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Usability Study of the Universal Anchorage System for Child Restraints in School Buses and Passenger Vehicles

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The study assesses the usability of the Universal Anchorage Systems (UAS) in cars and school buses, and provides guidance on potential UAS design improvements and recommendations concerning labelling and instructions related to the UAS.

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16. Résumé

Cette évaluation, de l'utilisabilité d'un dispositif universel d'ancrages (DUA) dans les voitures et les autobus scolaires, fournit des conseils sur les améliorations potentielles de la conception du DUA et fait des recommandations sur les instructions et l'étiquetage relatifs au DUA.

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1. ABSTRACT

Since 2002, Transport Canada has required that all new vehicles and child restraint systems (CRS) be equipped with the Universal Anchorage System (UAS), which includes lower anchorage, and top tether, attachments. Despite being designed to make CRS installation in vehicles easier and with fewer opportunities for misuse, there have been reports that the UAS is not as easy to use, or as effective, as hoped (Arbogast and Jermakian, 2007; Decina, Lococo & Doyle, 2006; Consumer Reports, 2003; Status Report, 2001). To date, however, there have been no systematic or experimental studies evaluating the usability of the UAS.

Based on research demonstrating that small children on school buses are not protected from injury in the same manner as larger children (Legault, 2004), Transport Canada will require, effective April 2007, that UAS anchorages be installed on a proportion of seats in all school buses, allowing for the installation of CRS. The present study, therefore, was designed to assess the usability of the UAS in both cars and school buses. The main objectives of the study were to provide guidance on potential UAS design improvements and to make recommendations concerning labelling and instructions related to the UAS.

Users installed CRS in a car and a school bus using three different types of lower anchorage connectors and top tethers. Surprisingly, many participants were not familiar with the UAS, and believed that CRS should only be installed using the seat belt. Over 40 per cent of participants did not know where the lower anchorage connectors were located in the car. While installation performance using the UAS was generally satisfactory (all CRS were installed correctly between 70 and 92 per cent of the time), UAS design improvements for both the CRS and the vehicles were identified. A supplementary, informal usability study (Appendix C) done in the school bus identified a number of additional issues relating to the use of CRS in these vehicles. The implementation of the proposed design improvements by CRS and automotive manufacturers should increase the overall usability of the UAS and increase its effectiveness in the event of collisions.

2. INTRODUCTION

Despite their use being mandated by all provinces and territories, CRS are improperly installed in vehicles at least 32 per cent of the time (Transport Canada, 1998). Transport Canada has investigated factors that may contribute to their misuse or non-use (Noy & Arnold, 1995; Rudin-Brown et al., 2003; Rudin-Brown et al., 2004). Because of the high rates of misuse, an alternative method of attaching the CRS to the vehicle was developed, and is now known as the Universal Anchorage System (UAS, or LATCH—Lower Anchors And Tethers for Children—in the U.S.). Designed to make the installation task easier and with fewer opportunities for misuse (Pedder et al., 1994), the UAS has been required on all new vehicles and CRS since September 2002 (Canadian Motor Vehicle Safety Standards 210.1 and 210.2).

Despite the intended benefits of the UAS system, there have been several reports that it is not as effective and easy to use as hoped. While it was originally intended that CRS would be outfitted with rigid lower anchorages (Turbell et al., 1993; Pedder et al., 1994), the final regulation gives CRS manufacturers the option of using either rigid, or flexible, attachments. In 2001, the Insurance Institute for Highway Safety tested three CRS equipped with flexible UAS attachments in 13 different passenger vehicles (Status Report, 2001). They compared these seats with a European model, which uses rigid UAS attachments. The researchers found it difficult to install the CRS with flexible attachments as securely as the CRS with rigid ones. They found it especially difficult to tighten the lower attachments enough so that the CRS would not move more than an inch from side to side. As well, the CRS with the rigid attachments was easier to use. They concluded that, at the time, CRS manufacturers were not yet offering anchor attachments that accommodate all the seating and anchor differences among cars, and that they may be choosing to offer only flexible attachments because these can be added to CRS with little or no fundamental design changes to the seats. The Insurance Institute concluded that flexible anchor attachments had not yet been perfected, and that CRS makers “still have a long way to go before parents have a foolproof means of correctly installing child seats in all cars” (Status Report, 2001, p.5).

Consumer Reports (2003) tested 25 CRS, including infant and booster seats, and found that seven performed ‘somewhat better’ in their crash tests when fastened with the vehicle seat belts rather than the UAS. They also found that some seats were impossible to install using the UAS; one system that used rigid lower connectors could not be installed in vehicles with steeply sloping rear seats. Tether straps on some models were found to be ‘very difficult’ to attach and adjust on some seats.

In 2002, CRS use and misuse observational data that was collected from six U.S. states (Decina & Lococo, 2005) revealed UAS misuse associated with both the upper tether and the lower anchorages. More recently, the U.S. National Highway Traffic Safety Administration (NHTSA) commissioned an observational CRS survey to ascertain whether drivers with UAS-equipped vehicles were using the system to secure their CRS to the vehicle and, if so, were they using the system correctly (Decina, Lococo, & Doyle, 2006). Interestingly, the study found that 41 per cent of parents and caregivers chose to use the vehicle seat belt to install the CRS, even though both the seating position in the vehicle and the CRS were fully equipped with the UAS. Sixty one per cent of seats installed using lower anchorages were installed securely, an improvement compared to previous surveys where seat belts were used (50 per cent installed securely). A surprising 44 per cent of UAS-equipped CRS were installed without using the top tether, even though the seating position was equipped with one. The majority (55 per cent) of people who did not use the lower anchors, even when their vehicle was equipped with them, cited lack of knowledge as the reason for not using them. Many drivers thought that seat belts were safer or better than the lower attachments, or stated that they used them simply because they knew how to use them. Many people falsely believed that their vehicle, or the seating position, was not equipped with UAS lower anchorages, even though it was. Although there were not many CRS with rigid lower attachments observed in the study (5 out of 354), ease-of-use ratings for rigid lower attachments were much more positive than for those that used flexible straps. Results from this study point to the need to educate the public on the capabilities and appropriate use of the UAS.

Finally, a field observational study that looked at the effectiveness of the UAS in actual collisions found frequent misuse of the system (Arbogast & Jermakian, 2007). Mistakes included incorrect use of outboard lower anchors when the CRS was installed in the centre seating position, and failure to tighten, and gross misuse of, the UAS lower attachment strap. While conclusions related to the overall effectiveness of the UAS could not be made from the data, the authors caution that continued evaluation of design specifications for the UAS is necessary.

Daycare centres and some schools are increasingly likely to transport pre-school age children on school buses. Whether small children are adequately protected when riding on school buses has, therefore, recently received considerable attention. Previous research and experience demonstrated that larger, school-aged, children on school buses are protected from injury by a feature called ‘compartmentalization’. In a collision, the occupant’s body moves forward, contacting and deforming the energy-absorbing seat back in front, distributing the force of the collision across the entire upper body area. Transport Canada conducted tests to evaluate the safety of small children in school buses (Legault, 2004) and found that they are not protected from injury as well as larger children. Researchers tested three sizes of child test dummy in simulated crash tests. When not restrained in a CRS, dummies representing an 18-month old and a 3-year old child experienced head and chest acceleration values that were significantly higher than allowed under the current regulation. The test dummy representing a 6-year old child did not experience these elevated acceleration values. To increase the protection of small children (those weighing less than 40 lbs or 18 kg) on school buses, Transport Canada decided to require, as of April 2007, that all new school buses in Canada be able to accommodate the installation of CRS using UAS lower bars and top tether anchors (Canada Gazette, 2006).

The International Organization for Standardization defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” (ISO, 1998). Transport Canada wants to determine if the UAS system is as effective in actual practice as it was designed to be. Canadian parents and caregivers must not only be aware of it, but they should find it easy to use correctly. As well, use of the UAS to install CRS on school buses should not have unexpected, or unreasonable, consequences. To address these two concerns, the present study focused on the usability of the UAS, both in a car, and a school bus, environment.

3. PURPOSE AND SCOPE OF THE STUDY

The purpose of the study was to evaluate and compare the usability of different types of top tether and lower anchorage connectors when users installed CRS in a car and a school bus. An additional study (Appendix C) investigated general usability issues concerning CRS installation in school buses.

4. GENERAL METHOD

4.1 RESEARCH DESIGN

A within-subjects design assessed the effect of UAS lower anchorage and top tether design on CRS installation performance in a car and a school bus.

4.2 PARTICIPANTS

A total of 48 people participated in the study. Participants were divided into two age groups (20 to 39 *vs*. 40 to 65 years). Half the participants in each age group were experienced CRS users, the other half, inexperienced. An individual was considered to be an experienced CRS user if s/he had installed a CRS into a vehicle within the past two years. An individual was considered to be an inexperienced CRS user if s/he had **never** installed a CRS into a vehicle. Individuals who were professionally affiliated with any organization involved with CRS, and/or with previous experience using any of the three specific CRS used in the study, were excluded.

Participants were recruited through flyers and newspaper advertisements and received $30.00 for their participation (approximately 1.5 hours).

4.3 EQUIPMENT

Three commercially available, UAS-equipped, convertible (those that can be installed either rear- or forward-facing) CRS were used. Although subjects were required to install the CRS in the forward-facing position only, convertible CRS were chosen due to their considerable installation complexity and their popularity among the public. A literature search determined that only lower attachments using flexible webbing are currently available in Canada. These flexible designs vary, however, in terms of the lower anchorage connector clip that secures the CRS to the vehicle. The three study CRS all differed in terms of their lower anchorage, and top tether, designs. Table One summarizes the differences between the three CRS.

Table 1. CRS top tether and lower anchorage connector features.

	CRS A	CRS B	CRS C
Top Tether Strap	• Double strap	• Single strap	• Single strap
Top Tether Connector Design	• C-clip (hook-on)	• C-clip (hook-on)	• C-clip (hook-on)
Top Tether Connector Attachment and Release	• Manual	• Manual	• Manual
Top Tether Tension Adjuster Release	• Pushbutton release (hold button down to pull strap through adjuster)	• Adjuster angled to allow tether strap to 'slide' through adjuster	• Adjuster angled to allow tether strap to 'slide' through adjuster
Top Tether Attachment Point on CRS	• 2 attachment points; each strap is attached at the top and corners of the CRS back	• Attachment point is located approximately one-quarter down from the top of the CRS back (under locking mechanism)	• Attachment point is located at the top of the CRS back
Lower Anchorage Strap Design	• Flexible Webbing • Two independent straps permanently attached to CRS	• Flexible Webbing • Single strap routed through the CRS (must re-thread when converting CRS to rear-facing)	• Flexible Webbing • Single strap routed through the CRS (must re-thread when converting CRS to rear-facing)
Lower Anchorage Connector Design	• Jaw-type (push-on)	• C-clip (hook-on)	• Push-button C-clip (hook-on)
Lower Anchorage Connector Attachment and Release	• Force applied against lower anchorage connector clip • Pushbutton release	• Manual	• Button press
Lower Anchorage Tension Adjuster Design	• Two tension adjusters; one for each lower anchor connector strap (e.g., each side of CRS)	• One tension adjuster; attached to one lower anchorage connector (e.g., one side of CRS)	• One tension adjuster; attached to one lower anchorage connector (e.g., one side of CRS)
Lower Anchorage Tension Adjuster Release	• Pushbutton release (hold button down to pull strap through adjuster)	• Pushbutton release (hold button down to pull strap through adjuster)	• Pushbutton release (hold button down to pull strap through adjuster)

The three CRS evaluated in the present study were: CRS A— jaw-type (push-on) lower anchors and double strap top tether (Figure 1); CRS B—C-clip (hook-on) lower anchors and single strap top tether (Figure 2); and CRS C—push-button C-clip (hook-on) lower anchors and single strap top tether (Figure 3).

Figure 1. Top tether and lower attachments on CRS A.

Figure 2. Top tether and lower attachments on CRS B.

Figure 3. Top tether and lower attachments on CRS C.

A top-selling, four-door sedan was used as the test passenger vehicle. The lower anchorage connector bars were located within the seat bight and were not visible. Two grey identifier decals indicated the general location of the bars (Figure 4). The top tether anchor was located behind the head restraint on the rear shelf (Figure 5), and was identified by a CRS indicator symbol (Figure 6).

Figure 4. Lower anchorages (car).

Figure 5. Top tether anchor (car).

Figure 6. Top tether anchor indicator symbol (car).

The school bus mock-up used in the present study is shown in Figure 7. It contained three standard school bus seats on one side of an open aisle. Lower anchorage bars were bright yellow in colour, and were located forward of the seat bight (Figure 8). The tether anchor was located at the bottom rear of the seat back (Figure 9). The placement and configuration of the lower anchorages and top tether were based on current industry practice and discussions with manufacturers.

