

Boosters for Shared Mobility

Lotta Jakobsson, Katarina Bohman, Isabelle Stockman, Sebastian Simmons, Charlie Johansson

Volvo Cars Safety Centre

Volvo Cars, Göteborg, Sweden.

Email: lotta.jakobsson@volvocars.com. Phone: +46 766 210314

Abstract

Shared mobility is increasing, especially in cities. To make these services more available for families with children, special consideration is needed to provide an easy and convenient way of ensuring children are restrained properly on child restraints.

The objective of this study is to identify the challenges of appropriate child car passenger protection in the context of increased shared mobility and to present and discuss safe booster concepts addressing the challenges. The study focuses on children who have outgrown the need for a toddler seat and can use the vehicle restraint together with a booster, typically 4 years of age to approximately 140cm stature and 10-12 years old.

The study is based on the protection principles for the children. It includes the children's and their parents' perceptions of usage, and the experience and development of boosters over time and into the future. Two booster concept studies are included, illustrating two identified areas of concern; portability and the type approval development, respectively.

It becomes obvious that there is a mismatch in users' needs and booster development trends. Collaborative efforts with a joint mindset are proposed as the way forward.

Protecting children in cars - the development and experience of boosters

Smaller children need infant or toddler seats with internal harness. For optimal protection they should be placed rearward facing to ensure that their neck has better chance to cope with high severity frontal impacts [23]. When outgrown the toddler seats, and approximately 4 years old, the children can benefit from the vehicle restraints, given they are raised into a good position for the vehicle seatbelt.

The protection principle of a seatbelt is to restrain the strong parts of the body; the pelvic bones, and across the chest and over the shoulder [1, 7]. The lap belt position is crucial in helping avoid lap belt interaction with the abdomen. The anterior superior iliac spines of the pelvis are important for good lap belt positioning and they are not well developed until a child is about 10 years old [11]. In addition, the size of the pelvis grows with age, having influence of the height position of the iliac spines in relation to the seat cushion. Through elevating the child, the lap belt will be routed on the pelvis, as for adults, instead of toward the abdomen. The shoulder belt position ensures a desired head and upper body kinematics during a frontal impact when positioned on the mid-shoulder, across the chest and remaining below the upper part of the sternal bone [27]. A seatbelt performs best when routed as straight as possible. When extensively re-directed or re-routed, its protective functions will be influenced due to introduction of slack.

A booster that elevates the child, shortens the seat cushion, positions the lap belt in contact to the pelvis and the shoulder belt across the mid-clavicle, serves the purpose to help position the vehicle seatbelt on the child so that it can perform as designed. The child will then also get access to the vehicle overall built-in protection, as for adults, helping to protect in different types of crashes.

In 1978, the world first belt-positioning booster was introduced [33]. The idea of boosters for children sprung from a study initiated by the discussion of enforcing rear-seat seatbelt use, where it was questioned whether seatbelts were safe for small adults [32]. The first-generation booster was a booster cushion, shown in Figure 1a.

Important features of the booster cushion are the belt-positioning guides, one on each side. Its purpose is to help keep the seatbelt in position during a crash by restraining the booster. Modern

boosters have guides protruding upwards (exemplified in Figure 1c) and they vary in height and design. The guides can also serve as a way to help position the shoulder portion of the seatbelt. By placing the shoulder belt over or under the guides, it can help to achieve the desired mid-shoulder belt routing for both shorter and taller children, resulting in desired dynamic performance [10].



Figure 1a. World-first booster cushion 1978



Figure 1b. Example of second-generation booster cushion from 1985, with a removable backrest



Figure 1c. Booster cushion with removable backrest from 1989.

The backrests were initially intended to provide head support in cars without head restraint, as shown in the example from 1985 (Figure 1b). The backrest was also a way of adjusting the length of the cushion to accommodate the shorter thigh length of the smallest children. When removed, the cushion length better accommodates the larger children. It can include shoulder belt-positioning devices with the ambition to help guide the belt into a comfortable and safe mid-shoulder position [38]. The backrest of the booster in Figure 1c allows for height adjustment, enabling the shoulder belt guide to adjust to different sizes of children. When no backrest, the shoulder belt position can be adjusted by the position of the lower part of the shoulder belt over or under the guides. Backrests can potentially provide sleeping support and help to control the lateral position of the child's upper body. In recent years, the designs of the backrests have evolved towards large side supports both at the height of the torso and the head. The child restraint manufacturers emphasize two reasons for this; to provide improved side impact protection and to provide comfort for children by keeping them upright when relaxed or asleep [5]. Although developed for crash protection, it is not evident that a backrest with head side supports offers lateral protection for the child in all real-world situations and the protruding side supports could result in unfavourable initial sitting positions increasing risk of head impacts in some situations [18, 22].

The booster sets the child in a more upright position, allow the legs to bend and more adaptive thigh support, so the child will not scoot forward in the seat to find a more comfortable leg position when seated. Slouching may result in sub-optimal belt geometry [12]. Involving 25 child volunteers aged four to 12, static beltfit for six different boosters, ranging from low boost to high booster, as well as a non-booster condition was performed [25]. The low height boosters produced postures that were more slouched, with the hips further forward than in other more typical boosters.

In 1990, the world first integrated (built-in) booster was introduced addressing accessibility, acceptance and reduced risk of misuse [31], Figure 2a. In 2007, a second-generation integrated booster was introduced providing two levels in height, adapting to the growing child [17], Figure 2b. The acceptance of integrated booster was shown to be higher, provided by the relative higher usage of the integrated boosters, in comparison to accessory boosters, among the older children, 8-10 years old [20, 21]. Reduced risk of misuse was confirmed by Osvalder and Bohman [35] providing evidence that misuse was almost eliminated when using integrated boosters. A follow-up study in China showed similar findings of reduced risk of misuse when buckling up on an integrated booster compared to an accessory booster cushion [8]. On road driving studies comparing integrated booster and a high-back booster indicated a more positive attitude on comfort as well as a higher degree of upright sitting posture towards the seatback for the integrated booster [36].



Figure 2a. World-first integrated booster, 1990



Figure 2b. Two stage integrated booster; high position (left) and low position (right)

Boosters are effective to help protect children in frontal impacts as well as other crashes [12, 15, 46, 17, 2, 3]. Arbogast et al. [3] showed that seatbelt syndrome related injuries to the abdomen and spine were nearly eliminated in crashes with children using boosters compared to those restrained by seatbelts only. Children aged 4 to 8 years old and using booster were 45% less likely to sustain injuries than similarly aged children who were using the vehicle seatbelt only. Children in side impacts derived the largest relative protection from boosters, with a reduction in risk of 68% and 82% for near-side and far-side crashes, respectively. No difference in booster seat versus booster cushions were seen [2, 3, 24, 4]. Comparing head injury between booster seated children and adults in similar cars and crashes, it was seen that there were no differences in injury patterns, providing evidence of similar mechanisms and needs of protection for both groups [16].

