Rearward Facing Child Seats – Past, Present and Future

Lotta Jakobsson

Volvo Cars Safety Centre
Volvo Cars, Göteborg, Sweden.
Email: lotta.jakobsson@volvocars.com . Phone: +46 766 210314

Abstract

Rearward facing child seats in cars have a long history, starting with a prototype seat by Bertil Aldman in 1964, and three years later as a production seat. This early seat was a role model for the rearward facing child seats, which significantly have contributed to protect children in car crashes since then. The rearward facing seat is the optimal protection for the small children. The basic protection principles of the rearward facing child seat result in distributed load over a large body area protecting the child's vulnerable neck and head both in both frontal and side impact situations. In addition, the rearward facing child seat is a very robust and forgiving protection system, simply by its design.

Most child safety experts agree that rearward facing mode is the safest alternative for infants and provide essential protection for toddlers up to 3-4 years. Today, the use of rearward facing infant seats is widely accepted and used globally. However, except for Sweden there is a reluctance to use rearward facing child seats for toddlers, whereby children in most countries are turned forward facing unnecessarily early in relation to their development. The arguments against rearward facing for this group are not due to safety but due to ease-of-use, lack of space and other comfort related aspects. Future transportation will include a higher degree of automation as well as shared transportation, emphasizing the needs for ease-of-use and robust solutions even more.

Inspired by the initial invention by Bertil Aldman; providing a shell for distributing the loads, a good attachment to the car and a harness to keep the child in the shell, the design of future seats should target ease-of-use and future transportation needs, still applying the same protection principles.

Past – development of rearward facing seats

In 1964, Bertil Aldman at Chalmers University of Technology in Gothenburg, Sweden, presented a child seat prototype, the first of its kind addressing protection of children in cars (Aldman, 1964). Inspired by the way astronauts were launched in space, he designed and crash tested a rearward facing child seat prototype, Figure 1.

Fig. 1. The first child seat prototype (child harness removed) by Bertil Aldman in 1964. Crash tested in a Volvo PV444. (Photos: Volvo).

A few years later (1967), the seat came into production by Klippan and was mainly sold in the Nordic countries. In 1975, there were three main rearward facing seats available in Sweden, by: Klippan (Fig. 2), Hylte (Fig. 3) and Volvo (Fig. 4) (Arnberg and Eriksson, 1976). The Volvo seat could accommodate children up to 6 years old, and could either be mounted on the front seat chassis

(removed seat cushion) or placed on the front or rear seat leaning against the dashboard or front seat, respectively (see Fig. 4). The seat mounting principles are shown in Fig. 5, which provided a rigorous fixation to the vehicle.

Fig. 2. Production seat by Klippan, AB Bröderne Ottosson & Co, Sweden,1967, (Photos: Arnberg and Eriksson, 1976)

Fig. 3. Production seat by Hylte, Hallgrens lndustri AB, Sweden, 1968, (Photo: Arnberg and Eriksson, 1976)

Fig. 4. Production seat by Volvo Sweden 1972, mounted on the seat chassis (left) or placed on top of front or rear seat (right). (Photos: Volvo)

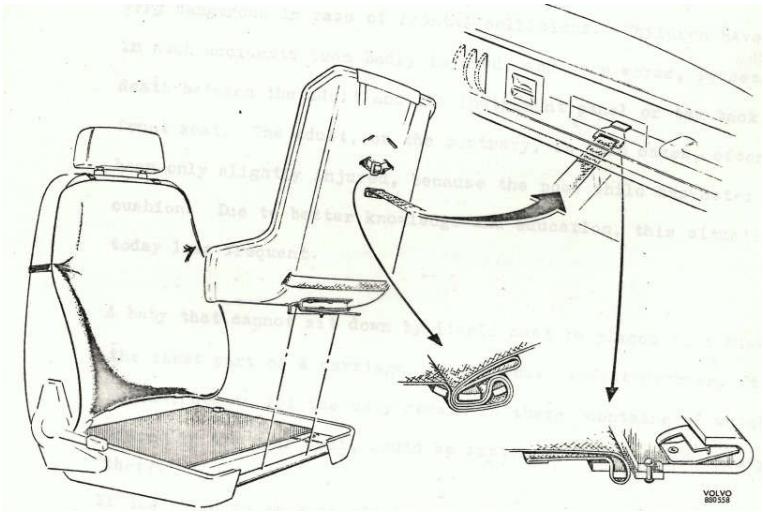

Fig. 5. Mounting instructions for the Volvo seat into Volvo Amazon (1965-), 140, 240, P1800

In 1983, more than 300,000 seats were sold in total since the start and a large second hand market made them theoretical available to all small children (Turbell and Aldman, 1983). 1983 was also the

year that proper infant restraints (replacing the transverse infant beds) were available in Sweden (Turbell and Aldman, 1983). This was done by adding a modification kit to the rearward facing child seat. These kits allowed the infant to be transported in semi-reclined position and the seat will obtain a vertical position, giving an optimal load-distribution at impact, see Fig. 6.