Figure 7. School bus mock-up.

Figure 8. Lower anchorages (school bus).

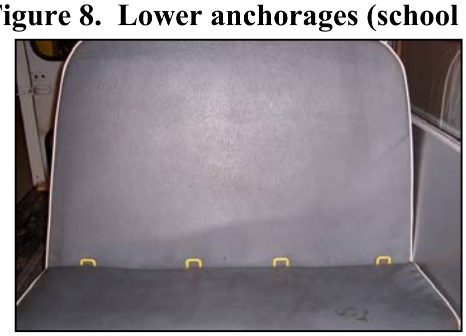


Figure 9. Top tether anchor (school bus).

Tether slack, lower attachment slack, side-to-side movement of the CRS, and the space between the back of the CRS and the vehicle/bus seat back was measured using 2.54 cm (1") through 15.24 cm (6") wooden spacers. Two digital video cameras recorded the experimental trials.

4.4 PROCEDURE

Each test session lasted approximately 90 minutes. Prior to the study, participants were briefed on the nature of the experiment and were informed of their right to withdraw from the experiment at any time.

Before being instructed to install any of the CRS, participants' knowledge of the existence of the UAS system was assessed by asking them the following general installation question: "You are installing a newly purchased child seat. How would you attach the child seat to a vehicle?"

The participant was then required to install each of the three CRS in both the car and the school bus. To control for sequencing effects, order of installation was varied according to a Latin Square design. Prior to each installation, the participant was instructed to install the CRS in the forward-facing position using the UAS connectors, as opposed to the seatbelt. For the first installation of each CRS, the participant was instructed to familiarise him/herself with it while disregarding the interior child harness straps.

During the familiarisation period, participants' knowledge of the UAS system was again assessed by recording whether they asked what the UAS connectors were. If a participant asked, the facilitator would instruct them to continue familiarising themselves in order to determine the function of the connectors. The time it took each participant to become familiar with each CRS was recorded (maximum of five minutes). Upon completion of the familiarisation period, if the participant still did not know the function of the UAS connectors, the facilitator again recorded that the question had been asked, and provided minimal instruction. Once the CRS familiarisation period was over, the participant was given the opportunity to familiarise him/herself with the car and school bus mock-up.

Each CRS was installed in the back seat of the car on the driver's side, or in the middle seat of the school bus, next to the window. The participant was reminded that the CRS would not be safe if it was improperly secured and, therefore, that they should take as much time as needed. The participant was encouraged to 'think out loud' so the facilitator could capture the participant's comments and opinions as the trial progressed.

The participant informed the facilitator when s/he had completed each CRS installation. The facilitator conducted a brief check of the installation to ensure that the tether strap was attached and, if not, prompted the participant to secure it. The error was noted on the *Participant Installation Error Form*. The completion time for the CRS installation was then recorded.

During the course of an installation, whether a participant needed prompting as to where the lower connector bars were located inside the car was noted on the *Participant Installation Error Form*. The first time it happened, s/he was prompted to look at the vehicle owner's manual. If, after reading the manual, the participant still could not locate the lower anchorage bars, the facilitator showed them where they were.

After each installation, the participant completed the *CRS Installation Usability Questionnaire* (Questions 1-3: Installation), as well as the *User Confidence Questionnaire*. After completing the questionnaires, the participant was instructed to remove the CRS from the vehicle. The time it took to remove the CRS was recorded. The participant then completed the *CRS Installation Usability Questionnaire* (Questions 4-5: Removal). While the participant completed the questionnaires, the facilitator inspected the CRS installation and recorded errors on the *Participant Installation Error Form*. The facilitator then reconfigured the CRS to its initial position. After the sixth and final installation trial, the participant completed the *General Usability Questionnaire*.

At the end of the test session, participants were briefed in more detail regarding the purpose of the study and were permitted to ask questions or voice concerns. The *Participant Installation Error Form, User Confidence Questionnaire, CRS Installation Usability Questionnaire,* and the *General Usability Questionnaire* are included in Appendix A.

4.5 Severity Scores

The severity of potential UAS-related usability errors was adapted from Noy and Arnold (1995) and Rudin-Brown et al. (2004) using Czernakowski and Müller's (1991; 1993) MMEA procedure. Three subject matter experts with backgrounds in CRS forensics and usability were asked to rate, on a scale from 0 to 10, an error's probable effect on safety, with 10 indicating the most negative effect. Final severity scores for each potential error were determined by averaging the subjective, independent ratings of all experts. Severity scores of four or more are considered unacceptable, and will likely compromise the effectiveness of a CRS in the event of a collision (Czernakowski & Müller, 1993). The severity scores for UAS-related usability errors are shown in Table 2.

Table 2. UAS-related severity scores for the car and bus.

	Error	Car	Bus
Top Tether Errors	Tether not used	7.75	4.25
	Tether not attached to correct anchor	5.75	5.5
	Tether strap twisted	1.25	1
	Tether strap threaded incorrectly	6.5	5
	Tether strap slack 1"	3.5	2.75
	Tether strap slack 2"	4.625	3
	Tether strap slack 3"	6.25	3.25
	Tether strap slack 4"	6.75	3.625
	Tether strap slack 5.5" or more	7.625	4.375
	Tether strap routed over top of head rest (rather than between headrest and vehicle seat)	3.75	N/A
Lower Anchorage Connector Errors	Lower anchorage connectors not attached to anchor	9.375	9.375
	Lower anchorage connectors attached to incorrect anchor	5.75	5
	Both lower anchorage connectors connected to the same anchor	6.75	6
	Lower anchorage connectors attached upside down	1.625	1.375
	Lower anchorage connector strap (webbing) twisted	1.625	1.375
	Lower anchorage connector strap slack 1”	3.375	2.875
	Lower anchorage connector strap slack 2”	4.125	3.625
	Lower anchorage connector strap slack 3”	5.5	4.5
	Lower anchorage connector strap slack 4”	6.875	5.625
	Lower anchorage connector strap slack 5.5” or more	8.125	6.875
General Errors	CRS moves 1” side-to-side	1	1
	CRS moves 2” side-to-side	2.5	2.25
	CRS moves 3” side-to-side	3.25	3.5
	CRS moves 4” or more side-to-side	4	4.25
	Space between CRS back and vehicle seat back 1”	1.25	1
	Space between CRS back and vehicle seat back 2”	2.25	2
	Space between CRS back and vehicle seat back 3”	4	3.5
	Space between CRS back and vehicle seat back 4”	5.75	5.25
	Space between CRS back and vehicle seat back 5”	6.875	6.375

4.6 Risk Priority Number (RPN)

The RPN is a composite measure of a potential error's severity score and the frequency with which the error actually occurs during testing. Typically, this number is derived using a subjective scale similar to the severity score rating scale, with 0 representing 'no misuse' and 10 representing 'misuse almost inevitable' (ISO, 1999). In the present study, however, the RPN was based on an actual count of the number of participants demonstrating a particular error, and did not depend on a subjective rating. In order to be able to compare results to other studies, the number of participants was normalized to n=100. By doing this, an RPN value for each error could potentially range from 0 to a maximum of 1000, if 100% of participants committed an error of severity 10.

4.7 Statistical Analysis

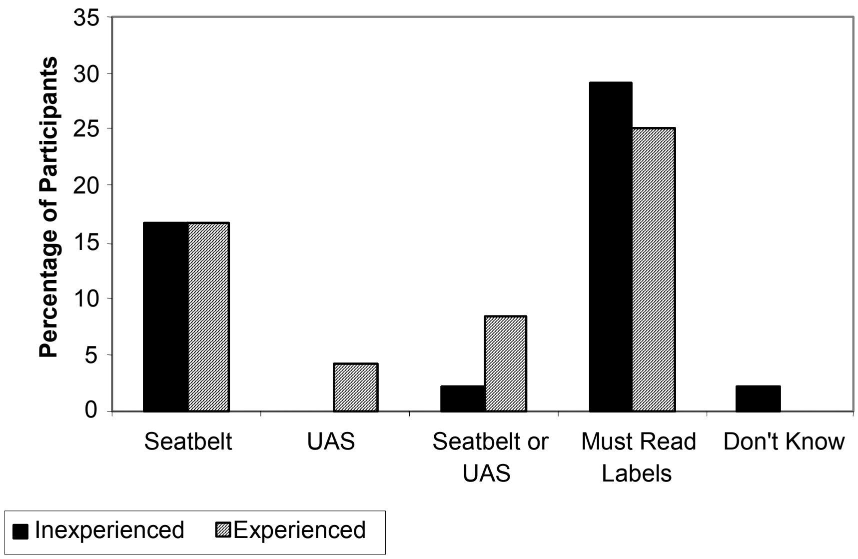
Descriptive statistics were calculated for the purposes of a general usability analysis, as was the percentage of correct installations. Where appropriate, mixed (between- and within-subjects) factorial analyses of variance (ANOVAs) were performed on the data. An alpha level of .05 was used to determine statistical significance.

5. RESULTS AND DISCUSSION

5.1 KNOWLEDGE OF UAS

Before being instructed to install any of the CRS, participants' knowledge of the existence of the UAS system was assessed by asking them the following question: "You are installing a newly purchased child seat. How would you attach the child seat to a vehicle?" Results are presented in Figure 10.

Figure 10. Responses to question: "How would you attach a CRS to a vehicle?"

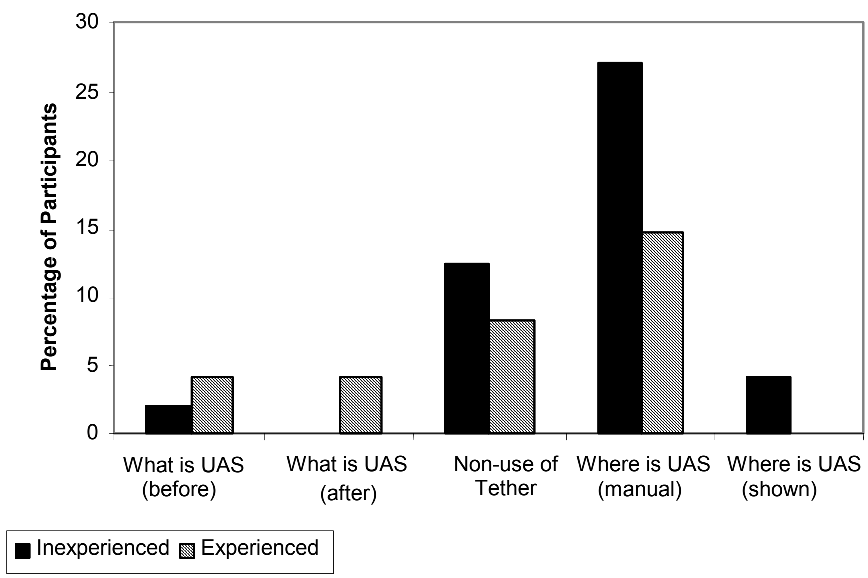


Fifty-four per cent of participants (29% inexperienced; 25% experienced) said they would have to read the labels and instructions to identify how to install the child restraint system. Thirty-three per cent of participants indicated that they would use the seatbelt to secure the CRS. Most of these participants indicated that their response was based on previous experience, either direct experience of installing CRS or indirect observational experience (e.g., from observing CRS installation, viewing installed CRS, or information in the media).

Only four per cent of participants, both of whom were experienced CRS users, indicated that they would use the UAS connectors. Approximately 10% of participants (80% of whom were experienced CRS users) responded that they would use either the seatbelt or the UAS to attach the child seat.

Knowledge of the UAS was further assessed during and after the CRS familiarisation period by noting whether participants asked what the UAS connectors were. Whether or not a participant connected the top tether strap, as well as whether or not they could locate the lower anchors in the car were also used to further characterise participants' familiarity with the UAS. Results for these three events are presented in Figure 11.

Figure 11. Percentage of participants requiring more information regarding the UAS.



Although initially not familiar with the UAS for installing CRS, once participants began to familiarise themselves with the CRS, most (94 %) did not ask what the UAS connectors were. Of the three people who asked what they were during the familiarisation period, two still needed information after the familiarisation period was over. Surprisingly, these two were both experienced CRS users.

Twenty-one per cent of participants (13% inexperienced; 8% experienced) did not attach the top tether during their first installation. Of these 10 participants, eight completed their first CRS installation in the school bus.

