is unlocked by releasing the buckle.

Buckle-knob Control

The "Buckle-knob Control" prototype device (D2) has a knob concealed in the vehicle pillar that moves out from its stowed position when the shoulder belt is pulled all the way out of the retractor. The user must turn the knob to lock the retractor. As the webbing feeds into the retractor, the knob returns to the stowed position. The retractor is unlocked by releasing the buckle (Figure 4).

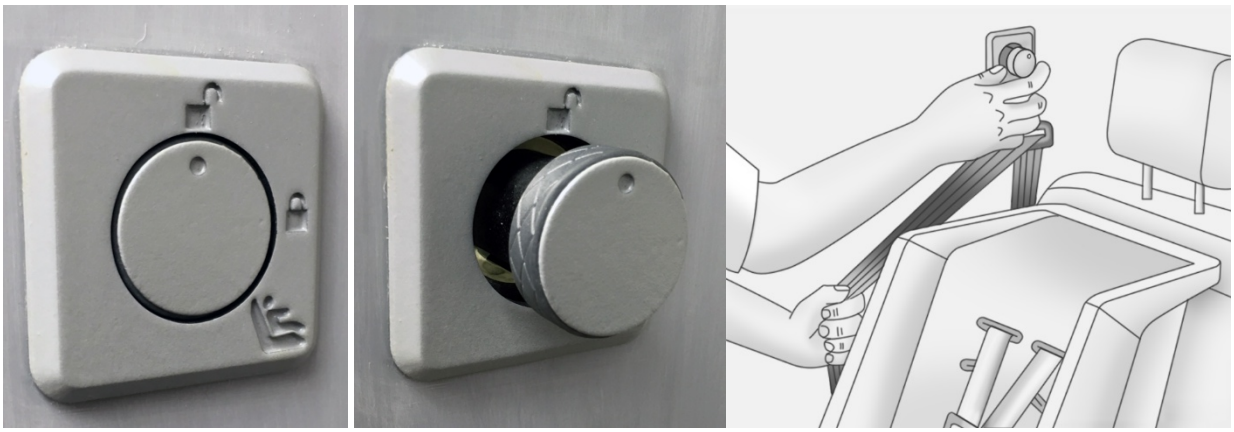


Figure 4. "Buckle-knob Control" moves out from its stowed position when the shoulder belt is pulled all the way out of the retractor. The user must turn the knob to lock the retractor. As the webbing feeds into the retractor, the knob returns to its stowed position. The retractor is unlocked by releasing the buckle.

Buckle-button Control

The "Buckle-button Control" prototype device (D3) has a button covered by a small door on the vehicle pillar. When the button is depressed, it locks the retractor if the belt is buckled. The retractor is unlocked by pressing the button again or by releasing the buckle (Figure 5).

Figure 5. "Buckle-button Control" is a button that when pressed locks the retractor if the belt is buckled. The retractor is unlocked by pushing the button again or by releasing the buckle.

Vehicle Mockup

The three prototype devices and the standard belt with retractor were mounted on rigid steel plates as shown in Figure 6. The plates then could be securely mounted to a C-Pillar on a vehicle mockup built for this study. When mounted, the location of upper anchorage pivot in the mockup was the same for each of the devices. The mockup shown in Figure 7 consisted of a second-row, passenger-side seat from a 2017 Chrysler Pacifica upholstered in cloth, a C-pillar, and a vehicle floor. The seat was chosen because it had relatively flat cushion surfaces, visible lower and tether anchorages that were easy to find, and an adjustable seat back recline angle. The vehicle floor was set to 400 mm above the laboratory floor,

which is an average height for an SUV. The vehicle seat was rigidly mounted to the platform with a seat height of 360 mm (SAE H30) above the platform. The C-Pillar was constructed so that the plates with the belt systems would mount with the upper anchorage pivot point located at the middle of the distribution measured in vehicles (Reed, 2013). This resulted in the D-ring 390 mm aft, 255 mm outboard and 600 mm above the seat H-point as measured with the J826 machine. The angle from the upper anchorage to the H-point relative to vertical was 23˚ as viewed from the front of the seat and 33˚ relative to vertical as viewed from the side of the seat. The lower anchors were mounted at an angle of 54˚relative to horizontal with respect to the seat H-Point (FMVSS 210). The interior of the C-Pillar was constructed with heavy steel and secured to the platform and the exterior was covered in foam and vehicle upholstery.

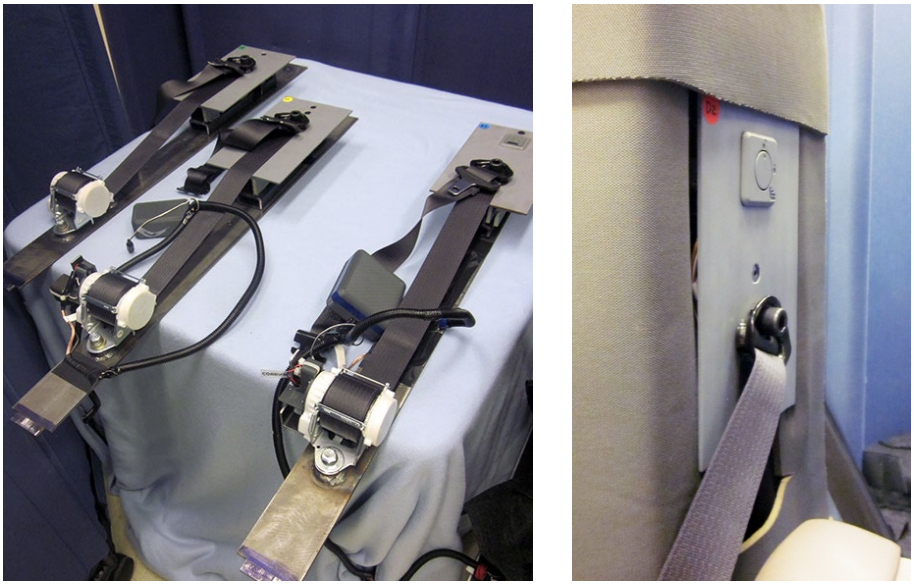


Figure 6. Modular D-ring system

Figure 7. Mockup of minivan/ SUV second row with Chrysler Pacifica seat and C-Pillar.

Child Restraint Systems

Four child restraint systems (CRS) that did not have integrated belt lock-off features were selected for this study to span a range of CRS manufacturers, types, sizes and locations of belt routing paths. Two of the systems were used in their forward-facing configuration, and two were used in their rear-facing configuration. The Evenflo Maestro (designated F1) is a combination harness and booster seat. The Baby Trend CV88a PROtect Series (designated F2), is a convertible CRS but was only tested in forward-facing mode. Figure 8 and Figure 9 show both forward-facing CRS in the vehicle mockup. For the rear-facing CRS, the Cosco APT 50 convertible (designated R1) was tested only in rear-facing mode. The Graco SnugRide 30 is a rear-facing only (designated R2) CRS with a base and removable shell.

Figure 8. Forward-facing CRS Evenflo Maestro combination CRS (left) and Babytrend CV88a PROtect Series Convertible CRS (right) in side view as installed in the vehicle mockup by a study participant

Figure 9. Forward-facing CRS Evenflo Maestro combination CRS (left) and Babytrend CV88a PROtect Series Convertible CRS (right) in front view as installed in the vehicle mockup by a study participant

Figure 10. Rear-facing CRS Cosco APT 50 Convertible CRS (left) and Graco SnugRide 30 Infant CRS (right) in side view as installed in the vehicle mockup by a study participant

Figure 11. Rear-facing CRS Cosco APT 50 Convertible CRS (left) and Graco SnugRide 30 Infant CRS (right) in front view as installed in the vehicle mockup by a study participant

Entanglement Conditions

A 6YO Hybrid II ATD was used as a surrogate for a child entangled in the seatbelt. This ATD was selected rather than the Hybrid III ATD because it has a more realistic face and smoother neck contour. It was dressed in cotton sweatpants which were pulled high up on the thorax and secured to the thorax with a gaffers tape as shown in Figure 12. The neck area was also wrapped with gaffers tape to create a smooth transition between the shoulders and the head. These measures were taken to reduce the risk of the vehicle seatbelt becoming caught on the ATD.

Figure 12. Preparation of the 6YO ATD included tape around neck (left) and pants (right) so that the belt would not get caught.

For each disentanglement trial, the investigator positioned the ATD in the vehicle seat. First the investigator straightened the legs of the ATD and then placed the ATD all the way back in the seat until the pelvis and the back were pressed against the vehicle seat back. The ATD was secured to the seat with a LATCH belt from a child restraint system. The LATCH belt webbing was covered in bright orange tape so that the study participant could easily distinguish it from the seatbelt. Figure 13 shows the investigator securing the ATD to the seat.

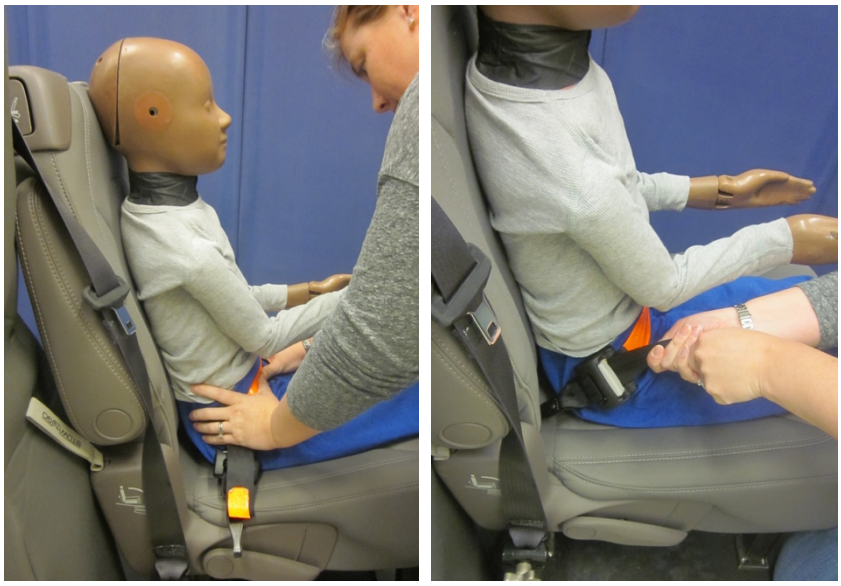


Figure 13. Investigator placing the ATD pelvis all the way rearward in the seat (left) and then securing with bright orange LATCH belt.

The vehicle belt was then wrapped around the ATD using the steps shown in Figure 14, and the retractor set to locking mode. Figure 15 shows how the ATD appeared when entangled. Several belt routings around the ATD were considered. This routing was chosen because it looped the lower length of the belt (closer to the lower outboard anchorage) around the ATD, and left the upper length of belt free to easily feed into the retractor when the buckle was released. Table 1 shows the results of an in-house pilot test of the time required to remove the seatbelt from the ATD using this routing. Figure 16 shows how, if the seatbelt is not held out of the retractor after unbuckling the belt, the belt becomes trapped on the ATD.

Figure 14. Steps to entangle a child surrogate routing the lower portion of the belt behind the ATD, under the left arm and then around the back of the neck (top row) and then crossing the upper portion of the belt across the chest to the buckle and engaging the ALR (bottom row)

Figure 15. Entangled dummy.

Table 1. Piloting Entanglement Routing

Pilot #	Time (min : sec : mil sec)
1	0:12:63
2	1:04:67
3	0:17:87
4	0:47:82
5	2:16:49
6	0:14:13
7	0:15:12
8	0:38:12
9	0:15:88
10	0:15:45

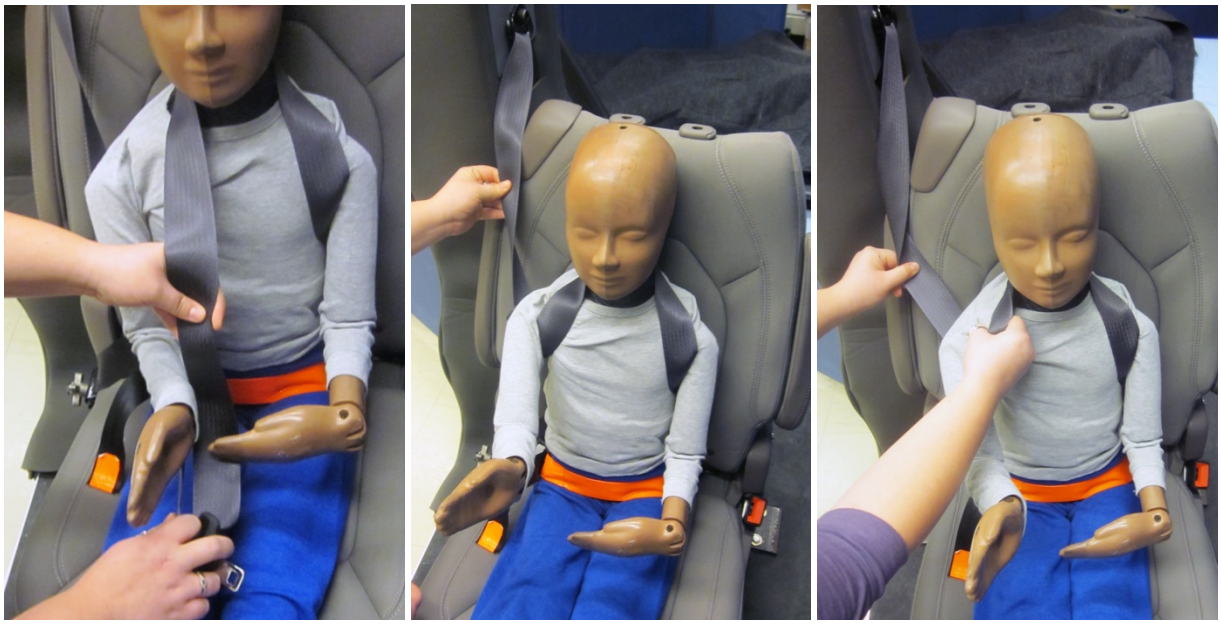


Figure 16. Two scenarios with the retractor locked: 1) catching the belt before it retracts (left) and having enough slack to remove the seatbelt or 2) not catching the belt (middle) and then trying to remove the belt after it has retracted (right).

Participants

Sixteen people, 8 men and 8 women, were recruited for this research study via online advertisements and the University of Michigan Health Studies website. Half of the men and half of the women had experience installing child restraints. Table 2 lists the age (range: 21 to 62 years) and education levels (range: some high school to graduate school) of the participants who were selected to have similar distributions in the experienced and inexperienced groups.

Table 2. Study Participants

No CRS Experience			**With** CRS Experience		
Gender	Age	Education	Gender	Age	Education
Female	21	College	Female	29	College
Female	27	Graduate School	Female	33	Some College
Female	46	College	Female	45	Some College
Female	54	Graduate School	Female	60	College
Male	25	College	Male	24	College
Male	32	College	Male	29	Graduate School
Male	45	College	Male	53	Graduate School
Male	60	Some High School	Male	62	College

Test Protocol

The study protocol was approved by the University of Michigan Institutional Review Board (IRB) for Health Behavior and Health Sciences (IRB # HUM00116550). Upon arrival to the University of Michigan Transportation Research Institute, the participants gave written informed consent (Appendix A).

Installations

The participants were presented with a belt system and a CRS as shown in Figure 17 and Figure 18 with instructions for the CRS, belt system, and vehicle (Appendix B). The participants were asked via scripted instructions (Appendix C) to install the child restraint either forward-facing or rear-facing with the seatbelt or with LATCH as shown in Figure 19. The investigator timed the participant and a webcam recorded the installation from the viewpoint shown in Figure 20. After each installation, the participant filled in a questionnaire (Appendix D). The participant sat behind a screen, and could not see the investigator who was assessing the installation. While the subject was answering questions, the investigator evaluated the quality of the installation using forms in Appendix E that assess elements that would be considered at a typical car seat check. The investigator tested the tightness of the installation by applying a 178 N force at the belt path and measuring the lateral movement of seat (Figure 21 and Figure 22). If the seat could move more than 25 mm, the installation was coded as "loose." The investigator also checked whether the retractor was locked, and the tether tight, and the angle of the CRS was correct.

Figure 17. Presentation of materials for installation

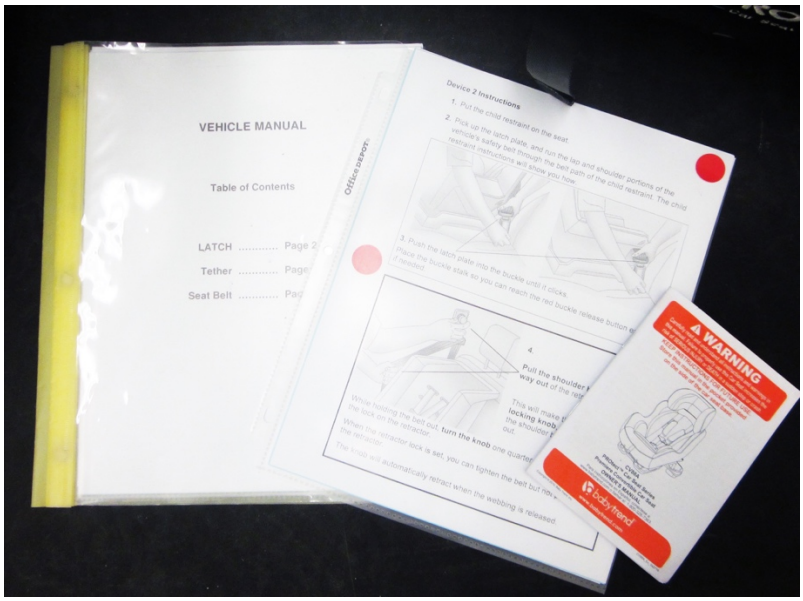


Figure 18. Written materials provided: sections of vehicle manual covering child seat installation, directions for the trial prototype, and CRS manual

Figure 19. Participant installing a forward-facing (left) and rear-facing (right) CRS

Figure 20. Mockup with video webcam mounted above and camera mount in front to document participant installations

Figure 21. Investigator loading the CRS installed by the participant at the belt path with 178 N force.

Figure 22. Measuring the amount of movement at the belt path

Entanglement

Immediately after installing a CRS with a prototype device or the standard seatbelt, the same seatbelt and retractor were used in an entanglement trial. The investigator secured the ATD to the seat, and then read the scripted instructions (Appendix C) and showed the participant the ATD and the orange LATCH webbing that they were not to remove in the subsequent attempt to remove the seatbelt from the ATD. The participant then went behind the screen where they could not see the mockup, and the investigator entangled the ATD. The investigator read the following instructions to the participant who was behind the screen.

> "We are going to time you to see how fast you can remove the seatbelt from the dummy. Imagine you look in your back seat and you see your child stuck in the seatbelt and in danger. Please try to get the seatbelt off the dummy as quickly as possible. Don't remove the dummy from the seat, just return the seatbelt to its stowed position."

The participant and the investigator then came out from behind the screen and the investigator said "Go!" and started the stop watch (Figure 23). The investigator then used the form in Appendix E to track and code the movements of the participant while removing the seatbelt. The participant then filled in a questionnaire about their experience (Appendix F).

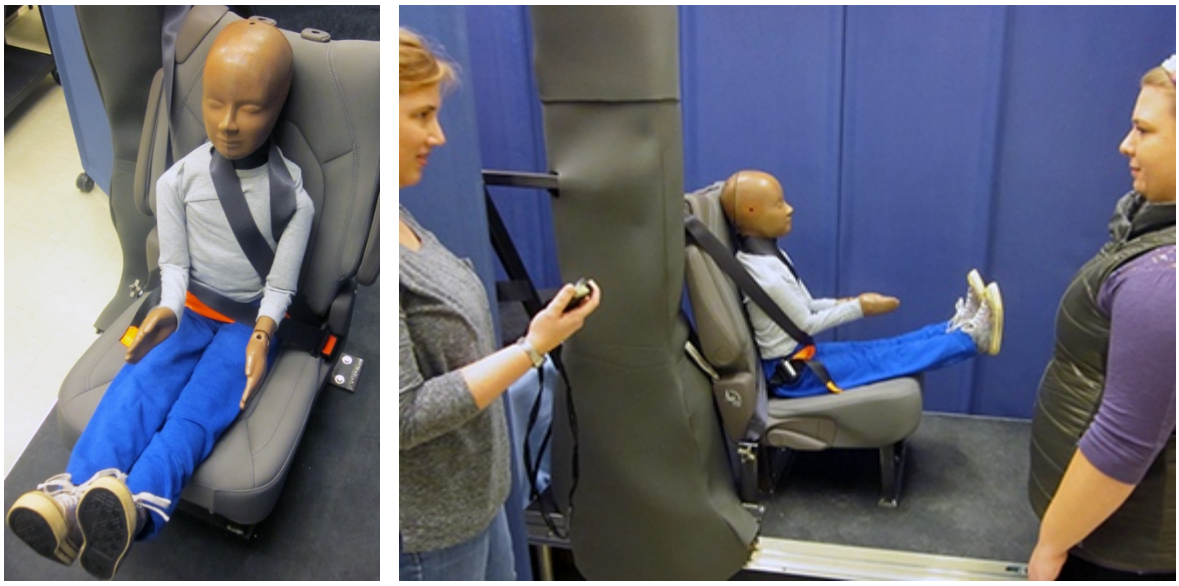


Figure 23. 6YO ATD, ready for the trial (left) and the investigator timing the participant (right)

Test Matrix

Table 3 lists the test variables and Table 4 lists the test matrix. In the first five trials, each subject performed an installation with the standard seatbelt, the three devices, and the LATCH lower anchors. Each child restraint was installed at least once. In the last four trials, subjects performed installations with the lower anchors and the three devices. If they installed a RF CRS with the device in the first trials, they performed an installation with a FF CRS in the second trial with that device. Order of installation systems and CRS was randomized to control for learning effects.

Table 3. Condition Variables

Code	Name	Description
F1	Forward-Facing CRS 1	Evenflo Maestro Combination CRS
F2	Forward-Facing CRS 2	Babytrend CV88a PROtect Series Convertible CRS
R1	Rear-Facing CRS 1	Cosco APT 50 Convertible CRS
R2	Rear-Facing CRS 2	Graco SnugRide 30 Infant CRS
LATCH	LATCH System	2017 Chrysler Pacifica
SB	Standard Seatbelt	2015 Chevrolet Suburban
D1	Seatbelt Device 1	Buckle Control Prototype
D2	Seatbelt Device 2	Hidden Control Prototype
D3	Seatbelt Device 3	Combined Button Control Prototype

Table 4. Randomized Test Matrix

	1		2		3		4		5		6		7		8		9	
1	*R1*	*D1*	F2	SB	**R2**	**D2**	F1	D3	*F2*	*LA*	*R2*	*LA*	*F1*	*D1*	**F2**	**D2**	R1	D3
2	*F1*	*D1*	R2	SB	**F2**	**D2**	R1	D3	*R2*	*LA*	*F2*	*LA*	*R1*	*D1*	**R2**	**D2**	F1	D3
3	F2	D3	**F1**	**D2**	F2	SB	*R1*	*LA*	*R2*	*D1*	*F1*	*D1*	**R2**	**D2**	R1	D3	*F2*	*LA*
4	R2	D3	**R1**	**D2**	R2	SB	*F1*	*LA*	*F2*	*D1*	*R1*	*D1*	**F2**	**D2**	F1	D3	*R2*	*LA*
5	F2	SB	R1	D3	*R2*	*LA*	*F1*	*D1*	**F2**	**D2**	**R1**	**D2**	F2	D3	*F1*	*LA*	*R2*	*D1*
6	R2	SB	F1	D3	*F2*	*LA*	*R1*	*D1*	**R2**	**D2**	**F1**	**D2**	R2	D3	*R1*	*LA*	*F2*	*D1*
7	**R1**	**D2**	*F1*	*LA*	*F2*	*D1*	F2	SB	R2	D3	F2	D3	*R1*	*LA*	*R2*	*D1*	**F1**	**D2**
8	**F1**	**D2**	*R1*	*LA*	*R2*	*D1*	R2	SB	F2	D3	R2	D3	*F1*	*LA*	*F2*	*D1*	**R1**	**D2**
9	*F2*	*D1*	F1	SB	**R1**	**D2**	R2	D3	*F1*	*LA*	*R1*	*LA*	*R2*	*D1*	**F1**	**D2**	F2	D3
10	*R2*	*D1*	R1	SB	**F1**	**D2**	F2	D3	*R1*	*LA*	*F1*	*LA*	*F2*	*D1*	**R1**	**D2**	R2	D3
11	F1	D3	**R2**	**D2**	F1	SB	*F2*	*LA*	*R1*	*D1*	*F2*	*D1*	**F1**	**D2**	R2	D3	*R1*	*LA*
12	R1	D3	**F2**	**D2**	R1	SB	*R2*	*LA*	*F1*	*D1*	*R2*	*D1*	**R1**	**D2**	F2	D3	*F1*	*LA*
13	F1	SB	F2	D3	*R1*	*LA*	*R2*	*D1*	**F1**	**D2**	**R2**	**D2**	R1	D3	*F2*	*LA*	*F1*	*D1*
14	R1	SB	R2	D3	*F1*	*LA*	*F2*	*D1*	**R1**	**D2**	**F2**	**D2**	F1	D3	*R2*	*LA*	*R1*	*D1*
15	**F2**	**D2**	*R2*	*LA*	*F1*	*D1*	F1	SB	R1	D3	F1	D3	*F2*	*LA*	*R1*	*D1*	**R2**	**D2**
16	**R2**	**D2**	*F2*	*LA*	*R1*	*D1*	R1	SB	F1	D3	R1	D3	*R2*	*LA*	*F1*	*D1*	**F2**	**D2**

After all the trials were complete, the participant ranked the devices using the form in Appendix G and reported their level of experience with different CRS via the form in Appendix H.

Data Analysis

Results from experimenter forms and subject questionnaires were coded for analysis. Univariate analysis was performed to identify significant predictors of outcome measures. Predictors that were considered were device type, installation number, child restraint system, gender, age group (<30, 30-49, and 50+), education level, and previous CRS experience. Outcome measures for entanglement trials were time to disentangle and number of steps taken. Outcome measures for installation trials were duration of installation, seatbelt correct, tether correct, LA correct, installation tightness, and overall installation correct. For continuous outcome measures, comparison of means was evaluated; for other measures, chi-squared analysis was performed.

METHODS: PHASE 2

Phase 2 used the methods of Phase 1 wherever possible for consistency. This section details differences in procedures compared to Phase 1.

Two prototype devices (D1 and D4) and one production seatbelt (SB) were received from Tool, Inc. D1 is the same design tested in Phase 1; D4 includes a buckle-mounted switch described in more detail below.

Buckle Switch

The "Buckle Switch" prototype device (D4) includes a switch on the buckle that the user must switch from adult mode to child mode before the belt will lock once it is pulled all the way out of the retractor. In addition, the retractor goes from ALR to ELR when the buckle is released, so the belt does not need to be fed all the way back into the retractor to disengage the ALR (Figure 24).

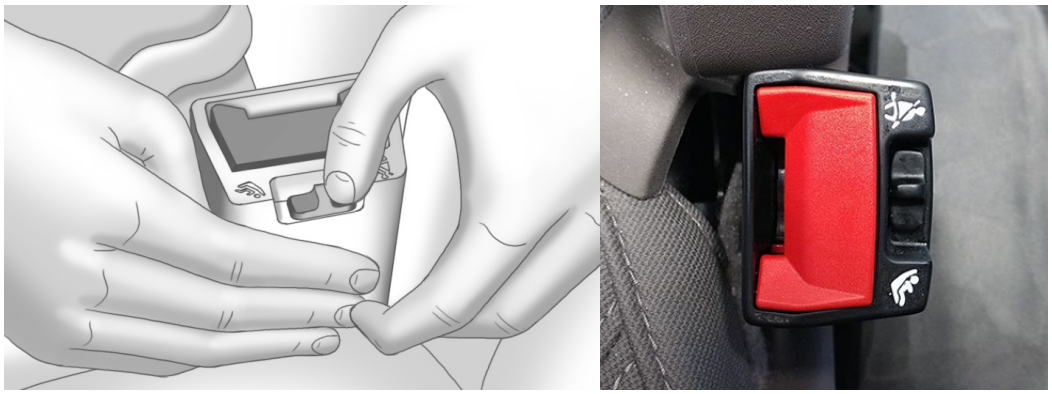


Figure 24. "Buckle Switch" must be buckled and shifted from adult mode to child mode for the belt to lock after pulling the shoulder belt all the way out of the retractor. The retractor is unlocked by releasing the buckle.

Vehicle Mockup

The vehicle mockup of Phase 1 was used again, with some minor adjustments as shown in Figure 25. Since some subjects seemed reluctant to step onto the platform to perform installations, we added carpet and a floor mat. In addition, we added a step to serve as a "running board" to facilitate stepping onto the platform.

Figure 25. Changes to the seating buck to make stepping on to the buck more intuitive include adding a longer step and carpeting and floor mats

Child Restraint Systems

For phase 2, we chose to have all subjects perform only forward-facing installations only. The Evenflo Maestro (F1) and he Baby Trend CV88a PROtect Series (F2) used in phase 1 were also used in phase 2. In addition, the Costco APT 50 convertible tested rear-facing in phase 1 was tested forward-facing in phase 2 as illustrated in Figure 26.

Figure 26. Cosco APT 50 Convertible installed forward-facing

Comfort/Nuisance Locking Trials

In addition to the assessments of child restraint installation and entanglement with the prototype systems, in phase 2 we also wanted to assess whether the participants could identify differences in the belt systems when they used them and performed a reach maneuver in the vehicle mock-up. Appendix I contains the directions and questions asked of the subject during these trials. For these trials, we instructed the subject to sit in the vehicle seat. We then directed the subject to reach for a water bottle placed on the edge of the platform as shown in Figure 27.

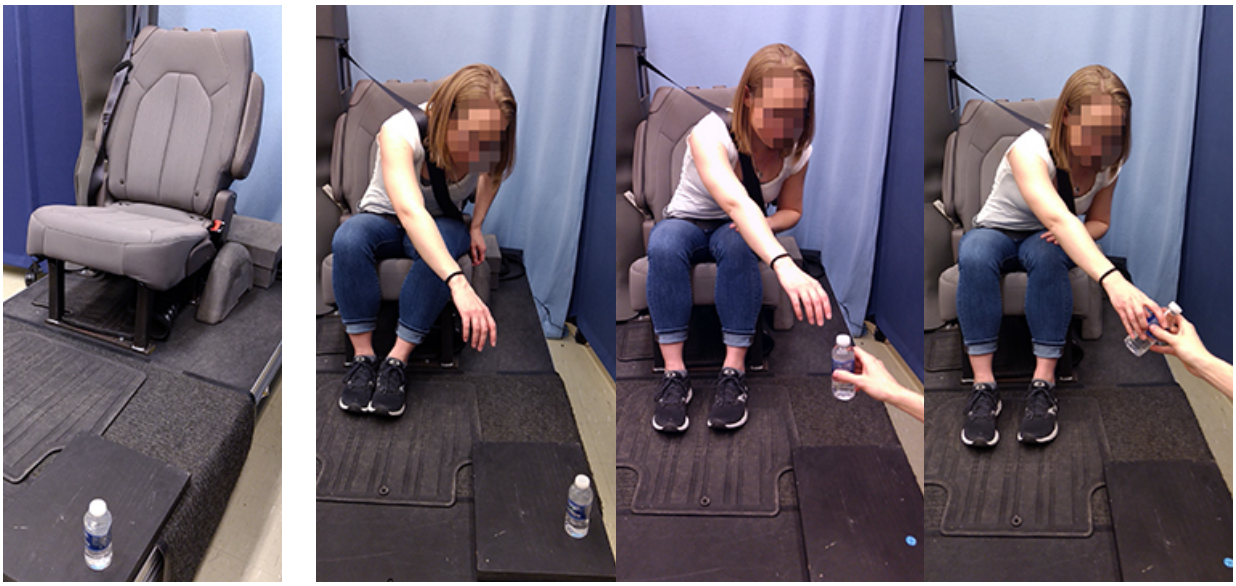


Figure 27. Illustration of reach maneuver to assess nuisance locking.

Instruction Manuals

The manuals used in phase 1 were revised so each belt condition had a "complete vehicle manual" specific for each device condition. Copies of the manuals are included in Appendix J.

Child Restraint Instruction

One of the challenges identified in phase 1 was that general low rate of good installations made it difficult to identify the differences in seatbelt devices. For this reason, we designed the test matrix in phase 2 to begin with three "naïve" installations, where each child restraint was installed with a different device. Before the second set of installations, where each subject installed each child restraint using a different device, we showed the participants an instructional video on how to test the child restraint installation to make sure it is tight, and how to use each device to lock the seatbelt. The video instructions did not include directions on how to attach the tether. Appendix J contains links to the videos.

Participants

Twenty-four people, were recruited for this research study via online advertisements and the University of Michigan Health Studies website. In addition to recruiting for CRS experience, we wanted to recruit a range of occupant sizes for assessing the comfort/nuisance locking condition. Subjects were split into four groups. Table 5 lists the characteristics of the phase 2 subjects in each group.