Several parts of the world are banning booster cushions, claiming lack of head protection in side impacts. Consumer information tests disqualify booster cushions which are lacking backrest with protruding side structure, claiming the side structure being essential for the child's protection in side impacts. The reasoning for this is not in correspondence with decades of real-world experience, where it is seen that the vehicle protection is serving to protect the booster seated children similar to adults [16] and no evident difference between booster seat and booster cushion is seen [4]. The Australian regulation, as well as the UN R129 type-approval, require protruding head side structure to pass the side-impact rig-test method, a method that lacks important state-of-the-art vehicle protection characteristics, for example inflatable curtains. UN R129 still includes booster cushions by allowing exception of the side-impact test. However, this is only for children 125cm and taller. Booster height specifications, with the ambition to get the child's head into a certain height position, makes it difficult, if not impossible, to design an attractive booster for the children it targets.

The challenges of today

In most motorized countries there is a high awareness of the need to use boosters for children in cars. Recent numbers for Sweden show that 93% of children aged 4 up to 8 years old report using appropriate restraints 'always', while 4% report 'sometimes' [45]. In 2015, these numbers were 69% and 6%, respectively [44]. In US in 2015, 63% of children aged 4-7 were using child restraints [30]. The usage frequencies vary between countries and the age of the children. A decreasing trend with increased age is seen in Sweden. Booster cushions or integrated boosters account for the vast majority of those using booster among the oldest [16]. In 2020, restrained children aged 8 up to 11 years old report 88% use of booster cushion and 23% booster seats (multiple choice possible) [45]. The booster cushion usage was 40% among those aged 4 up to 8 years old.

The reasons for non-use or part-time booster use are several; such as lack of knowledge, the child thinks it is childish or claims it to be uncomfortable and refuses or the booster is too big [37, 39, 14, 6]. Access and convenience are other reasons for non-use. The boosters may not be easily available e.g. when travelling with others, or when in a hurry [6]. Compared to private cars, the use of child seats is lower in taxis than in private cars, which was seen attributable to the inconvenience of carrying them to and from the taxi [29]. Another important safety challenge is misuse, having impact on the protection. The most frequent misuse modes for boosters relate to the belt routing; incorrect lap

belt path or non-optimal shoulder belt routing [34, 8]. Discomfort caused by the shoulder belt being too close to the neck may be solved by placing the belt off the shoulder away from the neck or even placing the shoulder belt under the arm or behind the back [14, 19], which increases risk of injury if exposed to a crash.

Shared mobility is an increasing trend all over the world. An overview of 47 countries showed that, in October 2018, car sharing businesses included 32 million users, sharing 198 000 vehicles [40]. In 2018, online car hailing accounted for 36% of the total traffic volume in China [41]. The use of taxi services, car-pool systems, and other car sharing, such as remote activation of borrowing your friend's car without long planning, are examples of not using the same car every day. In addition, an increase of multiple transportation modes during one trip; using cars only part of the trip, becomes a consequence of city planning and changes in mobility trends. These changes pose challenges for child car passenger protection in relation to the traditional way of car ownership/usage. A study of early adopters of car sharing services in Berlin, indicated that car sharing was attractive to people not being in charge of taking care of their children [27]. In a travel survey, it was found that households with children, especially in low- and mid-income households, were less likely to use car sharing and ride-sourcing mobility, compared to other households [13]. Hence, there is a need to further understand why the use of shared mobility is lacking behind for households with children and how to address their needs in order to make a change.

Study of user experience, needs and perceptions

To gather insights into users' experiences, needs and perceptions in the context of boosters and shared mobility, a study using interviews and questionnaires was performed as part of a students' project. The complete study is available in Johansson and Simmons [25] and summarized here.

Interviews

Interviews were conducted with five families in the area of Gothenburg, Sweden, involving seven adults and four children. All participants had experience of using boosters. The interviews covered questions on their booster experience and perceptions, including question on car sharing services and use of second-hand boosters.

Several participants pointed out that a portable booster should be reduced in volume and be easy to carry, preferably with a handle or similar, while the weight was secondary. To remove the backrest of the booster seat and only bring the cushion part when using taxi or car sharing services would be the solution for one family. While another family regularly travelling to relatives by train, had bought and left a booster seat at their relatives' house, to not have to bring one along with the argument that their booster seat was too big to bring on the train together with their luggage.

The participants' view on second-hand boosters varied. While some participants mentioned their reluctance of using second-hand boosters for which they had no history, although they would consider borrowing boosters from friends they trusted, others said they had no concerns using second-hand boosters. Concerns regarding trust of the booster brand were expressed; with high trust in well-known brands, in contrast to low-budget products available at the supermarket.

One family not owning a vehicle, rented a car two to three times a month. The reason for renting instead of using car sharing services was the availability of boosters to their two children. When renting the car, they could rent the boosters together with the car, while no such alternative was available with the car sharing service.

Online survey

An online survey was conducted, recruiting participants through Swedish Facebook groups; targeting family groups and sustainability groups. Eighty-six participants finished the questionnaire. The majority (93%) had at least one car in the household. Among the six participants not owning a car, one was using car sharing services. Forty-three participants responded that they were using boosters for at least one of their children, at the moment.

Regarding the questions on experiences of car sharing services and taxis, most of the participants answered that they had no experience of car sharing services. Among those who had, a majority stated they had experienced trouble with the child restraints. Mentioned solutions were; pick up the car and

drive to the house to limit the transport of the child restraints or place the boosters in a bag and carry them along to the car. Some participants stated that the difficulties with the child restraints were the reasons for them to not use car sharing services. When using taxis, the answers differed among the participants. Some brought their own booster, some said the taxi company provided it, while others had the experience of the taxi company not providing it. Several participants mentioned that when they order a taxi, they ask for boosters in advance.

Gathering insights into the perceptions and needs for booster design in shared mobility, three different scenarios were described for the participants. In the first scenario, the participants were asked to choose between the two attributes weight and volume, when buying a booster to be used for car sharing services, putting aside aspects as safety, comfort and usability. The advocates of volume argued that it should be possible to fit into a bag. The arguments for lightweight was primarily when there was a need to carry it around a lot, while some participants specifically stated that weight would not be a problem since a booster cushion cannot be unreasonably heavy. Portability was emphasized in this scenario, a difference to when they related to owning a car. Many participants mentioned some sort of carrying support such as a handle, shoulder strap or a bag for the booster.

The second scenario focused on whether the participants preferred to use their own booster while using a car sharing service, or if they preferred to be provided with a booster in the car. The answers deviated. Twenty-one percent of the participants refused to use a booster they did not know the history of, they would use their own. Some mentioned they would use the booster offered by the car sharing service if their own was too difficult to bring along. The vast majority (72%) would use the booster in the vehicle. Several of these responds were connected to statements given that the company could guarantee the safety of the booster. Most of the participants pointed out they expected the booster to be clean. Overall, the majority embraced the idea of the car sharing service providing the booster, stating that they would not have to carry around their boosters anymore.

The third scenario posed the question on what possibilities the user would like when it comes to carrying the booster. The participants could choose from several alternatives and provide own suggestion afterwards. Four alternatives were provided asking their preference for their child and for themselves, respectively. The alternatives were; a double backpack straps on their booster, a single shoulder strap, a hook that could be fasten on a backpack, or carry the booster in a bag. About 50 participants would consider having a double backpack strap for their child and for themselves. Forty-four participants would be okay with a single shoulder strap for themselves but only 13 for their child. Thirty-six participants would consider using a hook for their own bag, but only 11 would like to hook it onto their child's bag. Thirty-seven participants would consider the option of carrying the booster in their own bag, while only 20 participants considered this for their child. Additional input provided in the free text included; an ordinary handle to grab and carry the booster with and the idea of hooking or storing several boosters together, making it easier to handle in general. Many participants voted for several alternatives as different situations require different possibilities to carry the booster on.