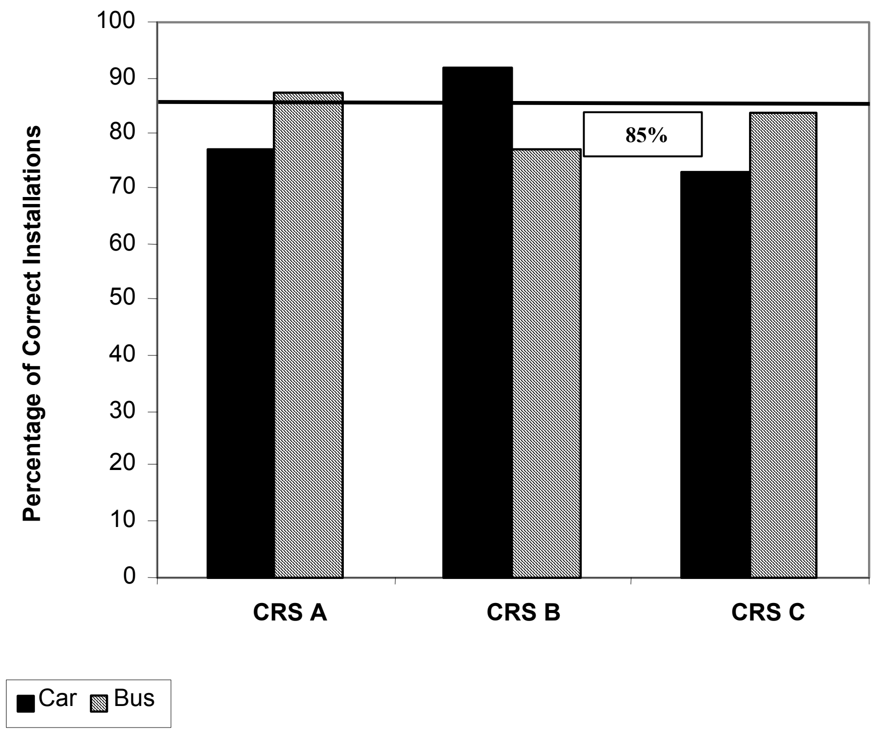
A surprising 42 per cent of participants could not find the UAS lower anchors in the car without the aid of the vehicle owner's manual. Even after reading the manual, two participants (4%) still needed help finding them.

5.2 Objective Measures of Usability

5.2.1 Percentage of Correct Installations

One measure of CRS usability is the percentage of installations that are performed correctly. To derive this measure for each environment (car *vs.* bus), the severity scores for all of the usability errors that occurred during each installation were evaluated. A CRS was considered correctly installed if there were no errors having a severity score of four or more. An 85% criterion value was chosen to represent acceptable performance, based on the requirements of ISO test procedure 13215-2 (Requirements and Test Procedures for Correct Installation; 1999), wherein a CRS is considered acceptable if at least 85% of the installations are performed correctly. Results are presented in Figure 12.

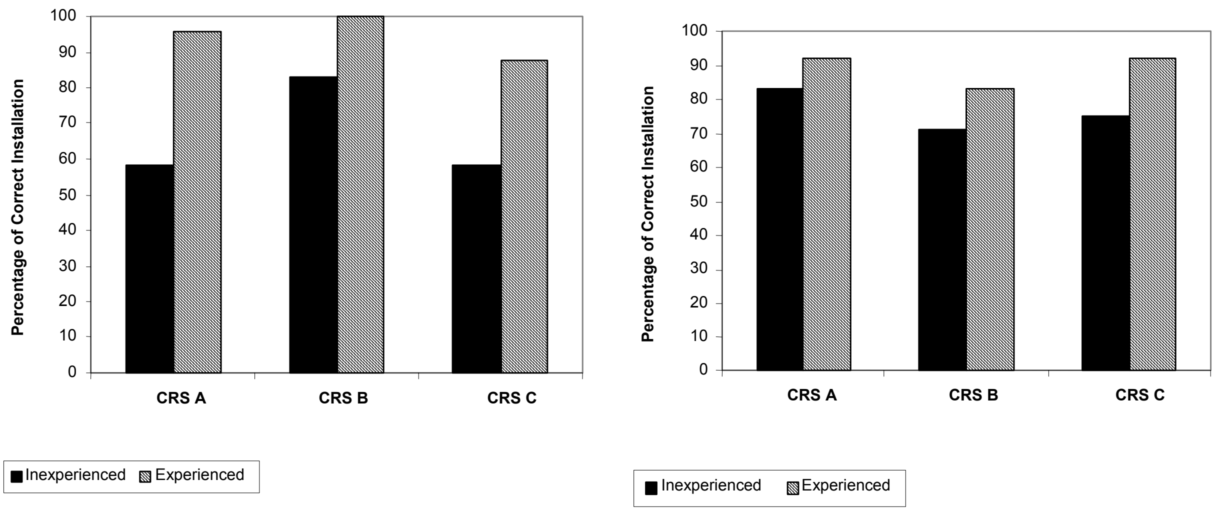
Figure 12. Percentage of correct installations.



The 85 per cent criterion for correct installations was only met by CRS A installed in the school bus, and CRS B installed in the car. However, for all three CRS, in all conditions, the percentage of correct installations came close to reaching the criterion value. These results are similar to those when CRS are installed forward-facing using the vehicle seat belt. For example, Rudin-Brown et al. (2004), looking at the effectiveness of CRS labels and instructions, found a popular model of convertible CRS was correctly installed forward-facing between 50 and 100 per cent of the time, depending on instructions. Using a similar method for determining 'correctness' of installation, Noy & Arnold (1995) found 61 to 86 per cent of forward-facing installations done correctly when using the vehicle seat belt, compared to 89 per cent when using prototype rigid UAS anchors. From these results it appears that, compared to the vehicle seat belt, using the UAS anchors to install CRS forward-facing does not improve the likelihood that the CRS will be installed correctly. It remains possible, and likely, however, that users find the installation easier when using the UAS.

The percentages of correct installations in the car and in the bus according to CRS experience are shown in Figure 13.

Figure 13. Percentage of correct installations in the car (left panel) and school bus (right panel) by participant's experience.



Experienced participants performed more installations correctly than inexperienced participants in both the car and bus environments. Except for the installation of CRS B in the bus (83.3%), experienced participants satisfied the 85% criterion for each CRS installed in both the car and the school bus. The inexperienced participants did not satisfy the 85% criterion for any CRS installation in either vehicle environment. Some reasons for this finding include:

- Experienced participants appreciate how tightly a CRS is supposed to be installed to the vehicle. Many inexperienced participants do not understand just how little side-to-side movement is permissible.
- Experienced participants know some 'tricks' for securely installing a CRS. For example, many kneeled or stood on top of the CRS to ensure that the top tether and lower attachments were secured as tightly as possible (Figure 14).

Figure 14. Experienced participant installing CRS in car (left panel) and bus (right panel).

- Since experienced participants understand how tightly a CRS should be installed, they may work harder than inexperienced participants when faced with installation problems, rather than giving up (e.g., some inexperienced participants could not correctly tighten the CRS and therefore uninstalled the CRS to start again).

5.2.2 Time to Familiarise, Install and Remove CRS

Another measure of the usability of a product is the time it takes a user to learn how to use it effectively. Three timings were recorded in the present study: time it took each participant to become familiar with the CRS, time to install the CRS in the car or bus, and time to remove each CRS.

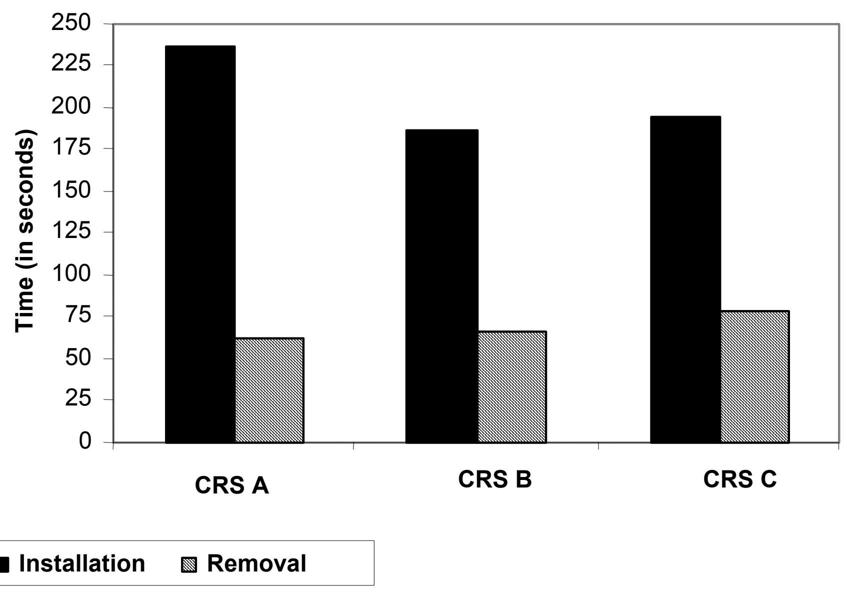
5.2.2.1 Familiarisation Period

There was no difference between the three CRS in terms of the time participants took to familiarise themselves with them. On average, participants took less than two minutes with each CRS (data not shown). Experienced and inexperienced participants took approximately the same amount of time, suggesting that both types of users consulted the labels and instructions, and visually inspected a CRS when installing it for the first time.

5.2.2.2 Installation and Removal

The average times taken to install and remove each CRS are presented in Figure 15.

Figure 15. CRS installation and removal times.

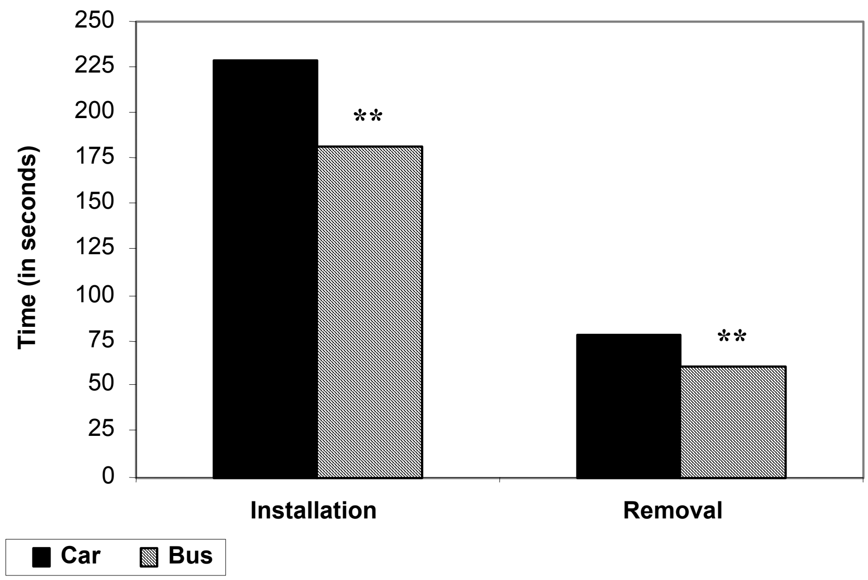


There was no effect of participant experience on the time it took to install or remove the CRS. There was a significant main effect of CRS on installation time [$F(2,96) = 6.715$, $p<0.05$], with CRS A taking significantly longer to install than either CRS B or C. This may have been due to the double tether strap on CRS A (Figure 1, left panel), which was more likely to become twisted during installation.

There was a significant main effect of CRS on removal time [$F(2,96) = 3.782$, $p<0.05$], with CRS C taking longer to remove from the vehicles than CRS A or B. Participants indicated they preferred the pushbutton release design on CRS A's lower attachments (Figure 1, right panel). These were simple to operate, and did not require the participants to manipulate their fingers between the seat bight to release the lower anchorages. Participants also stated that the lower attachments on CRS C (pushbutton C-clip; Figure 3, lower panel) were difficult and awkward to release.

Another analysis revealed significant effects of vehicle type on installation and removal times (Figure 16). It took participants longer to install [$F(1,47) = 14.202$, $p<0.001$] and to remove [$F(1,47) = 15.139$, $p<0.001$] the CRS from the car, compared to the school bus. This was likely due to the increased visibility of the lower anchorages on the school bus seat, as well as the amount of room available in the school bus, which allowed participants easier access to the CRS.

Figure 16. CRS installation and removal times for the car and the bus.