Fig. 6. Conventional rearward facing seat (left) with modification kit (right) that allows infants to travel in a reclined position (Turbell and Aldman, 1983)

The first rearward facing child restraints specifically targeting infants were developed late 1960s in USA by General Motors (Feles, 1970, Fig. 7a). This seat was also known as GM Infant Love Seat (Radovich, 1983, Fig. 7b) and provided the inspiration for infant seats developed since then. The seat was designed for children from birth to approximately 10 months old and was attached by the seat belt.

Fig. 7a. The GM Infant Safety Carrier (Feles, 1970)

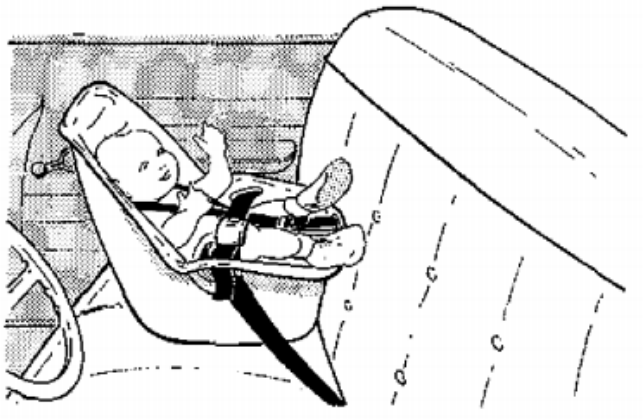

Figure 7b. GM Love seat (Radovich, 1983)

Although the basic protection principles have stayed the same, the designs of the rearward facing seats have evolved over the years. Besides adjustability and harness designs, the mounting of the seats in the cars have changed. It started with rigid attachments into the vehicle, as illustrated in Figures 4-5 for the Volvo seat, and special straps without using the seatbelt, as shown for Klippan in Fig. 2. Klippan required a central tether down between the back and cushion together with tethers to the floor or car seat rails forward and on either side of the child seat (Clark, 1983).

Starting with the ECE R44 regulation in 1980, the use of the vehicle seatbelt became best practice. As illustrated in Fig. 8a, in addition to the seatbelt, tethers to the floor or seat rails in front were used to restrict the child seat motion in a rear end impact, during the rebound in a frontal impact, in addition to rollover or other complex events. Additionally, if placed in the rear seat a support leg was used. Figures 8a-c, show the principles and two examples of seats from that time. These principles still apply for seat belt mounted rearward facing seats of today.

When the ISOFIX standard came into effect, the seat belt was replaced by the lower ISOFIX connectors. However there was still a need for lower tether attachments, or other anti-rotation measures (mainly a rebound bar against the seatback), as well as a support leg when not leaning against the dash board (Fig. 9). Within the preparation work for the ISOFIX standard, initiatives were taken to add a third point of attachment/anchorages to better suit the need for the rearward facing seat (Fig. 10, Turbell et al. 1993). During the voting process within the ISO working group, the top tether was selected as the third connection point, addressing the needs for the forward facing seats instead.

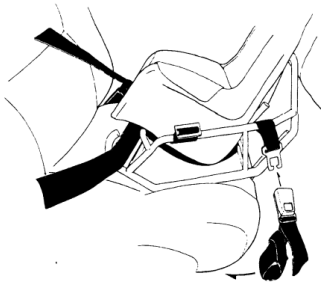

Fig. 8a. Conventional seat belt attachment. (Turbell et al., 1993)

Fig 8b. Seat for front seat mounting from 1986 and rear seat mounting (with addition of support leg) 1990. (Photo: Volvo)

Fig 8c. Seat from 1994. (Photo: Volvo)

Fig. 9. World First rearward facing child seat with ISOFIX; Base with infant (left) or child seat (right). (Photos: Volvo)

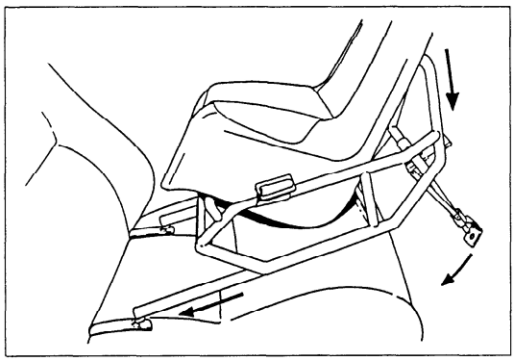

Fig. 10. ISOFIX prototype "DELTAFIX 3-point" (Turbell et al., 1993)