Table 5. Phase 2 Study Participants

	1	2	3	4
Mean age	36	39	43	37
Mean stature	1679	1690	1673	1713
Mean BMI	26	31	24	31
% male	50%	67%	17%	67%
% CRS experience	50%	33%	50%	33%

Test Matrix

The phase 2 protocol used the same procedures for assessing installation and entanglement as in phase 1. The comfort/nuisance trials were described above. For phase 2, we divided subjects into four groups. Half of them performed the comfort/nuisance trials before the installation/entanglement trials, while the other half had the installation/entanglement trials before the comfort/nuisance trials. Half of subjects in each group had the D4 switch set to adult mode for the comfort trials, while the other half had it set to child mode. All subjects completed these sets of trials, watched the video instruction, and performed three additional child restraint installations. For the second set of trials, the D4 switch was set to the same position as used in the comfort trials.

Table 3 lists the test variables and Table 4 lists the test matrix for phase 2. Order of installation systems and CRS was randomized to control for learning effects.

Table 6. Condition Variables

Code	Name	Description
F1	Forward-Facing CRS 1	Evenflo Maestro Combination CRS
F2	Forward-Facing CRS 2	Babytrend CV88a PROtect Series Convertible CRS
F3	Rear-Facing CRS 1	Cosco APT 50 Convertible CRS
SB	Standard Seatbelt	2015 Chevrolet Suburban
D1	Seatbelt Device 1	Buckle Control Prototype
D4_A	Seatbelt Device 4	Buckle Switch (set to adult mode)
D4_C	Seatbelt Device 4	Buckle Switch (set to CRS mode)

Table 7. Randomized Test Matrix

	I-1		I-2		I-3		C1	C2	C3	I-4		I-5		I-6	
1	SB	F1	D4_A	F3	D1	F2	SB	D1	D4_A	D4_A	F2	D1	F1	SB	F3
2	D1	F1	SB	F3	D4_A	F2	D1	D4_A	SB	D1	F2	D4_A	F3	SB	F1
3	D1	F2	D4_A	F1	SB	F3	D4_A	SB	D1	D4_A	F3	SB	F2	D1	F1
4	D4_A	F2	D1	F1	SB	F3	SB	D4_A	D1	SB	F2	D4_A	F1	D1	F3
5	SB	F3	D1	F1	D4_A	F2	D1	SB	D4_A	D1	F3	SB	F2	D4_A	F1
6	D4_A	F3	D1	F2	SB	F1	D4_A	D1	SB	SB	F2	D4_A	F1	D1	F3
7	D4_A	F1	D1	F3	SB	F2	D1	D4_C	SB	D1	F2	SB	F1	D4_C	F3
8	SB	F2	D1	F3	D4_A	F1	D4_C	SB	D1	D1	F2	D4_C	F3	SB	F1
9	D1	F3	D4_A	F1	SB	F2	SB	D4_C	D1	D4_C	F3	SB	F1	D1	F2
10	SB	F1	D4_A	F2	D1	F3	D1	SB	D4_C	D4_C	F1	D1	F2	SB	F3
11	D1	F2	SB	F1	D4_A	F3	D4_C	D1	SB	SB	F3	D4_C	F2	D1	F1
12	D4_A	F3	SB	F1	D1	F2	SB	D1	D4_C	SB	F2	D4_C	F3	D1	F1

	C1	C2	C3	I-1		I-2		I-3		I-4		I-5		I-6	
13	D4_A	SB	D1	D1	F1	D4_A	F2	SB	F3	D1	F3	D4_A	F1	SB	F2
14	SB	D4_A	D1	D4_A	F1	SB	F2	D1	F3	D4_A	F3	SB	F1	D1	F2
15	D1	SB	D4_A	SB	F2	D4_A	F1	D1	F3	SB	F3	D4_A	F2	D1	F1
16	D4_A	D1	SB	D4_A	F2	SB	F3	D1	F1	SB	F2	D1	F3	D4_A	F1
17	SB	D1	D4_A	SB	F3	D4_A	F1	D1	F2	D1	F3	D4_A	F2	SB	F1
18	D1	D4_A	SB	D1	F3	SB	F2	D4_A	F1	SB	F3	D4_A	F2	D1	F1
19	SB	D4_C	D1	D1	F2	SB	F3	D4_A	F1	D1	F3	SB	F2	D4_C	F1
20	D1	SB	D4_C	D4_A	F3	D1	F1	SB	F2	D4_C	F2	D1	F3	SB	F1
21	D4_C	D1	SB	SB	F1	D1	F2	D4_A	F3	SB	F3	D4_C	F2	D1	F1
22	SB	D1	D4_C	D1	F1	SB	F2	D4_A	F3	D1	F2	SB	F3	D4_C	F1
23	D1	D4_C	SB	D4_A	F2	D1	F3	SB	F1	D4_C	F3	D1	F1	SB	F2
24	D4_C	SB	D1	SB	F2	D4_A	F3	D1	F1	SB	F3	D4_C	F1	D1	F2

After all the trials were complete, the participant ranked the devices using the form in Appendix G and reported their level of experience with different CRS via the form in Appendix H.

Data Analysis

Phase 2 data analysis for installation and entanglement trials was similar to Phase 1, with the added predictors of before/after video instruction and D4 switch position. Analysis for the comfort/nuisance trials considered the size of the occupant as a predictor variable for the locking outcomes.

RESULTS: PHASE 1

Entanglement

Disentanglement Duration

One of the outcomes used to assess the ease of untangling a child from the different devices is the length of time it takes for the subjects to remove the seatbelt from the ATD. Figure 28 shows the disentanglement time by trial; Figure 29 shows the same graph with the axis adjusted to focus on the faster trials. There was a significant difference in mean time per trial, with mean values decreasing consistently from the first to the fifth trial ($p<0.0001$). Of the eight trials taking longer than 40 seconds, four were with the standard seatbelt, two were with D3 (combined), one was with D1, and one was with D2. Of the sixteen fastest trials taking less than 20 seconds, five were with D1, five were with D2, two were with D3, and four were with the standard seatbelt. Three subjects performed eleven of the fastest trials; four subjects performed the other four.

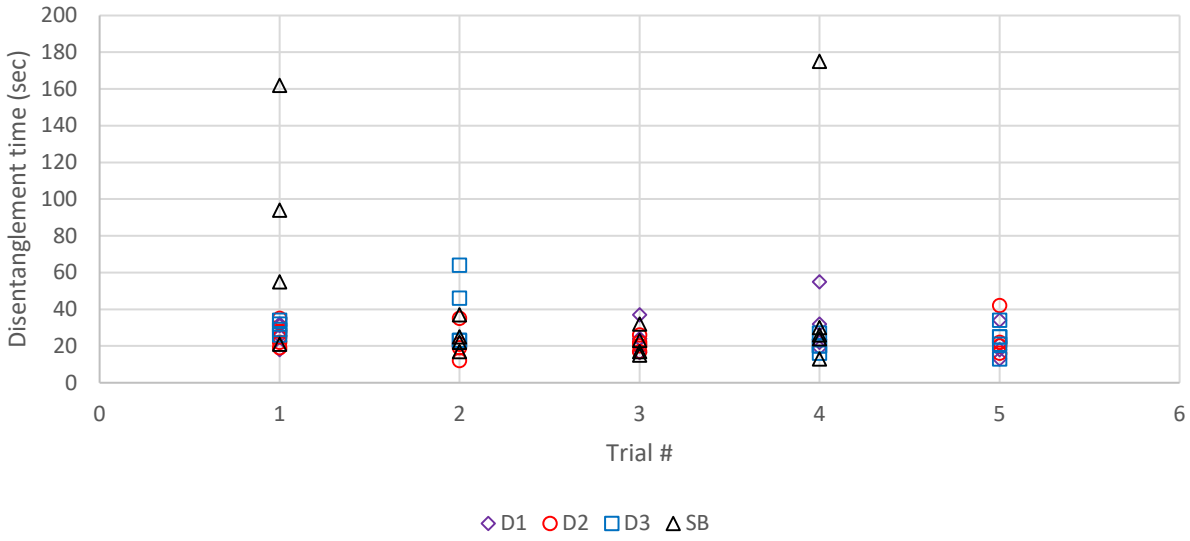


Figure 28. Disentanglement time by trial number for all trials.

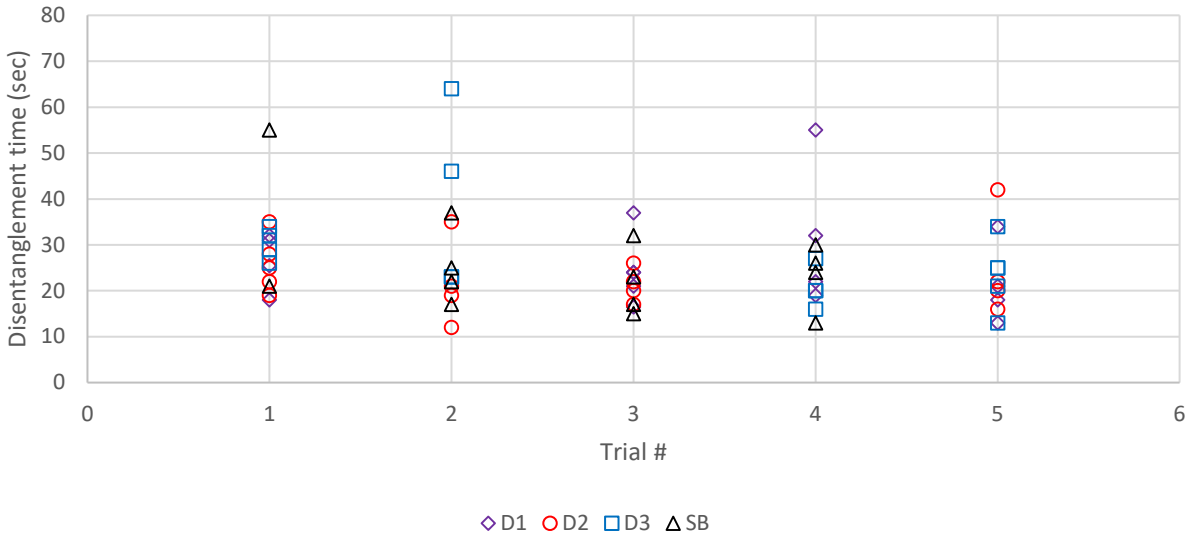


Figure 29. Disentanglement time by trial number for durations less than 80 sec.

Figure 30 shows the average disentanglement time by device; differences are marginally significant (p=.0058). On average, the standard seatbelt took almost twice as long to disentangle the ATD as the other three devices. The mean difference in time among the other three devices is not statistically significant. No subject factors had a significant effect on mean disentanglement time.

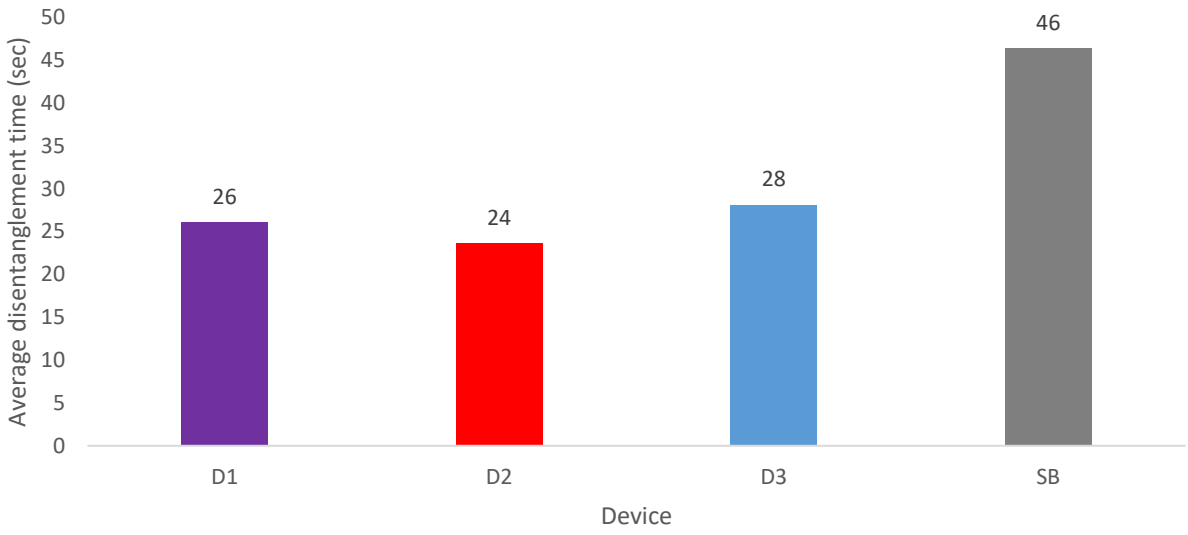


Figure 30. Mean disentanglement time by device.

Figure 31 shows the cumulative number of trials by disentanglement duration for each device. D1 and D2 had the most trials less than 20 sec and less than 40 sec; D2 had the most trials less than 30 sec.

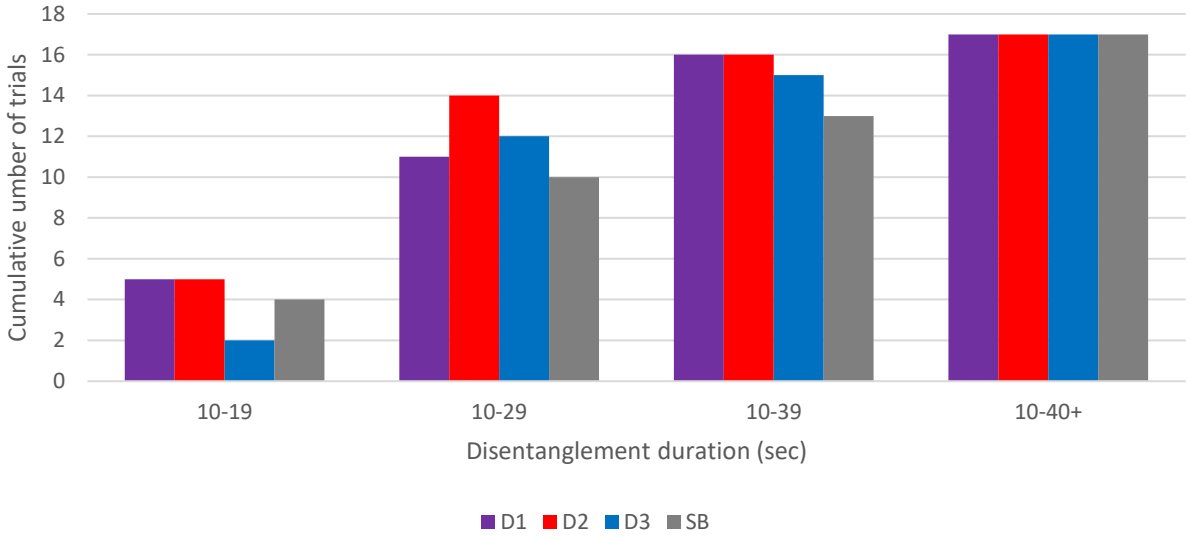


Figure 31. Cumulative number of trials by disentanglement duration.

Disentanglement process

Another factor considered in evaluating ease of disentanglement was the number of steps subjects took to release the ATD. Figure 32 shows the proportion of trials by device for the recorded number of steps. Device two had the highest proportion of 3-step trials, while the standard seatbelt had the highest proportion of trials with six or seven steps. Figure 33 shows the mean number of steps taken by subjects for each device.

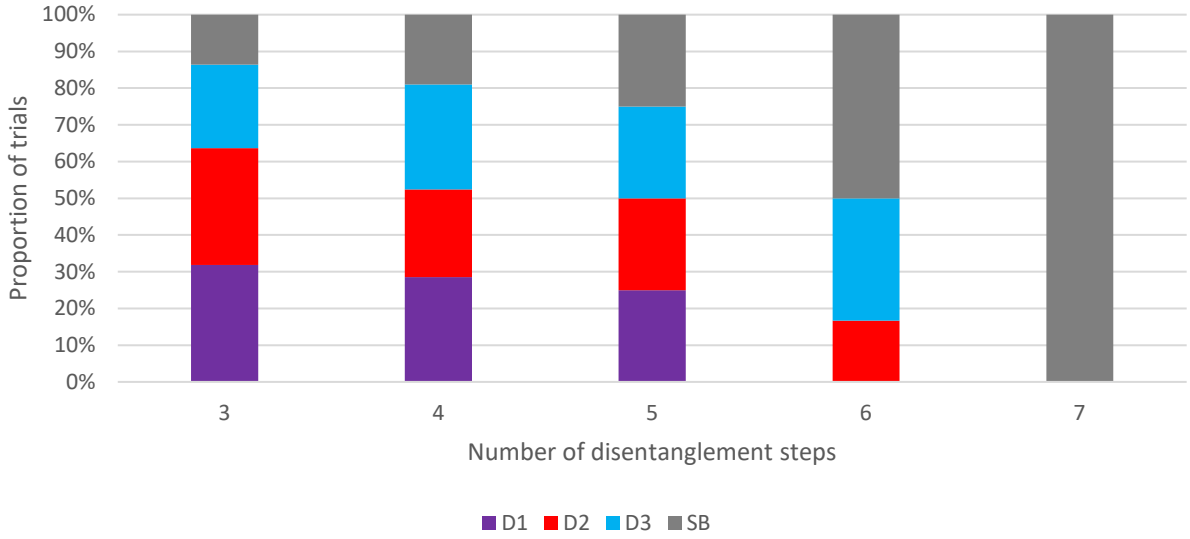


Figure 32. Distribution of trials by device and number of steps.

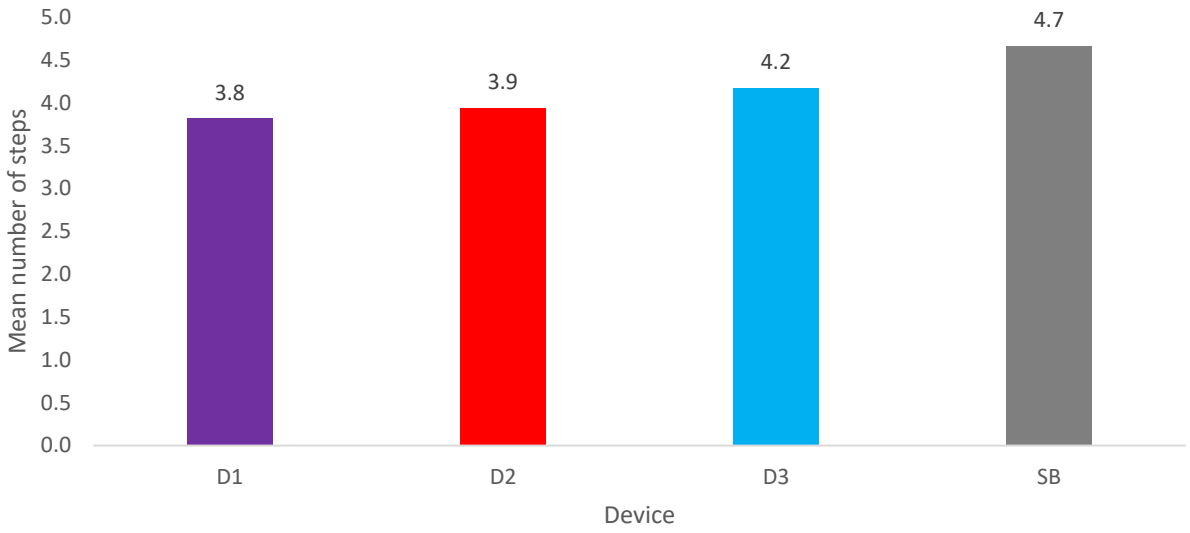


Figure 33. Mean number of steps for each device.

The following four figures show for each device the tasks performed by subjects in up to seven steps taken to disentangle the ATD. The most common sequence of steps was to unbuckle the belt, unwrap the belt, and then feed the belt into the retractor. The standard seatbelt condition had the most subjects who took more than four steps to disentangle the ATD. The same subject looked at the device labels first for D1, D2, and SB. The SB condition was the only one where any subjects looked at the manuals. No subjects interacted with the knob in trials with D2, and only two touched the button with D3.

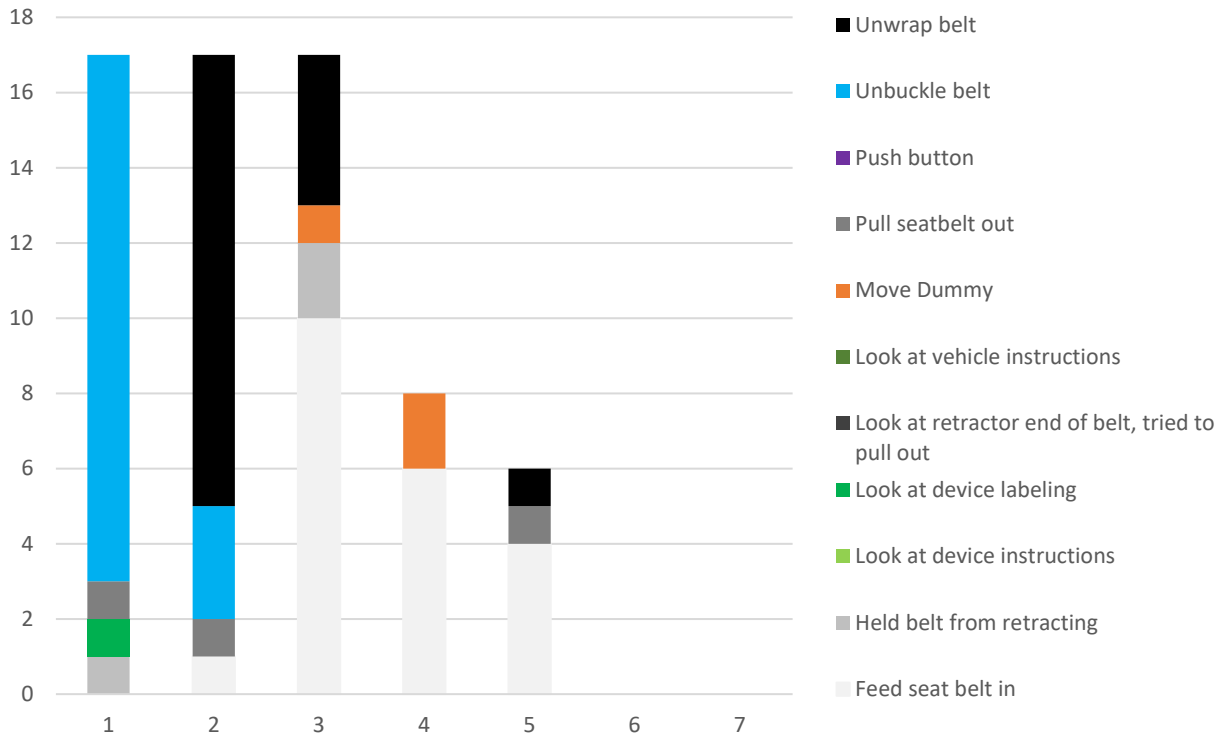


Figure 34. Actions by step for D1 disentanglements.

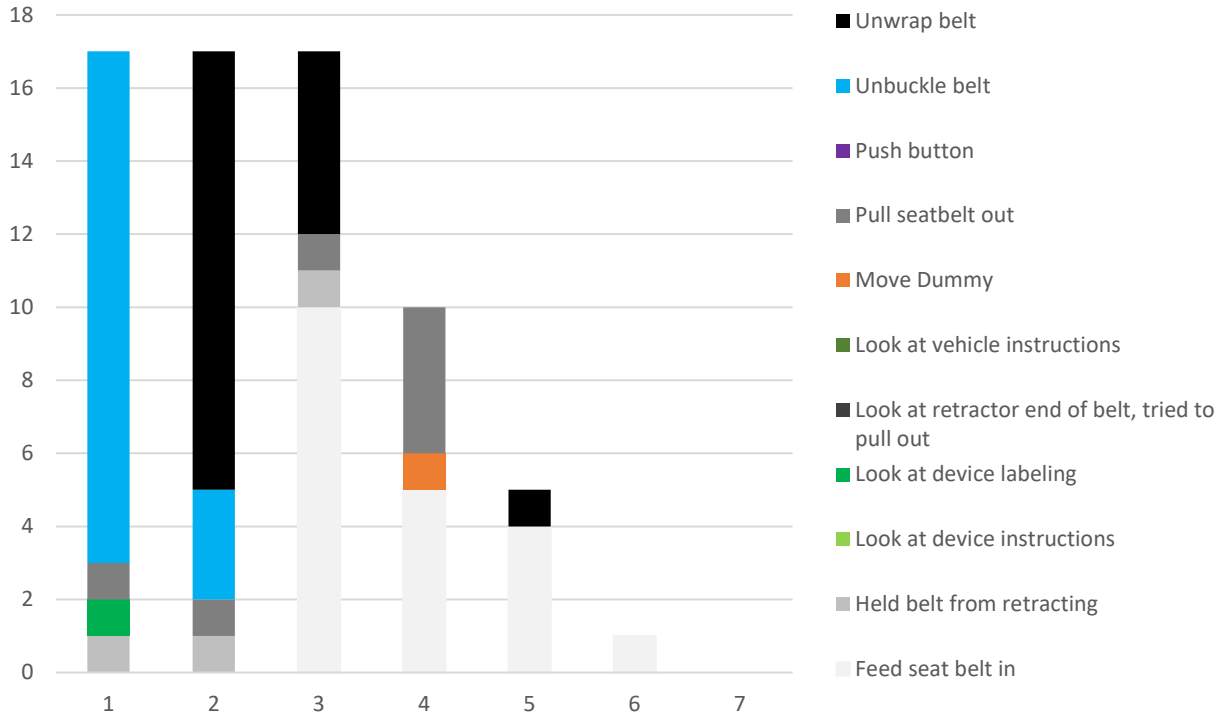


Figure 35. Actions by step for D2 disentanglements.

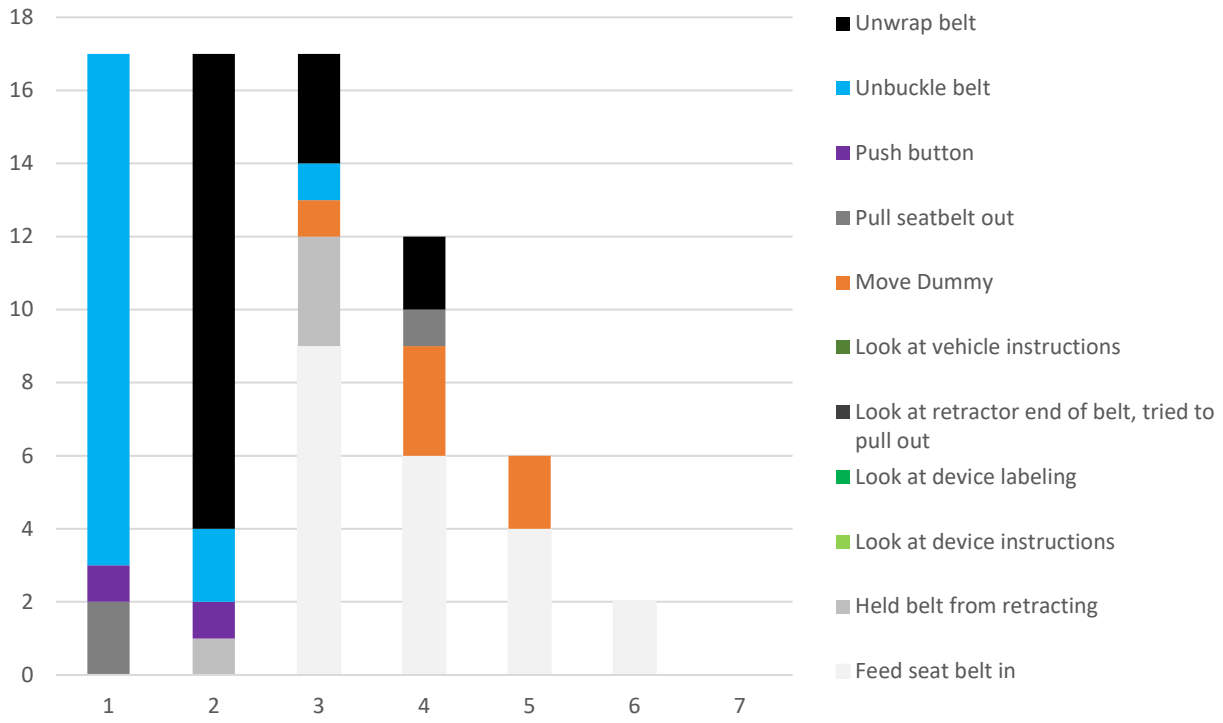


Figure 36. Actions by step for D3 disentanglements.

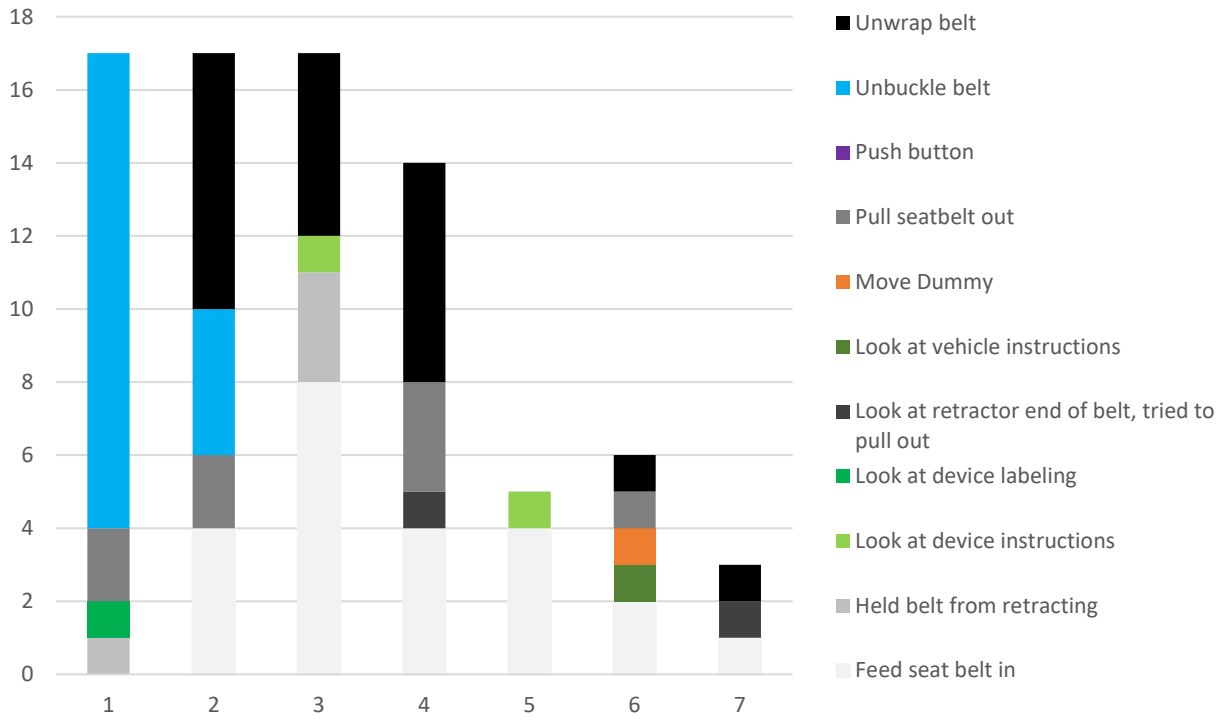


Figure 37. Actions by step for seatbelt disentanglements.

Subject Feedback

Subjects were asked five questions after each attempt to untangle the dummy from the seatbelt. None of the response distributions were statistically different among the four devices. Results for these questions are shown in Figure 38 through Figure 42.

Though not statistically different, fewer subjects said it was easier to get the belt of the dummy with the standard seatbelt compared to the prototype devices. All subjects said they were able to figure out how to release the belt. Although most subjects indicated symbols were easy to understand, only a few were actually documented as looking at the symbols during the entanglement trials, even though they may have studied them in the installation trial that preceded them. Many subjects said the manuals did not help them figure out how to disentangle the ATD; only one subject consulted the vehicle manual during an entanglement trial. Most subjects said they would take similar steps to disentangle a child in their own vehicle.

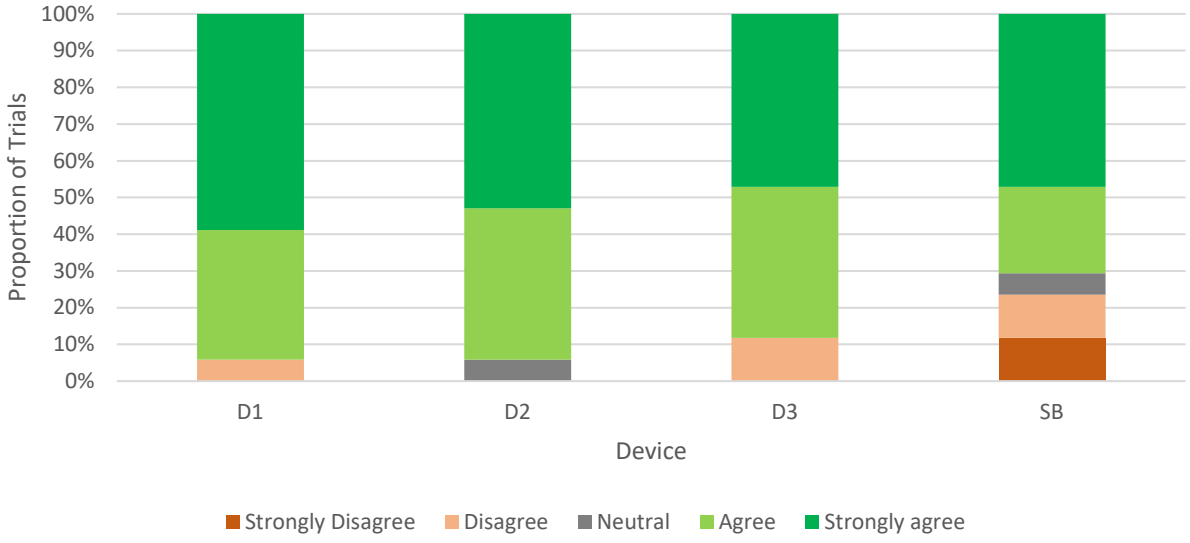


Figure 38. Subject responses to: It was easy to get the belt off the dummy.