The 43 participants who were using boosters for at least one of their children at the time of the survey, answered additional questions regarding boosters. Thirty-seven percent responded lack of a handle when carrying it in response to problematic situations with the booster in their current situation. Ten out of 43 found the booster too big to fit their cars, especially when using multiple boosters, or an adult seated next to the booster. When asked to reflect on changing from their personally owned car to using car sharing only, most comments related to the issues of carrying the booster, especially those having several children in need of child restraints. The participants, who also had younger children were most concerned about their large rearward facing child seats in comparison to the booster. Several participants suggested that the vehicles in the car sharing services should have integrated boosters, or that there should be booster cushions available in all cars.

The overall conclusion from the interviews and the survey was that portability was seen as a top priority including primary functions such as easy to carry, followed by reduced volume and reduced weight. If they would use car sharing services, the parents wanted a portable booster cushion that is easy to carry around, prioritizing the size of the booster. Most participants had similar view, that a booster cushion cannot be too heavy, however, a weight of 3 kg was still considered "light" according to many of the participants. The booster reference for most of the participants in the study was today's UN R44 type-approved booster cushion. Important conclusion is also that many of the participants

found car sharing services unavailable to them today, due to the hassle around moving child restraint systems.

Designing a booster for tomorrow

Integrated boosters offer optimal protection, by providing a boost, being stable during a crash and being designed together with the vehicle protection. However, today they are available in a limited number of car models and never in all passenger seat positions. Therefore, there is a need for a non-integrated booster matching the protection principles of the integrated booster, while being portable and easy to use. A well-designed booster cushion of today (and for 40 years) provides these prerequisites. Although, it can be improved mainly from a portability perspective, in addition to the individual needs for the large span of children sizes.

Two concept studies were performed to explore the challenge of portability and to understand the potential design consequences in the UN R129 type-approval, respectively.

Booster cushion concept addressing portability

The first concept study addressed the functions as identified in the interviews and online survey; focusing portability with the primary function of easy to carry, followed by reduced volume and reduced weight. Volume reduction was judged to be more challenging than weight reduction, whereby the strategy was that once the volume was reduced, continued improvement of the concept could be made in terms of reducing the weight. In addition, once a reduced volume was achieved, different carrier solutions could follow. The concept, as shown in Figure 3, is also presented in [25].

The overall arching prerequisite was to fulfil the protection principles, hence ensuring an elevation of the child and a good lap and shoulder belt position and interaction throughout the event. With this prerequisite in mind, a booster cushion concept was developed towards the goal to reduce volume, when not in use, in addition to overall portability.

The booster cushion concept comprised a two-step folding sequence. Figures 3a), b) and c) show how the concept is reduced in width by 10cm, as a first step. In the second step, the booster is folded resulting in a reduction of the depth by 15cm, Figures 3d) and e). In total, the volume then becomes 37% smaller in the compressed state compared to when in use. With some further refinements, it was estimated that the total weight could be less than 2 kg. The concept was created as a physical prototype, proofing the principles of folding were feasible. Static FEM analysis was performed to ensure the integrity when exposed to the loads in a crash.

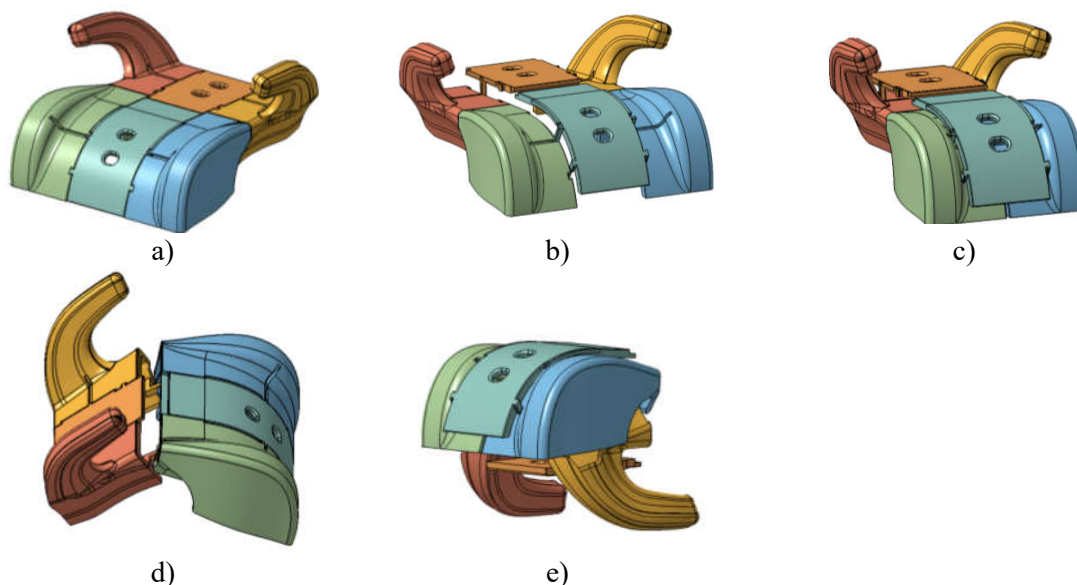


Figure 3. A sequence of picture showing the compression of the booster. a) unfolded booster, b) the middle plates are raised, c) the sides are pushed together, reducing the width, d) booster is folded to reduce the depth, e) the final size of the compressed booster.

As a next step to reduce the volume, the guides should be addressed. By folding them separately, the volume can be further reduced. Additional ideas of refinements and design details are presented and discussed in Johansson and Simmons [25], exemplified by carrier solutions to address aspects of easy to carry and handle.

Booster cushion concept addressing the design specifications in UN R129

A second concept study was performed exploring the specifications in UN R129 and its implication on booster cushion design. UN R129 allows booster cushions to be designed for children of statures from 125cm to 150cm. The static booster height specifications and the frontal impact sled test requirements are some of the requirements influencing the design, as summarized:

- Booster cushions shall ensure that the top of the child's head is at or above a horizontal plane at 770 mm vertically from the Cr axis when placed on the test bench, see Figure 4a.
- The height of the booster cushion is a result of applying data from a table specifying the sitting height in relation to child stature.
- The frontal impact test is performed with the Q10 for boosters that is accommodating a child from 126cm and higher, while the Q6 is used for a booster accommodating a child of 125cm.
- In the frontal impact test, the top of the dummy's head is not allowed to pass the horizontal DA plane, which is 840mm and 800mm above the Cr axis, for the Q10 and Q6, respectively, see Figure 4b.

In addition, it is regulated that only one adult safety belt route is allowed and one main load-bearing contact point on each side of the booster.