Rearward facing

The smallest children are optimally protected in a rearward facing seat, where the shell of the child seat provides the protection of the child's vulnerable neck and head both in frontal and side impact situations. In frontal impacts the child will move into the seat and the forces will be spread over the entire back and head distributing the load over a large surface of the child. In most side impacts there is a forward component, either by the crash direction or by that the vehicle being impacted moves forward when crashed into. Thereby, the child will move into the rearward facing child seat benefiting from the side structure of the child seat.

Rearward facing child seats for toddlers are available in most countries and have been used as best practice in Sweden from the beginning of child restraints in the 1960s (Jakobsson et al., 2005). In a survey in 1983, 80% of 200 parents reported use of rearward facing seat for their 1.5 year old child. Observations in real world traffic showed a 40-50% usage. In 2010, Gustafsson and Cosini (2011) performed an observational survey at 347 pre-schools comprising 5,000 children aged 0–10 years. Rearward facing child seats were used by 94% of 1-years-old, 80% of 2-year-old and 40% of 3-year-old children. A recent survey (2016) by the insurance company Volvia, interviewing 1000 people who transport children (0-10yo) regularly, show that 98% of children aged 0 to 1 year and 23 months travel rearward facing (Volvia, 2016). For the children aged 2 years to 3 years and 23 month, as many as 77% travel rearward facing. The trend is increasing compared to the numbers the year before; 97% and 72%, respectively.

This tradition has shown to influence the safety of the youngest car passenger on a national level. The Swedish national child occupant fatality statistics have declined over the years in line with increased child restraint usage (Carlsson et al., 2013). The robustness of the rearward facing child seat is proven by very few fatally injured children in those seats. Since 1992 only 15 children in rearward facing seats died as car passenger, only 4 of them were in a frontal impact. Local intrusion at position of the child and non-crash related factors such as fire and drowning were dominant factors for the 15 fatalities (Carlsson et al., 2013).

When comparing national child car passenger fatalities between Germany and Sweden, differences are seen, Fig. 11. The peak of 1 year old children in Germany is not seen in the Swedish data. It is likely that this peak is influenced by the tradition in Germany of changing from rearward facing to forward facing at this age, while this move takes place later in Sweden (Lesire et al., 2013, Carlsson et al., 2013).

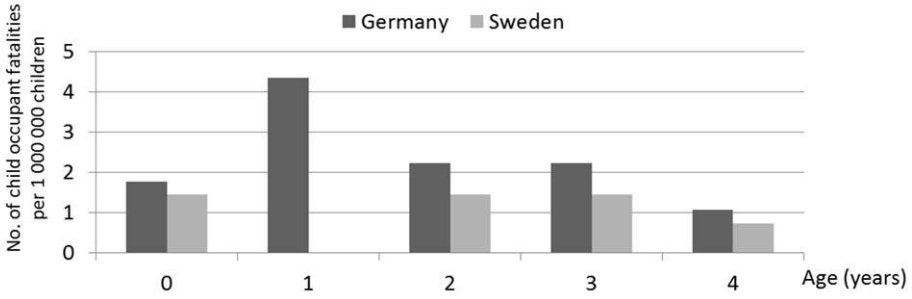

Fig. 11. Normalised number of fatally injured 0–4 years old car passengers in Sweden and Germany during 2006–2011 (Lesire et al., 2013, Carlsson et al., 2013).

Evidence of the benefits of restraining children in rearward facing seats in comparison to forward-facing child restraints has been provided through crash tests as well as real world data. Thomas Turbell at VTI in Sweden performed pioneering testing for the development of the Swedish type approval (Turbell, 1974). Twenty five different seats were tested in frontal impacts. Using 3 and 6 year old sized crash test dummies he showed that neck tension forces was substantially reduced when rearward facing compared to forward facing, claiming non-appropriate protection for the forward facing systems. Similar statements were also made based on early tests in USA (Appoldt, 1964, Roberts and McElhaney, 1972, Clark, 1983).