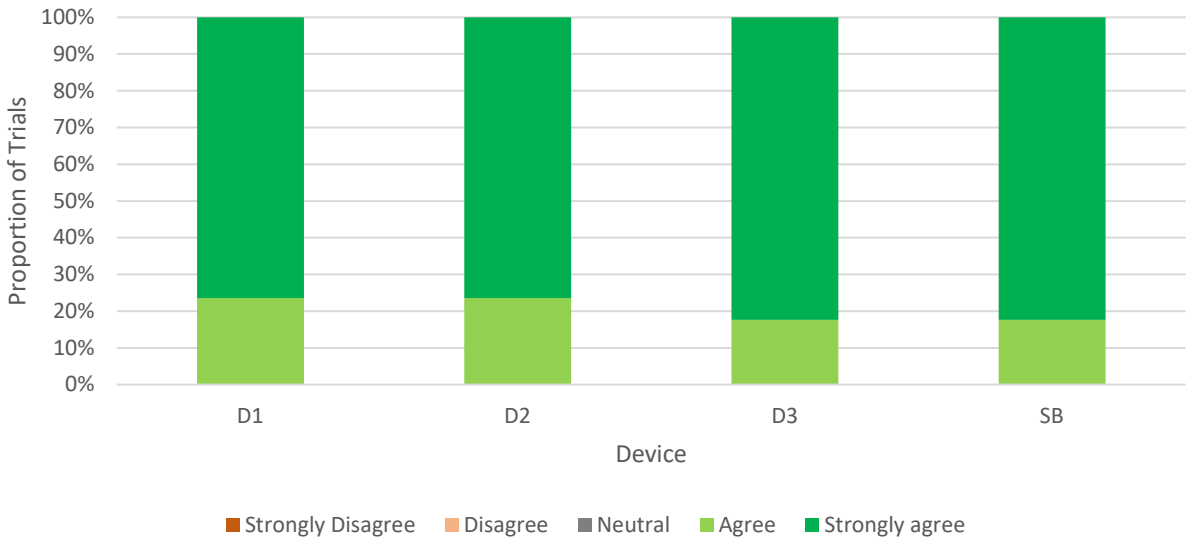


Figure 39. Subject responses to: I was able to figure out how to release the belt.

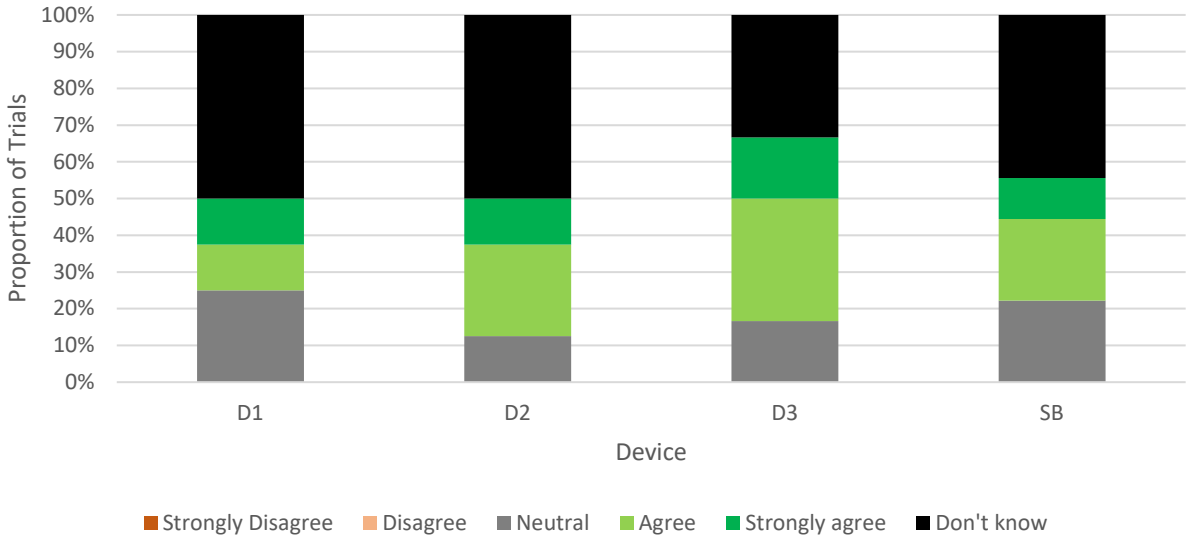


Figure 40. Subject responses to: The symbols were easy to understand.

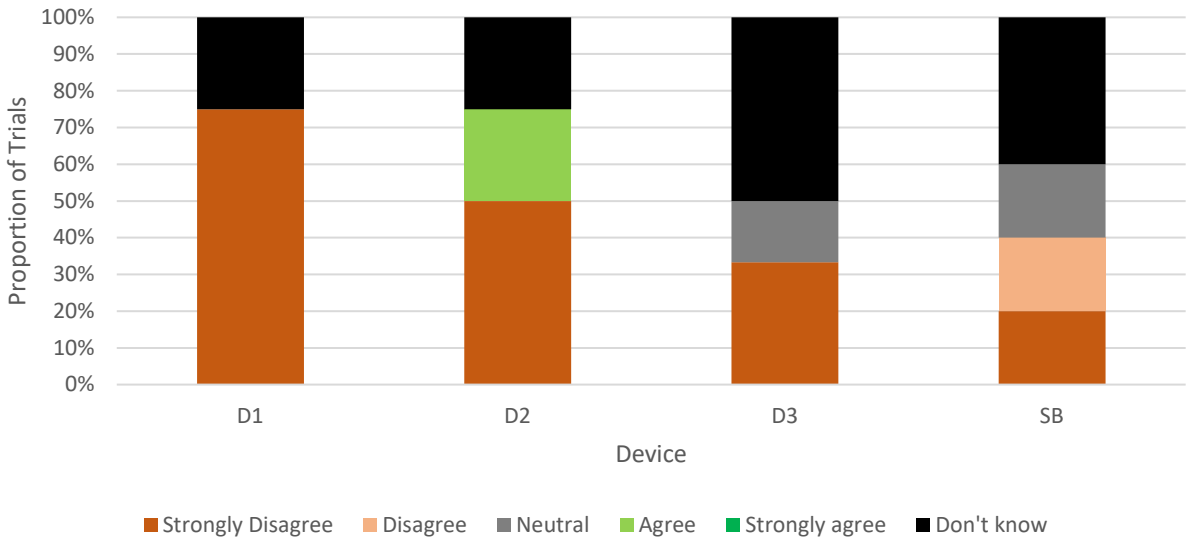


Figure 41. Subject responses to: The manual instructions helped me figure out how to get the belt off.

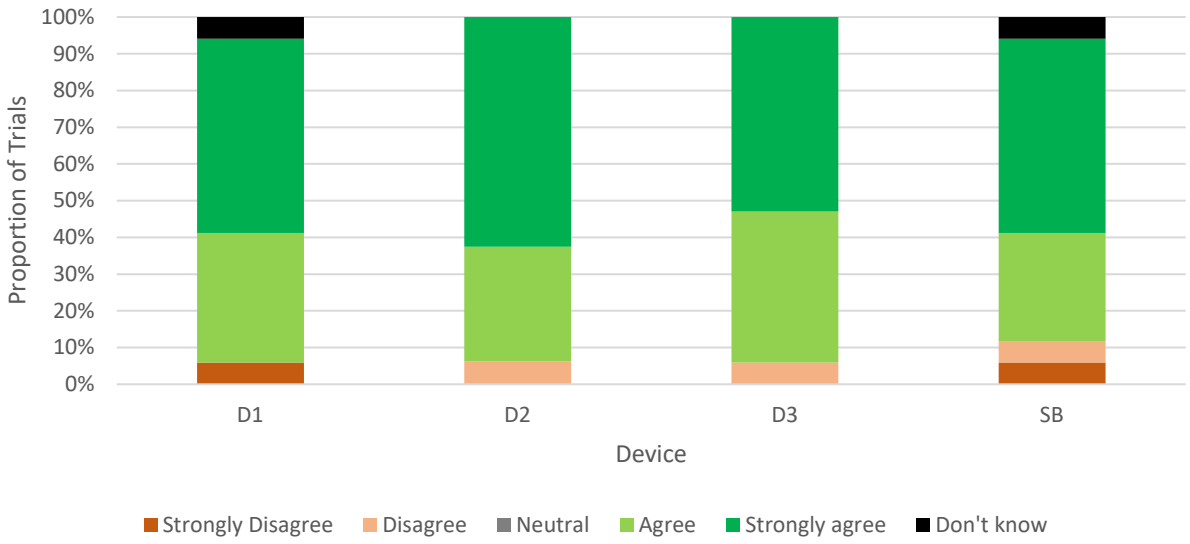


Figure 42. Subject responses to: What I did today was what I would do if this happened in my own vehicle.

Subject Comments

Most subjects did not add extra comments regarding their entanglement trials. A summary of comments by device and trial number is in Table 8.

Table 8. Summary of subject comments after entanglement trials.

Trial	Device	Comment
1	D1	I wouldn't worry about getting the SB back to its normal position. I would get it away from the child and grab child out.
3	D1	I did not use the manual or any symbols
3	D1	It took a moment to remove around the neck and arm
5	D1	This seemed the same as the last untangling exercise.
1	D2	I did not use manual instructions or symbols
1	D2	I knew how to release the SB easily. Any symbols I didn't pay attention to while trying to remove it quickly. I was a little surprised that the Sb got stuck under the arms after it was released, which in an emergency would take a moment, as it did for me to left the belt out from under the child's arm.
2	D2	I didn't have to consult the manual - lucky guess that the seatbelt lock would release when I unbuckled the belt.
3	D2	I wouldn't have put SB in stowed position
1	D3	I knew how to use the seatbelt lock release button from the previous exercise, so was able to quickly untangle the dummy. If I wasn't familiar with this feature, I may have had to look in the manual in order to figure it out.
5	D3	I did not use manual instructions or symbols
5	D3	It was easy to do but just took a moment to untangle the belt from around the neck and under arm
5	D3	This locking mechanism was the most user friendly and easiest to figure out how to unlock.
1	SB	The belt locked too soon, could not pull to release slack.
2	SB	I wouldn't worry about getting the SB back to its normal position. I would get it away from the child and grab child out.
3	SB	I was familiar with the seatbelt system, so didn't need to consult the manual or symbols.
4	SB	I did not use manual instructions or symbols
4	SB	I was able to remove the seatbelt easy but had to untangle them.
4	SB	This locking mechanism made removing the belt much more difficult than previous locking mechanisms. You were not able to release the lock when the belt was tangled and that made it difficult to remove the belt without removing the dummy

Experimenter Observations

Many subjects did not notice the difference in seatbelts. When the differences were explained at the end of testing to facilitate the subjects' filling in the questionnaires, most subjects liked the idea of alternate seatbelt unlocking methods.

Installations

Subject and Test Factors

Table 9 shows the p-values from chi-squared tests were performed for installation outcomes as a function of test and subject factors. The following sections provide plots and descriptions of how the results vary for the predictors that were significant (p<0.050).

Table 9. P-values from chi-squared tests and comparison of means.

	Tight (all)	Tether correct (FF only)	LA Correct (LA Only)	SB correct (SB only)	Install Correct (all)	Duration
Trial #	0.730	0.568	0.391	0.934	0.817	0.000
CRS	**0.004**	0.600	**0.018**	0.109	**0.000**	0.065
Gender	0.252	**0.002**	0.301	0.081	**0.045**	0.620
CRS Experience	**0.050**	0.567	0.289	0.833	0.166	0.159
AgeCat	0.570	**0.003**	0.405	**0.000**	**0.002**	0.080
EduCat	0.238	0.669	0.244	0.777	0.547	0.950

Figure 43 shows the significant difference in the percentage of trials that were tight according to CRS model. Almost no subjects achieved a tight installation with the two rear-facing CRS, and subjects had more tight installations with F1 compared to F2. Subjects with previous experience installing CRS had a rate of tight installations that was three times higher than subjects without previous experience (18% vs. 6%).

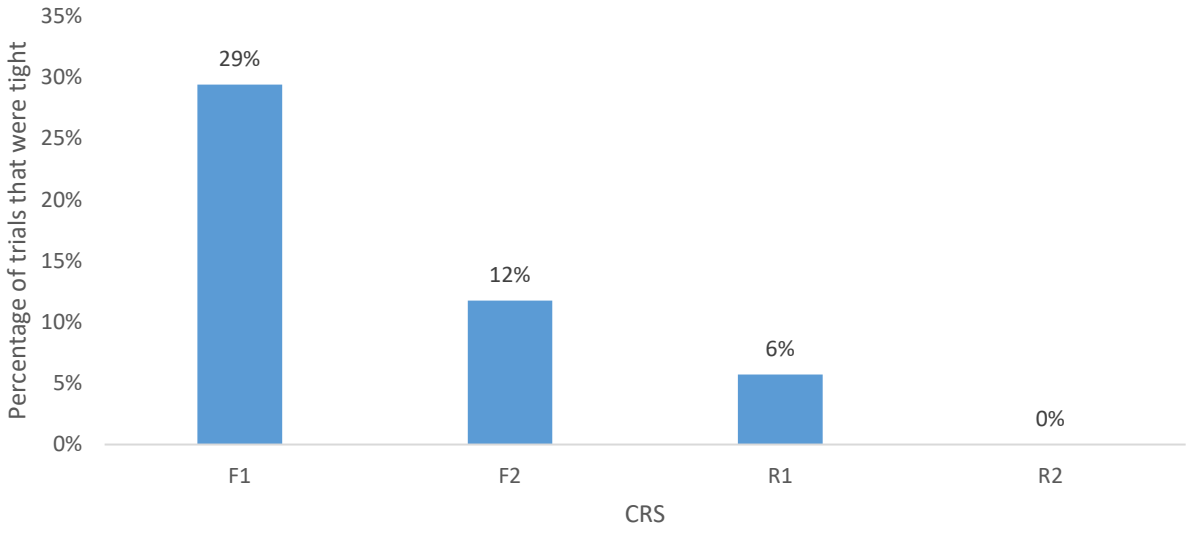


Figure 43. Percentage of trials with tight installation as a function of CRS.

When focusing analysis only on trials with the forward-facing CRS, women were more likely than men to use the tether correctly (86% vs. 50%). Subjects under age 30 had the highest rates of correct tether use at 93%; subjects aged 30-49 had a rate of 57% and those over 50 were at 44% of forward-facing trials.

For the trials where the CRS was attached using the lower anchors, F2 had a substantially lower rate of correct lower anchor use at 17% compared to 75%, 89%, and 100% for F1, R1, and R2, respectively. With F2, most of the subjects had twists in the LATCH belt.

The distribution of seatbelt errors by age group is shown in Figure 44. For trials performed by the five subjects in the 30-49YO age group, they only locked the seatbelt in 10% of trials. The rate was about 70% for the subjects under age 30 and 65% for those 50 and older.

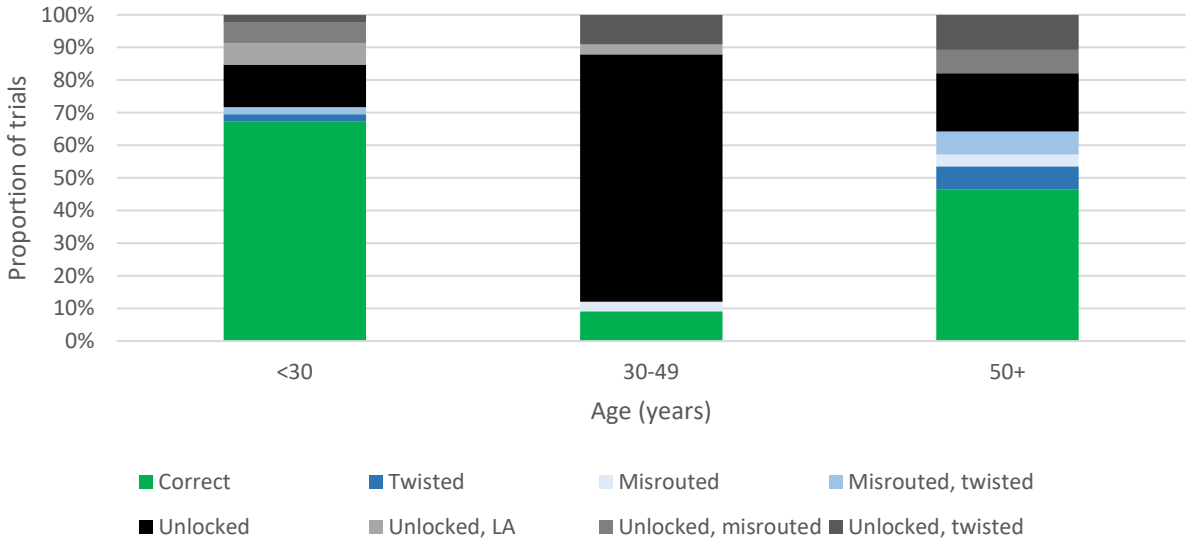


Figure 44. Distribution of trials by subject age group and installation errors.

Figure 45 shows the distribution of installations by the type of errors for each CRS. The most common error for all CRS was a loose installation. For the forward-facing CRS, looseness was the only error in about 20% of trials, while it was the only error in about half of rear-facing trials. For the other significant subject factors, men had no errors in 13% of their trials and women had no errors in 7% of theirs. Subjects in the middle age group had no errors in 7% of trials, compared to 54% in the younger age group and 39% in the older age group.

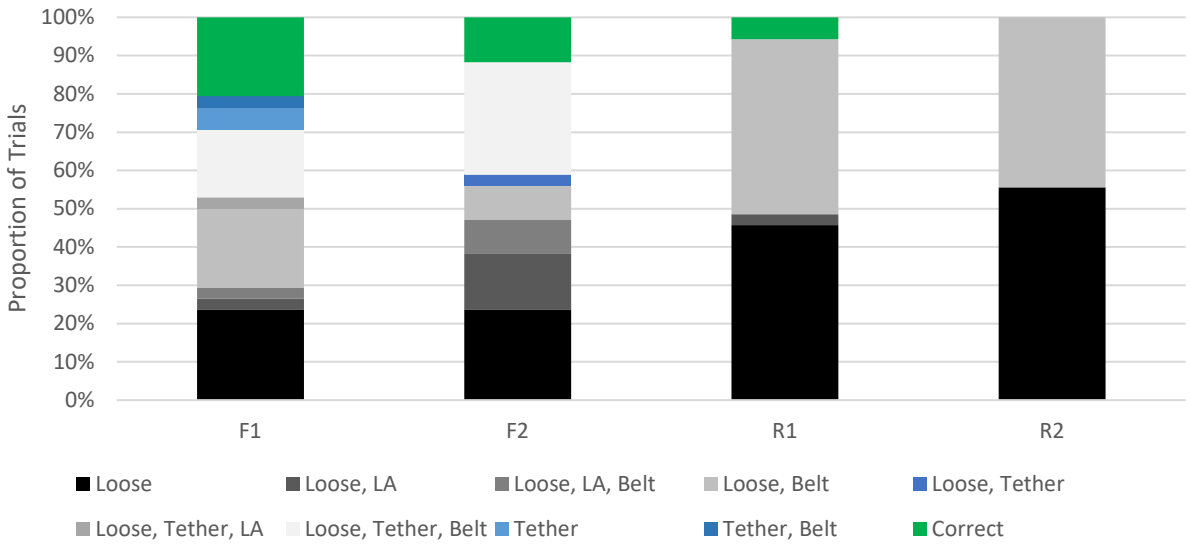


Figure 45. Distribution of trials by types of errors for each CRS.

Devices

The p-value results from chi-squared tests and comparison of means by device are shown in Table 10. The first row includes data from all the trials, while the second row excludes the trials where the subject was directed to install the CRS with the lower anchor. These values indicate a difference in correct installation rate between the lower anchor trials and the others, but there is not a significant difference in any of the outcome variables when only the seatbelt trials are analyzed.

Table 10. P-values from chi-squared tests and comparison of means.

	Tight (all)	Tether correct (FF only)	LA Correct	SB correct	Install Correct	Duration
Device (all)	0.348	0.618	**0.000**	**0.000**	**0.002**	0.657
Device (no LA)	0.392	0.858	NA	0.600	0.863	0.555

The distribution of seatbelt errors by device is shown in Figure 46. Though not statistically significant, D3 had the highest proportion of trials where the seatbelt was not locked. Figure 47 summarizes all of the installation errors for each device. Less than 10% of installations with any devices had no errors.

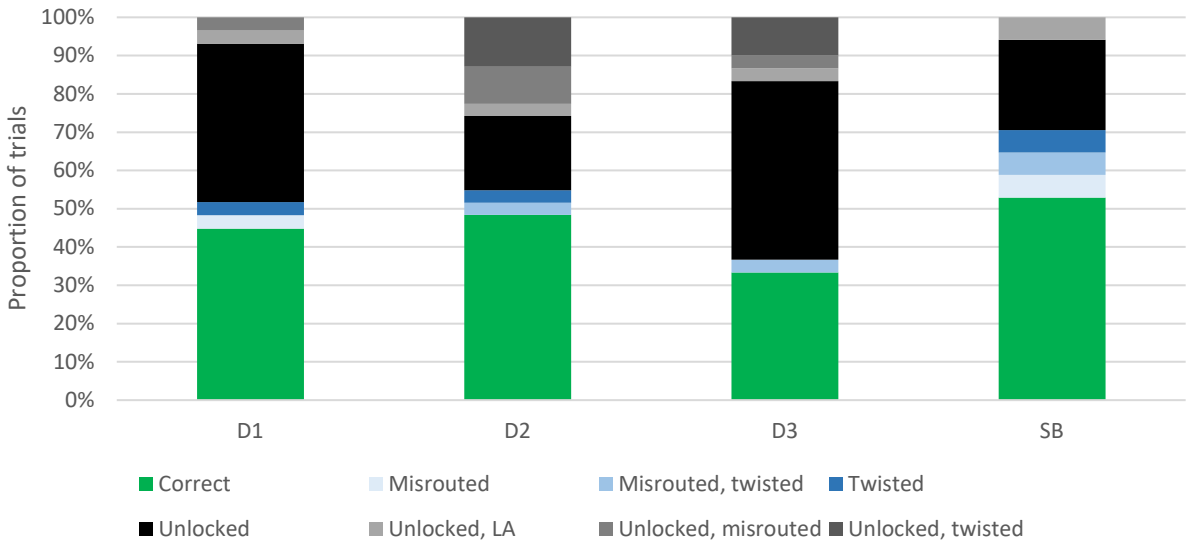


Figure 46. Seatbelt errors by device.

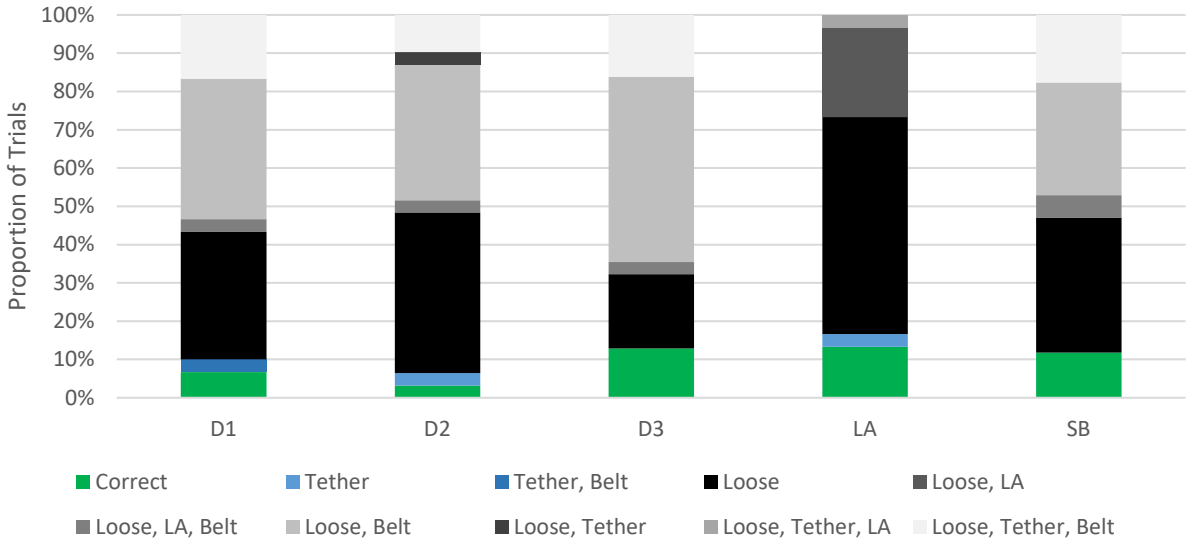


Figure 47. Installation errors by device.

The time of installation is shown by trial and device in Figure 48. The mean installation time per device is shown in Figure 49. All installations taking more than 12 minutes occurred in the first three trials. Of the four longest installation times, two were with D2 and two were with the standard seatbelt. These trials probably led to these two devices having the longest mean installation times (though results were not statistically different).

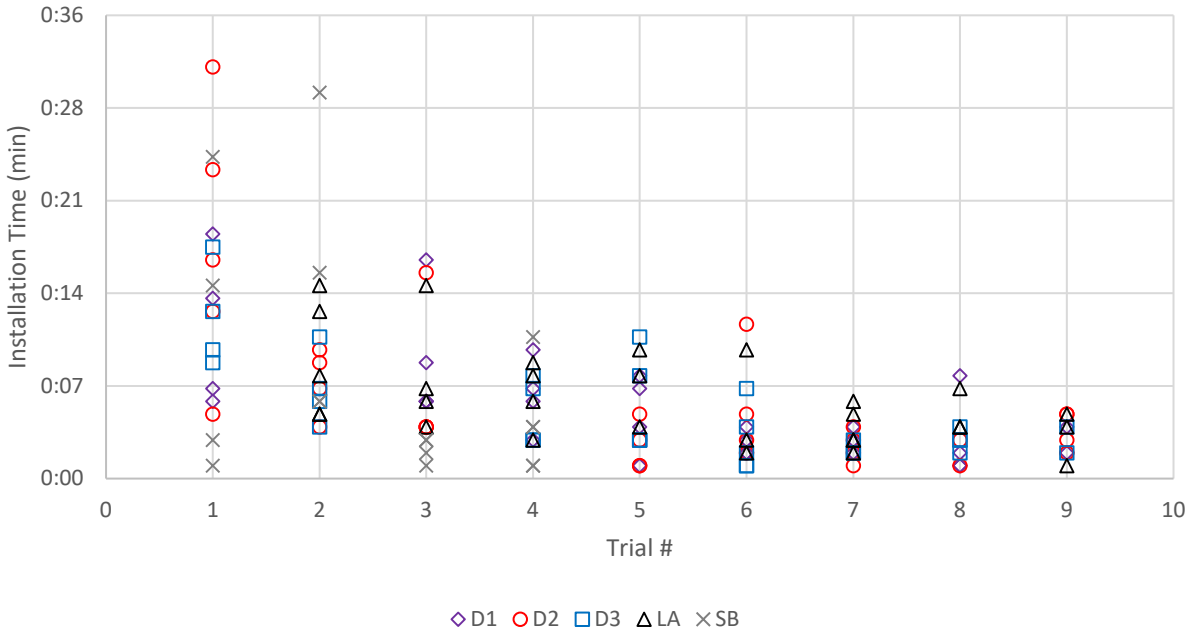


Figure 48. Installation time by trial for each device.

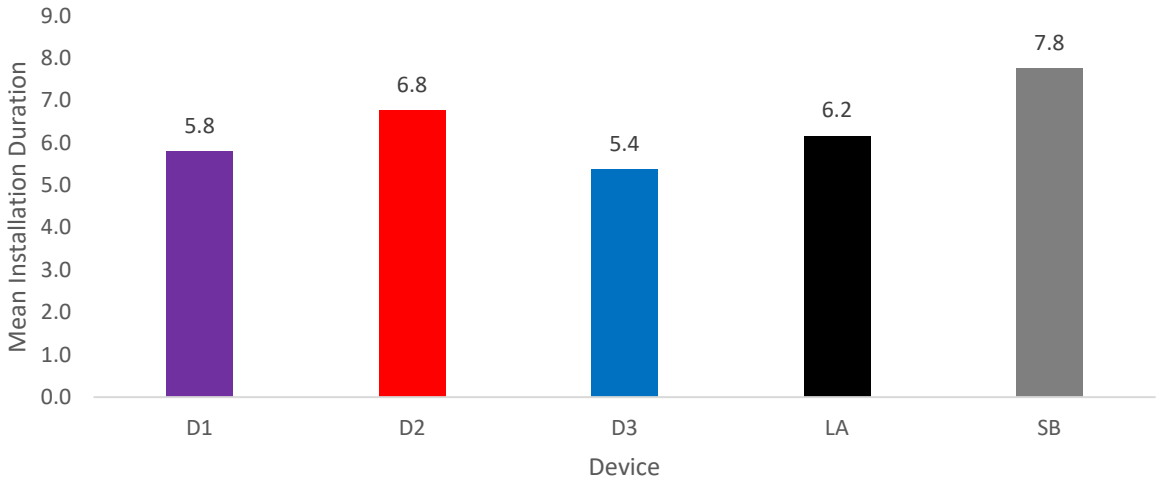


Figure 49. Mean installation time by device.

Subject Feedback

After completing all the trials, subjects rated how hard or easy each installation was. Results are shown in Figure 50 and Figure 51. The standard seatbelt system had more ratings in the harder end of the scale than the other systems, but most subjects rated the devices evenly across the scale. They were also asked to pick their favorite system for installing FF or RF CRS. LATCH was most popular, followed by standard seatbelt.

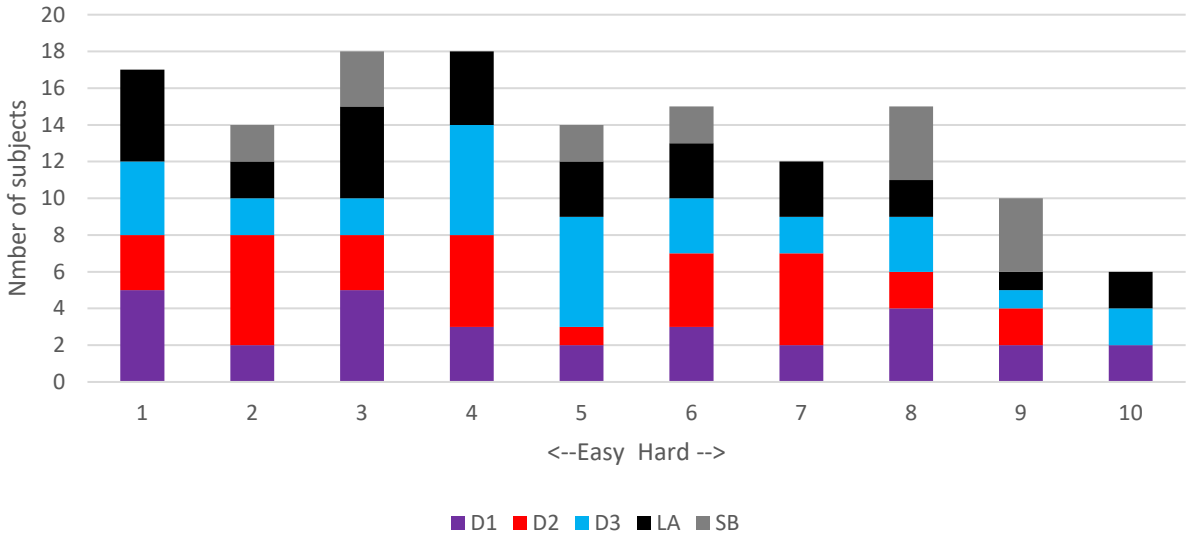


Figure 50. Difficulty ranking by device.