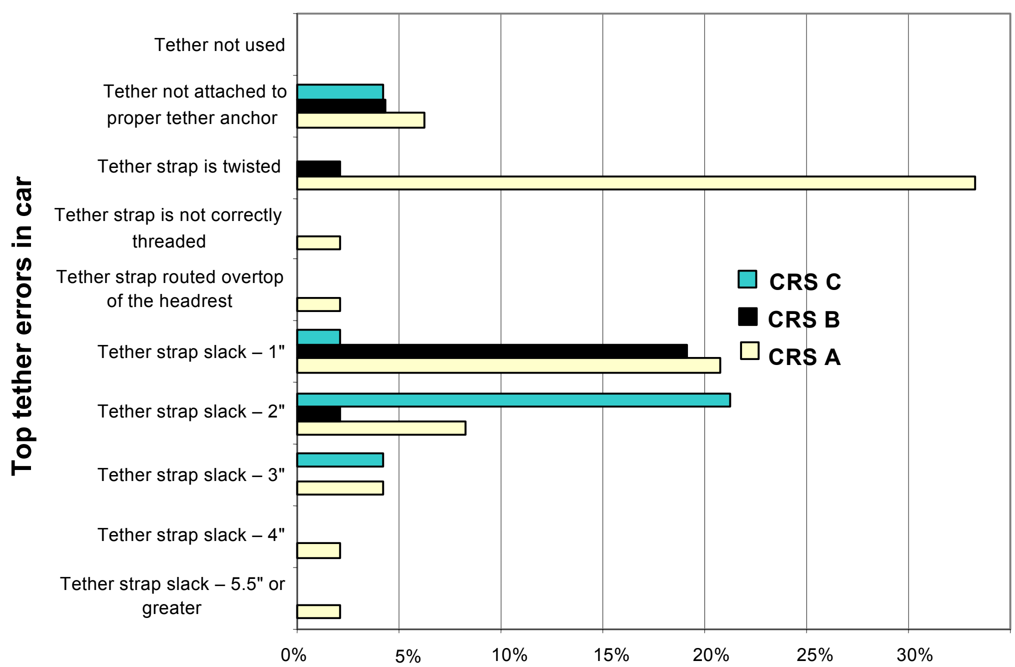
5.2.3 Error Frequencies

5.2.3.1 Top Tether Errors.

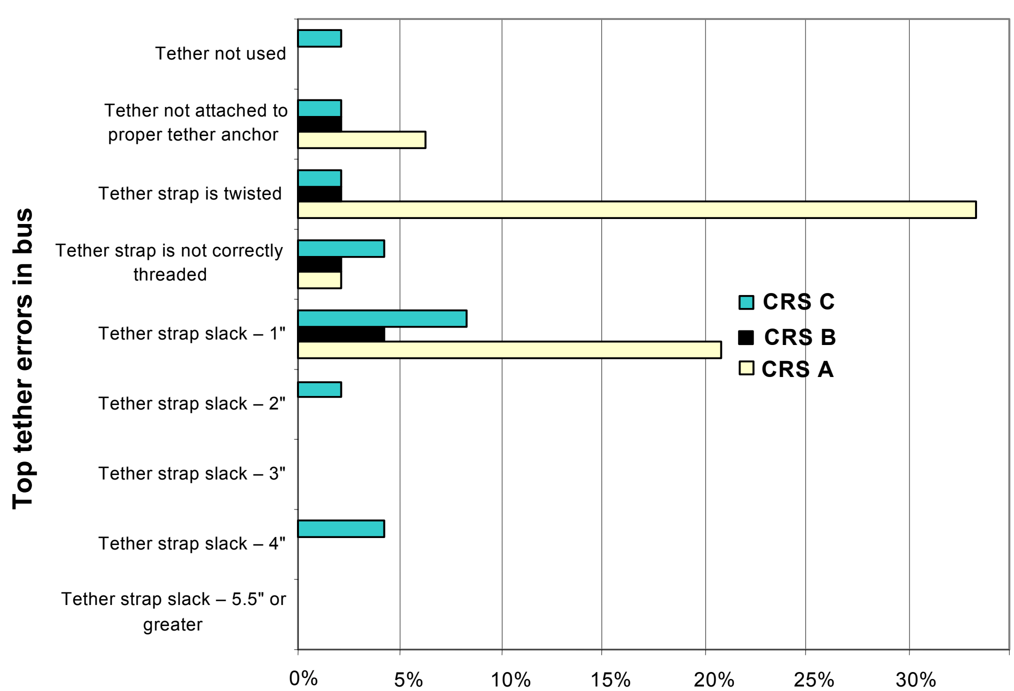
Figure 17 shows top tether error frequencies for installations made in the car (a) and in the bus (b). In 26 per cent of installations, participants failed to attach the top tether at all, or attached it to the wrong location. In the car, some attached it to the middle tether attachment on the back shelf, rather than the correct one to the right. In the bus, several participants attached the top tether to the lower anchorage in the seat behind.

Figure 17. Top tether errors in the car (a) and the school bus (b).

(a)



(b)



Over 30 per cent of participants twisted the top tether strap when installing CRS A in both the car and the bus. The routing and/or bunching of the strap through the tether clip generally caused this twisting (Figure 18). If the strap had been even slightly folded over as it ran through the clip, tightening would result in a twist. Participants who had twisted the tether were asked if they thought this error would have an impact on CRS safety. The majority of participants indicated that if the tether were correctly secured, with no slack, the twist would not jeopardize safety of the CRS in the event of a collision. Participants may have realized that they installed the CRS with tether strap twist, but did not correct the error because they did not think it would compromise safety.

Figure 18. Twisting of the double strap-type top tether on CRS A.

The second most common top tether error was slack in the tether strap. This occurred when participants installed CRS A in the car and the bus, and CRS C in the bus. Participants found that there was insufficient space in the car to manipulate and tighten the tether. In particular, the constrained space made it difficult to attach and adjust the double strap-type tether on CRS A.

Previous usability work demonstrated that correct adjustments should not act in a manner contrary to user expectations; if they do, they will result in frustration and lower usability ratings (Rudin-Brown et al., 2003). Even when participants were able to tighten the top tether on CRS C correctly (Figure 19, left panel), the CRS could still be pulled away from the vehicle seat back (Figure 19, right panel). This tether style caused participants particular concern, as they were not confident that the CRS would remain secure in the event of a collision.

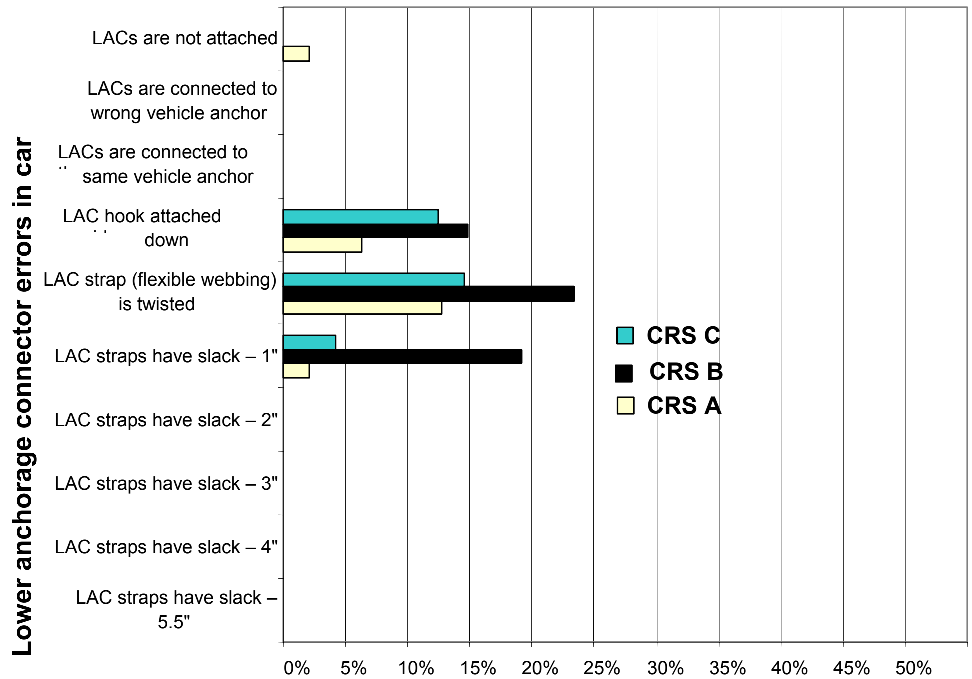
Figure 19. Correct top tether installation on CRS C (left) still allowed CRS to be pulled forward (right).

5.2.3.2 Lower Anchorage Connector Errors.

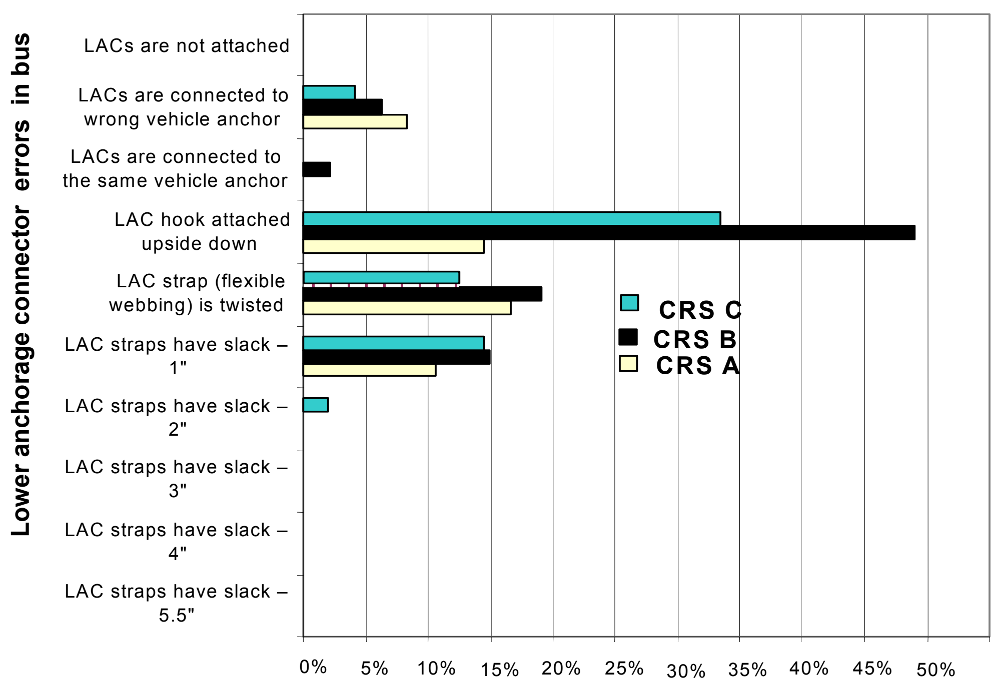
Figure 20 shows lower anchorage connector error frequencies for installations made in the car (a) and in the bus (b). There were very few instances where the lower attachments were not attached to the vehicle's anchors (only one installation in the car). In the school bus, 18 per cent of participants attached the CRS lower anchorage attachments to the wrong vehicle anchors (generally, they attached the inboard attachment to the outboard anchor for the aisle seating position).

Figure 20. Lower anchorage connector errors in the car (a) and the school bus (b).

(a)



(b)



Although participants eventually installed the CRS lower attachments to the correct anchor location in the car, they tended to make errors when first trying to locate the anchors. Incorrect locations in the car to which participants initially secured the lower anchorage attachments included: the top tether anchor, a latch found on the car door, and the seatbelt clip.

Participants tended to install the C-clip (CRS B; Figure 2) and push-button C-clip (CRS C; Figure 3) styles of lower attachment connector upside down, especially in the school bus (Figure 21, left panel). A review of participants' comments indicated that they did not think that attaching the connector upside down would compromise the safety of the CRS. They pointed out that these types of connectors had to be manually opened in order to latch it to the vehicle anchor and that they were better able to do this using their thumb, which required that the connector be inverted. Finally, the single strap lower attachment style that was routed through the back of the CRS tended to become twisted easily, which would cause at least one of the connectors to become attached upside down (Figure 21, right panel).

Figure 21. Push-button clip-on lower attachment connector installed upside down (left panel) and single-strap lower attachment style twist (right panel) in school bus.

On average, the lower attachment straps were not tightened adequately (1" of slack) in 11 per cent of installations. This error was particularly pronounced for the single-strap style connectors that use only one adjuster. Participants reported that they were aware the strap was loose, but they could not determine how to tighten it, because the adjuster/buckle had to be oriented a specific way for the strap to slide easily through it. Participants were more able to adequately tighten the two independent connector straps on CRS A (Figure 22).