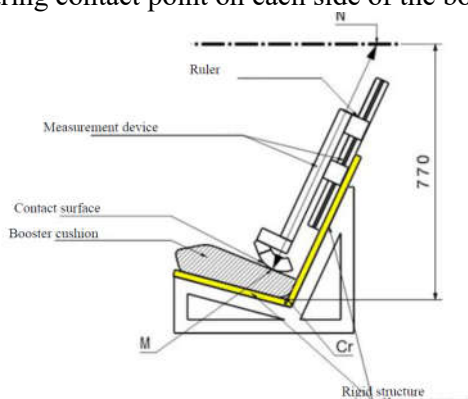


Figure 4a. Measurement device in UN R129 to check the booster cushion height, based on sitting height specifications. [43]

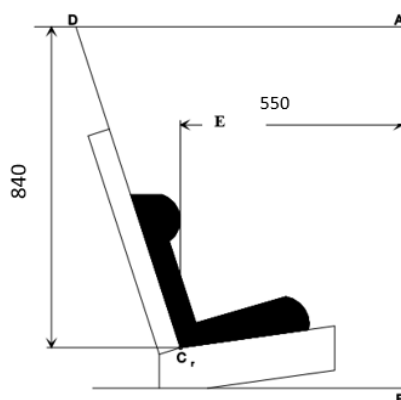


Figure 4b. The planes for which the Q10 head is restricted to pass in the frontal impact test; The requirement for DA plane for Q10 is 840mm. [43]

A booster cushion concept to fulfil the geometry specification of UN R129 was developed. It was based on an UN R44 type-approved booster cushion. The height of the booster cushion concept was dictated by the head position, based on the measurement device as shown in Figure 4a, and the specification of sitting height in relation to child stature. When applied for a 125cm child, the height of the booster cushion concept resulted in an elevation of 6.5cm in comparison to the reference booster cushion, i.e. a total height of approximately 13cm. Figure 5 provides a comparison of the booster cushion concept and the reference booster.



Figure 5a. Side view of the UN R129 booster cushion concept from 125cm and taller (left) and the reference booster cushion (right).



Figure 5b. Rear view of the UN R129 booster cushion concept from 125cm and taller (left) and the reference booster cushion (right).

Placing the booster cushion concept in the R129 test rig, it is estimated that the Q10 head is just below the horizontal DA plane limit of 840mm. This means that the head position at start is almost at the limit of head excursion during the frontal impact test. For the shorter Q6 (required for the 125cm child) a somewhat larger margin is likely, although the DA limit is lower (800mm). No crash tests have been performed at this stage. Appendix A1 shows Q6 and Q10 restrained on the two booster cushion variants in a vehicle rear seat. It can be seen that the crash test dummies are sitting higher on the booster cushion concept as compared to the reference booster cushion. However, from the lap belt position perspective, this extra boost is not required. Based on experiences from prior studies [10], several of the shoulder belt positions are likely to be challenging from a shoulder belt interaction performance perspective in frontal impact tests; exemplified by the far-out position (Figure A1a) and the too close to the neck positions (Figure A1f). However, the combination of shoulder belt positions; under for the Q6 (Figure A1e) and over for the Q10 (Figure A1b), would provide a more favourable shoulder belt position.

Three children were used to compare the booster cushion concept with the reference booster cushion, in addition to a R129 type-approved booster seat, in the same vehicle rear seat as the Q6 and Q10. One child represents the minimum size of child for the booster cushion concept and two children represent the sitting height of the Q10. The shorter child with a stature of 125cm ('short boy'), is 6 years old and has a sitting height of 67cm. The two taller children are both 11 years old and 139cm tall with sitting heights of 75cm ('tall girl') and 74cm ('tall boy'), respectively. The exercise included static seatbelt fit, in addition to evaluating convenience when getting in and out of the car and buckling up. The buckle-up procedure was also performed by the parent, evaluating the convenience of buckling-up, including access to the buckle.

The lap belt position is similar between the two booster cushion variants, providing the essential boost for both booster cushions. From that perspective, the extra height of the booster cushion concept is not required. With respect to shoulder belt position, appropriate positions across the chest and at mid-shoulder position were possible to obtain for both booster cushion variants. However, given the height difference between the children, there was a need for accommodating a positioning of the shoulder belt, by placing the lower part of the shoulder belt over or under the guide.



Figure 6a. 'Short boy' restrained on the booster cushion concept in a vehicle rear seat; shoulder belt positioned under the guide.



Figure 6b. 'Tall girl' restrained on the booster cushion concept in a vehicle rear seat; shoulder belt positioned over the guide.

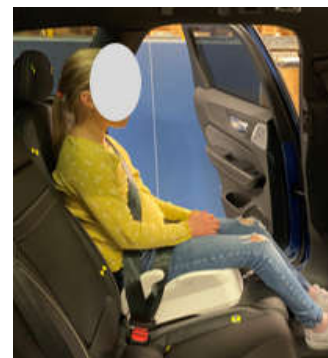


Figure 6 shows frontal and lateral views of the 'short boy' and 'tall girl' when seated on the booster cushion concept in a vehicle rear seat. The most appropriate shoulder belt positioning was selected for each child; under the guide for the 'short boy' and over the guide for the 'tall girl', respectively. Photos of all three children for both combinations of shoulder belt positions for the booster cushion concept and the reference booster cushion, respectively, in addition to the booster seat, are shown in Appendix A2. When positioned over the guide for the 'short boy', the shoulder belt was positioned too close to the neck to ensure a comfortable position, see Figure A2:1b. Shoulder belt positions further out on the shoulder were seen for the 'tall girl' (Figure A2:1f) and the 'tall boy' (Figure A2:1k), when positioned under the guide, although it was not as far out as for the Q10 (Figure A1a).

When the children were seated in the booster seat, the shoulder belt position was adjusted using the height adjuster in the seatback / headrest of the booster seat, according to the manual. This helped to adapt to a comfortable mid-shoulder position for each of the three children (Figures A2:1e, A2:1j and A2:1n). The UN R129 specification of “one adult safety belt route is allowed”, has the implication for booster cushions that it is likely not allowed to use the possibility of choosing shoulder belt position under or over the guide to accommodate for comfortable mid-shoulder position. The UN R44 did not restrict this possibility for booster cushions; using the means available of the child restraint system, guiding the lower part of the shoulder belt to be positioned in multiple ways. When comparing the photos in Appendix A2, the need of providing adjustability for the shoulder belt remains for the booster cushion, in analogy with the need still addressed by the booster seats.

The convenience of getting seated and buckling-up for the children differed between the three boosters evaluated, see Appendix A3. The height difference between the booster cushions influenced the stability. Compared to the reference booster cushion, the ‘short boy’ had more difficulties to climb on/off the booster cushion concept (see Figure A3a). The booster wobbled and moved sideways resulting in a non-centralized position in the seat. The ‘short boy’ spent some time to manage to buckle-up; he had to stretch and bend downwards to reach and find the buckle. Both tall children experienced less unstable situation when getting seated on the booster cushion concept compared to the ‘short boy’, however, both children found it less convenient to get up on the high booster cushion concept compared to the lower reference booster cushion. The booster seat was more stable, due to its attachments to the ISOFIX anchorages. However, all the children needed more space to enter the seat and to reach around the inboard side support of the booster seat. In addition, especially the tallest children found it “tricky” to get their torso to fit into the booster seat. It should be noted that the front seat was in maximum forward position for photo reasons, whereby the available space for the study was substantially more than what is usually the case in most vehicle rear seats.