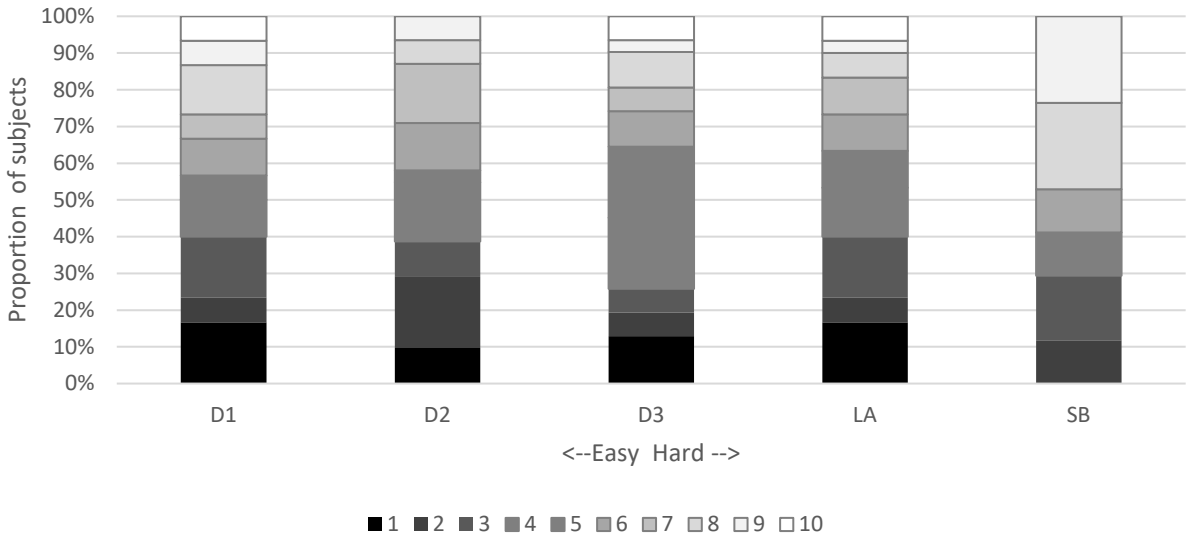


Figure 51. Distribution of difficulty rankings by device.

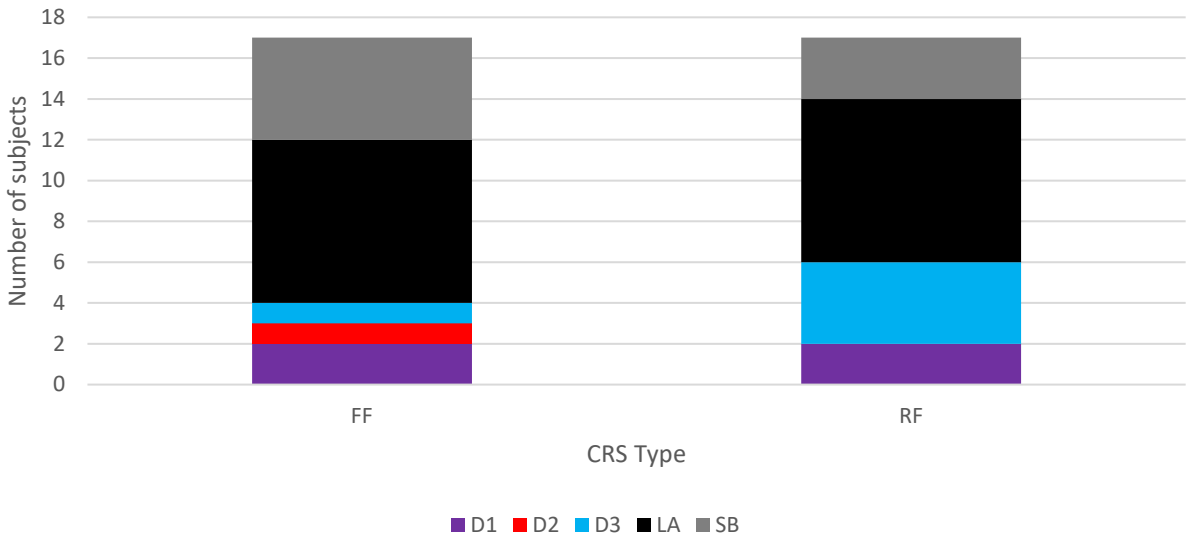


Figure 52. Subjects favorite device for installing FF and RF CRS.

Figure 53 through Figure 61 show the distribution of subject responses to their post-installation questionnaires. In general, there is limited variation in response across devices. Like we have found in most of our past studies involving volunteers installing child restraints, most subjects (70-90%) felt confident that they had installed the CRS correctly even though less than 10% had no installation errors. Confidence was higher for the three prototype devices compared to LATCH or seatbelt. As shown in Figure 54, subjects with previous CRS experience felt that the laboratory experience agreed with their personal experience in a similar pattern for each of the devices.

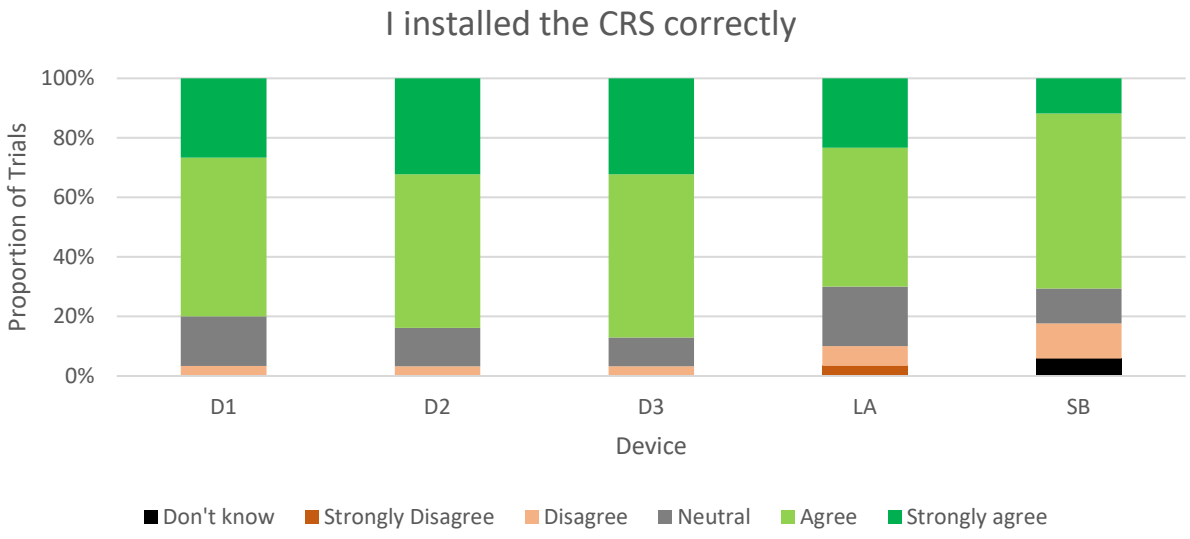


Figure 53. Distribution of subject responses to: I installed the CRS correctly.

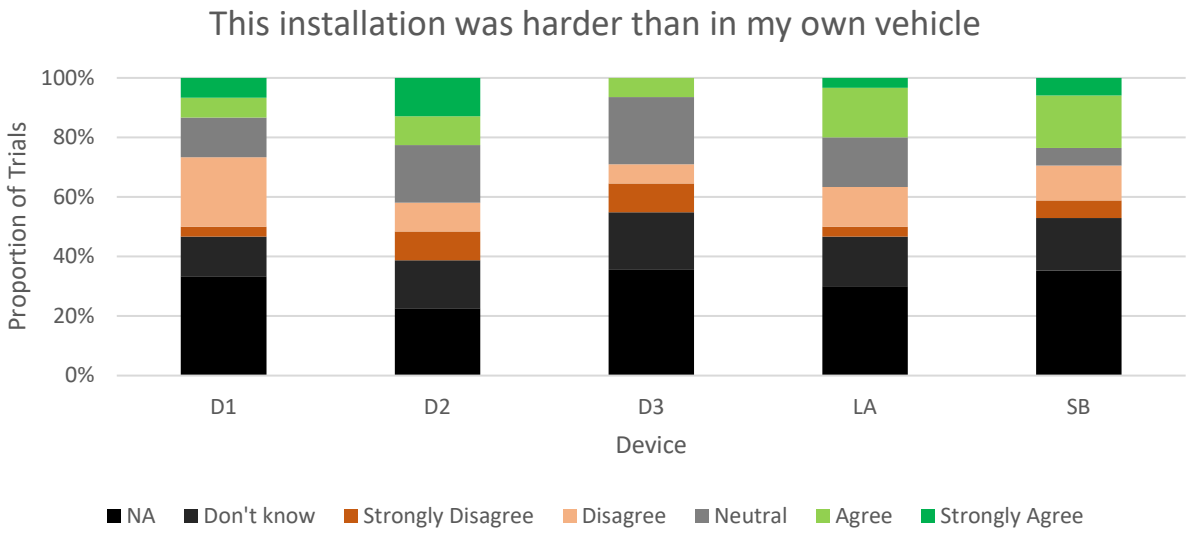


Figure 54. Distribution of subject responses to: this installation was harder than in my own vehicle.

With regard to the instruction manual, more subjects found the manuals for devices and LATCH easier to understand than for the standard seatbelt system (Figure 55). Figuring out how to lock the seatbelt (Figure 56) and route the seatbelt (Figure 57) had similar distribution of responses for each system.

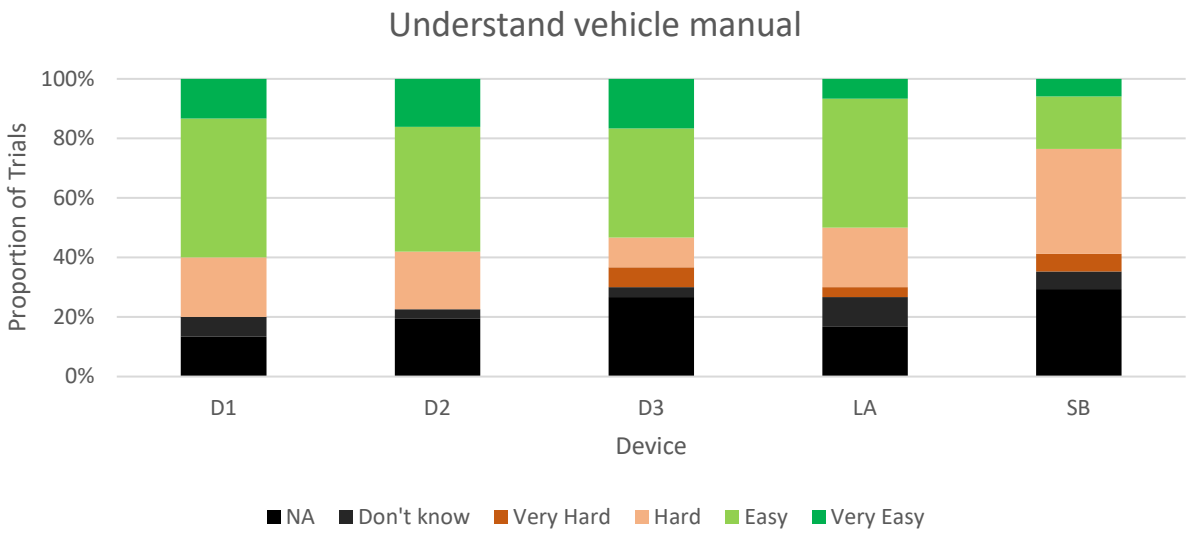


Figure 55. Distribution of subject responses to: rate how hard or easy it was to understand the vehicle manual.

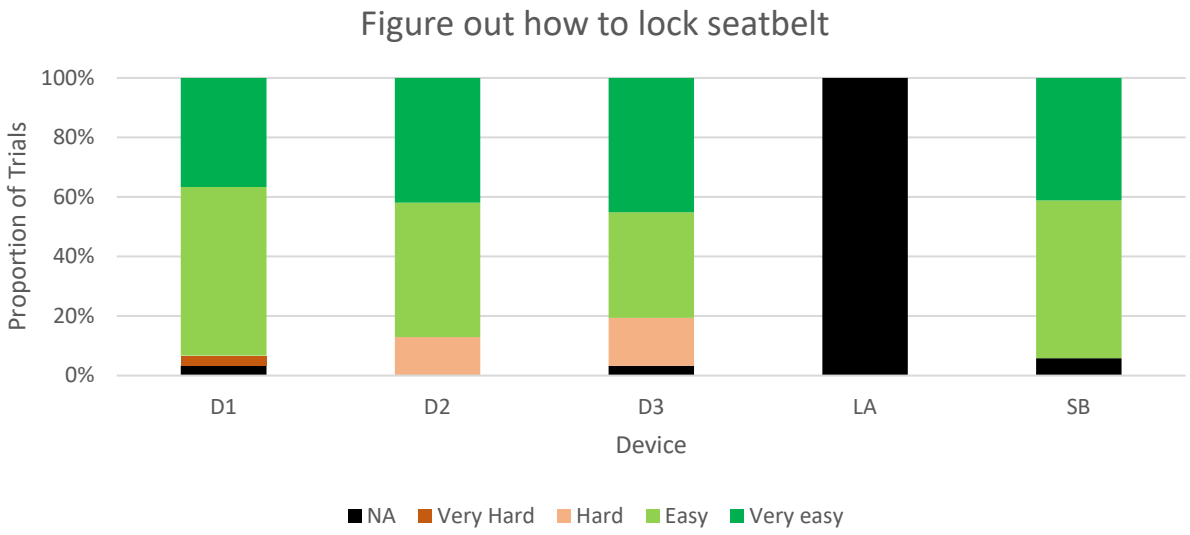


Figure 56. Subject responses to: rate how hard or easy it was to figure out how to lock the seatbelt.

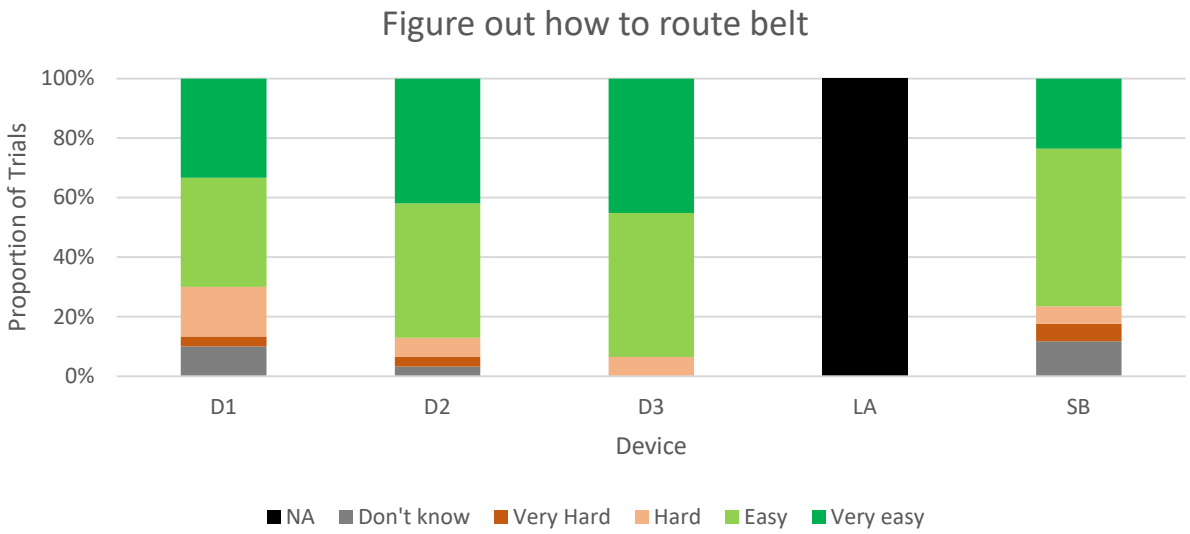


Figure 57. Subject responses to: rate how hard or easy it was to figure out how to route the belt.

As shown in Figure 58, more subjects reported difficulty in tightening the CRS installation with the LATCH belt compared to the seatbelt systems. They indicated the greatest difficulty in adjusting CRS angle in the standard seatbelt system (Figure 59). Subjects found the tether easier to find and tighten with the LATCH system compared to other systems (Figure 60 and Figure 61); we hypothesize that they looked for the tether more often when using the lower anchors and may not have realized that the tether can also be used with seatbelt installations.

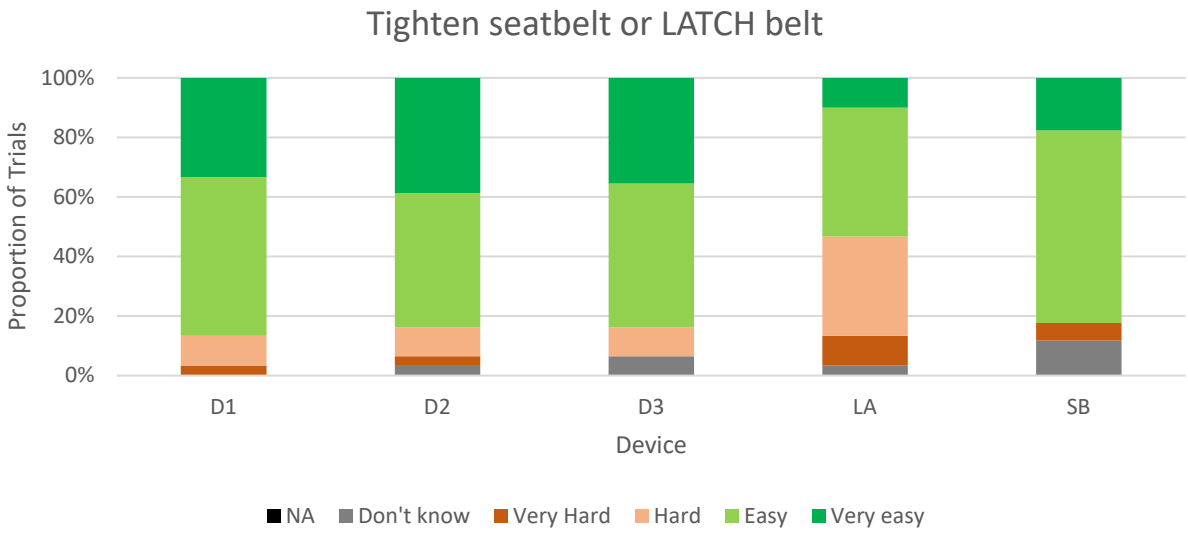


Figure 58. Subject responses to: rate how hard or easy it was to tighten seatbelt (or LATCH belt)

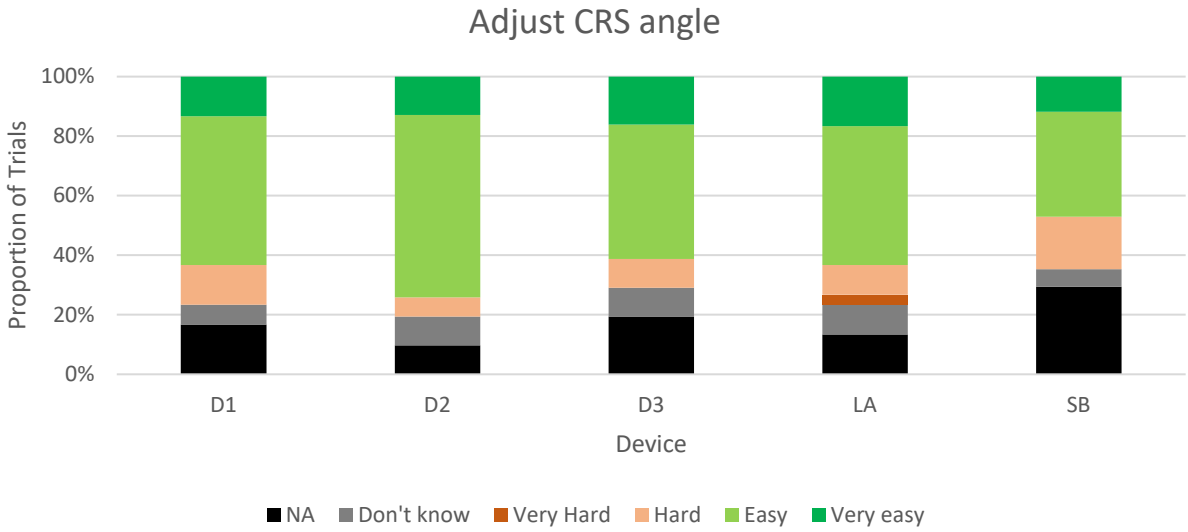


Figure 59. Subject responses to: rate how hard or easy it was to adjust CRS angle.

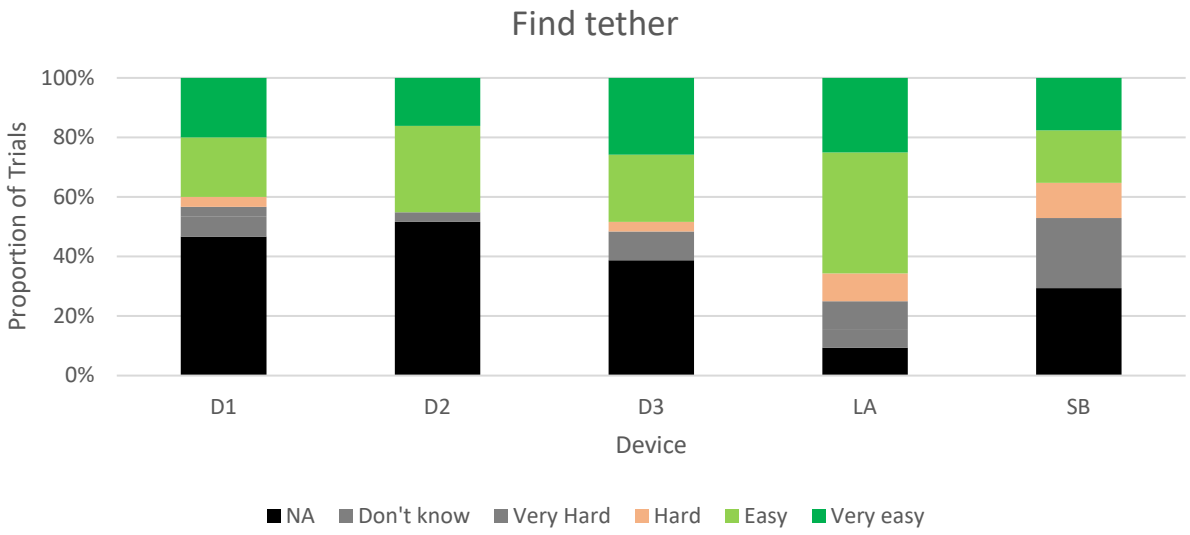


Figure 60. Subject responses to: rate how hard it was to find the tether anchor.

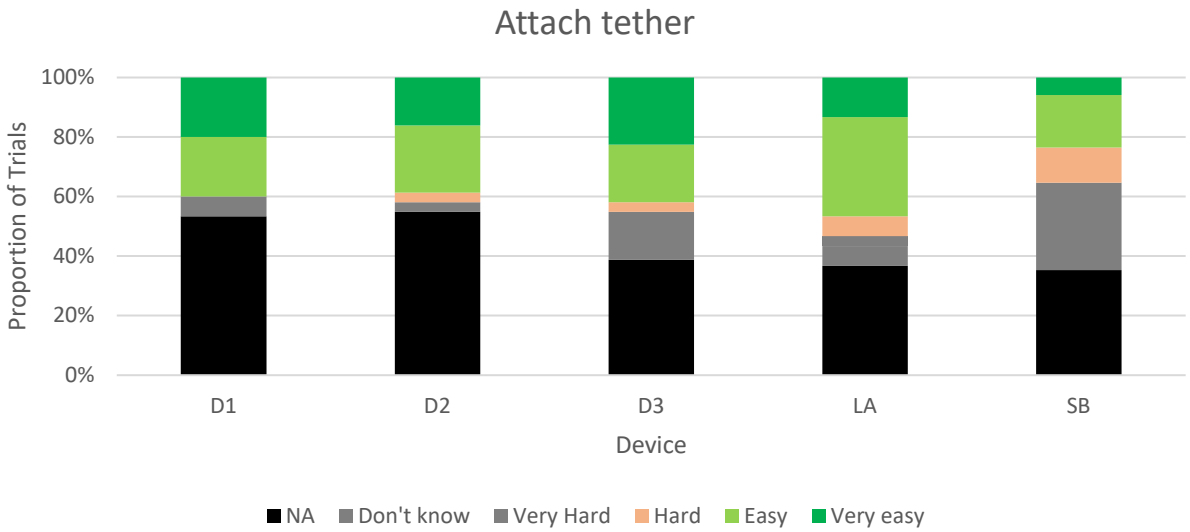


Figure 61. Subject responses to: rate how hard or easy it was to attach tether.

Experimenter Observations

Several people were confused by the instructions and needed help finding the correct section of the manual. After the first few subjects, the experimenter more explicitly pointed out each set of instructions at the start of testing.

One person believed her vehicle locked the seatbelt when the vehicle was started, taking up any slack in the belt. One person commented that he already knew how to lock a seatbelt – but the retractor wasn't locked. It may be possible that he thought locking a seatbelt meant buckling a seatbelt.

One person said the seatbelt installation was very easy once they read the instructions, and loved the seatbelt lock (D2).

In one of the trials, the subject broke the door off of the D3 system, and the button did not seem to be working. While the cause of the button not working was not determined at the time of the trial, later examination of the device found that when the button is depressed and released too quickly, the solenoid slide blocks the actuator.

In another trial, the subject was able to turn the knob of D2 into locking mode without pulling the belt out all the way to have the knob pop out.

RESULTS: PHASE 2

Entanglement

Disentanglement Duration

Figure 62 shows the disentanglement time for each trial and device. Three of the five longest trials were with the standard seatbelt system. Mean disentanglement time, shown in Figure 63, was significantly different among the three devices (p=0.037), but mean time for D1 was not significantly different from mean time for D4 (p=0.571).

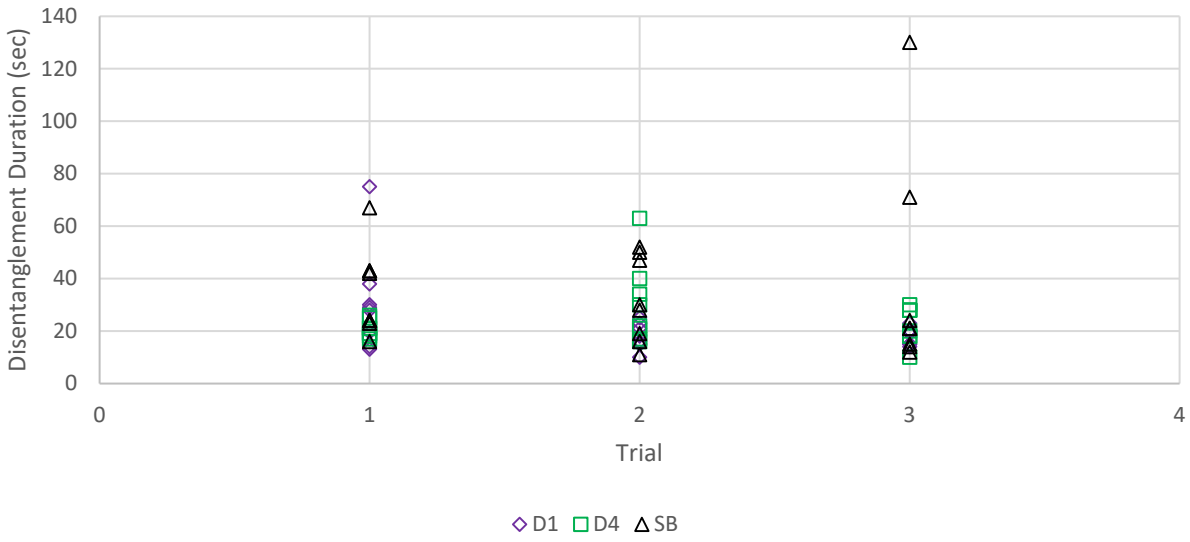


Figure 62. Disentanglement time by trial number for all trials.

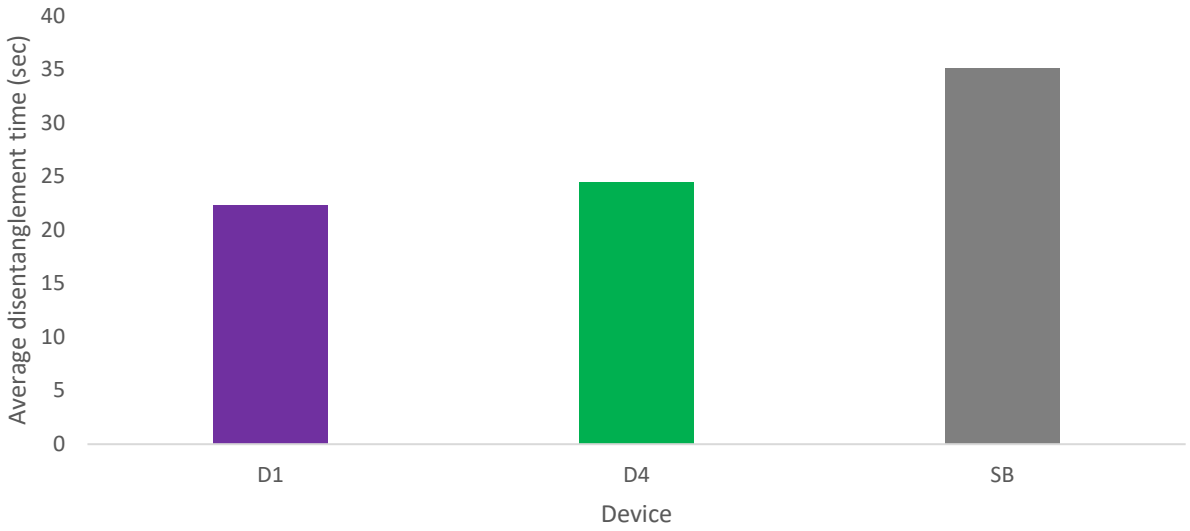


Figure 63. Mean disentanglement time by device.

The distribution of entanglement trials by device and duration is shown in Figure 64. D1 had the fewest trials lasting 30 seconds or longer. The standard seatbelt system had the most trials lasting more than 40 seconds.

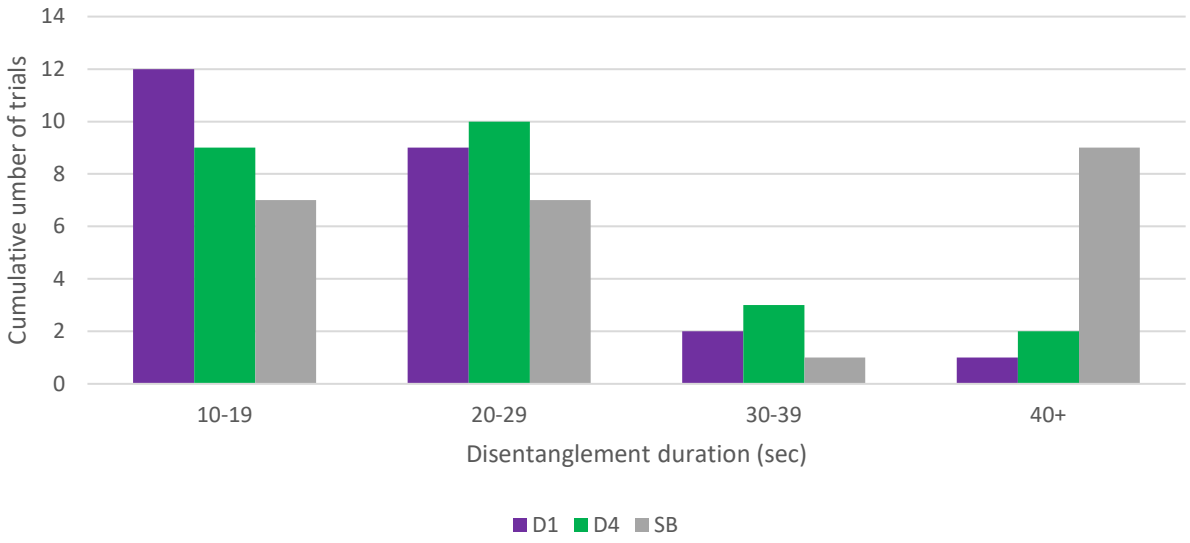


Figure 64. Cumulative number of trials by disentanglement duration.

Disentanglement process

Figure 65 shows the distribution of the number of steps taken by each subject to disentangle the ATD, while Figure 66 shows the mean number of steps. D1 had the lowest mean number of steps, and no subjects took more than 7 steps with this device.