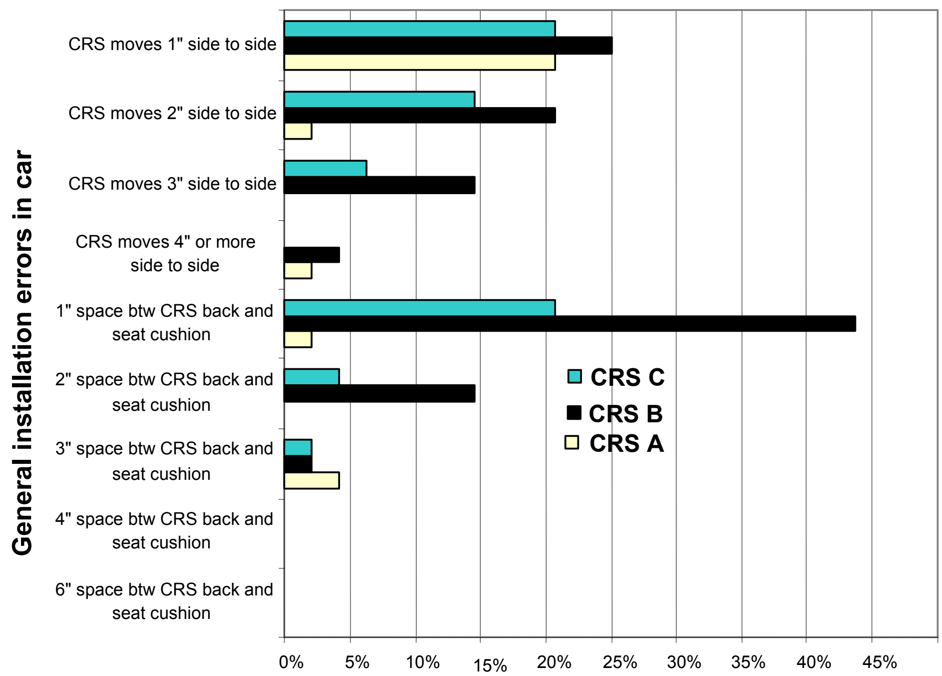
Figure 22. Independent connector strap on CRS A.

5.2.3.3 General Installation Errors

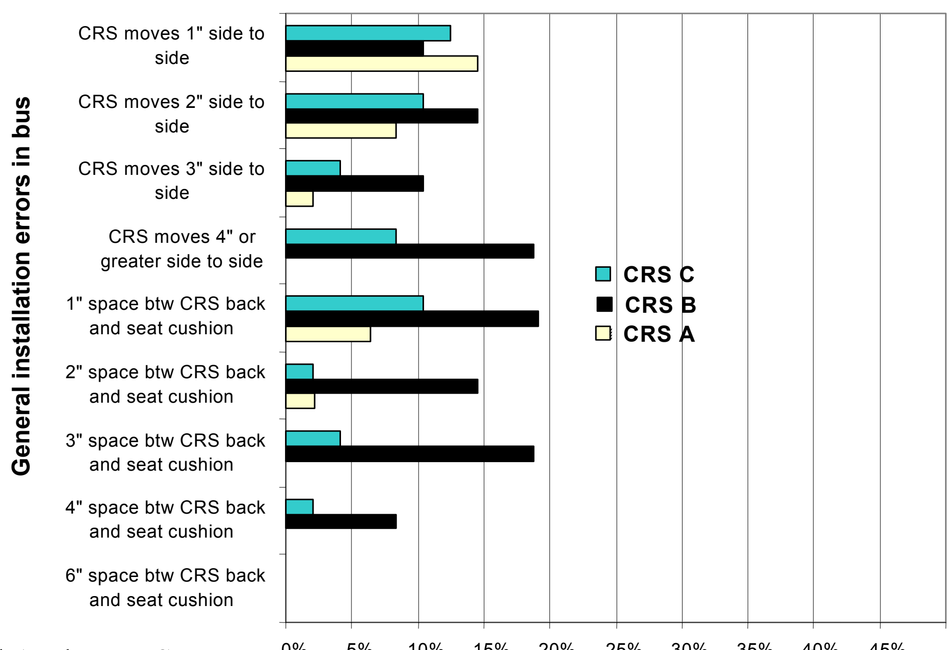
Figure 23 shows the percentage of general installation errors that were made in the car (a) and in the bus (b). These errors were more prevalent in installations of CRS B and C, compared to CRS A. In general, lower anchorage errors contributed to the general installation errors seen with CRS B and C, while top tether errors contributed to the general installation errors seen with CRS A. It is important to note that, in some installations, even though the lower attachments and top tether were correctly attached and tightened, a general installation error still occurred due to the incorrect positioning of the CRS in the vehicle. For example, in one case, one of the vehicle's seat belt buckles became lodged behind the CRS, creating space between the seat cushion and the CRS and, consequently, unacceptable side-to-side movement of the CRS.

Figure 23. General installation errors in the car (a) and the school bus (b).

(a)



(b)

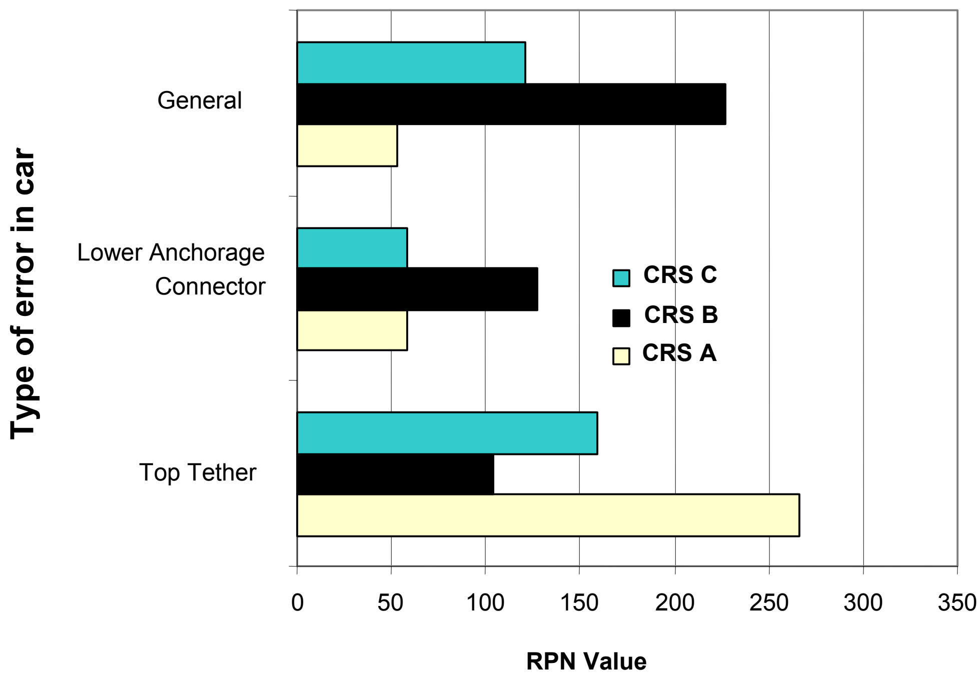


5.2.4 Risk Priority Numbers (RPNs)

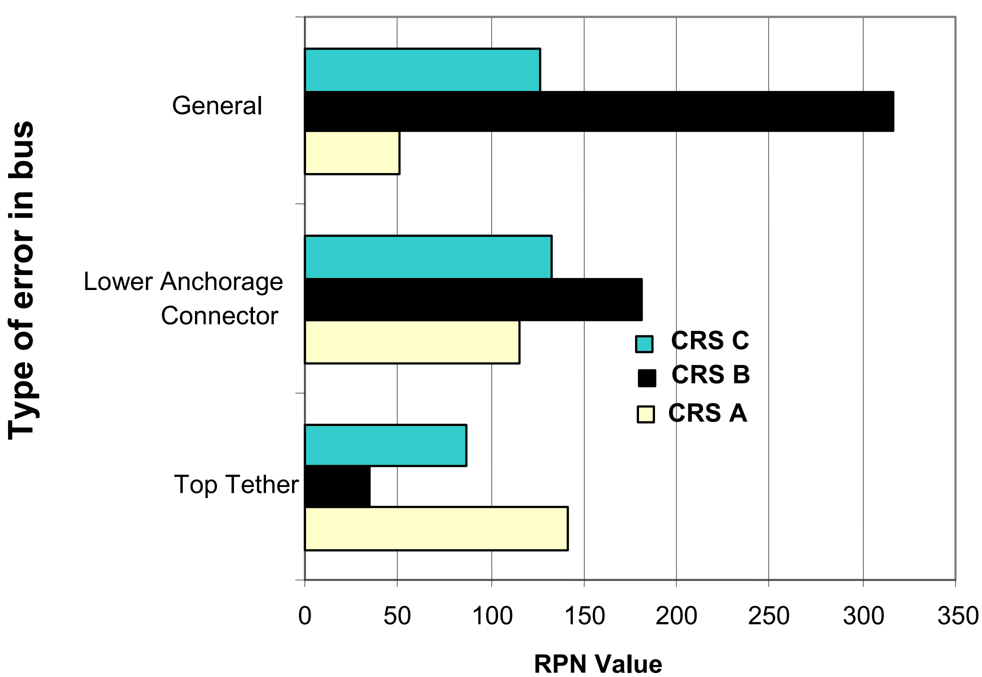
RPN values for top tether, lower anchorage connector, and general errors are presented in Figure 24. Individual errors' severity scores, frequencies (normalized to n=100) and RPN in each of these categories are listed in Appendix B.

Figure 24. Total CRS RPN values for errors in the car (a) and the school bus (b).

(a)



(b)



Compared to the single tether strap, the double tether strap on CRS A resulted in the highest RPN value when installed in both the car and the bus. This tether style's high RPN was generally due to the large percentage of people who installed it twisted (33.3%) and with 1" of slack (20.8%), which are not, in terms of severity score, considered to be particularly serious errors. Because of the way the tether strap threaded through the narrow opening in the tether clip, the straps had a tendency to twist in many cases. Also, participants would tighten the tether on one side of the tether clip, but slack would remain on the other side, again due to the narrow opening in the clip.

It is noteworthy that the top tether error RPN for CRS A was higher when this CRS was installed in the car, as compared to the bus. Participants reported that it was difficult to secure the double-strap style top tether in the car due to: the constrained space between the vehicle's rear shelf and window, the angle at which the strap had to be held in order to tighten it, and its very long length.

The lower anchorage connector RPNs in both the car and the bus were highest for the C-clip style connectors (CRS B) that are part of a single strap routed through the CRS. Similar results were found for general installation error RPNs. Twenty per cent of participants found it difficult to securely tighten the lower anchorage strap, which ultimately permitted the CRS to move excessively from side-to-side and left space between the CRS and the vehicle seat back. Excessive side-to-side movement, and space between the CRS and vehicle seat back also contributed to the RPNs for installations of CRS C, which also used a single lower attachment strap routed through the CRS. The two independent lower straps on CRS A allowed it to be tightened adequately, preventing this CRS from moving side-to-side or from front-to-back, even when the top tether was installed somewhat loosely.

It is interesting to note that the lower anchorage connector RPNs for all three CRS were higher in the bus than in the car. This occurred primarily because participants tended to attach one lower attachment to the incorrect vehicle anchor.

5.3 Subjective Measures of Usability

5.3.1 CRS Usability Ratings

Participants completed a *CRS Installation Usability Questionnaire* after each CRS installation in the car and the bus. Participants were required to rate, on a scale of 1 to 7 (1 = Strongly Disagree to 7 = Strongly Agree), how easy they found several top tether and lower anchorage connector tasks. At the completion of testing, participants filled out a *General Usability Questionnaire*, which assessed the UAS features of the car and the bus, and allowed participants to compare and state preferences regarding the various CRS UAS designs.

5.3.1.1 Top Tether Usability Ratings

Figure 25 presents the top tether usability ratings. The ease of completing the top tether tasks was generally rated between five ('slightly agree') to seven ('strongly agree'). A repeated measures ANOVA revealed a significant effect of vehicle type on top tether usability. Participants generally found all of the top tether tasks easier to perform in the school bus, compared to the car. This was due to the limited space in the car, which impeded participants' view of the anchor, as well as adequate tightening of the tether strap. In the bus, participants could directly see the tether either by sitting in the seat behind the CRS, or by standing in the aisle. In the car, many participants looked through the rear window in order to see the vehicle anchor (see Figure 26). Further, if the participants failed to remove the headrest during the CRS installation, it would block their view of the top tether anchor.

Figure 25. Top tether usability ratings.