More recently, frontal impact sled tests comparing rearward and forward facing child seats provided additional evidence that rearward facing seats provide support to the head and spine that significantly reduces neck loading in crashes having a frontal component and can provide the greatest safety potential for children aged 1-3y (Sherwood and Crandall, 2007). The authors also highlighting the benefits of rigid ISOFIX connectors and support legs. The consumer information tests by Stiftung Warentest report twice or higher upper neck tension force for the toddler size dummies in forward facing seats as compared to rearward facing seats (Görlitz, 2007). Jakobsson et al. (2013) presented tests with a Q3 dummy in a vehicle sled buck simulating severe frontal impacts. Two state-of-the art child seats were selected; one forward facing seat attached using the ISOFIX and a top tether strap, and one rearward facing seat using the ISOFIX, a support leg and an anti-rotational bar against the

vehicle seat backrest, Fig. 12a and 12b, respectively. It is obvious that the forces are distributed over the entire back and head when rearward facing, resulting in a minimum of relative motion between the head and the neck, while the head is restrained by the neck when forward facing (Fig. 12a-b). When rearward facing, the upper neck tension force was below 500N, while in the forward facing it was more than six times higher (Jakobsson et al. 2013).

Figure 12a. Forward facing seat, initial position (left) and maximum forward excursion (right). (Jakobsson et al., 2013)

Figure 12b. Rearward facing seat, initial position (left) and maximum forward excursion (right). (Jakobsson et al., 2013)

The risk of children (0–14yo) being injured was shown statistically significantly lower for children in rearward facing seats (1.3%) as compared to forward-facing child restraints (6.9%) in real world data by Tingvall (1987). A study based on data from Volvo Cars accident database in Sweden calculated an 80–90% effectiveness of rearward-facing child seats, compared to 30–60% for forward facing child restraints (Carlsson et al., 1991). Another study reviewing the same database revealed that children aged 2-4, when restrained in forward facing child restraints, were estimated to be at approximately double the risk of sustaining MAIS2+ injuries than when restrained in rearward facing seats (Jakobsson et al. 2005). In the above real world studies, the forward facing child restraints were primarily of belt-positioning booster types, since forward-facing seats with an integrated child harness have not been endorsed in Sweden and are thus very rare. Analysing NASS-CDS data in USA of children up to 2 years of age involved in crashes 1988-2015, it was found that rearward facing child seats provide a safety benefit compared to forward facing child seat with internal harness (McMurry et al., 2017). Lower MASI2+ injury rates for the rearward facing child seats were seen in both frontal and side impacts, however at a border line of statistical significance, due to sample size and influence by the confounding between age and type of seat. Studies of real world cases highlight the importance of protection of the neck for the smallest children (Fuchs et al., 1989, Stalnaker, 1993), recommending rearward facing seats for as long as possible, preferably until 3–4 years of age.

Real world data, biomechanical facts (Burdi et al., 1968, Tarriere, 1995) and experience from crash tests clearly show that rearward facing is the safest for babies and toddlers. Over recent years, this has been more globally acknowledged, exemplified by the change in US car seat recommendation for children in 2011 and the enforcements in ECE R129 resulting in no forward facing seats for children less than 15 months. Nevertheless, a reluctance of using large rearward facing seats up to 3-4 years age exists.

The reluctance of using rearward facing seats has a long history. Already in the early times of rearward facing Thomas Turbell stated that although convinced about the very good protection abilities, most non-Swedish researchers regarded the rearward facing seats as an unrealistic solution to the problem (Turbell, 1974). The main objections was that the child will not accept the seat or get motion sickness or that the seat will obstruct the driver's vision. Rogers and Silver (1968) discussed child restraint systems in terms of impact performance, child contentment, convenience and market appeal. Even if convinced about their superior protection, they considered the rearward facing seats to be too inconvenient to use, that the child's need to look outside the car was not met, and an assumed risk for motion sickness. In a report in 1975, Thomas Turbell's colleague Peter Arnberg summarized studies on normal everyday use of rearward-facing, addressing some of the concerns on child comfort and convenience (Arnberg, 1975). He claimed the above mentioned arguments to be hypothetical and not grounded on any proven data. He argued that the problems have been shown to be very rare in Sweden where about 100,000 rearward-facing child seats were sold in total at that stage, which corresponds to approximately every second seat used in Swedish cars in 1975. He raised the importance of publicity from the press, radio, and TV making Swedish parents quite aware of the advantages of these rearward facing seats. In a questionnaire study performed 1976, rearward facing

seats were found to be both practical and usable in Sweden based on data from 1,575 parents (Arnberg, 1978). Rearward facing seats were found to give the child the best protection while also offering good contact with and supervision of the child, when mounted in the front seat which was most common. Problems assumed to exist such as carsickness and the child's difficulty in see out were found to be rare, although general problems in connection with all types of restraints were observed and investigated.