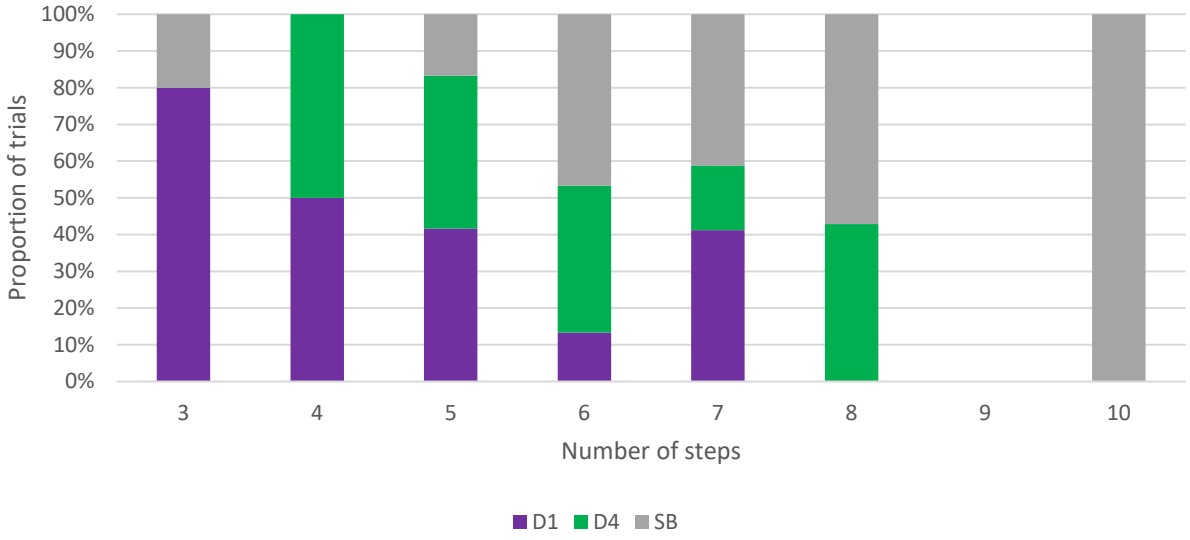


Figure 65. Number of disentanglement steps by device.

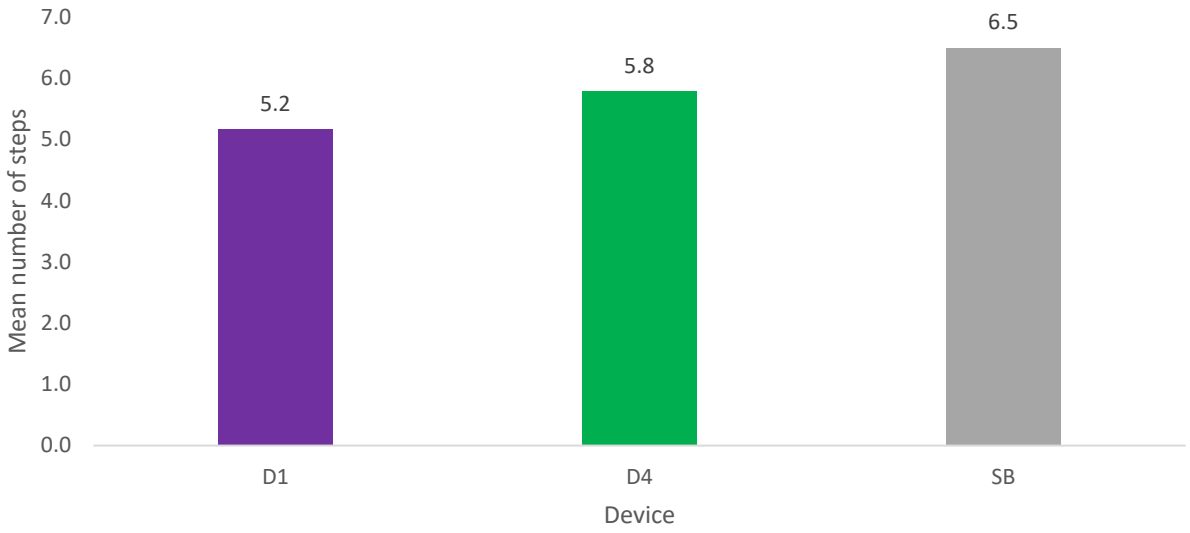


Figure 66. Mean number of disentanglement steps by device.

The following three figures show the tasks performed by subjects in up to nine steps taken to disentangle the ATD using D1, D4, and SB. In phase 2, the most common task order was unbuckle the belt, unwrap the belt, and then feed the belt into the retractor. As in phase 1, the standard seatbelt condition had the most subjects who took more than four steps to disentangle the ATD. Subjects moved the dummy as part of the process most frequently with the SB condition. With D4, five subjects switched the buckle control from child to adult mode as the first or second step, although one person switched it into child mode.

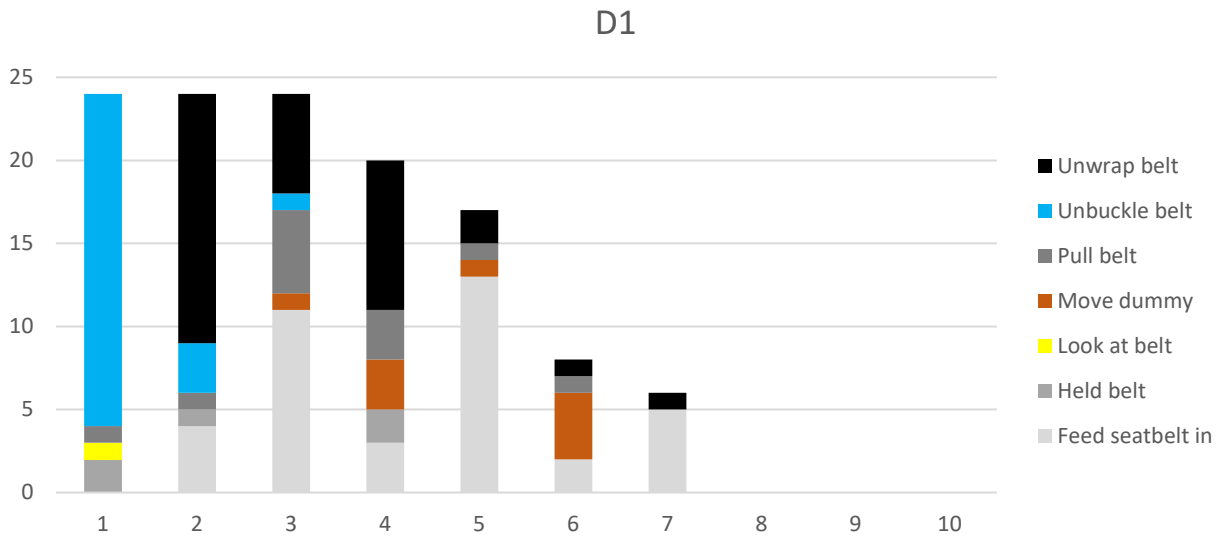


Figure 67. Disentanglement steps used with D1

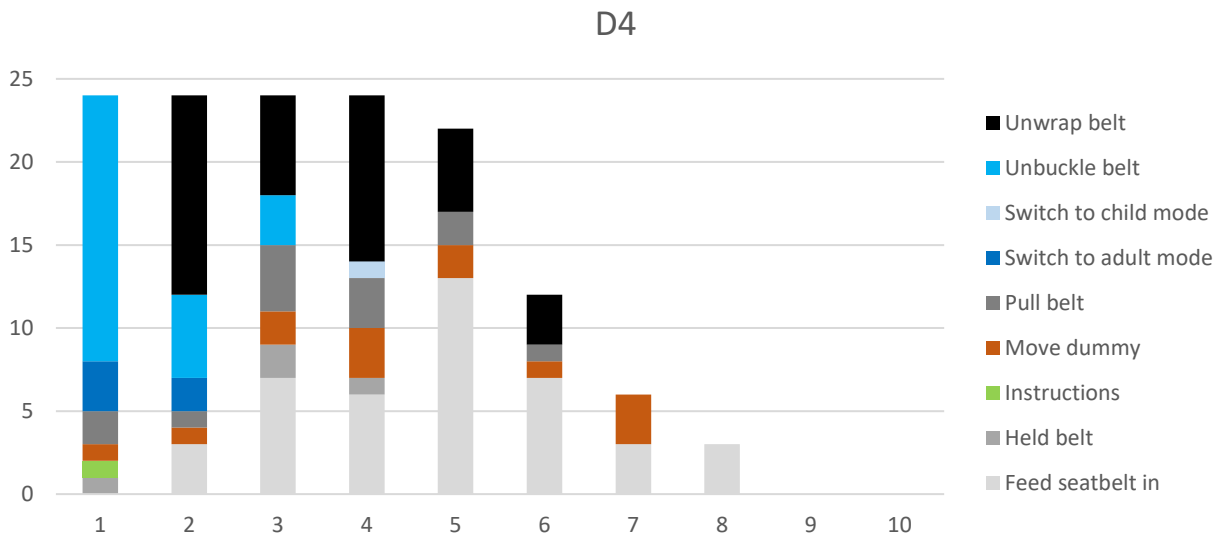


Figure 68. Disentanglement steps used with D4

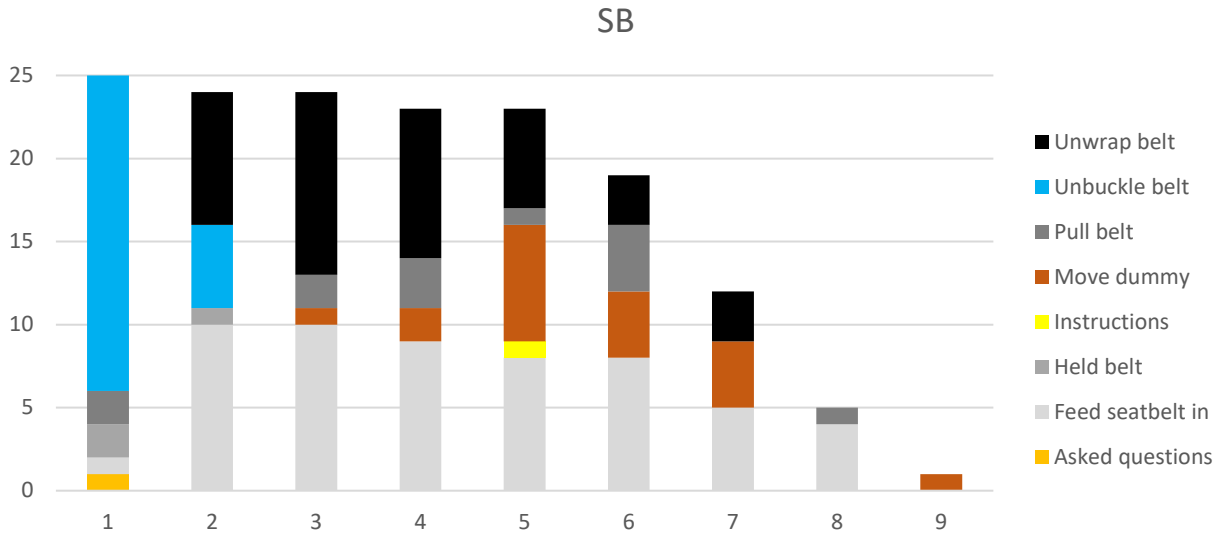


Figure 69. Disentanglement steps used with SB.

Subject Questionnaires

Subjects were asked five questions after each attempt to untangle the dummy from the seatbelt. None of the response distributions were statistically different among the three devices. Results for these questions are shown in Figure 70 through Figure 74.

Though not statistically different, fewer subjects said it was easier to get the belt of the dummy with the standard seatbelt compared to the prototype devices. All but two responses indicated that they were able to figure out how to release the belt; they were different subjects but both in the third trial. A large number of subjects did not answer the questions regarding the symbols on the belt, regardless of device, even though D4 was the only one that had symbols on the switch for during phase 2. Only two responses per device indicated that the manuals were helpful in figuring out how to disentangle the ATD; only the two "strongly agree" answers were from the same subject. Most subjects said they would take similar steps to disentangle a child in their own vehicle.

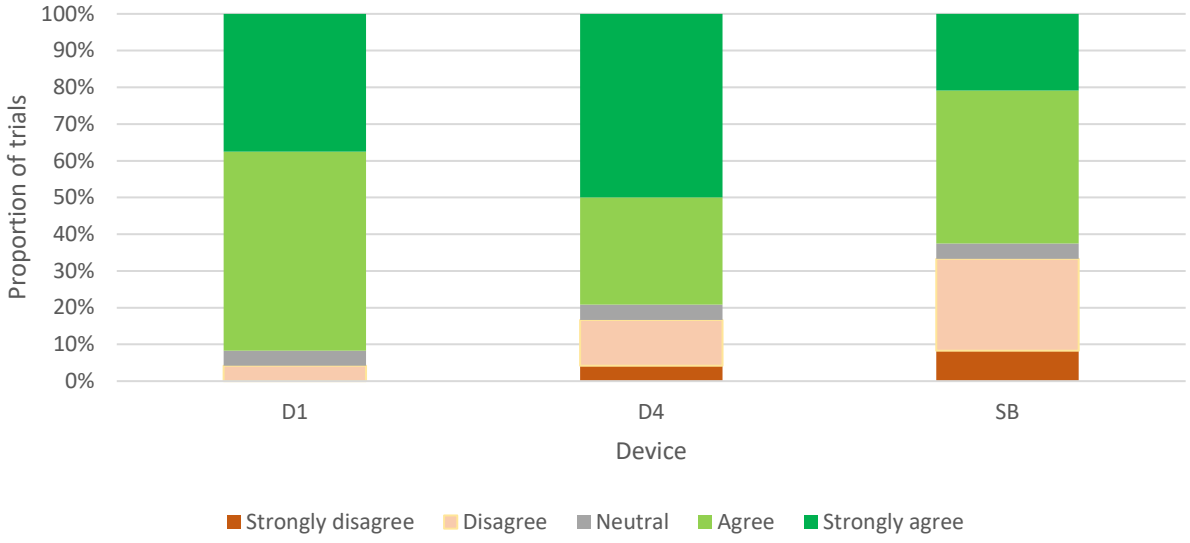


Figure 70. Subject responses to: It was easy to get the belt off the dummy.

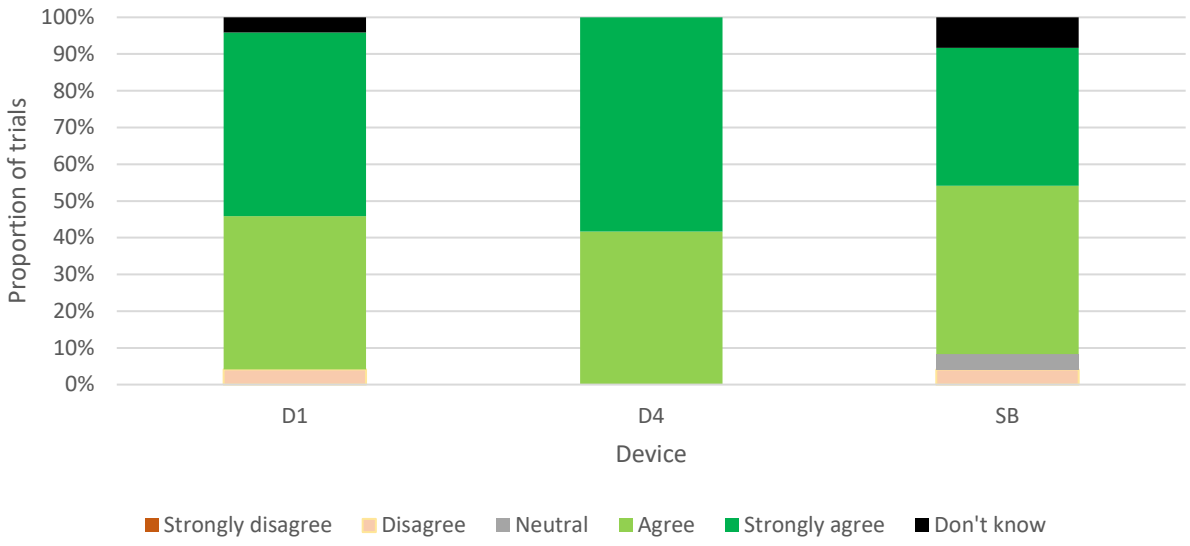


Figure 71. Subject responses to: I was able to figure out how to release the belt.

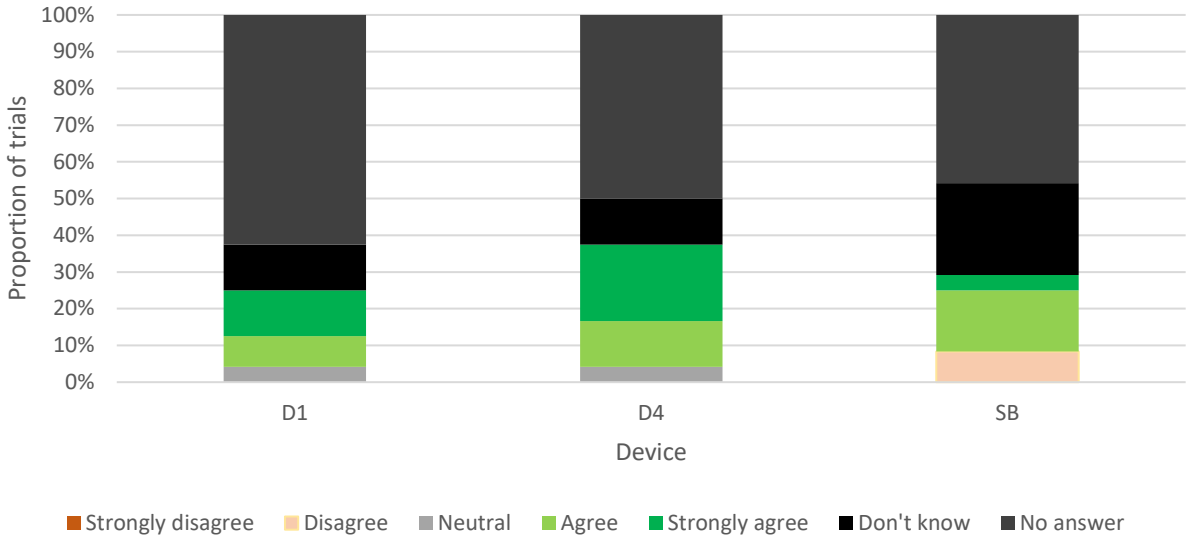


Figure 72. Subject responses to: The symbols were easy to understand.

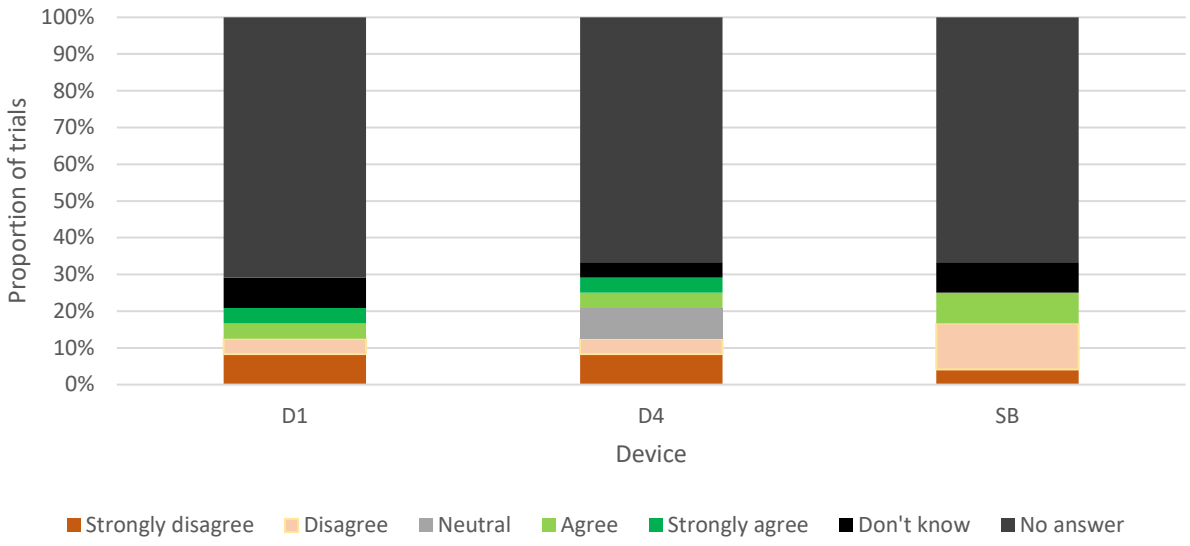


Figure 73. Subject responses to: The manual instructions helped me figure out how to get the belt off.

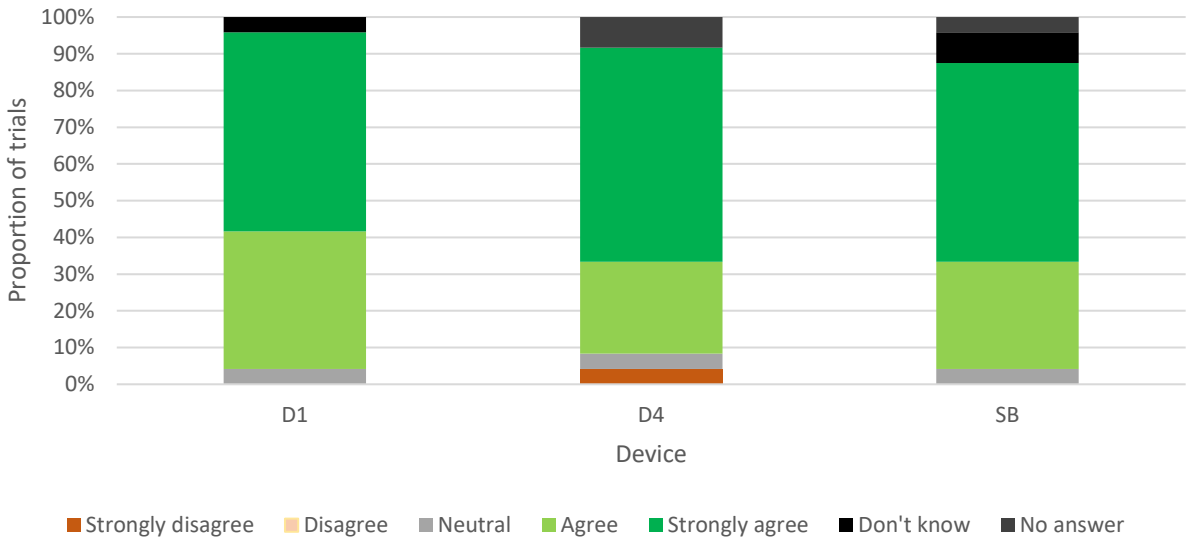


Figure 74. Subject responses to: What I did today was what I would do if this happened in my own vehicle.

Subject Comments

Table 11 lists subject comments recorded after the entanglement trials. The device code and trial number are included for each comment.

Table 11. Subject comments for phase 2 entanglement trials.

#	Device	Comments
1	D1	Did not use instruction manual
1	D1	I didn't realize the belt was around the arm of the dummy so I hesitated for a second because I thought I was done.
1	D1	Not sure I realized that is the correct way to buckle in a child. Never saw that way of buckling in a child - how does one learn that these days
2	D1	Easier to take off and release the dummy because it isn't locking so quickly
2	D1	Easier to understand it was tangled because second time and saw it was around child/dummy's neck which would have freaked me out.
2	D1	I could figure out how to unclip the seatbelt but not how to unlock/undo the locking mechanism on the seatbelt.
2	D1	This was very easy again, no issues, nothing complicated, just untwisting
3	D1	Did not use instructions
3	D1	In an emergency I would just unbuckle the seat belt to help my child.
1	D4	Belt was stuck under the dummy but overall was simple to untangle
1	D4	Did not refer to the manual instructions for this part
1	D4	The seat belts I have are not normally strapped that way don't know if that was by design or the child/adult put it on wrong.
1	D4	This was very easy and there was nothing unusual about it.
1	D4	Very easy to unhook the belt and unravel the belt from the dummy
2	D4	If there were symbols I was not aware
2	D4	That button on the seatbelt was super helpful - though I didn't know for sure if switching it back from the baby symbol would loosen the seatbelt fully, but I'm glad it did.
3	D4	Again, I know what to expect but this was easiest because the seat belt didn't lock up on me
3	D4	Looked at manual briefly but was able to release belt without instructions
3	D4	This was the easiest one because the seat belt did not retract
1	SB	Had I not checked to see if it was locked, I would not have known how to release the seat belt. Probably if it had gotten too tight/retracted I would have resorted to scissors/knife to cut seat belt loose. (Rather than thought to release the seat belt - did not know how to in this situation).
1	SB	I figure that seatbelt entanglement occurs when children are in seats alone and in a crash or if they're still riding and horse playing and get stuck.
1	SB	It felt real for a moment, if it was real life I probably would have panicked but would be able to get the seat belt off without cutting it
1	SB	Might have moved quicker
1	SB	The belt locked and I was unable to unlock it so untangling became nearly impossible.
1	SB	The seat belt was loose enough that I was able to get it off the dummy without having to use the manual. To be honest I probably wouldn't have thought to use it

#	Device	Comments
2	SB	I felt more prepared since this was the second time I had seen the dummy. The seat belt didn't seem to retract as quickly
2	SB	Manual helped figure out how to unlock the belt. Did not see any symbols.
2	SB	The seat belt got tighter and tighter - such that wrong moves were unforgiving
3	SB	Got easier probably through repetition I did have to think it through a bit more but no problems that I noticed
3	SB	I would work to untangle the passenger
3	SB	No issues, just untangled the belt
3	SB	trying to get the belt off as swiftly as possible and loosen tension on the dummy

Installations

Subject and Test Factors

Table 12 shows the p-values from chi-squared tests performed for installation outcomes as a function of test and subject factors. The following sections provide plots and descriptions of how the results vary for the predictors that were significant ($p<0.05$).

Table 12. P-values from chi-squared tests and comparison of means.

	Tight	Tether correct	SB correct	Install Correct	Duration
Trial #	<0.**001**	0.214	**0.004**	**0.007**	**<0.001**
CRS	0.075	0.646	0.656	0.522	**<0.001**
Gender	0.067	**0.042**	0.600	**0.028**	0.083
CRS Experience	0.205	0.066	0.328	0.736	0.851
AgeCat	**0.031**	**0.007**	**<0.001**	**<0.001**	0.539
EduCat	0.089	**0.013**	0.478	0.078	0.438
Group	0.404	0.081	0.508	0.072	0.688
Post Instruction	**<0.001**	0.715	**<0.001**	**<0.001**	**<0.001**

Results by CRS model were similar, except subjects had a harder time getting F2 tight; the mean installation duration of F2 at 6.6 minutes was about double the mean installation time of F1 and F3, which were both 3.4 minutes. Across all outcomes, subjects in the oldest age groups had lower rates of correct installation outcomes than the other two age categories; men had higher rates of correct installation than women. Although we noted it, education was not a selection criteria for phase 2, and only three subjects were in the lower education category. The absence of significance for group indicated that there was no difference in installation performance if the subjects experienced the comfort trials before or after the installation trials.

The most significant subject or test factor was trial number and post instruction. As shown in Figure 75, correct rates generally increase over the first three trials, except for tether use. Subject viewed videos on correct installation before the last three trials, which did not include demonstration of tether use.

Rates of tether use were the same (or went down), while the rates of tightness, correct seatbelt use, and overall correct installation increased by a factor of 1.6 to 2.6. The mean duration by trial number is shown in Figure 76. The mean value for the last three trials of 2 minutes is substantially lower than the mean value of the first three trials at 6.8 minutes.

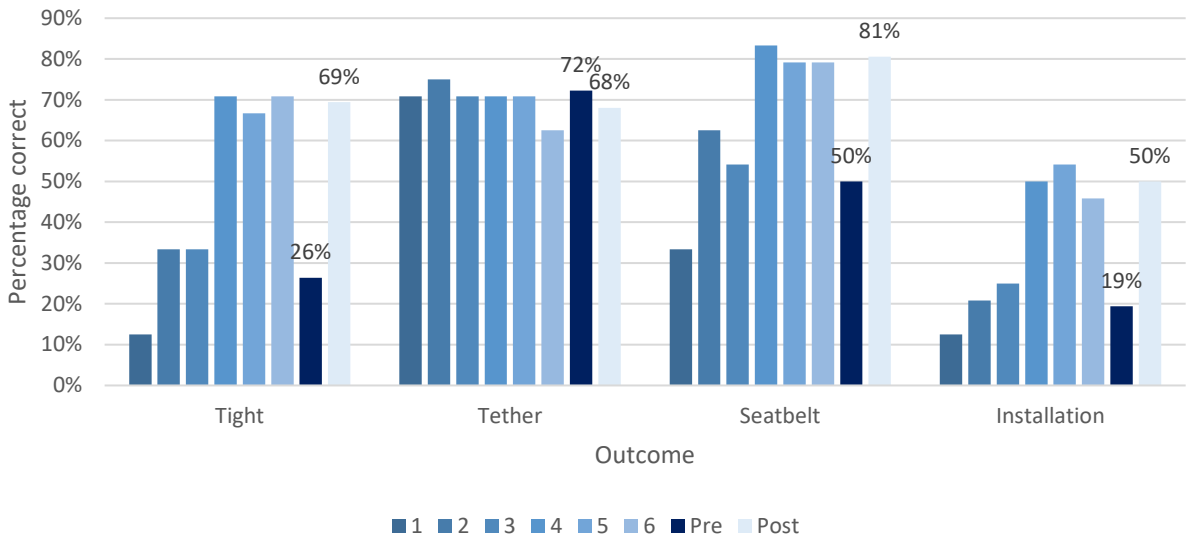


Figure 75. Correct installation outcomes by trial and pre and post instruction.

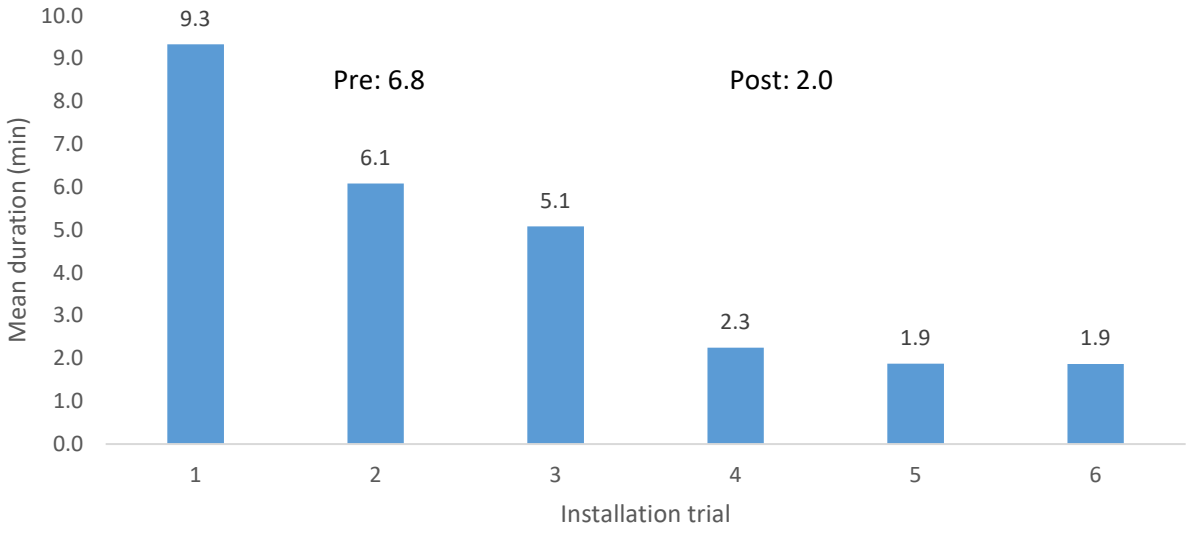


Figure 76. Mean duration by trial number.

Devices

Table 13 shows that for all installation outcomes, there were no significant differences between the three devices. Results did not vary when the analysis was limited to the three pre-instruction trials.

Table 13. Installation outcomes and p-values by device.

Device	Tight	Tether correct	Seatbelt correct	Installation correct	Duration (min)
D1	48%	73%	69%	33%	4.3
D4	48%	71%	58%	33%	4.5
SB	48%	67%	69%	38%	4.5
p-value	1.0	0.875	0.434	0.748	0.948

The types of installation errors for each device are shown in Figure 77. The most common errors for all devices included a loose installation. Almost half of subjects did not use the tether correctly across all devices.

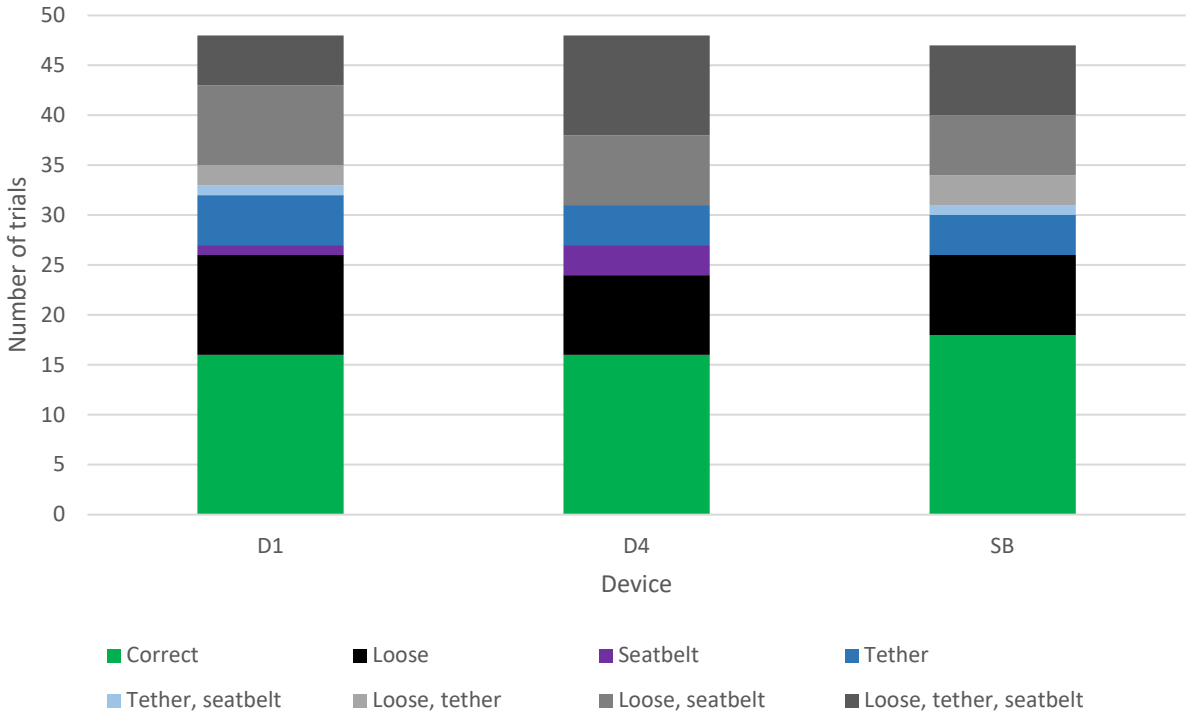


Figure 77. Distribution of installation errors by device.