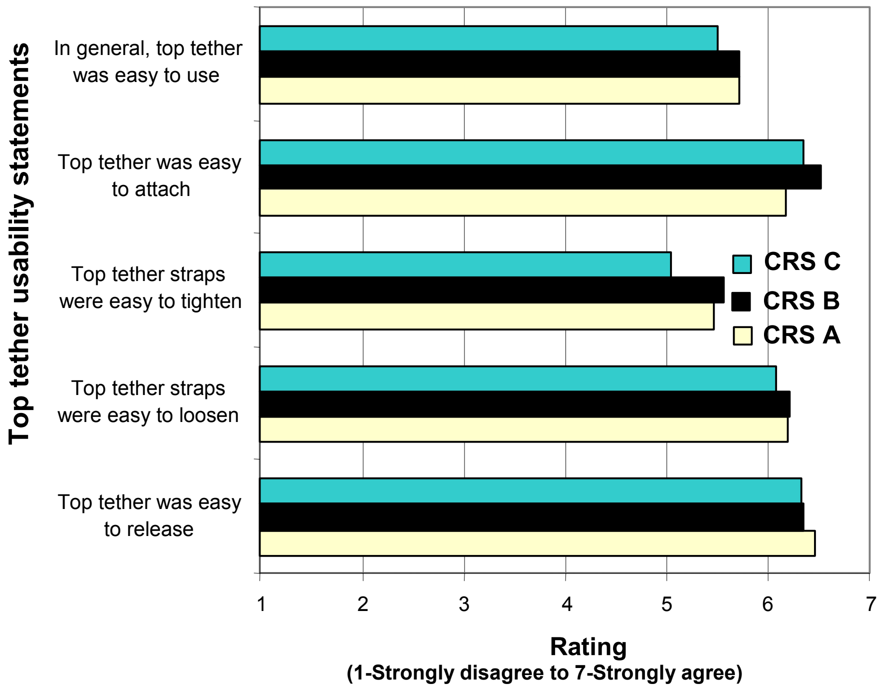
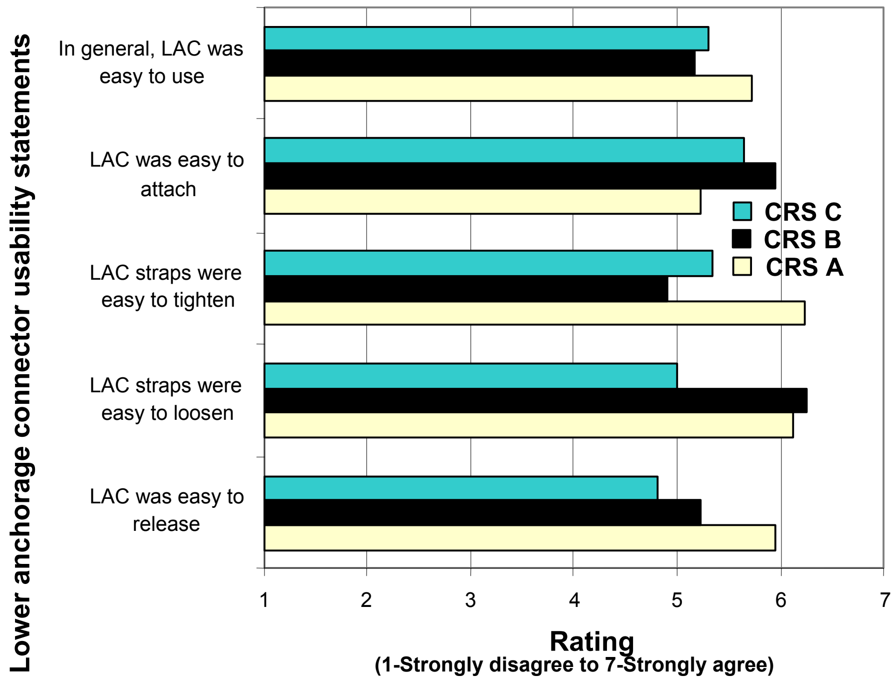


Figure 26. Attaching the top tether in the car (left) and bus (right).

5.3.1.2 Lower Anchorage Connector Usability Ratings

Figure 27 presents the lower anchorage connector usability ratings. The ease of completing the lower anchorage connector tasks was generally rated between five ('slightly agree') to six ('moderately agree'). Ratings were highest for the push-on lower attachments on CRS A compared to the clip-on attachments on CRS B and C, in terms of being easy to use, easy to tighten, and easy to release. A review of participants' comments indicated that they preferred the push-on design of the attachments on CRS A, because it provided auditory feedback, and they did not have to manually create an opening on the connector to latch it onto the vehicle anchor.

Figure 27. Lower anchorage connector usability ratings.



Participants found it easier to tighten and loosen all lower attachment designs in the car *vs.* the school bus. In the car, many participants could manoeuvre within the back seat to easily reach and see each connector (Figure 28); in the bus, participant access was constrained by the seat in front, as well as by the side of the bus. Finally, participants rated the push-on lower attachments on CRS A as being easiest to release. They required much less effort and force to release than the clip-on designs. Further, the pushbutton release remained outside of the seat bight, so that participants did not have to insert their hands into the seat bight when removing them. Another advantage of this type of lower attachment design was that their straps did not have to be completely loosened before being able to remove them. When releasing the clip-on designs, participants found that they had to completely remove all strap tension before being able to remove the attachments.

Figure 28. Attaching the lower anchorage connectors in the car (left) and the bus (right).

5.3.1.3 General Usability Ratings

The G*eneral Usability Questionnaire* assessed three variables: how easily participants located the top tether, and lower, anchors in the car and the bus; how effective they found the different lower attachment clips' feedback; and how effective they found the labels that were affixed to the CRS. The questionnaire also allowed participants to rank the UAS features of the three CRS, and state preferences (see Section 5.3.3).

A significant main effect of vehicle type was found for the ease of finding the top tether [F=6.255), p<.05], and lower[F=39.217, p<.001], anchors. Participants found it easier to locate the top tether anchor in the car, and the lower anchors in the school bus (data not shown). Because the position of top tethers on the back of CRS implies to users that a vehicle's tether anchor will be situated at a location behind the CRS, the only reasonable location for a tether anchor in the car (which was a sedan) would be somewhere on the back dash. The location of the top tether anchor in the car, in addition to its identification with a universally accepted UAS symbol (see Figure 6), ensured that it would be easily identified. Unlike the car, the tether anchor on the school bus was located underneath the rear of the seat (Figure 9). Other than it not being in an entirely intuitive location, it was concealed by the vehicle's seat back, was quite small in size, and had no graphic or label identifying its location. Participants reported that, had they been installing a CRS in a real school bus, there would have been even less room within which to manoeuvre, making the task of finding the tether anchor even more difficult.

Participants found it easier to locate the lower anchors on the school bus than the car. The lower anchors on the bus were relatively large in size and were bright yellow, making them immediately visible to the participants (Figure 8). On the other hand, the lower anchors in the car were not visible, and could only be detected by participants inserting their hands into the seat bight and feeling for them. The only identification provided in the car was two small, grey, circular buttons on the vehicle seat back (Figure 4).

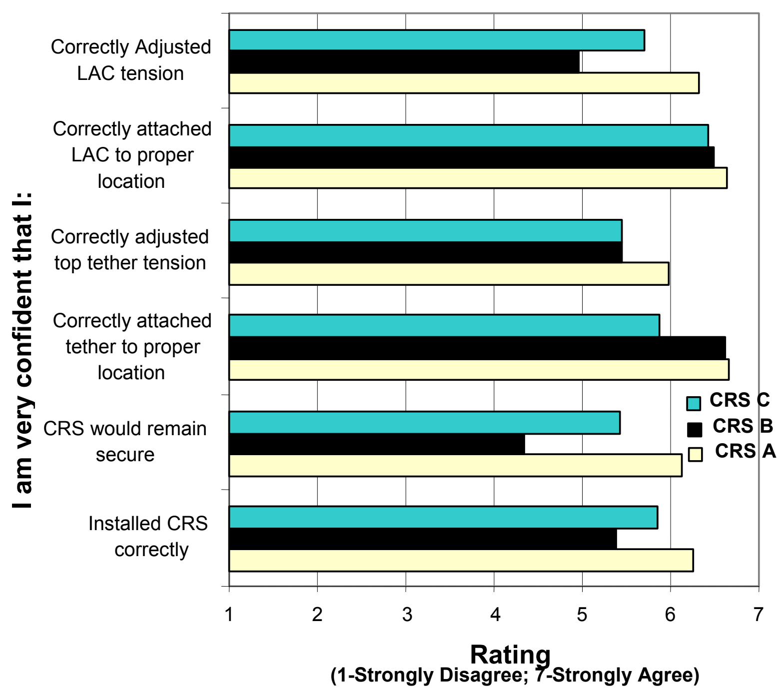
With respect to lower anchorage connector feedback, a repeated measures ANOVA revealed a significant main effect of CRS, with the push-on connectors on CRS A being rated as providing the best feedback to indicate that they were secure [F=9.071, p<.001]. Participants liked that, with these connectors, a loud click occurred when the latch was secured, which was particularly beneficial since the latch was not visible. Participants found it difficult to ensure that the other two connector designs were attached to the vehicle anchors properly: neither provided adequate auditory feedback, and visual access was impossible. Users were required to manoeuvre their hands within the seat bight, or pull on the lower strap, to ensure the C-clip and push-button C-clip designs were secure.

Finally, there was no difference among the CRS in terms of label effectiveness. All three CRS received only 'Borderline' ratings for whether their labels helped the participant during installation. Participants commented that CRS labels were difficult to read, that diagrams were too small and difficult to interpret, and that they did not understand the acronyms used on the labels (e.g., UAS). They thought that labels should be affixed directly on the feature that they describe; however, they also thought that paper labels attached to top tethers would easily degrade over time. Finally, they reported that labels did not clarify issues such as which direction the lower anchorage connectors should face, or if the CRS could be installed using both the seatbelt and the UAS at the same time.

5.3.2 User Confidence Ratings

Participants were required to rate, on a seven-point scale, how confident they were that they had performed the installation tasks correctly. Figure 29 summarises the confidence ratings.

Figure 29. Confidence ratings.



For all installation tasks, CRS A received the highest confidence ratings. Repeated measures ANOVAs revealed a significant main effect of CRS for the following statements: 'I am very confident that I installed the CRS correctly', 'I am very confident the CRS would remain secure in an accident', and 'I am very confident that the lower anchorage connector tension was correctly adjusted'. Participants reported that the single-strap lower attachments on CRS B and C were difficult to tighten adequately, allowing the CRS to move side-to-side. Even though they knew that the CRS was installed loosely, they were unable to determine how to make the straps any tighter. They found the push-on lower attachments on independent straps easier to tighten: the straps needed only to be pulled upwards to adjust them, and the straps moved easily through the adjuster/buckle when being tightened. The single strap adjuster had to be held at a specific angle in order to be tightened easily.

Participants were more confident that they had attached the top tether to the proper location in the car, as opposed to the bus. They stated that the top tether attachment in the car was easily identifiable, but found it difficult to find the tether attachment on the bus, as it was small in size and was hidden below the seat back. Participants also could not determine if the tether attachment on the bus was specific for attaching the tether or if it was another part of the seat's construction. There was no label either on, or above, the tether anchor in the bus.

On the other hand, participants, in particular those who were experienced CRS users, were more confident that they had correctly adjusted the top tether tension in the bus, compared to the car. The distance between the top and bottom of the school bus seat back provided more space to manoeuvre and tighten the top tether, while the shorter distance between the car's rear window and tether attachment made it very difficult to pull the tether tight.

5.3.3 User Preferences

Participants were required to rank the CRS in order of preference for four top tether statements and four lower anchorage connector statements (see *General Usability Questionnaire*, Appendix A).

There was no significant difference found in terms of top tether preferences. This may have been due to the similarity among the three tether clip designs. Although the participants made considerable tether strap errors when installing the double-strap tether on CRS A, they perceived the ease of tightening this top tether as similar to that of CRS B and slightly easier than CRS C. This suggests that participants were unaware they had not secured the top tether appropriately. The single strap tether on CRS B that was attached low on the CRS back was the least preferred for all top tether statements. Participants were able to adjust this top tether more tightly than the other two designs, however, even when it was tightened, the CRS could still be pulled forward.

For all four lower anchorage connector statements, the push-on anchorage connectors connected to two independent straps (CRS A) were most preferred, followed by the C-clip connectors on CRS B, then the push-button C-clip connectors on CRS C. Participants found the connectors on CRS A easier to manipulate into the seat bight; the force of inserting the connector caused the latch to open automatically. The C-clip and push-button C-clip connectors had to be manually opened by the users, and caused pain in participants' fingers (CRS B) and thumbs (CRS C). The push-on clips were larger, and allowed for an easier grip.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 TOP TETHERS

- The top tether anchor was not easily identified in the bus. It should be clearly visible and identifiable (e.g., painted yellow to match the lower anchorage connectors). A label could also be placed above the anchor, or at the top of the seat back, to identify the location of the tether anchor.
- The double strap top tether (CRS A) created the most tether errors. This design should either be improved by increasing the size of the slot on the tether clip, or avoided in future CRS models.
- The top tether on CRS B was attached too low on the CRS. Although the top tether could be tightened and secured, the CRS attachment location still allowed the CRS to be pulled in the forward direction without much force. The top tether should be attached as high as possible on a CRS. This would help to ensure that the CRS does not move forward in the event of a collision, or behaves counterintuitive to users' expectations.
- There was insufficient space between the top tether anchor and the car's rear window for users to easily manipulate and tighten the top tether in the car. The angle at which the top tether strap must be positioned in order for it to easily slide through the adjuster buckle should be considered, and manufacturers are encouraged to improve designs so that they can be used in a greater number of vehicle models.