Appendix A4 shows the buckling-up made by the parents. The booster cushion concept, with its increased height of approximately 6.5cm, obstructed the view for the parent, who had to lean into the vehicle over the child, to have a view of the buckle and to be able to access the buckle. However, when in this inboard leaning and bended position, they perceived the access to the buckle was better for the booster cushion concept than for the other two boosters. This was mainly due the relatively more space available around the buckle.

In addition, an interaction with the vehicle seatback contour was seen due to the height of the booster cushion concept. With a height increase of the booster cushion, it becomes more important to address the interaction with the vehicle seatback contours when designing the shape of the booster cushions rear side. As for an adult, a child on a booster cushion will benefit from the vehicle seatback contour for their comfort and sideways support.

Discussions

Children aged 4 to 10-12 years old are well protected if using boosters that elevate them, shorten the seat cushion length, position the lap belt in contact with the pelvis and position the shoulder belt across the chest and shoulder. The protection is a combination of the vehicle design, the booster design and how the child is using the restraints. Integrated (vehicle built-in) boosters benefit from being designed together with the vehicle restraints, optimizing their protective performance. Studies have confirmed them to reduce likelihood of misuse, being comfortable, and a way to attract the older children to use boosters [35, 20, 36, 21, 8]. However, integrated boosters are available in a limited number of car models and never in all passenger seat positions, whereby there is a need for a non-integrated booster matching the protection principles of the integrated booster, while being portable and easy to use.

Changing from the habit of using one car from start to destination, to flexible use of several different cars, in addition to change of transportation modes within one trip or during the day, is a challenging task when addressing the needs of families. The surveys performed highlighted the need of portable boosters; prioritizing the size and different ways to carry it, rather than weight. However, the participants’ reference was mainly booster cushions of today, which they perceived light enough. One of five parents wanted to bring their own, being reluctant to use a second-hand booster potentially available in the car. The size aspect of portability would also provide opportunities to store

boosters in the car and still have luggage space for those who don't need the boosters during the trip. A general view was that car sharing service was not perceived as an alternative for the participants in the study, mainly due to the hassle of bringing child restraints along and lack of child restraint availability in the cars.

The foldable booster cushion concept, as the result of the portability concept study, provided an example of a solution enabling reduction of size without influencing the protective performance during a crash. As shown by the surveys performed, it is essential to address the need of portability when moving towards increased shared mobility. However, it is of outmost importance that the portability aspect does not jeopardize the protection needs. These needs, as described by the protection principles, emphasize a stable boost during the whole crash, and that the seatbelt interaction is kept over the strong parts of the body. No boost, non-stable booster performance and substantial re-routing or other influence of the seatbelt are examples of solutions not in line with the protection principles.

This study highlights a mismatch in users' needs in shared mobility and booster development trends. The booster development trends include moving towards large booster seats with backrest and large side structure. The booster seat serves a good purpose, especially during long trips, for the younger children in need of side support and when the same car is used frequently. The main concern in the booster development trend is the exclusion of booster cushions, which is becoming reality in several parts of the world. The booster cushion, as an alternative to the booster seat, is attractive in several situations, e.g. where the car is highly occupied, or when the car is shared, and the booster needs to be brought to the car. Both these situations are part of the increased trend of shared mobility.

The consequences of banning the booster cushion could result in children not using a child restraint, due to the hassle of bringing a booster seat along to the car sharing service. The trend of decreased use of booster seat by increased age is seen today [45], in most cases replaced by non-use. Today in conventional car ownership, there is a relative high rate of 'seatbelt only restraint' among the oldest children required to use boosters. If no safe and convenient alternative is available, this is likely to increase when car ownership change and multiple transport modes during one trip will increase. Obviously, this will influence the protection in a crash and the overall traffic safety will be negatively impacted.

In some parts of the world, the booster cushion is completely banned. In other parts, the banning relates to type-approval for some sizes, such as shorter than 125cm. Allowing booster cushions for children from 4 years of age is essential for safe shared mobility. Real-world data shows that boosters, irrespectively of backrest or not, provide protection for the child. Given the child is sitting upright and within a good beltfit, the protective contributions of the different types of boosters that boost are equal. The seatbelt is the most essential part of the protection, supported by the overall vehicle protection, as for adults. The vehicle protection contribution is obvious in frontal impacts, where the booster primary task is to position the seatbelt. It is also shown essential in side impacts [41, 9].

Banning a well-performing booster cushion based on arguments not substantiated by real-world data, is not in line with the users' needs. Instead efforts should be focused on providing information on the importance of beltfit and sitting upright, whereby the child could fully benefit from the vehicle protection. This is in line with the proposed joint efforts by the vehicle, the booster and the user for the protection of the child in the car. The main safety concern for the younger booster-seated children, is their need of lateral restriction to ensure good shoulder belt fit throughout the ride. This need varies by individual and by the trip taken. Likely more support is needed during long trips, as compared to shorter trips. Other strategies, than a large backrest with side supports, can be applied to address this; adding low-weight comfort support helping to stabilize the child laterally into an upright sitting posture when resting. These should not be attached to the booster nor the seatbelt and should not influence during a crash.

The design specifications in UN R129 type-approval regulate the possible dimensions of the booster cushion. When developing the booster cushion concept addressing the height specifications, it resulted in a twice as high booster cushion as the UN R44 reference booster cushion. Worse is that by following the height specifications for the 125cm tall child, the booster is challenging to get passed the frontal impact test for the whole span of children up to 150cm, due to the small margins in the frontal impact test using the Q10. Unfortunately, the consequences are obvious; the booster cushions as we know of it today, and proven very capable of protecting children in car crashes, not only is

banned for children shorter than 125cm, they will be larger and heavier, in addition to less flexible with respect to the shoulder belt positions. This is not in line with the users' needs today and especially not when moving towards a higher degree of shared mobility.

While the booster height is determined by a static measurement procedure, the clearance of the horizontal DA plane is depending on the frontal impact test dynamics. Whereby one inappropriate solution could include a deformable booster cushion, helping to provide some additional dynamic height clearance, providing margins for the Q10 to pass the DA plane requirement. Another way could be taking advantage of the soft foam in the UN R129 test rig seat bench. A design of the booster cushion base to trigger the deformation of the bench foam could be such a solution. Both these solutions would be to sub-optimize for test rig compliance, but are not recommended from a real-world perspective, nor likely in-line with the intent of the 'enhanced child restraint system' standard.

With the booster's fundamental purpose to help position the vehicle seatbelt on the child so that it can perform as designed, several parts of the booster cushion regulation in UN R129 can be questioned. As seen in Appendix A1 and Figure 6, the height of the reference booster cushion serves the purpose to position the lap belt appropriately. The doubled height of the booster cushion concept does not improve that. Appropriate shoulder belt was possible to obtain for the booster cushion concept, however only when adapting the positioning of the lower part of the shoulder belt by the belt guide; to fit both the short and the tall children. Using the same wording 'one adult safety belt route' for booster cushions, as for the integral child seats, is unfortunate and restricts the booster cushion to be a part of the shoulder belt routing. This is not in line with the allowance of adjustments of the upper part of the shoulder belt in booster seats. In analogy, the harness adjustments for the integral child seats serve the same purpose. For the integral child seats, the single belt routing is addressing the connection to the vehicle. It is logical and essential to separate the functions of restraining a child restraint and restraining the child. The booster cushion is not restrained by the shoulder belt. The booster cushion is restrained, together with the child, through the lap belt portion of the vehicle seatbelt. Allowing possibilities to position the shoulder belt, such as exemplified in Appendices A1 and A2, would help avoid shoulder belt positions far out on the shoulder for the tall child or too close to the neck and wrong side of sternum for the short child. Restricting shoulder belt adaptivity for the booster cushion is not in line with the essential protection principles, resulting in poor protection in frontal impact as described by Bohman et al. [10]. Unfortunately, UN R129 seems to restrict alternative shoulder belt positions over/under the guides as a help to position the shoulder belt.