The types of errors associated with the seatbelt are shown in Figure 77. The most common error was not locking the seatbelt. With D4, 8 subjects did not switch the device into CRS mode; 9 switched to CRS mode but did not pull the belt all the way out to switch it into locking mode.

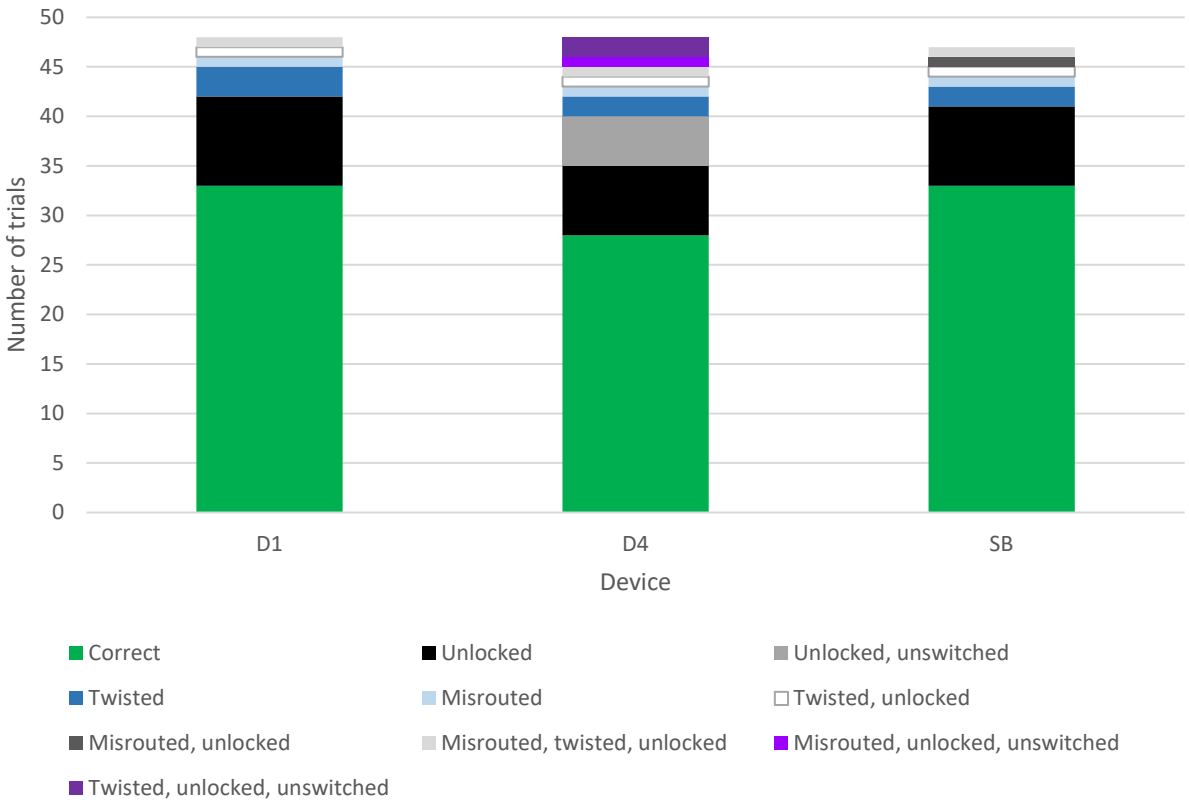


Figure 78. Distribution of seatbelt errors by device.

Subject comments

When asked for their favorite device for installing CRS, 2 chose seatbelt, 7 chose D1, and 15 chose D4. The distribution of difficulty ratings by device is shown in Figure 79 and Figure 80. The SB had the fewest ratings at the easy end of the scale.

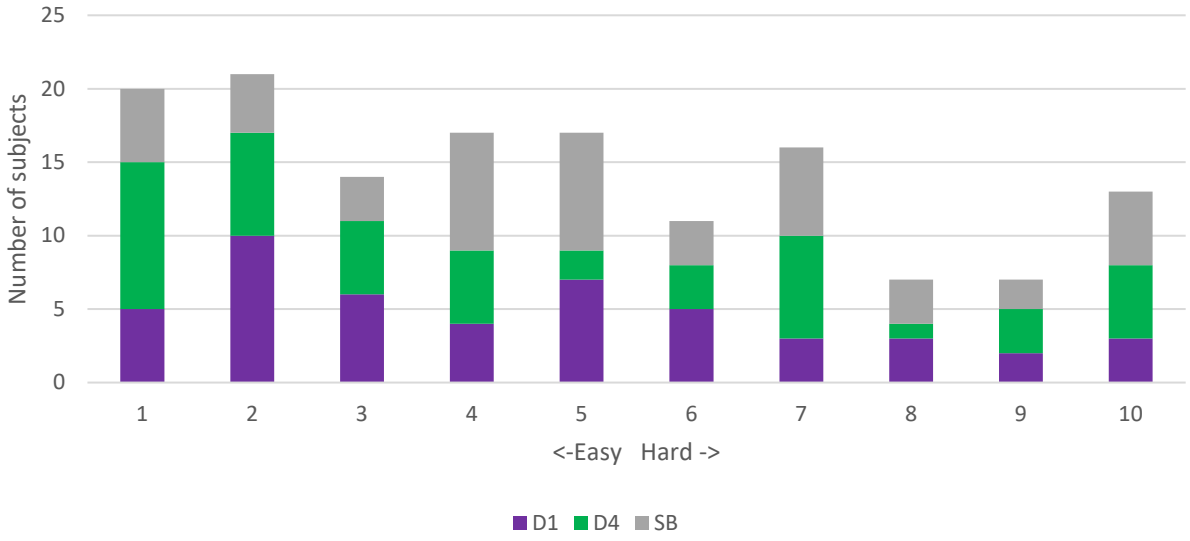


Figure 79. Distribution of difficulty ratings.

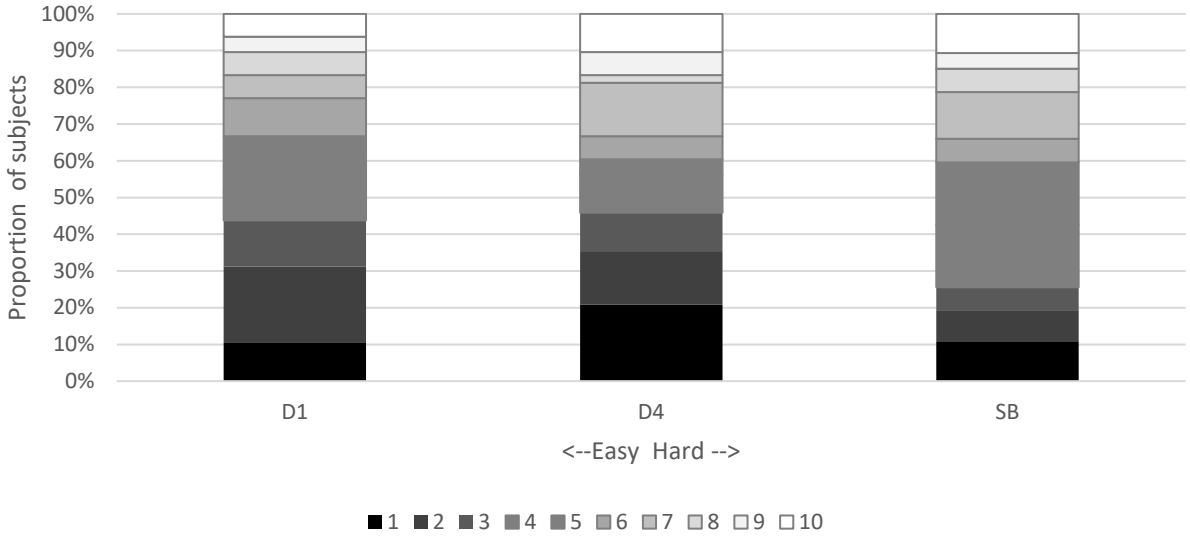


Figure 80. Difficulty ratings by device.

Subject responses to installation questions are shown in Figure 81 through Figure 87. As in many past studies, about two-thirds of subjects thought they installed the CRS correctly, while correct CRS installation rates are closer to one-third. There is minimal variation in responses with device for all questions.

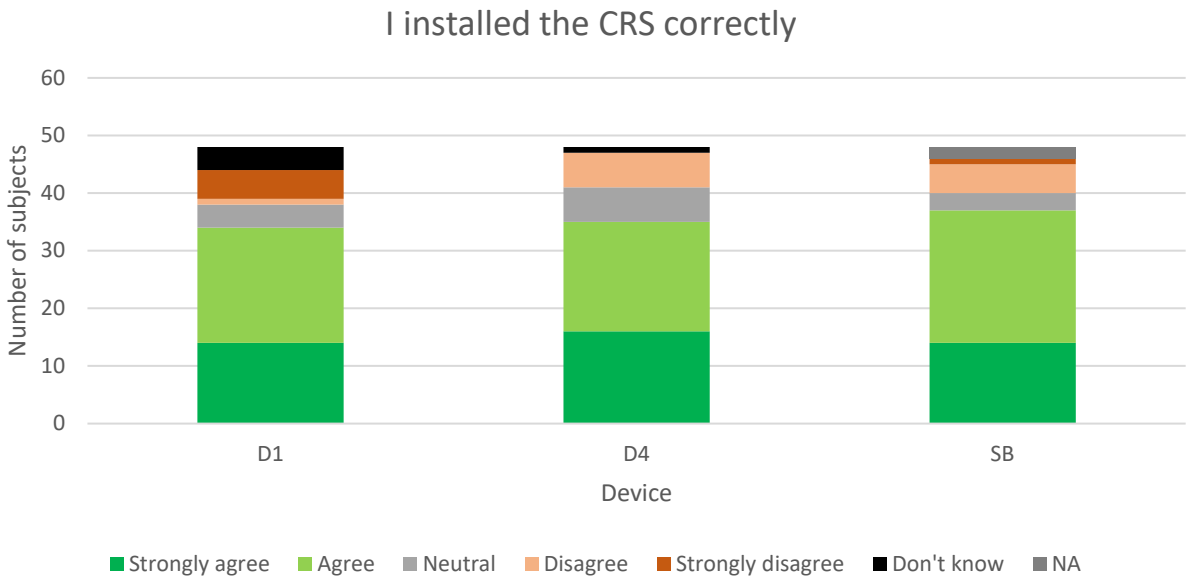


Figure 81. Distribution of subject responses to: I installed the CRS correctly.

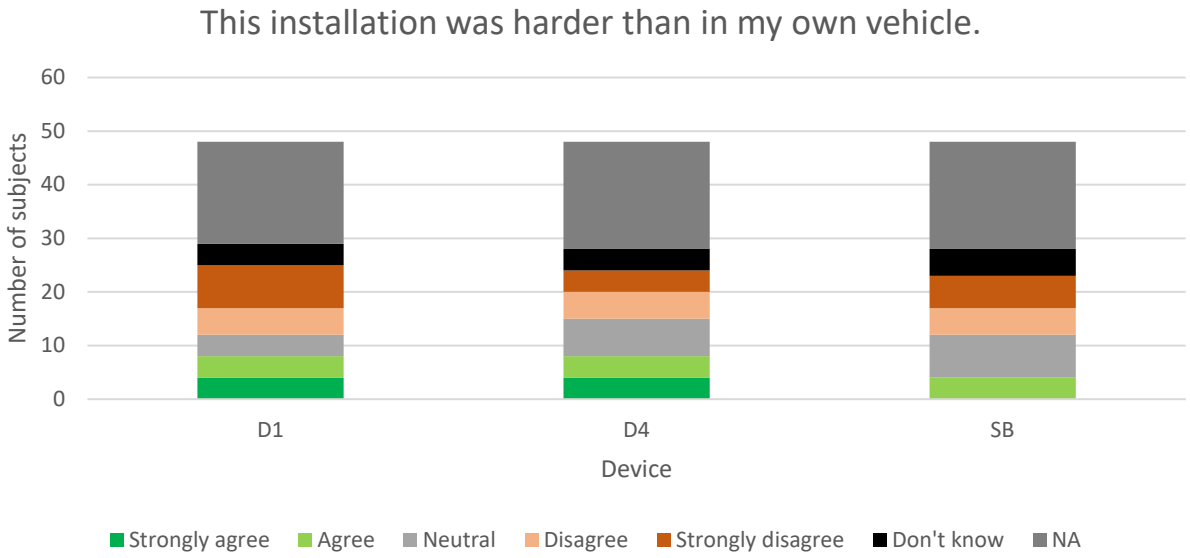


Figure 82. Distribution of subject responses to: This installation was harder than in my own vehicle.

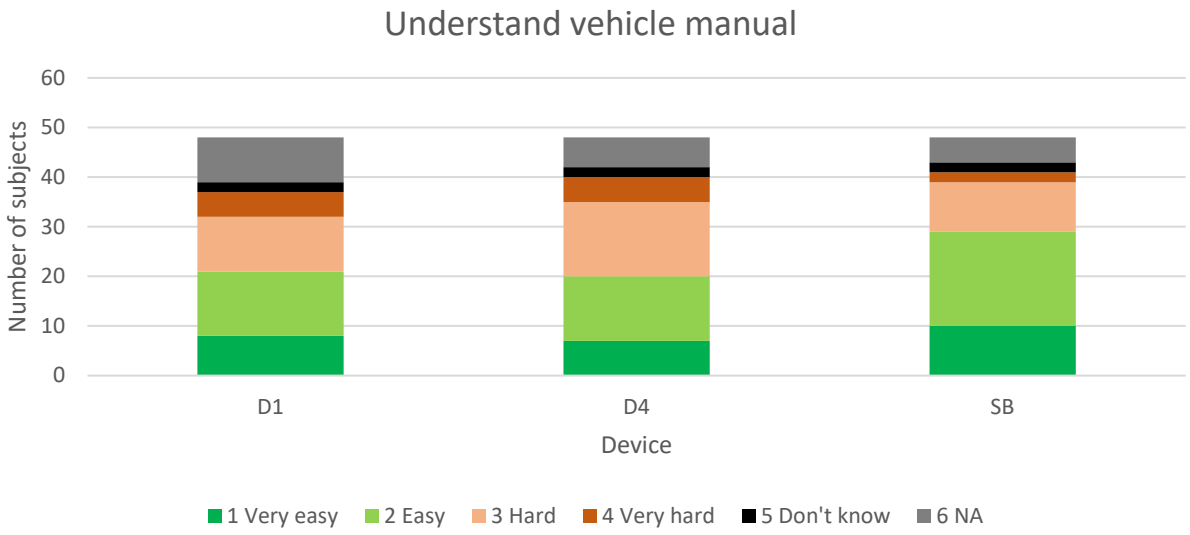


Figure 83. Distribution of subject responses to: How hard or easy was it to understand the vehicle manual.

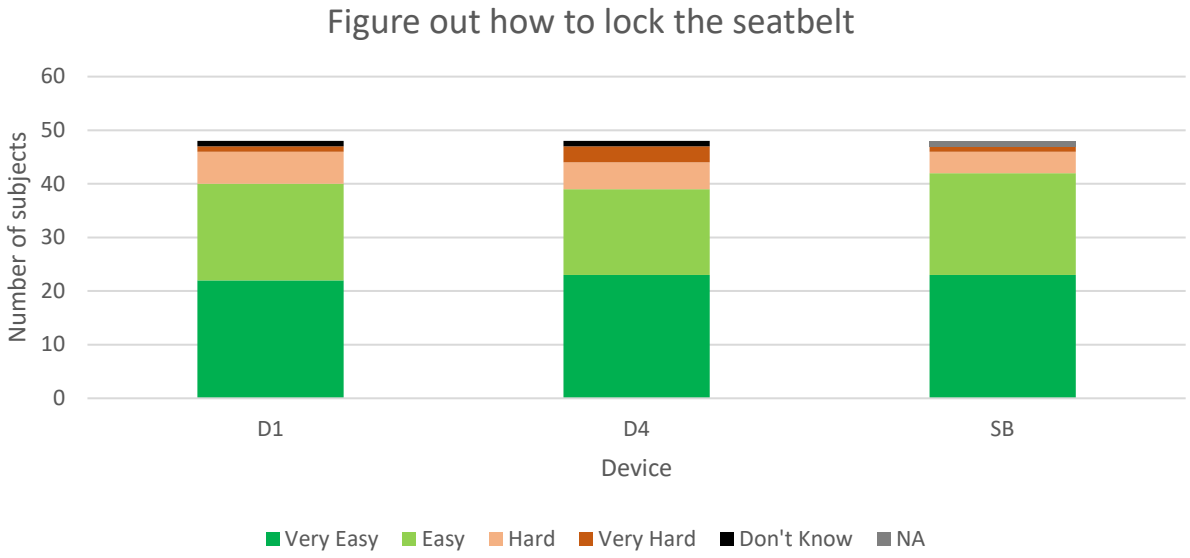


Figure 84. Distribution of subject responses to: How hard or easy was it to figure out how to lock the seatbelt.

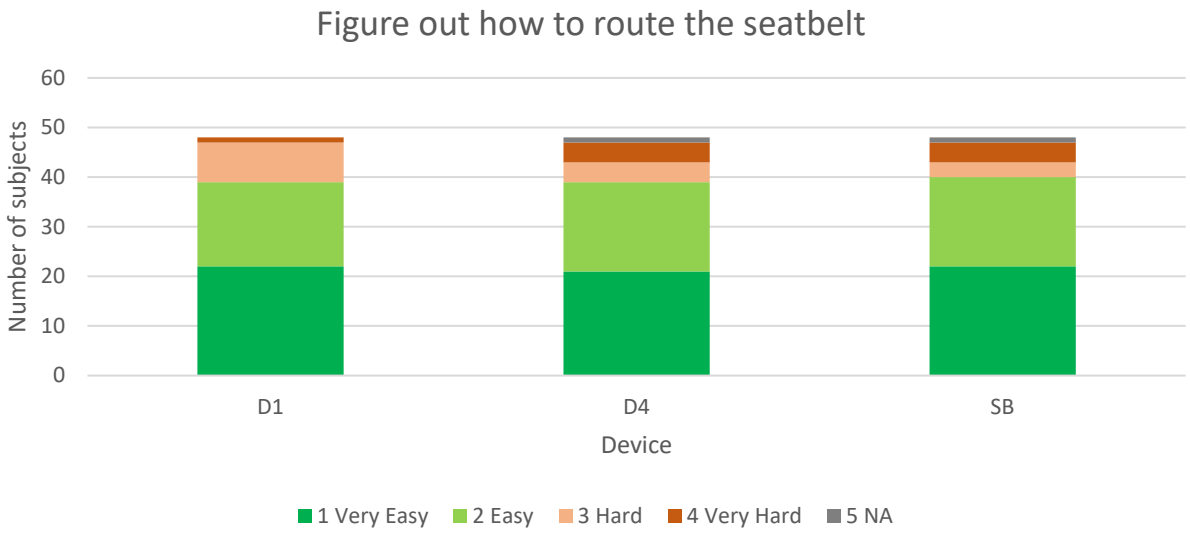


Figure 85. Distribution of subject responses to: How hard or easy was it to figure out how to route the seatbelt.

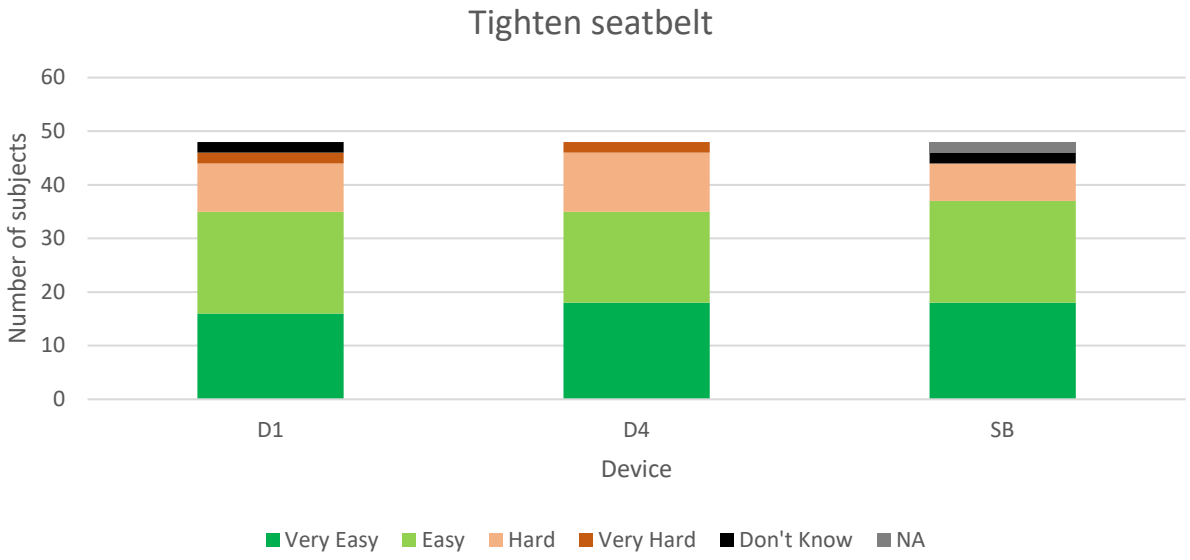


Figure 86. Distribution of subject responses to: How hard or easy was it to figure out how to tighten the seatbelt.

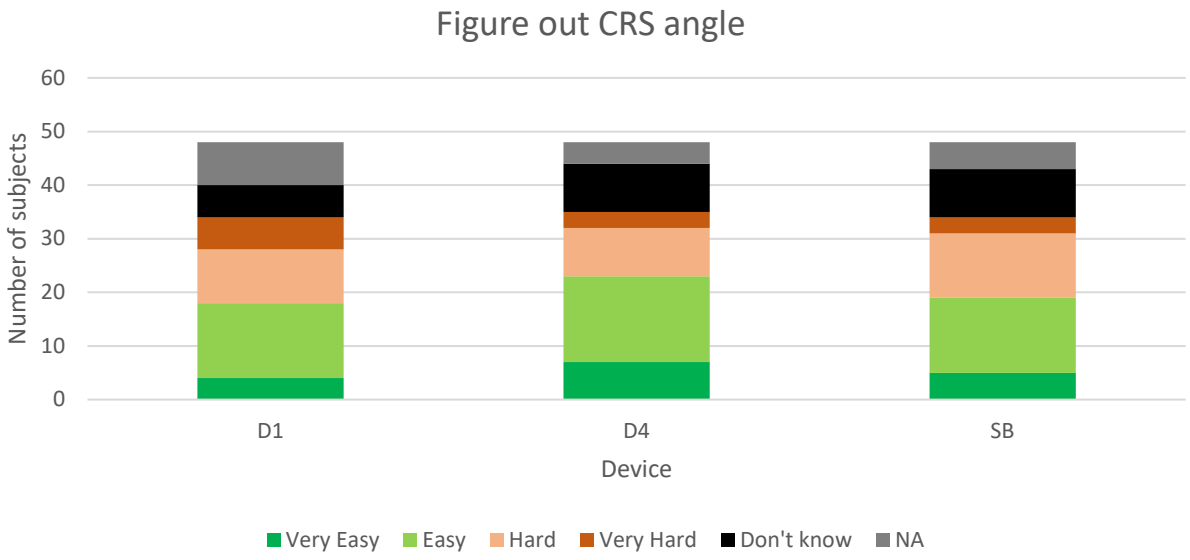


Figure 87. Distribution of subject responses to: How hard or easy was it to figure out how to adjust the CRS angle.

Subject comments

Subject comments regarding installation are found in Table 14. In general, there were more comments about CRS features than devices, and many comments in the later trials noted that the video instruction is helpful.

Table 14. Subject comments on installations.

Trial	CRS	Device	Comment
1	F1	D1	Have not done in my own vehicle. Seemed to be attached correctly, maybe missing one step. Did not adjust angle of child seat.
1	F1	D1	No experience ever with child seats - so didn't know angle is important or any other characteristics for placing car seat in vehicles
1	F2	D1	First attempt at ever installing a child seat
1	F3	D1	I think I "did it correct" AKA-followed instructions, but I know its not tight enough and I would not want my child in it. Maybe I should have adjusted the angle to more properly secure the seat.
2	F1	D1	I liked the locking button made it easier put the seat didn't seem secure. I couldn't set it to place right I wouldn't use it if I owned it Uncertain if it was installed correctly. Strap was easier due to the button after I found out how it worked. I don't feel I could place the straps flat and never felt good about the car seat being safe. Straps didn't rest flat lots of give on car seat position.
2	F2	D1	Was not totally sure if the route of seatbelt was correct
2	F2	D1	Wasn't sure about raising the top of the car seat at first
2	F3	D1	After 1st install, this was way easier. I feel like this was installed correctly. Directions seemed easier but that may just be because it was 2nd install.

Trial	CRS	Device	Comment
2	F3	D1	Much easier than with the locking clip on the "better and safer" seat. Better diagrams. Quality protection of head and neck in a side impact situation.
3	F1	D1	Didn't understand the tether system well enough to know where it was to attach - or if it should even attach.
3	F2	D1	There were a lot of pieces in that seat that I didn't know what to do with.
3	F2	D1	Was too complicated. I would not purchase this car seat for my child.
3	F3	D1	Didn’t see any where to actually attach tether strap, but I feel like I could in a real car.
3	F3	D1	This one had to be at an angle in the seat vs. being flat, which was a bit awkward to install. This belt didn’t lock easily, and may have come unlocked as I installed it.
3	F3	D1	Used pictures / diagrams on side of seat in place of manual
4	F2	D1	I felt more confident that the seat was secure. It was easier to install the second time without instructions, though I did the steps out of order at first.
4	F3	D1	Seeing the car seat from side there seems to be so much space between car seat and child seat.
5	F1	D1	This seat belt was a little harder to tighten. Felt like it wasn’t responding the right way. Slightly more of a challenge because of comment above, but overall easy with no big issues.
5	F3	D1	Not secure no difference in either set of instructions it moves too much even using my full body weight. Too much movement I wouldn't use this car seat I would return it.
6	F1	D1	Almost forgot to pull belt all the way to lock
6	F1	D1	This was easier than my vehicle. Seemed the easiest and most secure
6	F2	D1	Based on video instructions.
6	F3	D1	Locking mechanism definitely keeps it in place better. I prefer to buckle first then lock it.
1	F1	D4	No place for the top clip to attach, so just did the normal seat belt through the seat.
1	F2	D4	I have never done a seat belt install before, only LATCH. Car seat instructions were very difficult I had no clue what the pictures were showing, especially the seat belt path.
1	F3	D4	Using both manuals together definitely helped. Was not sure where to attach tether without using the manual
1	F3	D4	I believe I may have, not sure if I locked the belt should have double checked. Had to resolve two sets of instructions which could be confusing. Was not able to [illegible] the child seat worked with this set up assuming it did a quick guide of what to check to confirm it was set up correctly would have helped.
2	F1	D4	Much easier than the first one.
2	F2	D4	Expected to have tether point closer to top of seat. Once I found it I was able to install. First seat install did not see tether point.
2	F3	D4	Knowing how to install a child seat from previous experience helped me a lot.

Trial	CRS	Device	Comment
3	F1	D4	Seemed the most light weight and simple to install. I would still like someone stronger to tighten anchor tether strap
3	F2	D4	There were some instructions on hook/flap use that I didn't fully understand. Very clear instructions on how to adjust angle of seat and how to switch belt to child lock.
3	F3	D4	Did not like the anchor straps. Was confused on how it was. Didn't pull them through both openings (right and left). Seat belt did not lock like I wanted it to
4	F2	D4	Video had clear instruction easy to understand I was more confident. Remind me of important steps like child seat button, gave criteria for safe secure installation. Much easier I didn't reference manual. Just followed video draw back is a did check the angle setting cause it wasn't in video. I did only what was in video, less problem solving engagement/assignment/?
4	F3	D4	Actually used "Child Seat Mode" on the seat belt
4	F3	D4	Videos helped! Didn't notice button before and didn't understand locking seat belt until now. Super easy and feel confident in install.
5	F1	D4	Based on video instructions.
5	F1	D4	I was confused until I saw the video on the correct position of the switch on the seat button.
5	F1	D4	Video gave clues but needed to watch more to develop confidence. Video better than instructions written in normal.
5	F1	D4	Video helped with child seat mode to lock the car seat in and not shake much at all
5	F2	D4	Car seat too heavy - route for seat belt too narrow
5	F2	D4	I still (even after watching video) find it isn't tight enough.
5	F2	D4	This one has the most difficult instructions. Even the pictures on the car seat itself are unclear.
5	F3	D4	Did not adjust angle of seat
6	F1	D4	This installation seemed easier!
1	F1	SB	Instructions were hard to follow. Not knowing where the seatbelt went through the back of the child seat was a problem for me.
1	F2	SB	It seems loose but also is definitely strapped in a couple different ways. Installation instructions were confusing to follow. Didn't really understand what any of the things were called except "seatbelt" and "child seat". (Like "tether", "anchorage" etc.)
1	F2	SB	This particular handbook has orange highlighted parts that correspond with where something goes in the written instructions. The part about the metal belt loop was a smidge "hard" because it didn't show, I think an image of the belt loop, just the section of the seatbelt where it goes. A "legend" of seat parts would be extremely helpful.
1	F3	SB	I have not had to install a car seat on my current vehicle. I am not sure if it has the tether feature
2	F2	SB	Bit easier than the last one, but now I know what to do. The hole to thread through the seat belt was a bit small and that was hard to get it through

Trial	CRS	Device	Comment
2	F2	SB	The hole to weave lap belt through was very narrow even for my small hands. I could not figure out how to get it tighter even though I thought I followed the instructions
2	F3	SB	It seems to move side-to-side too easily but I felt that I followed the steps correctly. Did not see how to adjust angle or what it should be.
3	F1	SB	This manual was easiest to follow based on diagrams and simple language in instructions
3	F1	SB	Very easy again because I think I know the process now. Have figured out where seat belt goes and how to tighten.
3	F2	SB	Best instructions I had more confidence it seemed to set itself well having consistent problems seat strap to lay flat would have difficulty if my hands were larger fitting it through. The instructions were confusing as they indicated 5 when there was no 5. Also no indication of when to use 3 or 4. Overall best instructions yet.
3	F3	SB	I forgot to tighten the tether
3	F3	SB	It was hard to adjust the tether strap Could not figure that out.
4	F2	SB	Unsure of what the "hook and loop fasteners" were in the instructions, but at end seat seemed secure. Mechanism to adjust reclining angle was hard to find
4	F2	SB	I didn't install this one correctly in the first trial
4	F2	SB	Video instructions were very helpful to see how to properly tighten the car seat. Would not have figured it out from only the manual
4	F3	SB	About the same as my own vehicle. It was easier after watching a video.
4	F3	SB	Did not attach tether strap on the top
4	F3	SB	I rated this based on video instructions that were given on this - not the manual.
4	F3	SB	The videos were helpful for tightening the seat belt
5	F1	SB	Forgot to unhook the tether, and had to undo the belt to get the tether unhooked so I could attach it to the seat
6	F1	SB	Did not use manual, felt the seat was secure
6	F1	SB	Easiest
6	F2	SB	Same difficulty level, no issues.

Comfort/Nuisance Locking

Figure 88 through Figure 90 show the percentage of comfort trials where the seatbelt locked after the subject's first attempt to grab the water bottle. When comparing by device in Figure 88, D4 had the lowest percentage. This is expected, as only half the subjects began their comfort trials with the switch in the CRS mode which would allow it to lock. Figure 89 shows that the rate of nuisance locking for the tallest subject group was approximately double that of the two shorter stature groups (p=0.026). The rate of nuisance locking also increases with subject BMI (p=0.009), as shown in Figure 90.