6.2 LOWER ANCHORAGE CONNECTORS

- Lower anchors were not easily identified in the car. The grey buttons in the test vehicle did not adequately indicate the location of the lower anchors. To make them more obvious, labels depicting a universally accepted UAS symbol should be placed above the anchors. The use of arrows to indicate location should also be considered. Similar labels could be applied to the CRS lower anchorage connectors to indicate that the connectors should latch onto the vehicle's lower anchors.
- The lower anchorage bars were difficult to access in the car. It was difficult to insert a large-sized lower connector into the seat bight; individuals with large hands had particular trouble. Auditory feedback from clips would be useful to deal with this issue, as would clips that do not require the user to hold them open manually. Also, using flexible cushion material in areas around lower anchors in vehicles would help.
- The design of the lower anchorage connectors that are attached by a single strap that is routed through the CRS (and that needs to be re-routed when converting the CRS from rear- to forward-facing) makes them difficult to manipulate and tighten, resulting in the connectors being insecurely fastened. This allows the CRS to move side-to-side when installed. These designs should be avoided, unless they can first be improved. Lower anchorage connector straps should be separate, and should each incorporate an individual adjuster buckle.
- Connector clips that need to be manually opened are least preferred by users. These clips require the user to create and maintain an opening while inserting the clip into the seat bight, and manipulate the clip around the lower anchor. Participants generally used their thumbs to create this force, which ultimately inverted the connector clip. This caused the connector clips to be attached upside down, and the anchorage connector strap became twisted.

6.3 GENERAL

- Individuals are not familiar with the Universal Anchorage System. Awareness needs to be raised, and parents/caregivers need to be encouraged to use the system correctly.
- There is limited space between school bus seats to manipulate and install a CRS. It was difficult for users to reach the lower anchors and to locate and reach the top tether anchor. Maximum seat spacing in school buses that are equipped with UAS is recommended.
- CRS labels were not positioned in appropriate locations for easy reference during installation. The labels and diagrams were confusing, and the instructions were difficult to interpret. Clearer, more conspicuous UAS labeling, that relies more on pictograms than text, are recommended.
- CRS installation time and removal time were both quicker when the CRS were installed in the bus, as compared to when they were installed in the car. This is encouraging news for those who may be responsible for installing CRS on school buses in the future.

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8. APPENDIX A: Forms.

8.1 Participant Installation Error Form

1. How would you attach a car seat to a vehicle?				
☐ Seatbelt Only	☐ UAS Only	☐ Seatbelt or UAS	☐ Need to read labels/instructions	☐ Don't Know

Prompts – likely for only 1st Installation

What is UAS/How do I install child seat?	**Before Familiarisation** ☐	**After Familiarisation** ☐
Tether Strap	**Use of Tether** ☐	
Location of UAS lower vehicle attachments	**Use of Manual** ☐	**Identify General Location** ☐

CRS A / CRS B / CRS C

	Car		**Bus**	
Installation Performed….	1 | 2 | 3 | 4 | 5 | 6		1 | 2 | 3 | 4 | 5 | 6	
	Yes | No	**Error**	**Yes | No**	**Error**
1. Tether strap not secured	Y | N		Y | N	
2. Tether not attached to proper tether anchor	Y | N		Y | N	
3. Tether strap twisted	Y | N		Y | N	
4. Tether strap not correctly threaded	Y | N		Y | N	
5. Tether strap routed overtop of headrest	Y | N			
6. Tether strap slack of: (1" no error CRS C)	Y | N	1 | 2 | 3 | 4 | ≥ 5.5	Y | N	1 | 2 | 3 | 4 | ≥ 5.5
7. Lower anchorage connectors are not attached	Y | N		Y | N	
8. Lower anchorage connectors are connected to wrong UAS location	Y | N		Y | N	
9. Both lower anchorage connectors are connected to same UAS anchor	Y | N		Y | N	
10. Connector hook opening faces upwards	Y | N		Y | N	
11. Lower anchorage connectors flexible webbing is twisted	Y | N		Y | N	
12. Lower anchorage connectors strap have slack of:	Y | N	1 | 2 | 3 | 4 | ≥ 5.5	Y | N	1 | 2 | 3 | 4 | ≥ 5.5
13. CRS moves side-to-side when installed (only parallel shift is an error)	Y | N	1 | 2 | 3 |≥ 4	Y | N	1 | 2 | 3 | 4
14. Space between Back of CRS and Seat Cushion (entire seat must move forward)	Y | N	1 | 2 | 3 | 4 | 6	Y | N	1 | 2 | 3 | 4 | 6
Correct Installation	Y | N		Y | N	

	Familiarization Period	**CRS Installation**	**CRS Removal**
Car			
Bus			

8.2 User Confidence Questionnaire (Car/Bus)

1. Please rate your level of agreement with the following statements.

I am very confident that:	Strongly Disagree	Moderately Disagree	Slightly Disagree	Borderline	Slightly Agree	Moderately Agree	Strongl y Agree	NA
1. I installed the child seat correctly in the car/bus	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
2. The child seat would remain secure in an accident	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
3. I correctly attached the top tether clip to the right location in the car/bus	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
4. I correctly adjusted the top tether strap tension	☐	☐	☐	☐	☐	☐	☐	☐
Comments								

I am very confident that :	Strongly Disagree	Moderately Disagree	Slightly Disagree	Borderline	Slightly Agree	Moderately Agree	Strongly Agree		NA
5. I correctly attached the lower anchorage connectors to the right locations in the car/bus	☐	☐	☐	☐	☐	☐	☐		☐
Comments									
6. I correctly adjusted the lower anchorage connector strap(s) tension	☐	☐	☐	☐	☐	☐	☐		☐
Comments									

8.3 CRS INSTALLATION USABILITY QUESTIONNAIRE (CAR/BUS)

1. Please rate your level of agreement with the following statements.

TETHER STRAP	**Strongly Disagree**	**Moderately Disagree**	**Slightly Disagree**	**Borderline**	**Slightly Agree**	**Moderately Agree**	**Strongly Agree**	**NA**
1. The top tether strap clip was easy to attach to the car	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
2. The top tether strap tension was easy to tighten	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
3. In general, the top tether was easy to use/secure	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
Answer After Removing Car Seat								
4. The top tether strap tension was easy to loosen	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
5. The top tether strap clip was easy to release from the car	☐	☐	☐	☐	☐	☐	☐	☐
Comments								

2. Please rate your level of agreement with the following statements.

<u>LOWER ANCHORAGE CONNECTORS</u>	Strongly Disagree	Moderately Disagree	Slightly Disagree	Borderline	Slightly Agree	Moderately Agree	Strongly Agree	NA
1. The lower anchorage connector <u>clips</u> were easy to attach to the car/bus	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
2. The lower anchorage connector strap(s) <u>tension</u> was easy to tighten	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
3. In general, the lower anchorage connectors were easy to use/secure	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
Answer After Removing Car Seat								
4. The lower anchorage connector strap(s) <u>tension</u> was easy to loosen	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
5. The lower anchorage connector <u>clips</u> were easy to release from the car/bus	☐	☐	☐	☐	☐	☐	☐	☐
Comments								

8.4 General Usability Questionnaire

1. Please rate your level of agreement with the following statements.

It was easy to:	Strongly Disagree	Moderately Disagree	Slightly Disagree	Borderline	Slightly Agree	Moderately Agree	Strongl y Agree	NA
2. Find the location of the tether strap attachment in the car	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
3. Find the location of the tether strap attachment in the bus	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
3. Find the location of the lower anchorage connector attachments in the car	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
4. Find the location of the lower anchorage connector attachments in the bus	☐	☐	☐	☐	☐	☐	☐	☐
Comments								

2. Please rate your level of agreement with the following statements.

FEEDBACK Provided by Lower Anchorage Clips	**Strongly Disagree**	**Moderately Disagree**	**Slightly Disagree**	**Borderline**	**Slightly Agree**	**Moderately Agree**	**Strongl y Agree**	**NA**
1. The lower anchorage clips on CRS A provided good feedback indicating that the clips were secure	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
2. The lower anchorage clips on CRS B provided good feedback indicating that the clips were secure	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
3. The lower anchorage clips on CRS C provided good feedback indicating that the clips were secure	☐	☐	☐	☐	☐	☐	☐	☐
Comments								

4. Please **order** the child seats from 1 - 3 based on your perceived ease of use (1 being high ease of use and 3 being low ease of use)

Example:

	CRS A	CRS B	CRS C	Comments
Statement	**3**	**1**	**2**	

Tether Strap	**CRS A**	**CRS B**	**CRS C**	**Comments**
1. Ease of attaching the top tether strap clip				
2. Ease of releasing the top tether strap clip				
3. Ease of tightening the top tether strap tension				
4. Ease of releasing the top tether strap tension				
Lower Anchorage Connectors	**CRS A**	**CRS B**	**CRS C**	**Comments**
5. Ease of attaching lower anchorage connectors				
6. Ease of releasing lower anchorage connectors				
7. Ease of tightening lower anchorage connector strap tension				
8. Ease of releasing lower anchorage connector strap tension				

5. Please rate your level of agreement with the following statements (please refer to the car seats if required)

Labels	**Strongly Disagree**	**Moderately Disagree**	**Slightly Disagree**	**Borderline**	**Slightly Agree**	**Moderately Agree**	**Strongl y Agree**	**NA**
1. The labels on CRS A helped me to install the car seat	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
2. The labels on CRS B helped me to install the car seat	☐	☐	☐	☐	☐	☐	☐	☐
Comments								
3. The labels on CRS C helped me to install the car seat	☐	☐	☐	☐	☐	☐	☐	☐
Comments								

5. In terms of the top tether strap and the lower anchorage connectors, do you have any comments as to what would increase the ease of use of their installation?

9. APPENDIX B: Severity scores, frequencies, and RPN values.

9.1 IN CAR

		CRS A		CRS B		CRS C	
	Severity Score	Frequency (%)	RPN	Frequency (%)	RPN	Frequency (%)	RPN
Top tether errors							
Tether not used	7.750						
Tether not attached to proper tether anchor	5.750	6.25	35.9375	4.26	24.4950	4.17	23.9775
Tether strap is twisted	1.250	33.33	41.6625	2.13	2.6625		
Tether strap is not correctly threaded	6.500	2.08	13.5200				
Tether strap routed overtop of the head rest rather than between the headrest and the vehicle seat	3.750	2.13	7.9875				
Tether strap slack – 1"	3.500	20.83	72.9050	19.15	67.0250	2.08	7.2800
Tether strap slack – 2"	4.625	8.33	38.5263	2.13	9.85125	21.28	98.4200
Tether strap slack – 3"	6.250	4.17	26.0825			4.17	26.0625
Tether strap slack – 4"	6.750	2.08	14.0400				
Tether strap slack – 5.5" or greater	7.625	2.08	15.8600				
Total top tether RPN			266.5215		104.0338		158.7100

Lower anchorage connector errors							
Lower anchorage connectors are not attached	9.735	2.083	20.2780				
Lower anchorage connectors are connected to wrong vehicle anchor location(s)	5.750						
Both lower anchorage connectors are connected to the same vehicle anchor	6.750						
Lower anchorage connector hook attached upside down	1.625	6.250	10.1563	14.89	24.1963	12.50	20.3125

		CRS A		CRS B		CRS C	
	Severity Score	Frequency (%)	RPN	Frequency (%)	RPN	Frequency (%)	RPN
Lower anchorage connector strap (flexible webbing) is twisted	1.625	12.77	20.7513	23.40	38.0250	14.58	23.6925
Lower anchorage connector straps have slack – 1"	3.375	2.128	7.1820	19.15	64.6313	4.17	14.0738
Lower anchorage connector straps have slack – 2"	4.125						
Lower anchorage connector straps have slack – 3"	5.500						
Lower anchorage connector straps have slack – 4"	6.875						
Lower anchorage connector straps have slack – 5.5" or more	8.125						
Total lower anchorage connector RPN			58.3675		126.8525		58.0788