Restricting the booster cushion usage from 130cm or 135cm, due to difficulties to obtain a type approval, or requiring two sizes of boosters to cover the stature span from 125cm to 150cm, is not in line with an enhanced progress of child occupant protection. Already today, it is a challenge to keep the taller children restrained on boosters. Getting parents to buy a specific restraint for the tallest children is likely not a successful way forward. In summary, the reduced allowable usage range, the increased booster cushion height and thereby size and weight, in addition to the shoulder belt position limitations are opposite to the users' need, especially for shared mobility. Whereby it is likely that in countries adhering the UN R129 type-approval, the use of booster may decrease in car sharing services scenarios.

The trend in recent booster developments is likely a result of lack of cooperative efforts between the involved stakeholders; the users, the child restraint manufactures and the car manufacturers. Obviously, the booster regulation methods are done with the best for the children in mind. However, there seems to be a lack of understanding of the larger context, such as the environment in which the child will be using the booster. A booster is always used in a car passenger seat. A passenger seat is designed to protect car passengers. The vehicle protection, e.g. the seatbelt, the car interior and side airbags, will help protect the child as well. Hence the vehicle safety technologies are essential, and the booster's main purpose is to complement with the child specific needs, i.e. to raise the child in position for the seatbelt. Another aspect is the user's perspective. The overall protection of children in cars calls for a need of some different types of boosters, complementing each other.

It is clear that the booster development trend, exemplified by the type-approval challenges in the concept study addressing the UN R129, is not in line with the users' needs identified in the surveys performed. The participants prioritized portable and trust-worthy boosters if they were to use shared services. Today there is a reluctance among families to use car sharing services, of which one of the main reasons is their concerns regarding the child restraints. The journey towards increased shared

mobility, being an enabler for more sustainable traffic situation, is a collaborative task by all involved stakeholders. The car manufactures, as well as the child seat manufacturers and the users, in addition to rulemaking and organizations influencing the design of the different parts, such as consumer information testing, need to work together and aligned towards the common goal of sustainable and safe transportation. For the boosters, it is essential that we acknowledge the real-world evidence and experience and adhere the protection principles. The protective performance of a well-designed booster cushion is proven, and there is evidence that booster cushions, as well as integrated boosters, increase usage especially among the older age group. Adapting these to the protection needs of children aged 4 to 10-12 years old and making them portable, reduced in size and light, will help keep children safe in the increased trend of shared mobility.

Conclusions

This study highlights an area where there is a mismatch between the users' needs in the increasing degree of shared mobility and the booster development trends. The booster cushion deserves to be acknowledged for its protective effect for children from four years of age, as a part of the children's protection in cars. For shared mobility, the booster cushion is the primary candidate to address the users' needs, today and tomorrow. Until recently, the booster cushion was a natural alternative for children outgrowing their toddler seats. When banning the booster cushion in some parts of the world, there is a likelihood of increased injury occurrence, due to a higher share of children incorrectly using seatbelts only or being unrestrained. The booster development trend promotes booster seats. However, booster seats do not address the users' needs in car sharing services and will likely not be used to a high degree.

The users' needs in shared mobility mainly include portable solutions. The parents in the current study wanted a booster that is easy to bring along, if they would use car sharing services. Several parents emphasized that they did not consider car sharing services to be an alternative for them today due to the hassle around the child restraints. This highlights the importance of understanding the needs of the users' and to address them.

When addressing the booster cushion design specifications in UN R129, another mismatch was apparent. While the ambition is to be an 'enhanced child restraint systems' standard, the booster cushion concept developed in the present study demonstrates the opposite, both from a user-centred perspective and for optimal protection. The combination of the booster cushion height specification and the size intervals for the different dummies used in the dynamic testing, in combination with the frontal impact head excursion requirement, makes it difficult to certify a booster cushion for the shortest children allowed, and at the same time also for the tallest children allowed. The study highlights the need of allowing adaptive shoulder belt routing, such as over or under the guide. The booster cushion concept developed for a child of 125cm stature provided extensive boost and was perceived instable when tried out by a child of this size. Hence, not only is UN R129 forbidding booster cushions up to 125cm, in reality it is questionable whether the booster cushions will be attractive to the large portion of the taller children that really need them.

This study urges all stakeholders to be aligned towards a common goal of sustainable and safe transportation for children aged 4 to 10-12 years. The way forward is to focus on the essential protection principles and always consider the real-world context; which includes the car, the child restraint and the user as an entity.