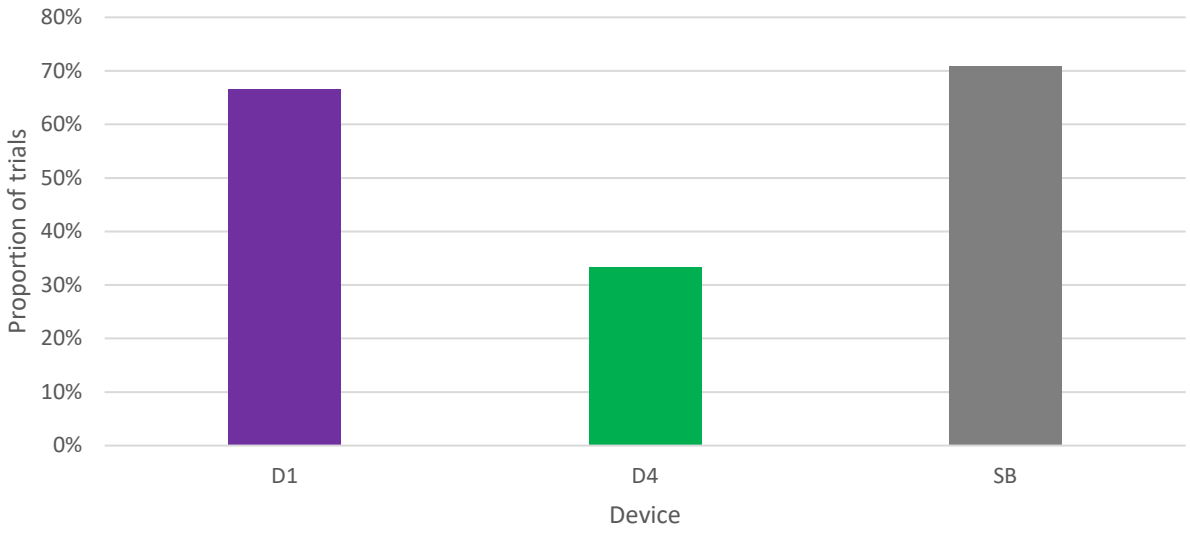


Figure 88. Proportion of trials with nuisance locking after first attempt at reach task by device.

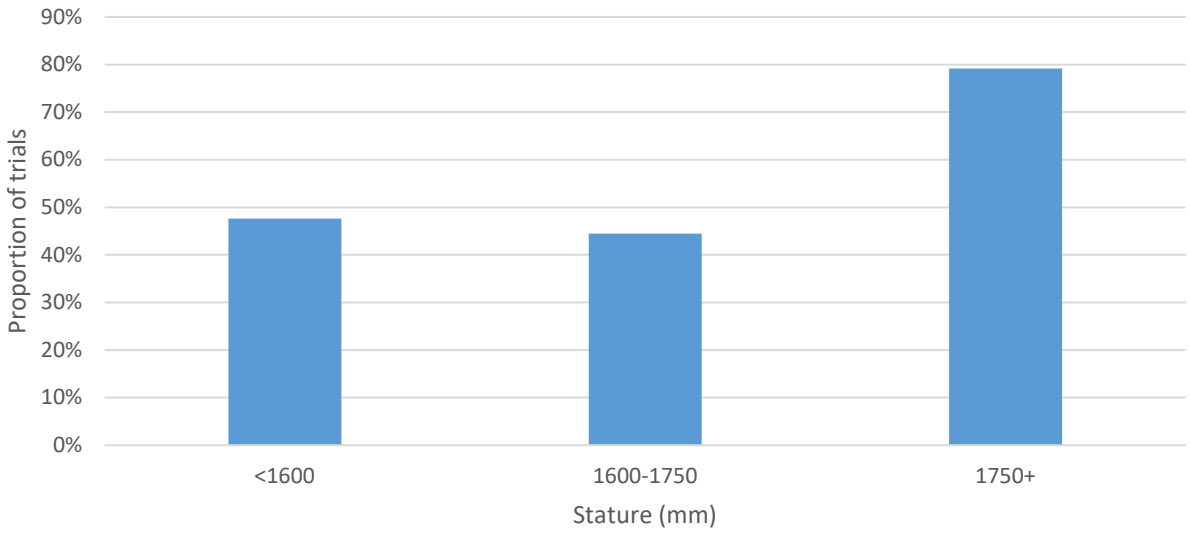


Figure 89. Proportion of trials with nuisance locking after first attempt at reach task by subject stature.

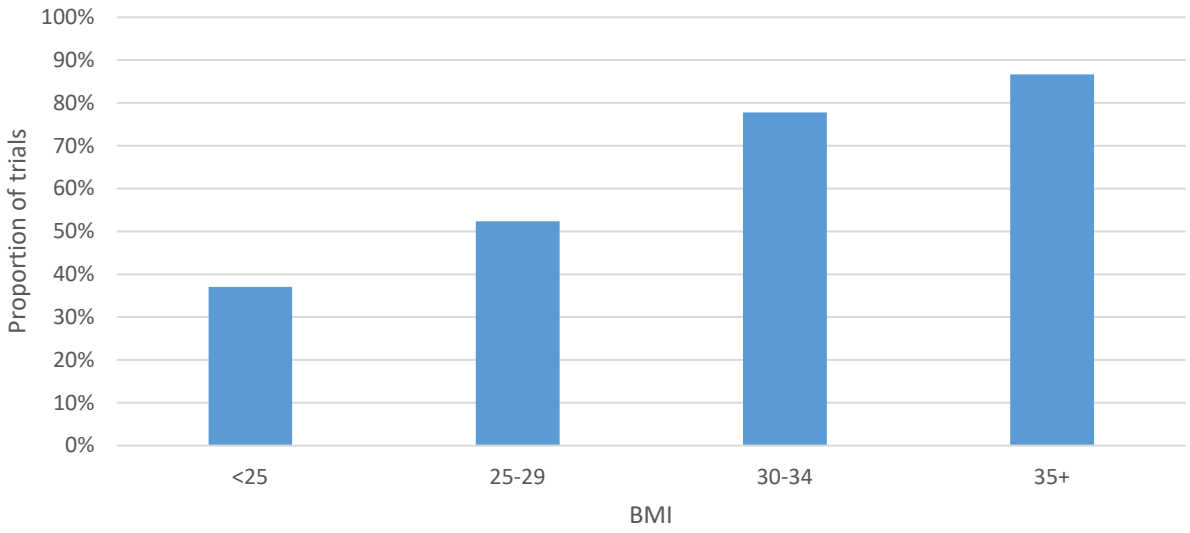


Figure 90. Proportion of trials with nuisance locking after first attempt at reach task by subject BMI.

As described in more detail in Appendix I, subjects were asked if they noticed anything different after their first attempt at the reaching task, after a second attempt at a reaching task, and a third time after the experimenter locked the belt if it hadn't previously locked during the reaching tasks. Subject responses after each query for each device are shown in Figure 91.

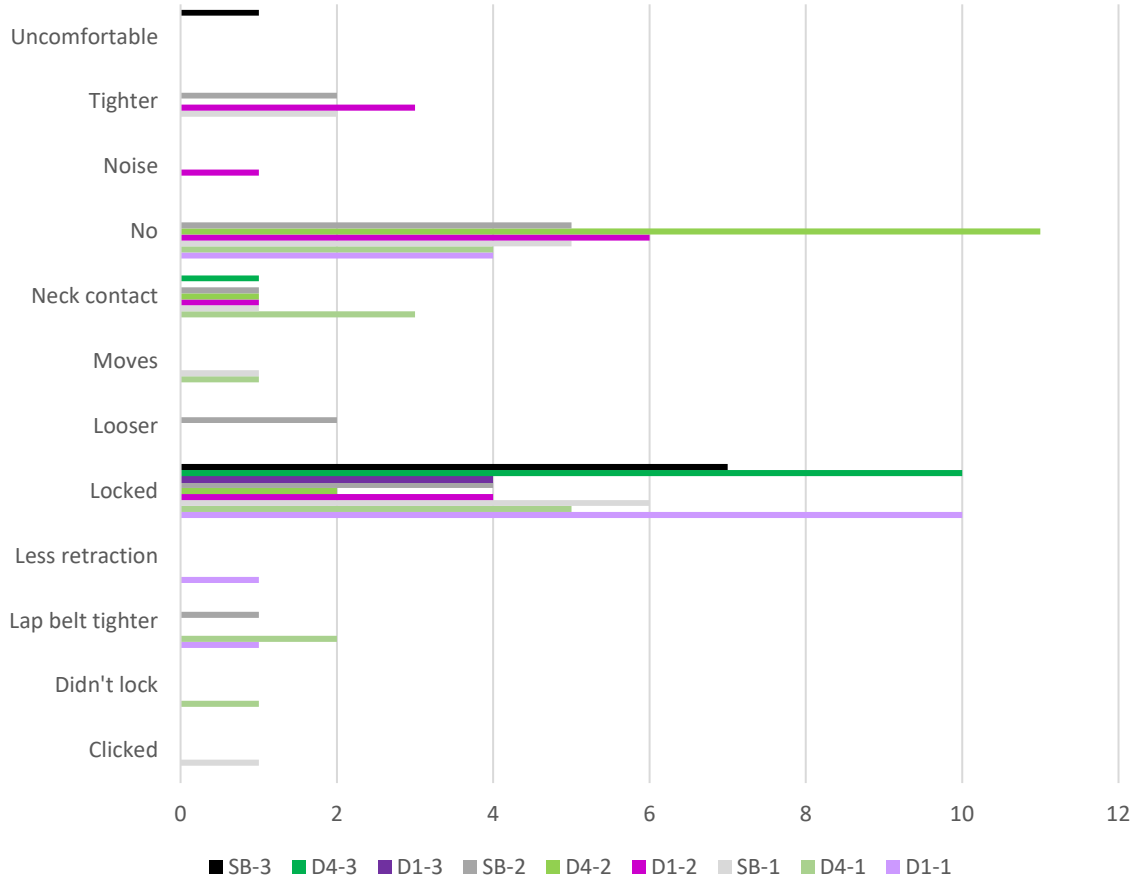


Figure 91. Subject responses regarding "anything different about the seatbelt" after each action in the comfort trials.

Because the first few subjects seemed somewhat confused about the question, for remaining subjects, they were asked if they had ever accidentally locked the belt in the rear seats of their own vehicles. Only 54% had personally had this experience.

At the end of the comfort trials, subjects were asked to demonstrate what they would do in their own vehicles. The distribution of the sequence of steps is shown in Figure 92 through Figure 94 for each device.

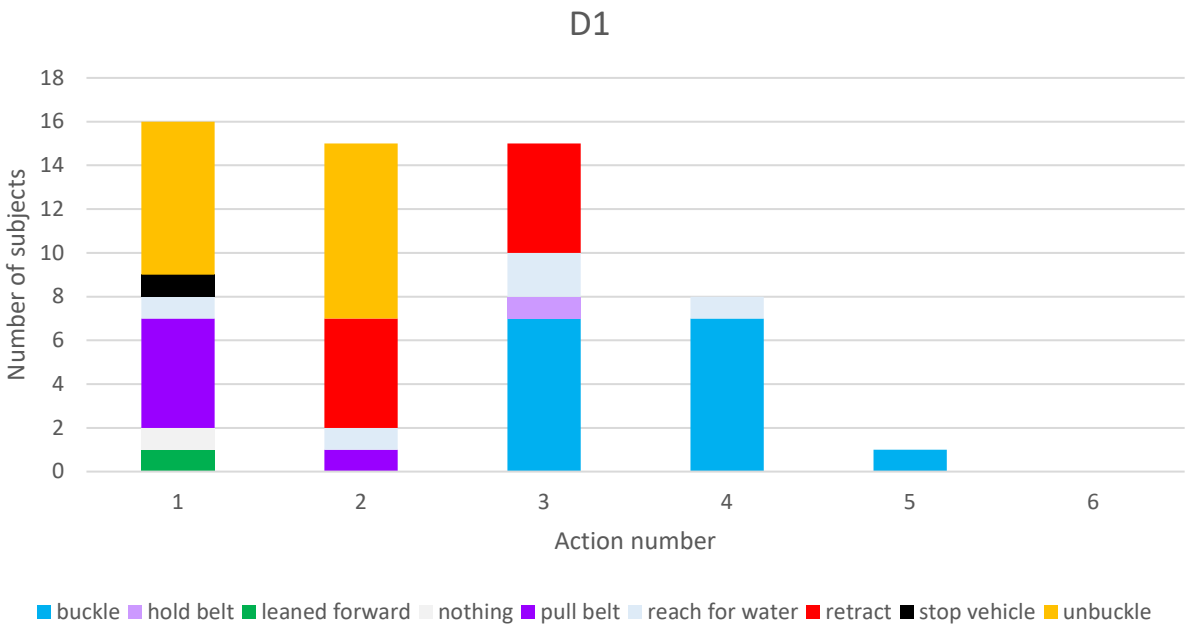


Figure 92. Steps taken by subjects to deal with nuisance locking with D1.

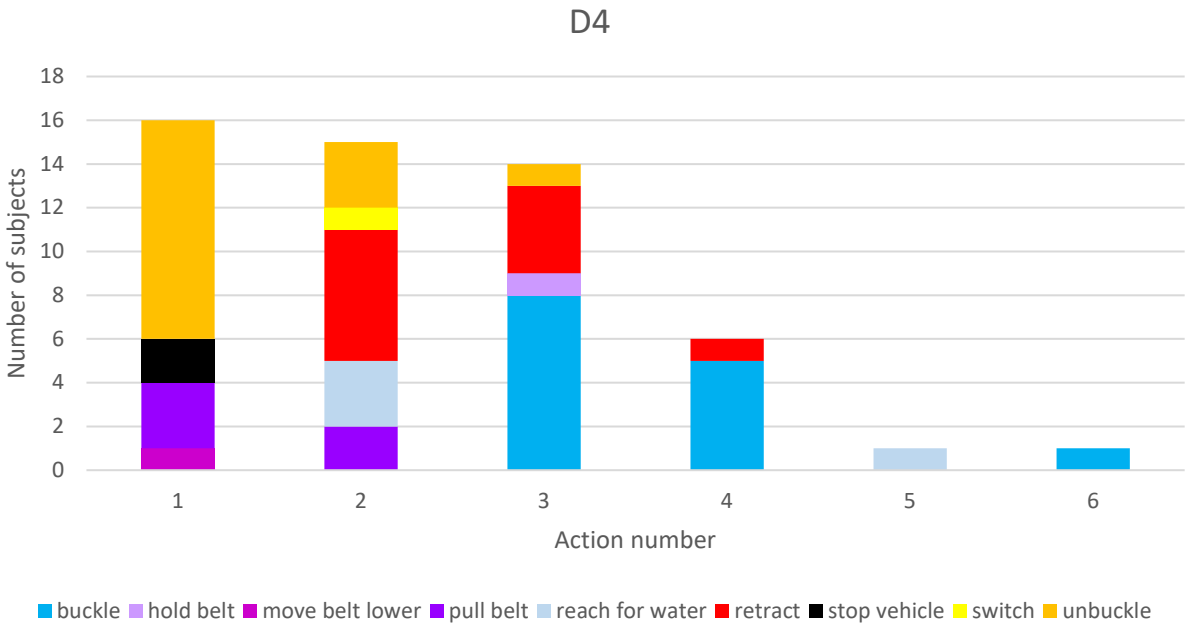


Figure 93. Steps taken by subjects to deal with nuisance locking with D4.

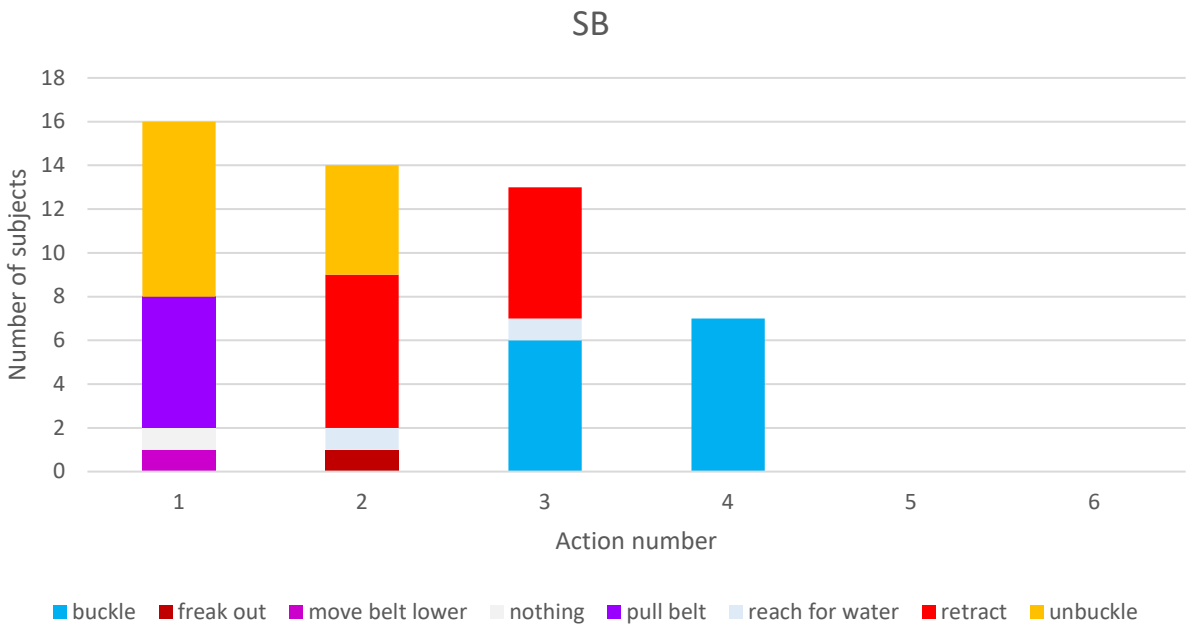


Figure 94. Steps taken by subjects to deal with nuisance locking with SB.

SUMMARY AND DISCUSSION

In phase 1, all three prototype devices had shorter disentanglement times compared to the standard seatbelt system but they were not different from each other. During disentanglement trials, subjects almost always released the belt by unbuckling it and rarely used the knob or button features to unlock the belt. When reviewing the cumulative number of disentanglement trials by duration, D3 had the fewest of the fastest trials.

Regarding the phase 1 installation trials, none of the prototype devices seemed to improve the quality of installations compared to LATCH or the standard seatbelt system. When asked their favorite device for installing CRS, most subjects chose LATCH or standard seatbelt over the prototype devices. For installation trials, there were no differences in outcome variables between subjects with and without CRS experience, indicating that previous experience with locking standard seatbelts did not affect use of the different devices.

For phase 2, devices D1 and D4 had shorter disentanglement times compared to the standard seatbelt but were not different from each other. D1 had the most short disentanglement times and the least long disentanglement times.

In phase 2, none of the devices led to fewer installation errors. The most significant factor relative to correct installation and shorter duration was the video instruction after the first three installation trials. Subjects expressed a preference for D4, although they did not rate it easier to use or have better installation results with it.

For the comfort/nuisance locking trials in phase 2, there were no unexpected results with device. Subjects with taller stature or greater BMI were more likely to experience nuisance locking. Just over half of subjects had previously experienced nuisance locking in their own vehicles.

REFERENCES

Reed, M.P. and Ebert-Hamilton, S.M. (2013). Distribution of belt anchorage locations in the second row of passenger cars and light trucks. Technical Paper 2013-01-1157. SAE International Journal of Transportation Safety. 10.4271/2013-01-1157.

SafeRideNews 2009.

APPENDIX A: CONSENT FORM

The University of Michigan Transportation Research Institute
Informed Consent for Research Procedure
Evaluation of Child Seats Using Devices to Reduce Seat Belt Entanglement

The purpose of this study is to obtain data on how people might use new seat belt systems designed to reduce problems of children becoming entangled with the seat belt. The information gathered in this study will help engineers design vehicle seat belts that are safer for children. If you agree to participate in this research study, we will ask you to install different child seats in a vehicle mockup. After each installation, you will answer some questions about the installation. We will also ask you to remove a seat belt wrapped around a crash test dummy seated in the vehicle mockup.

Your participation in this study is voluntary and conditional on our review of your physical qualifications relative to experimental design criteria. You will be paid $40 for your participation. You may discontinue your involvement at any time with payment for participation up to that time of $12/hr. If we feel that you are not performing the instructed tasks or becoming frustrated to the point that further trials would not provide usable data, we can end the test session with payment for participation up to that time of $12/hr. You are responsible for the cost of transportation to our testing facility, but we will provide you with a parking pass upon your arrival.

The Transportation Research Institute is a research organization and, as such, research staff may review your records and personal information. The data gathered in this study will be used in scientific publications and presentations only in coded form not identifying you. The data obtained will be retained indefinitely for analysis. Photographs and video will be taken of you to document your installation of the child seats. Your identity will be obscured in any photographs used in publications or presentations.

The researchers have taken steps to minimize the risks of this study. Even so, you may still experience some risks related to your participation, even when the researchers are careful to avoid them. These risks include injury due to exertion when performing the requested tasks and frustration from installing child seats. Please tell the researchers about any concerns or problems you have during the study. By signing this form, you do not give up your right to seek payment if you are harmed as a result of being in this study.

Should you have questions about the study, please contact the primary investigator, Kathleen D. Klinich, Ph.D. at 734-936-1113. If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board, 2800 Plymouth Rd. Building 520, Room 1169, Ann Arbor, MI 48109-2800, (734) 936-0933, or toll free, (866) 936-0933, irbhsbs@umich.edu.

One copy of this document will be kept together with research records on this study. A second copy will be given to you.

By signing this document, you are agreeing to participate in this research study and are willing to have photographs and video taken of you. You may not participate in the study if photographs and video are not taken. Your identity will be obscured in any photographs of you that are used in publications or presentations.

_____
Participant Name (Printed)

_____ _____
Participant Signature Date

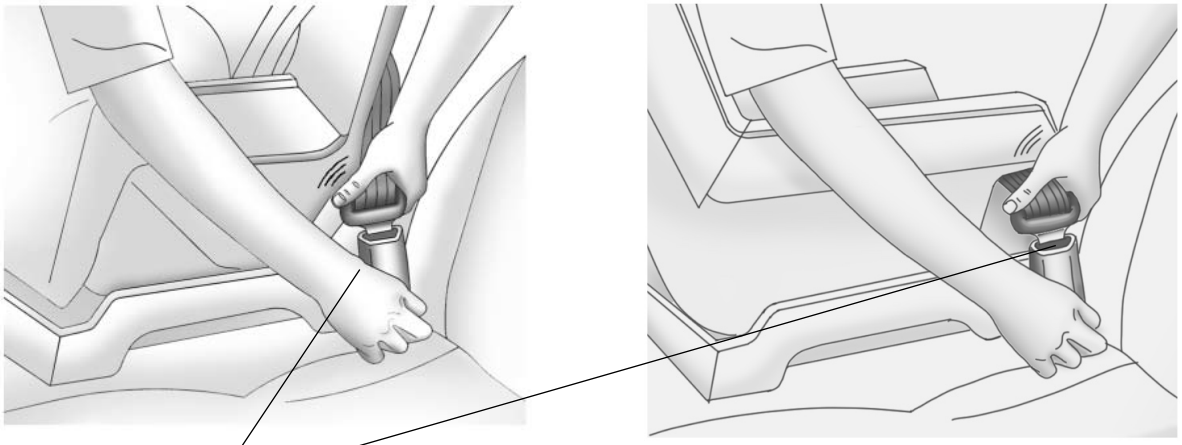
_____ _____
Witness Name Witness Signature

APPENDIX B: PHASE 1 INSTRUCTIONS AVAILABLE TO PARTICIPANT

Standard Belt Instructions

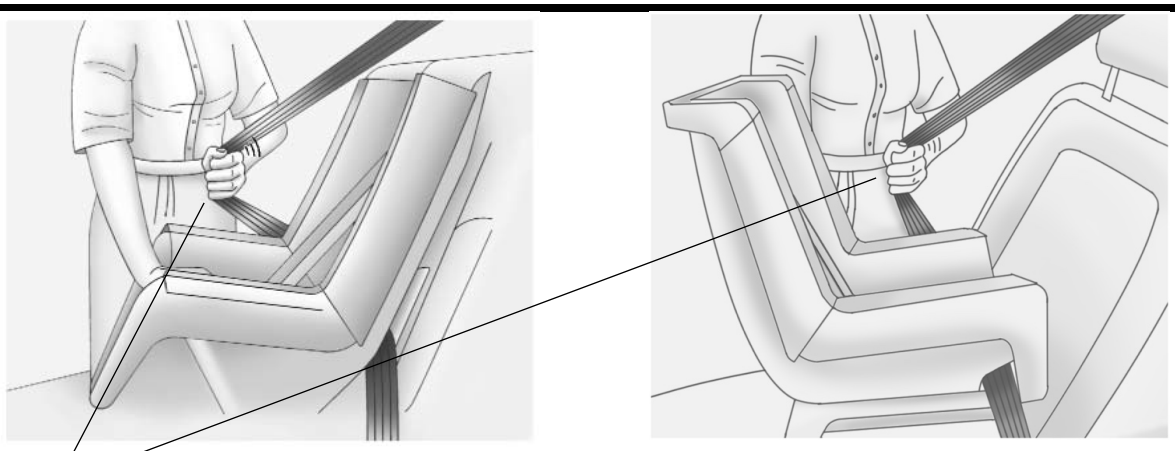
1. Put the child restraint on the seat.

2. Pick up the latch plate, and run the lap and shoulder portions of the vehicle's safety belt through the belt path of the child restraint. The child restraint instructions will show you how.



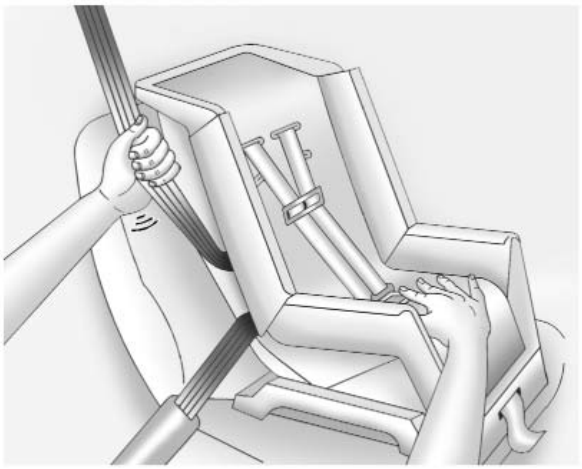
3. Push the latch plate into the buckle until it clicks.

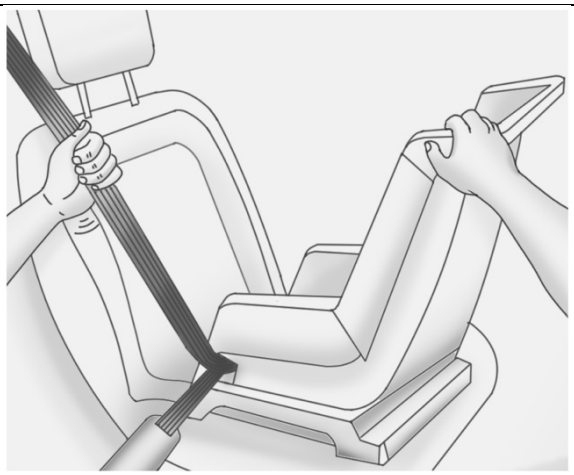
Place the buckle stalk so you can reach the red buckle release button easily if needed.



4. Pull the shoulder belt all the way out of the retractor to set the lock.

When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.





5. To tighten the belt, push down on the child restraint, pull the shoulder portion of the belt to tighten the lap portion of the belt, and feed the shoulder belt back into the retractor.

When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.

6. Try to pull the belt out of the retractor to make sure the retractor is locked.

If the retractor is not locked, repeat Steps 3 through 5.

7. For forward-facing child restraints, attach the top tether. Tether instructions are in the child restraint instructions and in the vehicle manual "Tether" section.

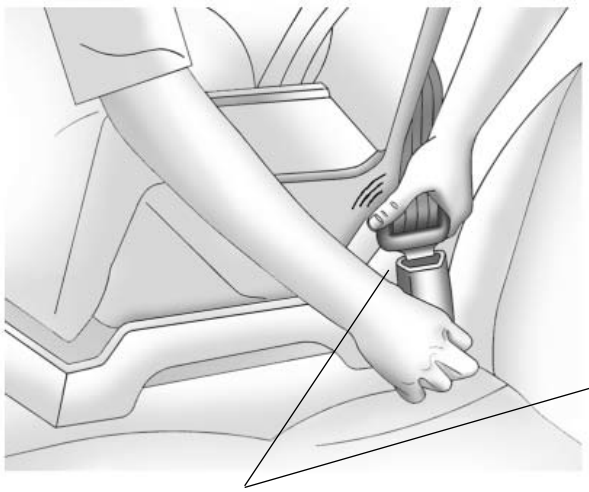
8. Before placing a child in the child restraint, make sure it is securely held in place. To check, grasp the child restraint at the safety belt path and attempt to move it side to side and back and forth. When the child restraint is properly installed, there should be no more than 2.5 cm (1 in) of movement.

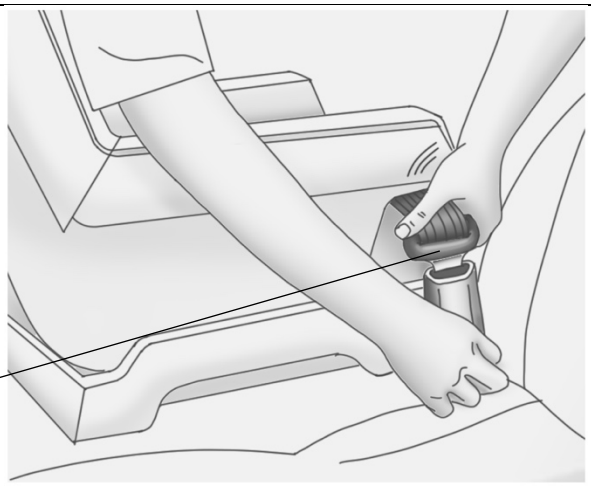
To remove the child restraint, unbuckle the vehicle safety belt and remove it from the restraint. If the top tether is attached to a top tether anchor, disconnect it.

Device 1 Instructions

1. Put the child restraint on the seat.

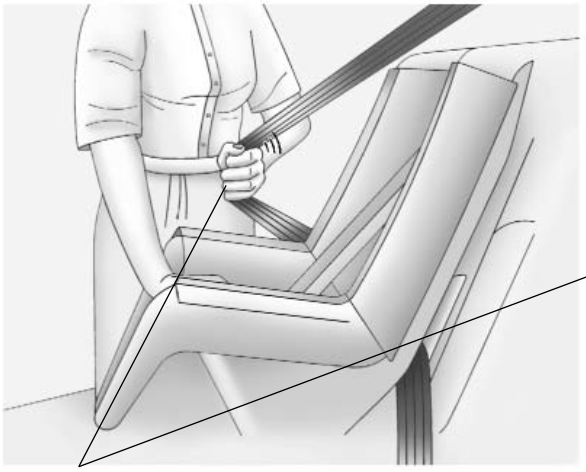
2. Pick up the latch plate, and run the lap and shoulder portions of the vehicle's safety belt through the belt path of the child restraint. The child restraint instructions will show you how.

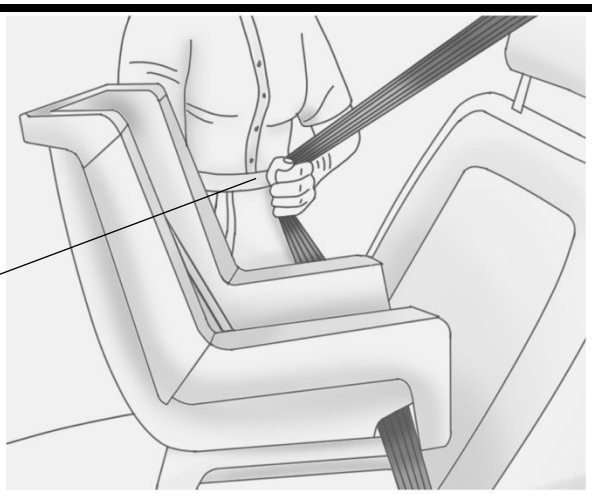




3. Push the latch plate into the buckle until it clicks.

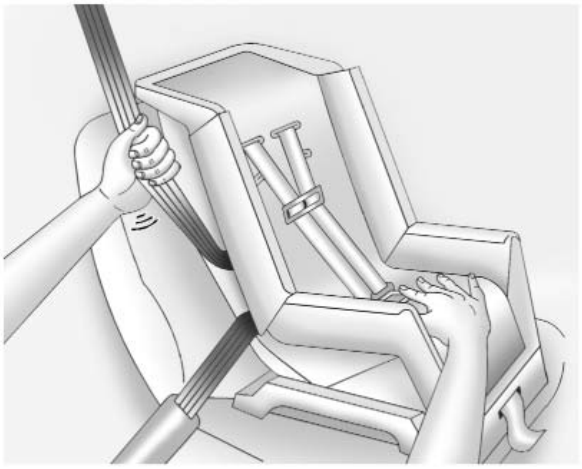
Place the buckle stalk so you can reach the red buckle release button easily if needed.