General installation errors							
CRS moves 1" side-to-side when installed	1.000	20.83	20.8300	25.00	25.0000	20.83	20.8300
CRS moves 2" side-to-side when installed	2.500	2.08	5.2000	20.83	52.0750	14.58	36.4500
CRS moves 3" side-to-side when installed	3.250			14.58	47.3850	6.25	20.3125
CRS moves 4" or greater side-to-side when installed	4.000	2.08	8.3200	4.17	16.6800		
Space btw. CRS back and vehicle seat cushion – 1"	1.250	2.08	2.6000	43.75	45.0000	20.83	26.0375
Space btw. CRS back and vehicle seat cushion – 2"	2.250			14.58	32.8050	4.17	9.3825
Space btw. CRS back and vehicle seat cushion – 3"	4.000	4.17	16.6800	2.08	8.3200	2.08	8.3200
Space btw. CRS back and vehicle seat cushion – 4"	5.750						
Space btw. CRS back and vehicle seat cushion – 5"	6.875						
Total general installation RPN			53.6300		227.2650		121.3325

Total RPN Value (top tether+LAC+general)			373.42		458.15		338.12

9.2 In school bus

		CRS A		CRS B		CRS C	
	Severity Score	Frequency (%)	RPN	Frequency (%)	RPN	Frequency (%)	RPN
Top tether errors							
Tether not used	4.250					2.08	8.8400
Tether not attached to proper tether anchor	5.500	6.25	34.3750	2.08	11.4400	2.08	11.4400
Tether strap is twisted	1.000	33.33	33.3300	2.08	2.0800	2.08	2.0800
Tether strap is not correctly threaded	5.000	2.08	10.4000	2.08	10.4000	4.17	20.8500
Tether strap slack – 1"	2.750	20.83	57.2917	4.17	11.4675	8.33	22.9075
Tether strap slack – 2"	3.000	2.08	6.2400			2.08	6.2400
Tether strap slack – 3"	3.250						
Tether strap slack – 4"	3.625					4.17	15.1163
Tether strap slack – 5.5" or more	4.375						
Total top tether RPN			141.6367		35.3875		87.5413

Lower anchorage connectors errors							
Lower anchorage connectors are not attached	9.375						
Lower anchorage connectors are connected to wrong vehicle anchor location(s)	5.000	8.33	41.6500	6.38	31.9000	4.17	20.8500
Both lower anchorage connectors are connected to the same vehicle anchor	6.000			2.13	12.7800		
Lower anchorage connector hook attached upside down	1.375	14.58	20.0475	48.94	67.2925	33.33	45.8288

		CRS A		CRS B		CRS C	
	Severity Score	Frequency (%)	RPN	Frequency (%)	RPN	Frequency (%)	RPN
Lower anchorage connector strap (flexible webbing) is twisted	1.375	16.67	22.9213	19.15	26.3313	12.50	17.1875
Lower anchorage connector straps have slack – 1"	2.875	10.64	30.5900	14.89	42.8088	14.58	41.9175
Lower anchorage connector straps have slack – 2"	3.625					2.08	7.5400
Lower anchorage connector straps have slack – 3"	4.500						
Lower anchorage connector straps have slack – 4"	5.625						
Lower anchorage connector straps have slack – 5.5" or greater	6.875						
Total lower anchorage connector RPN			115.2088		181.1125		133.3238

General installation errors							
CRS moves 1" side-to-side when installed	1.000	14.58	14.5800	10.42	10.4200	12.50	12.5000
CRS moves 2" side-to-side when installed	2.250	8.33	18.7425	14.58	32.8050	10.42	23.4450
CRS moves 3" side-to-side when installed	3.500	2.08	7.2800	10.42	36.4700	4.17	14.5950
CRS moves 4" or greater side-to-side when installed	4.250			18.75	79.6875	8.33	35.4025
Space btw. CRS back and vehicle seat cushion – 1"	1.00	6.38	6.3800	19.15	19.1500	10.42	10.4200
Space btw. CRS back and vehicle seat cushion – 2"	2.000	2.13	4.2600	14.58	29.1600	2.08	4.1600
Space btw. CRS back and vehicle seat cushion – 3"	3.500			18.75	65.6250	4.17	14.5950
Space btw. CRS back and vehicle seat cushion – 4"	5.250			8.33	43.7325	2.08	10.9200
Space btw. CRS back and vehicle seat cushion – 5"	6.375						
Total general installation RPN			51.2425		317.0500		126.0375

Total RPN value (Top tether+LAC+general)			308.09		533.55		346.92

10. APPENDIX C: Usability issues concerning CRS use in a school bus.

INTRODUCTION

As of April 2007, Canadian school bus manufacturers will be required to equip a portion of each bus's seats with Universal Anchorage System (UAS) top tether, and lower, anchors. In this way, school buses will be capable of safely accommodating smaller, pre-school age children. While providing advantages in terms of children's safety, the installation and use of child restraint systems (CRS) on school buses may have consequential effects that are, at present, unknown. The purpose of the present informal usability study was to identify, and make recommendations regarding, human factors issues associated with the use of CRS in school buses.

METHOD

Participants. Previous research found that children weighing 18 kg (40 lbs) or less would benefit from being restrained in a CRS when traveling in a school bus (Legault, 2004). In terms of age, this translates roughly to children aged 4.5 years or younger. Study participants included one adult female and her two daughters. The first child was 2.5 years old, weighed 14 kg (31 lbs), and was 95 cm (37.5") tall. The second child was 4.5 years old, weighed 17 kg (37 lbs), and was 109 cm tall.

Equipment. The school bus seat mock-up, as well as CRS A and B from the main UAS Usability Study, were used. Their features are fully described in Section 4.3 of that report.

Procedure. Direct observation, video recording, participants' verbal comments and informal interviews were used to collect usability data. To begin the study, the adult was asked to install the two CRS side-by-side, in the middle seat of the school bus mock-up, using the top tether, and lower, anchorages. CRS A was installed next to the window, and CRS B next to the aisle. Once they were installed, she placed and secured each child into the CRS. She then removed both. Then the children were asked to climb into, and position themselves within, the CRS, at which point the adult secured the CRS harnesses. The children were then instructed, once the harnesses had been undone, to independently remove themselves from the CRS. Finally, the adult removed both CRS from the mock-up.

Throughout testing, participants were encouraged to speak out loud so that their comments and opinions could be recorded. By using this method, the observer could more fully assess the behavioural techniques that participants used to complete the tasks.

At the completion of testing, the facilitator conducted an informal interview with the adult and the 4.5 year-old participants. The adult responded to questions concerning the installation and removal of the CRS, and the installation and removal of the children. The 4.5 year-old was asked how easy it was to climb into, and out of, the CRS. The adult participant completed a debrief form, and was compensated for her, and her children's time.

RESULTS.

CRS Installation and Removal. The participant was able to correctly install both CRS in the school bus seat. Direct observations and comments from the participant indicated, however, a number of issues:

- The CRS in the window position should be installed first. It would be difficult to lift and position a CRS next to the window if there was already another installed CRS in the aisle side of the seat. It would also be difficult to access the lower anchors. Likewise, the CRS should be removed in the reverse order.
- The height of a school bus seat back prevents adults from leaning over it to install or remove a CRS on the seat behind. Similarly, because CRS are wider than the centre aisle, they will have to be carried over the tops of the seat backs when being taken on and off a school bus. Carrying an object of this weight and awkward shape will likely cause problems for adults who have minimal lifting capability or who have a tendency to experience back and/or shoulder discomfort (Figure 1).

Figure 1. Carrying a CRS over the bus seat backs.

- Connecting the CRS lower attachments near the window first, then proceeding inboard towards the aisle, will make installation easier. The reverse will facilitate CRS removal. However, the stooped, twisted postures that are necessary for installing CRS will make the bus drivers/other responsible adults more susceptible to back injuries.
- A CRS that uses a single lower attachment strap routed through the CRS (CRS B) should have the tension adjuster positioned to the inboard (aisle) side of the CRS. It would be difficult to achieve adequate tension if it is located next to the window or between two CRS. This situation would also make it difficult to release the tension in the strap (and subsequently disengage the lower attachment connectors).

Placing child in the CRS (by adult). The adult participant was required to physically lift and place the children in both CRS, and then remove them. The participant experienced difficulty with this task, particularly when positioning the child in the CRS next to the window. Observations and comments from the participant revealed that:

- It was physically awkward to lift and hold the child over one CRS in order to place her in the other CRS, and especially to do this in a gentle manner. It was also difficult and frustrating when lowering the children into the CRS, as their feet and legs would tend to get stuck between the front edge of the CRS and the back of the vehicle seat in front.
- Individuals with limited lifting capacity, including back or shoulder discomfort, will find it very difficult to lift and place a child into a CRS and remain in an awkward position while securing the child. Consequently, an adult may hurry, and be more likely to make mistakes.
- Lifting a child over the seat back from the seat in front of the CRS would require considerable upper body and arm strength, and would place extreme loads on an adult's back.
- Because of the weight of a typical preschool child, and the awkward postures that must be adopted by an adult during a task of this nature, there is a significant risk of musculoskeletal injury to the adult. This risk would increase if the task were to be repeated on a regular basis.

Child positioning themselves in CRS. The children positioned themselves into, and then removed themselves from, each CRS in the school bus. While the 4.5 year-old was able to do this, the 2.5 year-old was unable to do either task on her own and required adult assistance.

To position herself in the CRS that was installed next to the window, the 4.5 year-old first placed one foot on the bus seat that was in front of the CRS. Then, holding onto the top of this seat for leverage, she stepped on the bus seat where the CRS were installed and walked across the CRS. She stepped into the CRS and sat down, allowing her feet to slide downwards. To remove herself, she slid downwards between the CRS and the seat back and squeezed herself in front of the other CRS (Figure 2). Issues with this positioning/removing method include:

- The child would not have been able to position herself in the window CRS if there had been another child seated in the aisle-side CRS.
- Winter clothing would make it more difficult for the child to manoeuvre herself in this way.
- Over time, this technique would likely cause the bus seat and the CRS to be damaged, especially in poor weather conditions.
- There is a significant risk of a child slipping and falling when performing manoeuvres of this nature.

Figure 2. Child participant removing herself from CRS installed next to window.

Securing child in CRS. In both phases of the study, the adult participant was required to secure the CRS harness over the child. The participant successfully completed this task, however, several issues were raised:

- The participant positioned herself on the seat in front of the children in order to secure their harnesses. This could not be done if other children were seated in this seat.
- Standing in the aisle, the participant was able to correctly secure the child in the CRS that was positioned next to the window, however, to do this, she was required to maintain an uncomfortable posture (Figure 3). The 4.5 year-old was able to independently secure the harness and crotch strap clips; the adult only needed to check them.

Figure 3. Securing child in CRS installed next to window.

Child seated in CRS. The space between the front edge of the CRS and the seat back in front is only 10 cm (4”) (Figure 4, left panel). This limited space made it difficult for both children to comfortably position their legs when they were seated in the CRS. Surprisingly, the limited space affected the smaller participant more significantly, as her legs remained more in an extended position when she was seated in the CRS (Figure 3, right panel). Even when she was seated in CRS B, which allowed her legs to fit between the CRS and the seat, she chose to remove her shoes so that she could comfortably position her feet. Snowsuits and winter boots would be expected to exacerbate this issue.

Figure 4. Limited space between CRS and seat in front made it difficult for 4.5 year-old (centre) and 2.5 year-old (right) to comfortably position their legs/feet.

CONCLUSIONS AND RECOMMENDATIONS. The results of this informal usability study point to a number of issues that should be considered when installing small children in CRS on school buses. Consideration of these issues leads to a number of recommendations, which fall into four basic categories: injury, safety, comfort and convenience. Recommendations include:

- School bus manufacturers are encouraged to use maximum seat spacing for those school bus seats equipped with the UAS. **Safety/comfort.**

- Those jurisdictions responsible for the transport of small children in school buses should put processes into place that ensure the correct installation of CRS. For example, they might require bus drivers to receive certified child passenger safety technician training, and carry out periodic checks of CRS and their installation **Safety.**

- All efforts should be made to use only one CRS per bus seat (i.e., next to window). This will increase the ease of installation and removal of the CRS, as well as the ease of installing the child. This arrangement is also preferred for issues relating to emergency egress. **Safety/comfort/convenience.**

- The postures adopted by adults when installing CRS in school buses, and when lifting children into, and out of, CRS, are associated with an increased risk of back injury. These risks should be considered when deciding where in the bus to seat small children in CRS. The placement of small children in CRS one to a seat, near the front of the school bus, is recommended, both for the convenience of the driver, as well as in consideration of emergency egress issues. **Injury/comfort/convenience.**

- School bus drivers should be encouraged to make regular inspections of the CRS on their bus. It is possible that older, unrestrained children will tamper with them. Likewise, excess top tether and lower attachment webbing should be adequately stored within the CRS at all times. **Safety/convenience.**