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Appendix A1

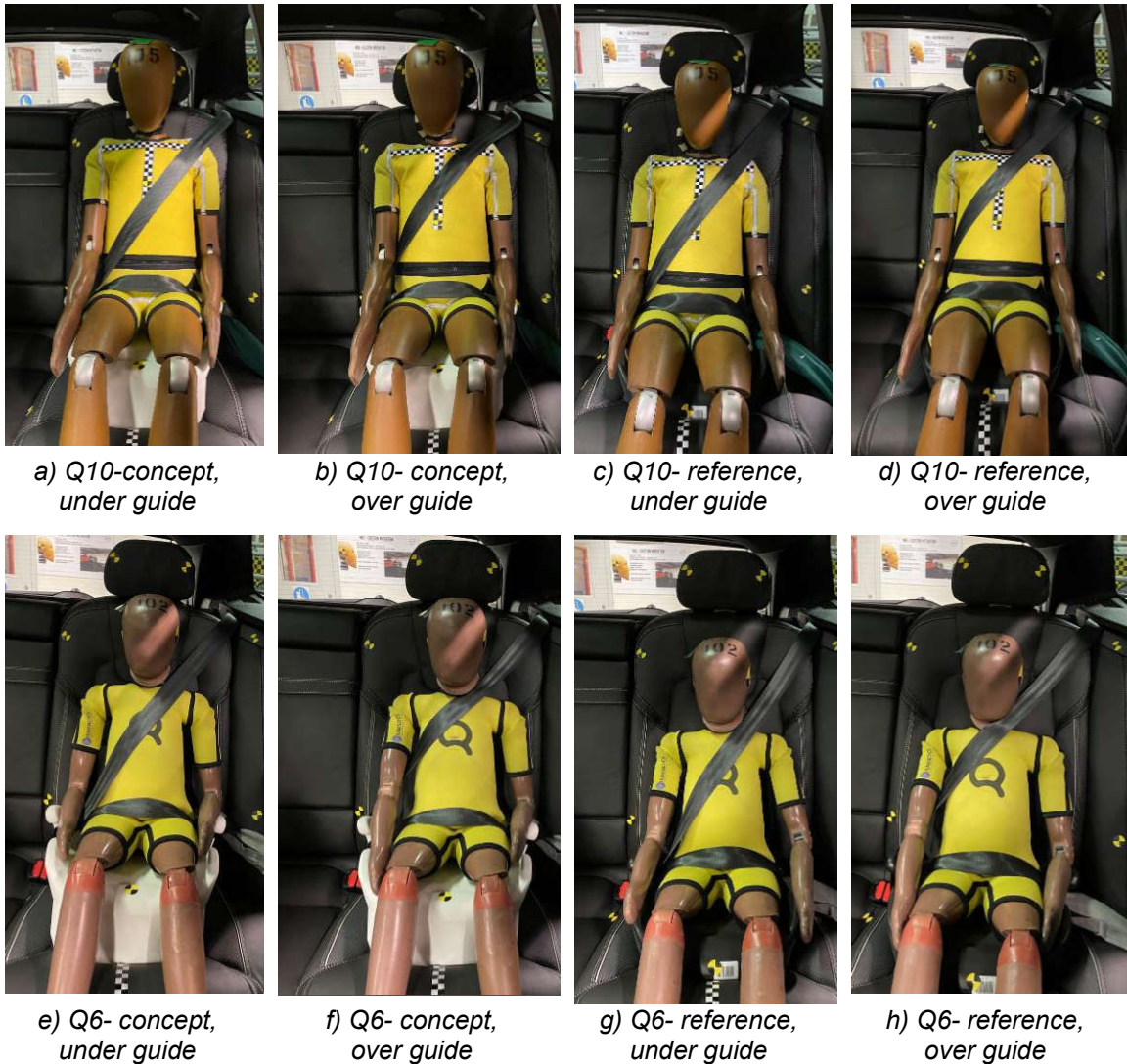


Figure A1. Front views of Q10 and Q6 restrained on the booster cushion concept (concept) and the reference booster cushion (reference), with shoulder belt positioned under or over the guide.

Appendix A2

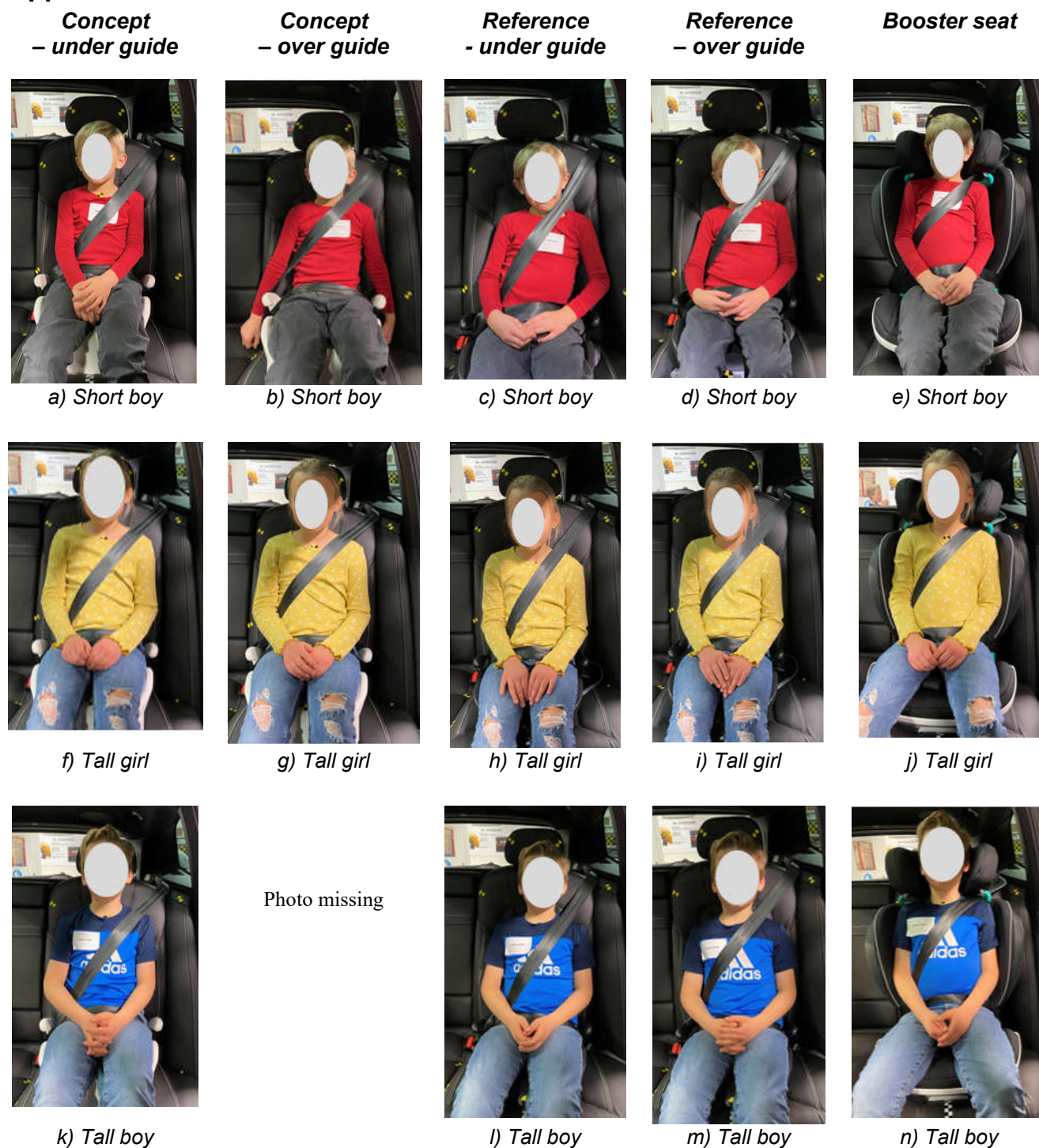


Figure A2:1. Front views of 'short boy', 'tall girl' and 'tall boy', restrained on the booster cushion concept (concept), and reference booster cushion (reference), with shoulder belt positioned under or over the guide; in addition to the booster seat, with shoulder belt positioning according to instructions for that seat (by adjusting the headrest / seatback).