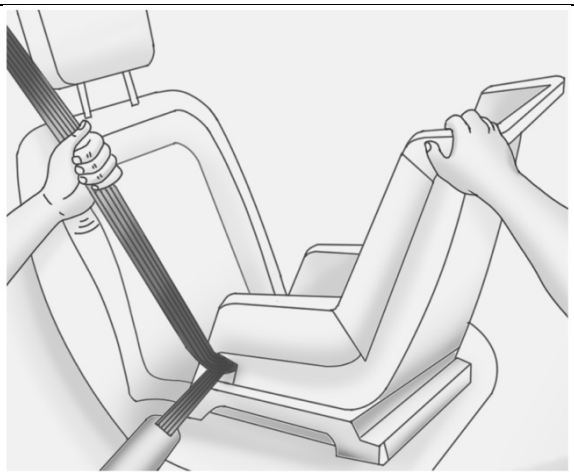




4. Pull the shoulder belt all the way out of the retractor to set the lock.

When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.





5. To tighten the belt, push down on the child restraint, pull the shoulder portion of the belt to tighten the lap portion of the belt, and feed the shoulder belt back into the retractor.

When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.

6. Try to pull the belt out of the retractor to make sure the retractor is locked.

If the retractor is not locked, repeat Steps 3 through 5.

9. For forward-facing child restraints, attach the top tether. Tether instructions are in the child restraint instructions and in the vehicle manual "Tether" section.

10. Before placing a child in the child restraint, make sure it is securely held in place. To check, grasp the child restraint at the safety belt path and attempt to move it side to side and back and forth. When the child restraint is properly installed, there should be no more than 2.5 cm (1 in) of movement.

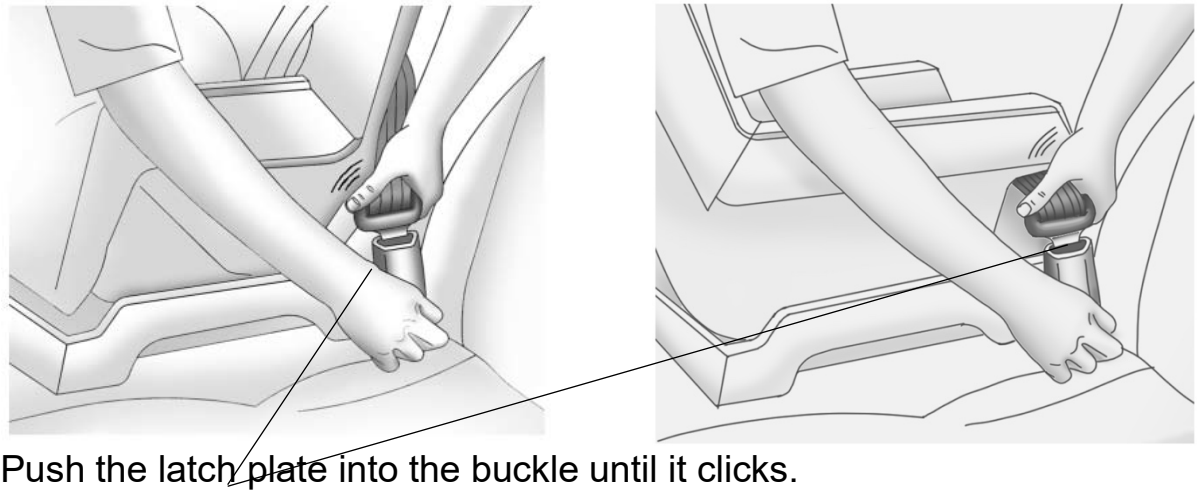
Note: the retractor lock will not set if the latch plate is not buckled.

To remove the child restraint, unbuckle the vehicle safety belt and remove it from the restraint. If the top tether is attached to a top tether anchor, disconnect it.

Device 2 Instructions

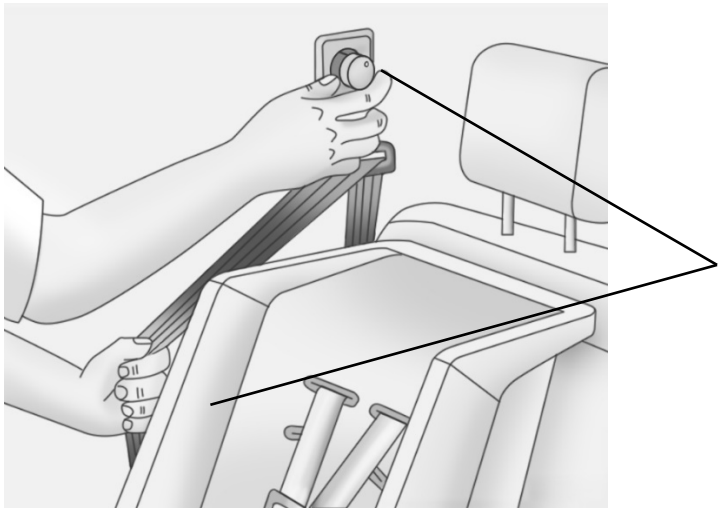
1. Put the child restraint on the seat.

2. Pick up the latch plate, and run the lap and shoulder portions of the vehicle's safety belt through the belt path of the child restraint. The child restraint instructions will show you how.



3. Push the latch plate into the buckle until it clicks.

Place the buckle stalk so you can reach the red buckle release button easily if needed.



4.

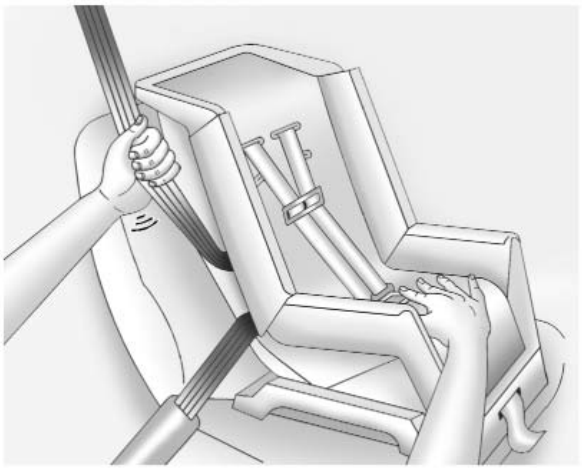
Pull the shoulder belt all the way out of the retractor.

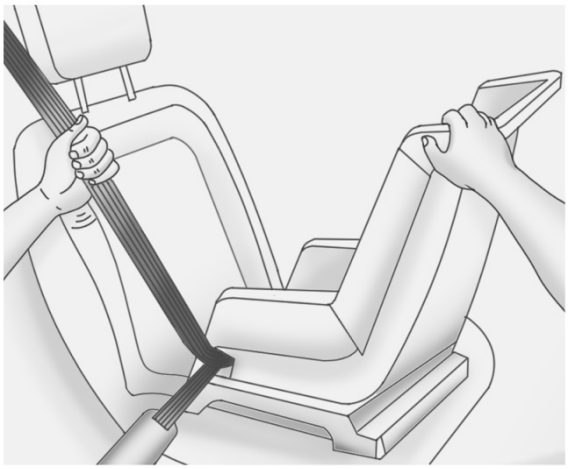
This will make the **retractor locking knob**, located above the shoulder belt anchor, pop out.

While holding the belt out, **turn the knob** one quarter turn clockwise to set the lock on the retractor.

When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.

The knob will automatically retract when the webbing is released.





5. To tighten the belt, push down on the child restraint, pull the shoulder portion of the belt to tighten the lap portion of the belt, and feed the shoulder belt back into the retractor.

When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.

6. Try to pull the belt out of the retractor to make sure the retractor is locked.

If the retractor is not locked, repeat Steps 3 through 5.

11. For forward-facing child restraints, attach the top tether. Tether instructions are in the child restraint instructions and in the vehicle manual "Tether" section.

12. Before placing a child in the child restraint, make sure it is securely held in place. To check, grasp the child restraint at the safety belt path and attempt to move it side to side and back and forth. When the child restraint is properly installed, there should be no more than 2.5 cm (1 in) of movement.

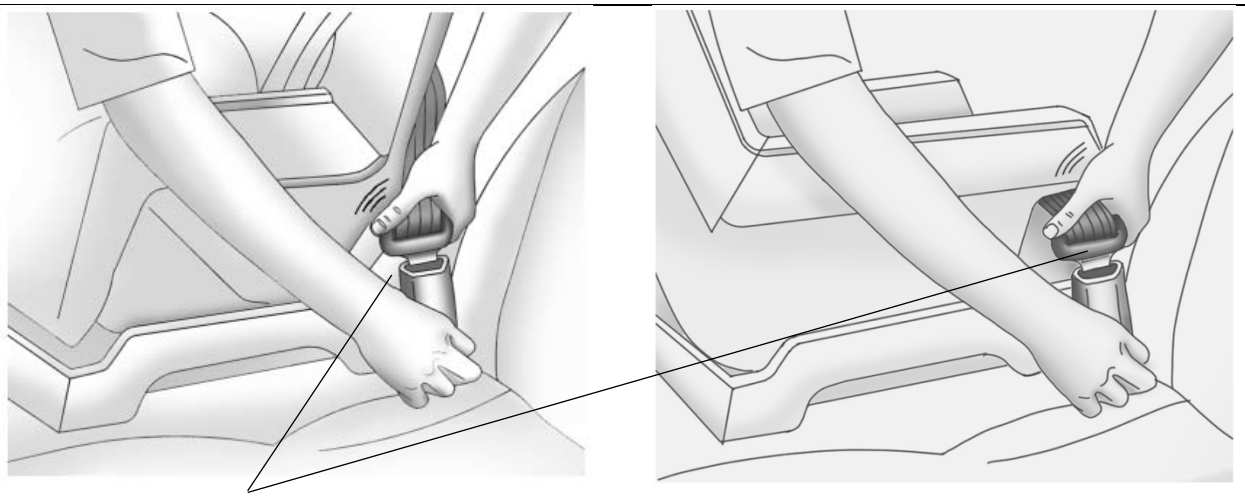
Note: the retractor lock will not set if the latch plate is not buckled.

To remove the child restraint, unbuckle the vehicle safety belt and remove it from the restraint. If the top tether is attached to a top tether anchor, disconnect it.

Device 3 Instructions

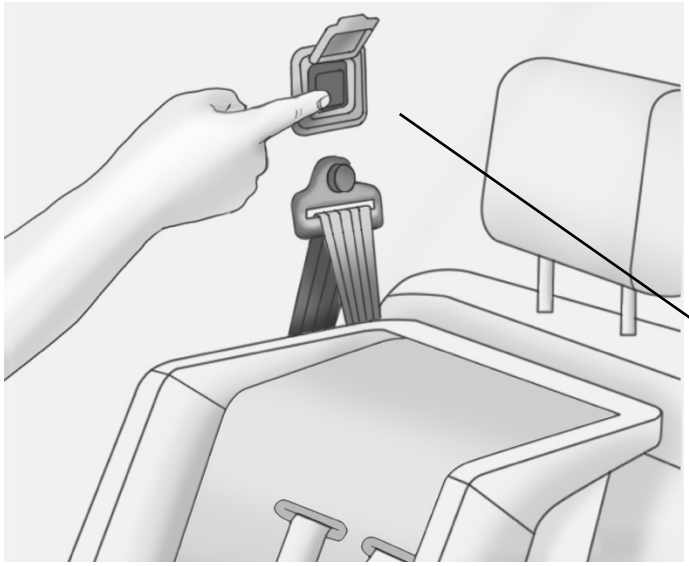
1. Put the child restraint on the seat.

2. Pick up the latch plate, and run the lap and shoulder portions of the vehicle's safety belt through the belt path of the child restraint. The child restraint instructions will show you how.



3. Push the latch plate into the buckle until it clicks.

Place the buckle stalk so you can reach the red buckle release button easily if needed.

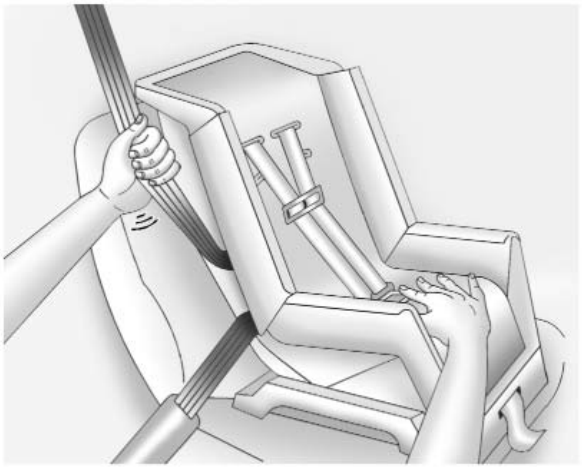


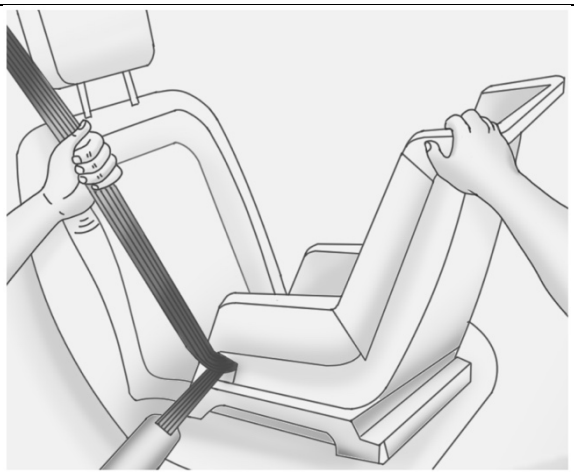
4.

Open the cover of the retractor locking button, located above where the shoulder belt attaches to the vehicle.

Press the button to set the lock. When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.

You can unlock the belt by pushing the button again or by releasing the buckle





5. To tighten the belt, push down on the child restraint, pull the shoulder portion of the belt to tighten the lap portion of the belt, and feed the shoulder belt back into the retractor.

When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.

6. Try to pull the belt out of the retractor to make sure the retractor is locked.

If the retractor is not locked, repeat Steps 3 through 5.

13. For forward-facing child restraints, attach the top tether. Tether instructions are in the child restraint instructions and in the vehicle manual "Tether" section.

14. Before placing a child in the child restraint, make sure it is securely held in place. To check, grasp the child restraint at the safety belt path and attempt to move it side to side and back and forth. When the child restraint is properly installed, there should be no more than 2.5 cm (1 in) of movement.

Note: the retractor lock will not set if the latch plate is not buckled.

To remove the child restraint, unbuckle the vehicle safety belt and remove it from the restraint. If the top tether is attached to a top tether anchor, disconnect it.

VEHICLE MANUAL

Table of Contents

Vehicle Manual LATCH Instructions

Locating LATCH Lower Anchorages

The lower anchorages are round bars that are found at the rear of the seat cushion where it meets the seatback, below the anchorage symbols on the seatback. They are just visible when you lean into the rear seat to install the child restraint. You will easily feel them if you run your finger along the gap between the seatback and seat cushion.

2nd Row Lower Anchorages

Using the LATCH Lower Anchors

1. Loosen the adjusters on the lower straps and on the tether strap of the child seat so that you can more easily attach the hooks or connectors to the vehicle anchorages.

2. Attach the lower hooks or connectors of the child restraint to the lower anchorages in the selected seating position.

3. If the child restraint has a tether strap, connect it to the top tether anchorage. See below for directions to attach a tether anchor.

Vehicle Manual TETHER Instructions

Locating TETHER Anchorages

There are tether strap anchorages located behind all second row seating positions. The third row has a tether anchor on the 40% seat for the right outboard position and in the center of the 60% seat for either the center or left outboard seating position. All tether anchorages are located onthe back of the seat, near the floor.

2nd Row Tether Anchorages

Tether Strap Attachment

When installing a forward-facing child restraint, always secure the top tether strap, up to the tether anchor weight limit, whether the child restraint is installed with the lower anchors or the vehicle seatbelt.

1. Route the tether strap to provide the most direct path for the strap between the anchor and the child seat.
2. If your vehicle is equipped with adjustable rear head restraints, raise the head restraint, and where possible, route the tether strap under the head restraint and between the two posts. If not possible, lower the head restraint and pass the tether strap around the outboard side of the head restraint.
3. Attach the tether strap hook of the child restraint to the top tether anchorage and remove slack in the tether strap according to the child restraint manufacturer's instructions.

Vehicle Manual SEATBELT Instructions

Installing the Child Restraint Using the Vehicle Seatbelts

The seatbelts in the passenger seating positions are equipped with a Switchable Automatic Locking Retractor (ALR) that is designed to keep the lap portion of the seatbelt tight around the child restraint. Any seatbelt system will loosen with time, so check the belt occasionally, and pull it tight if necessary.

To Install a Child Seat Using An ALR

1. Pull enough of the seatbelt webbing from the retractor to pass it through the belt path of the child restraint. Do not twist the belt webbing in the belt path.
2. Slide the latch plate into the buckle until you hear a "click."
3. Pull on the webbing to make the lap portion tight against the child seat.
4. To lock the seatbelt, pull down on the shoulder part of the belt until you have pulled all the seatbelt webbing out of the retractor. Then, allow the webbing to retract back into the retractor. As the webbing retracts, you will hear a clicking sound. This means the seatbelt is now in the Automatic Locking mode.
5. Try to pull the webbing out of the retractor. If it is locked, you should not be able to pull out any webbing. If the retractor is not locked, repeat the last step.
6. Finally, pull up on any extra webbing to tighten the lap portion around the child restraint while you push the child restraint rearward and downward into the vehicle seat.
7. If the child restraint has a top tether strap and the seating position has a top tether anchorage, connect the tether strap to the anchorage and tighten the tether strap. See below for directions to attach a tether anchor. Test that the child restraint is installed tightly by pulling back and forth on the child seat at the belt path. It should not move more than 1 inch (25.4 mm) in any direction.

Attaching the Top Tether Strap (With Either Lower Anchors or Vehicle Seatbelt)

When installing a forward-facing child restraint, always secure the top tether strap, up to the tether anchor weight limit, whether the child restraint is installed with the lower anchors or the vehicle seatbelt.

APPENDIX C: INSTALLATION/ENTANGLEMENT SCRIPTS

Introduction Script

CRS should be set up in test configuration. Remove optional padding and cup holders for toddlers, but leave harness covers in place. Leave locking clip in stowed location.

Thank you for coming in today. We're doing a study on how people would use new seatbelt designs. We are going to ask you to put child seats in this vehicle mockup today using different seatbelts. You will use the instructions for the child seat and the vehicle. Let me know each time when you are done. When you are done, I will take some measurements, and you will answer some questions. Then we will go onto the next child seat. We will also do some tests simulating possible problems with the seatbelt.

We will videotape or photograph some of the installations. When we do, we would like you to talk about what you are doing and thinking. You might want to remove your jewelry. Please remember that most people make mistakes when installing child seats. It is common for people to feel frustrated installing a child seat. If you do feel frustrated, please just try to do your best. We are testing the seatbelts, not you.

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

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

Give participant the consent form to read and sign. Give participant the ParticipantForm1_RaceEthnicitySurvey form to fill out.

This platform represents the floor of a vehicle. Please feel free to step up on the platform or move around the platform to install the child restraints.

On this platform are the child restraint that for you to install and instructions if you would like to use them.

We will be recording you with this camera. We would like you to talk about what you are doing and thinking as you install the child restraints.

INSTALL # 1 (SEATBELT)

(1a. if seat is forward facing)

Please install this seat forward-facing using the seatbelt. By forward-facing, I mean the child would be facing the same direction as the driver.

Point participant towards first child restraint to be installed. Record start time of installation.

(1b. if seat is rear facing)

Please install this seat rear-facing using the seatbelt. By rear-facing, I mean the child would be facing the trunk of the vehicle.

Point participant towards first child restraint to be installed. Record start time of installation.

INSTALL # 2 (LATCH)

(2a. if seat is forward facing)

Please install this seat forward-facing using the LATCH system. By forward-facing, I mean the child would be facing the same direction as the driver.

Point participant towards first child restraint to be installed. Record start time of installation.

(2b. if seat is rear facing)

Please install this seat rear-facing using the LATCH system. By rear-facing, I mean the child would be facing the trunk of the vehicle.

Point participant towards first child restraint to be installed. Record start time of installation.

INSTALL # 3 up to 9

(1a. if seat is forward facing)

Please install this seat forward-facing using the seatbelt. By forward-facing, I mean the child would be facing the same direction as the driver.

Point participant towards first child restraint to be installed. Record start time of installation.

(1b. if seat is rear facing)

Please install this seat rear-facing using the seatbelt. By rear-facing, I mean the child would be facing the trunk of the vehicle.

Point participant towards first child restraint to be installed. Record start time of installation.

After each installation give the participant the ParticipantForm2_AssessInstalls form.

After all the installations give the participant the ParticipantForm4_PostRanking form.

Question Handling for Installations

If participant asks for help, experimenter can refer them to the instructions.

If the participant asks the experimenter questions, say "I'm not allowed to help you, but can point you to information in the instructions for the child seat."

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

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

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

Record end time of installation. Give participant questionnaire. Assess installation using check form.

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

Entanglement Scenarios

Show ATD in seat without belt.

For this part, you will be removing a seatbelt from this crash test dummy. It is secured to the seat with this orange belt. Do not remove the dummy or the orange belt while removing the seatbelt.

Move participant behind screen and read the following

We are going to time you to see how fast you can remove the seatbelt from the dummy. Imagine you look in your back seat and you see your child stuck in the seatbelt and in danger. Please try to get the seatbelt off the dummy as quickly as possible. Don't remove the dummy from the seat, just return the seatbelt to its stowed position.

Apply seatbelt.

Bring participant out

Go.

Point participant towards first child restraint to be installed. Record start time of installation.

After each entanglement scenario give the participant the ParticipantForm3_AssessEntanglement form.

At the end of all installations and entanglement scenarios give the participant the ParticipantForm5_PostTestQuestions

APPENDIX D: PARTICIPANT INSTALLATION QUESTIONNAIRES

SEATBELT

Participant ID: _____ Date: _____

Installation number: 1 2 3 4 5 6 7 **CRS:** R1 R2 F1 F2

Device: SB D1 D2 D3

Check one answer for each question

Do you agree with these statements?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Don't know	NA
I attached the child seat to the vehicle seat correctly.							
This installation was harder than what I do at in my own vehicle.							

Other comments:

Please rate how hard or easy you found it to….	Very Hard	Hard	Easy	Very Easy	Don't know	NA
Understand the vehicle instruction manual about installing the child seat						
Figure out how to lock the seatbelt						
Figure out where to route the vehicle belt						
Tighten the vehicle seatbelt						
Figure out what angle the child seat should be						
Adjust the angle of the child seat						
Find the tether anchorage in the vehicle						
Attach the tether strap on the top of the child seat to the vehicle						

Other comments:

LATCH

Participant ID: _____ Date: _____

Installation number: L1 L2 **CRS:** R1 R2 F1 F2

Device: LATCH

Check one answer for each question

Do you agree with these statements?	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Don't know**	**NA**
I attached the child seat to the vehicle seat correctly.							
This installation was harder than what I do at in my own vehicle.							

Other comments:

Please rate how hard or easy you found it to….	**Very Hard**	**Hard**	**Easy**	**Very Easy**	**Don't know**	**NA**
Understand the vehicle instruction manual about installing the child seat						
Find the lower anchorages in the vehicle						
Figure out what angle the child seat should be						
Adjust the angle of the child seat						
Find the tether anchorage in the vehicle						
Attach the LATCH belt connectors to the lower anchorages						
Tighten the LATCH belt						
Attach the tether strap on the top of the child seat to the vehicle						
Tighten the tether strap on the top of the child seat						

Other comments:

APPENDIX E. INVESTIGATOR FORMS

CRS Installation Assessment From

Participant ID: _____ Date: _____

Installation number: 1 2 3 4 5 6 7 8 9 **CRS:** R1 R2 F1 F2

Device: SB D1 D2 D3 LATCH

Start time: End time: Evaluator:

CRS

	Yes	No	NA	Comments
Does CRS pass 1" movement test				
Angle correct				

Tightness measurement:

TETHER

	Yes	No	NA	Comments
Recommended				
Used				
Attached to correct vehicle hardware				
Oriented correctly				

Tightness measurement:

LATCH

	Yes	No	NA	Comments
Fully engaged				
Connectors oriented properly				
Attached to correct vehicle hardware				
LATCH belt flat				

VEHICLE BELT

	Yes	No	NA	Comments
Routed correctly through belt path				
Seatbelt flat (not twisted)				

	Retractor	CRS Lockoffs
Recommended:		
Participant Used:		

Investigator Entanglement Assessment Form

Participant ID: _____ Date: _____

Trial number: 1 2 3 4 5 6 7 8 9

Device: SB D1 D2 D3

Duration: Evaluator:

Evaluator should record actions taken by subject to disentangle dummy by numbering them in order.

_____	Unbuckle belt		_____
_____	Unwrap belt		_____
_____	Move dummy		_____
_____	Move belt		_____
_____	Look at vehicle instructions		_____
_____	Look at device labeling		_____
_____	Feed seatbelt in		_____
_____	Pull seatbelt out		_____
_____	Turn knob		_____
_____	Push button		_____
_____	Other 1	note:	_____
_____	Other 2	note:	_____
_____	Other 3	note:	_____
_____	Other 4	note:	_____
_____	Other 5	note:	_____

APPENDIX F. PARTICIPANT SESSION ENTANGLEMENT ASSESSMENT FORM

Participant ID: _____ Date: _____

Trial number: 1 2 3 4 5 6 7 8 9

Device: SB D1 D2 D3

Check one answer for each question

Do you agree with these statements?	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Don't know**	**NA**
It was easy to get the belt off the dummy.							
I was able to figure out how to release the belt.							
The symbols were easy to understand.							
The manual instructions helped me figure out how to get the belt off.							
What I did today was what I would do if this happened in my own vehicle.							

Other comments:

APPENDIX G: PARTICIPANT INSTALLATION RANKING FORM

Participant ID: _____ Date: _____

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

LATCH Seatbelt Device 1 Device 2 Device 3

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

LATCH Seatbelt Device 1 Device 2 Device 3

Please give each trial a rating on how easy it was to install the child seat. 1 is easiest, 10 is hardest.

		Easiest									Hardest
Trial	Name of Installation	1	2	3	4	5	6	7	8	9	10
1											
2											
3											
4											
5											
6											
7											
8											
9											

Comments:

APPENDIX H: PARTICIPANT POST-STUDY QUESTIONNAIRE

Participant ID:_____ Date:_____

Before today, I have installed these types of car seats (check all that apply):

- ☐ none
- ☐ Infant seat
- ☐ Convertible seat, with the child facing the rear of the vehicle
- ☐ Convertible seat, with the child facing the front of the vehicle
- ☐ Forward-facing seat with harnesses
- ☐ Booster seat

Before today, I have installed car seats using (check all that you have used)

- ☐ no previous experience
- ☐ Seatbelt
- ☐ Lower anchors (part of LATCH)
- ☐ Tether (part of LATCH)

What level of school did you finish?

- ☐ Some high school
- ☐ High School
- ☐ Some college
- ☐ College
- ☐ Graduate school

APPENDIX I: COMFORT TRIAL SCRIPT AND QUESTIONS

Comfort and Usability

Please sit in the vehicle seat and put on the seatbelt. This is seatbelt A (or B or C)

Subject follows directions.

Please rate the comfort of this seatbelt on a scale of 1 to 5, where 5 is most comfortable and 1 is least comfortable.

Comfort rating 1 2 3 4 5

Please use your right hand to reach for the water bottle.

Subject will lean forward and to the left to reach the water bottle. This may extend the seatbelt to the point where it switches to locking mode. If the seat belt locks and they cannot reach the bottle, hand it to their outstretched hand.

Seat belt switched to locking mode: ___Yes ____ No

Do you notice anything different about the seatbelt?

Please use your right hand to reach for the water bottle again.

If the seat belt is locked and they cannot reach the bottle, hand it to their outstretched hand.

Seat belt switched to locking mode: ___Yes ____ No

Do you notice anything different about the seatbelt now?

Show me what you would do in a vehicle if this happened.
(Record what subject does.)

If seatbelt doesn't lock:

Experimenter pulls out the seatbelt to lock it (and moves buckle switch if needed)

Do you notice anything different about the seatbelt now?

Show me what you would do in a vehicle if this happened.
(Record what subject does.)

Please remove the seatbelt. **Record issues in removing seatbelt.**

POST: Comfort Questionnaire

Can you describe the differences between the three seatbelts you tried?

Have you ever accidentally locked the seatbelt in the back seat of your vehicle?

____Yes ___ No

APPENDIX J: PHASE 2 INSTRUCTION MANUALS

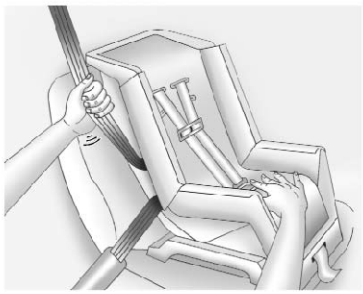
VEHICLE MANUAL for Installing with Seatbelt System "B" and Tether

1. Put the child restraint on the seat.
2. Pick up the latch plate, and run the lap and shoulder portions of the vehicle's safety belt through the belt path of the child restraint. The child restraint instructions will show you where the belt path is.

3. Push the latch plate into the buckle until it clicks.
4. Place the buckle stalk so you can reach the red buckle release button easily if needed.

5. **Pull the shoulder belt all the way out of the retractor to set the lock.**

   When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.



6. To tighten the belt, push down on the child restraint, pull the shoulder portion of the belt to tighten the lap portion of the belt, and feed the shoulder belt back into the retractor.
7. Try to pull the belt out of the retractor to make sure the retractor is locked.

   >>> If the retractor is not locked, repeat Steps 3 through 5. <<<
8. For forward-facing child restraints, attach the top tether. Tether instructions are in the child restraint manual and on the next page of this document.
9. Before placing a child in the child restraint, make sure it is securely held in place. To check, grasp the child restraint at the safety belt path and attempt to move it side to side and back and forth. When the child restraint is properly installed, there should be no more than 2.5 cm (1 in) of movement.

Note: The retractor lock will not set if the latch plate is not buckled.

To remove the child restraint, unbuckle the vehicle safety belt and remove it from the restraint. If the top tether is attached to a top tether anchor, disconnect it.

VEHICLE MANUAL for Installing with Seatbelt System "C" and Tether

1. Put the child restraint on the seat.
2. Pick up the latch plate, and run the lap and shoulder portions of the vehicle's safety belt through the belt path of the child restraint. The child restraint instructions will show you where the belt path is.

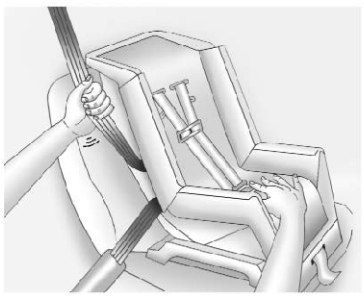
3. Push the latch plate into the buckle until it clicks
4. Place the buckle stalk so you can reach the red buckle release button easily if needed.

5. Switch the buckle to child seat mode

6. **Pull the shoulder belt all the way out of the retractor to set the lock.**

   When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.

7. To tighten the belt, push down on the child restraint, pull the shoulder portion of the belt to tighten the lap portion of the belt, and feed the shoulder belt back into the retractor.



8. Try to pull the belt out of the retractor to make sure the retractor is locked.

   >>> If the retractor is not locked, repeat Steps 3 through 5. <<<

9. For forward-facing child restraints, attach the top tether. Tether instructions are in the child restraint manual and on the next page of this document.

10. Before placing a child in the child restraint, make sure it is securely held in place. To check, grasp the child restraint at the safety belt path and attempt to move it side to side and back and forth. When the child restraint is properly installed, there should be no more than 2.5 cm (1 in) of movement.

Note: The retractor lock will not set if the latch plate is not buckled.

To remove the child restraint, unbuckle the vehicle safety belt and remove it from the restraint. If the top tether is attached to a top tether anchor, disconnect it.

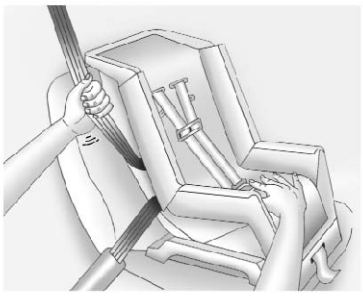
VEHICLE MANUAL for Installing with Seatbelt System "A" and Tether

1. Put the child restraint on the seat.
2. Pick up the latch plate, and run the lap and shoulder portions of the vehicle's safety belt through the belt path of the child restraint. The child restraint instructions will show you where the belt path is

3. Push the latch plate into the buckle until it clicks.
4. Place the buckle stalk so you can reach the red buckle release button easily if needed.

5. **Pull the shoulder belt all the way out of the retractor to set the lock.**

   When the retractor lock is set, you can tighten the belt but not pull it out of the retractor.



6. To tighten the belt, push down on the child restraint, pull the shoulder portion of the belt to tighten the lap portion of the belt, and feed the shoulder belt back into the retractor.
7. Try to pull the belt out of the retractor to make sure the retractor is locked.

   >>> If the retractor is not locked, repeat Steps 3 through 5. <<<
8. For forward-facing child restraints, attach the top tether. Tether instructions are in the child restraint manual and on the next page of this document.
9. Before placing a child in the child restraint, make sure it is securely held in place. To check, grasp the child restraint at the safety belt path and attempt to move it side to side and back and forth. When the child restraint is properly installed, there should be no more than 2.5 cm (1 in) of movement.

To remove the child restraint, unbuckle the vehicle safety belt and remove it from th restraint. If the top tether is attached to a top tether anchor, disconnect it.

Link to video instructions