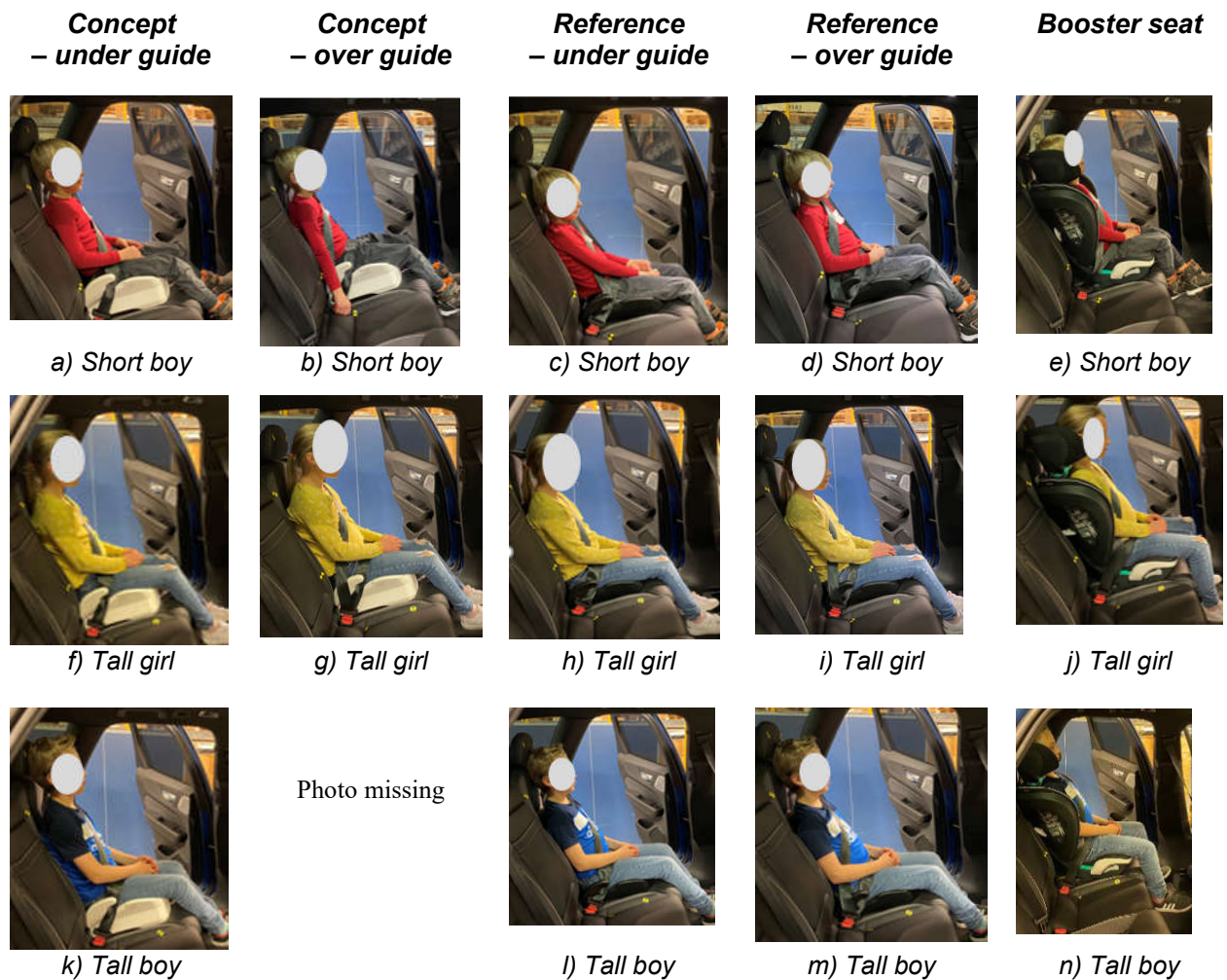
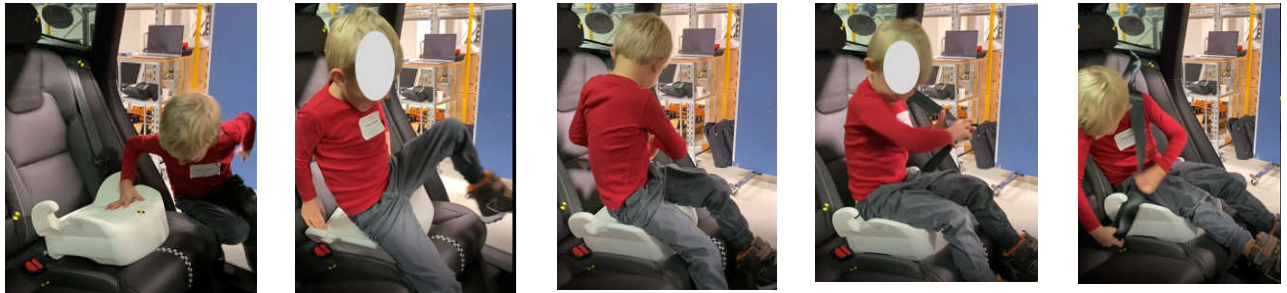


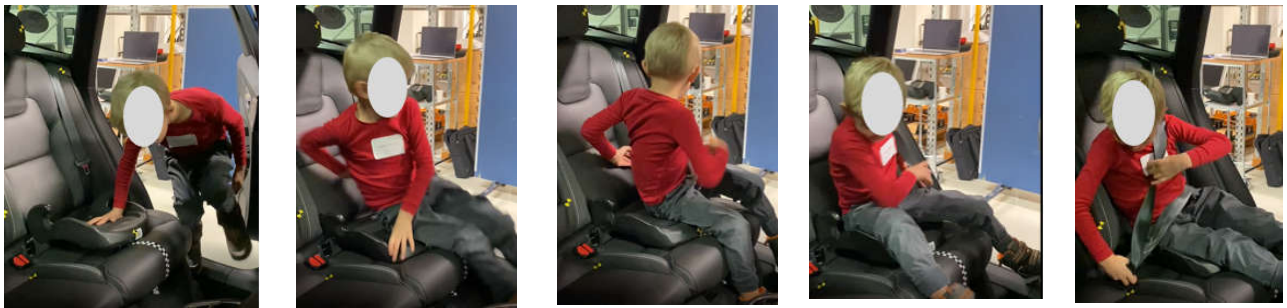
Figure A2:2. Side views of ‘short boy’, ‘tall girl’ and ‘tall boy’, restrained on the booster cushion concept (concept), and reference booster cushion (reference), with shoulder belt positioned under or over the guide, in addition to the booster seat, with shoulder belt positioning according to instructions for that seat (by adjusting the headrest / seatback).

Appendix A3

Note: The front seat is in maximum forward position for photo access purpose, whereby the available space for the study is substantially more than what usually is the case in a rear seat of a vehicle.



a) Short boy and booster cushion concept



b) Short boy and reference booster cushion



c) Tall girl and booster cushion concept



d) Tall girl and reference booster cushion

Figure A3. Photos capturing the entering and buckling-up phase, comparing booster cushion concept and reference booster cushion; 'short boy' and 'tall girl'.

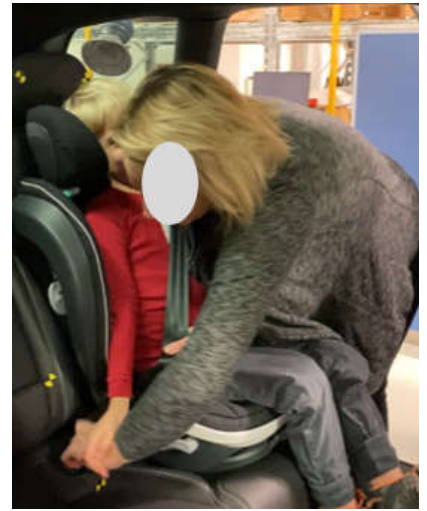
Appendix A4



a) Short boy and concept



b) Short boy and reference



c) Short boy and booster seat



d) Tall girl and concept



e) Tall girl and reference



f) Tall girl and booster seat

Figure A4. Parents assisting with buckling-up their child using the booster cushion concept (concept), the reference booster cushion (reference) and the booster seats. Photos are taken when the parent is most leaned into the vehicle.