An early joint Australian-Swedish study made parents compare different types of child restraints (Trinca et al., 1981). Among the 32% being opposed to the rearward facing position, 12% felt that the rearward seats were unsafe, disturbing to the driver or inconvenient for family use, and 20% were opposed because of the need to drill holes in the car floor. 68% of the parents were interested in the rearward facing seat ('Klippan' mounted in the front seat) because of better contact with the child while driving. The study emphasized the importance of understanding the individual families' needs.

More recently, Stiftung Warentest summarized the main con of rearward facing seats that they are heavy, bulky and difficult to install (Görlitz, 2007). Also, concerns were raised that the principal advantages of travelling rearward facing is not recognized by many parents. The main stated reason for turning forward facing, even in countries like Sweden with a high awareness, is lack of space, especially for the legs. Other reasons relate to car sickness, the reduced direct contact when the child is seated in the rear seat as well as motives such as "the child wants to travel forward facing".

Present and future

In recent years, there has been an increase in use and focus on rearward facing child seats. The rearward facing infant seat is the state-of-the-art transportation mode for babies in cars today. In addition, the usage of the larger toddler seats is slowly increasing globally. The fact that UN ECE R129 regulates rearward facing as the only allowable mode for children up to 15 months old is a proof of this trend. However, 15 months old is not good enough. Children up to 3-4 years benefit from rearward facing and it is possible to achieve. Decades of experiences in Sweden have shown this.

Today, the vast majority of Swedish families with small children have rearward facing child seats mounted in their vehicles. Approximately half of the seats are positioned in the front passenger seat (Fig 13a) and half of them are in a rear seat position, usually on one of the outboard positions (Fig. 13b). When using the front seat position, the front passenger airbag is required to be inactive. Front seat use is preferred for surveillance and interaction but also due to more space for the child's legs, enabling him/her to stay rearward facing for a longer time. Thanks to the rather upright position of the large rearward facing child seat, the occupant sitting in front of such a seat mounted in the rear seat can have a comfortable sitting posture (Fig. 14a). Usually it is difficult to accommodate three child seats (of any kind) in the rear seat, but in some combinations it is possible (Fig 14b).

Fig. 13a. Axkid Duofix in the front seat of a Volvo V40CC.

Fig. 13b. Britax Multitech in the rear seat of a Volvo V40CC.

Fig. 14a. Adult sitting in front of a large rearward facing seat positioned in the rear seat. Britax Multitech in a Huyndai i30.

Fig. 14b. Three large rearward facing seats mounted in the rear seat.

The main driving factors behind the high usage in Sweden is mainly a combination of awareness, education and tradition, also leading to a social pressure on parents to follow best practice. The Swedish experts speak with one voice, and have done so consistently since decades. To assist in the communication, a voluntary child seat test, called 'Plus test', was created by the national Swedish child safety group ten years ago. The purpose of the test procedure is to help provide consumers and sales persons on which child seats that help protect the neck of the child. Before becoming a member of the EU, the Swedish type approval (developed in the 1970s) included evaluation of loads transferred in the neck. This information was lost when type approval was made using ECE regulation, since measurements of the neck loads are not included at this stage. In the 'Plus test', neck measurements are evaluated in a frontal impact test. Child seats providing appropriate neck protection can use a label providing additional information to the users. So far, only pure rearward facing seats have passed the test. Moreover, all Swedish stakeholders (incl. OEMs) signed an agreement in 2006 urging front passenger airbag switch-off (manually by switch or at a workshop) to facilitate the use of the front passenger seat by children. In 2016, the agreement was updated and re-emphasized that children should be seated rearward facing at least up to the age of four. (Folksam, 2017).

Important topics today and in the future are easy mounting and dismounting of the seat, easy handling of harness, in addition to size when mounted in the car. Ease-of-use is of increasing importance in today's and future transportation use, with an increasing use of different cars, including taxis and shared fleet cars. It is then of great benefit if the weight and the exterior size is kept low, while still maintaining the same high level of protection. With the ambition to make rearward facing the desired choice even for toddlers, Jakobsson et al. (2013) presented a child seat concept especially targeting the weight, ease of installation and roominess as well as size when not in use. The concept was made of inflatable material, controlled by an air regulator, and the attachments were low-weight through smart design using straps in the direction of loading (Claeson, 2001). The concept is a good example of how new material, design and new technical solutions can enable a combination of high protection and ease-of-use. Future child seats would benefit from being developed using in-vehicle testing and knowledge, since the complexity of the seat (eg. reclined positions, extra side impact interaction devices) could be reduced if designed working together with the in-vehicle protection. In a real world situation, the child seat and in-vehicle protection will work together. For future developments it is essential to ensure that regulations target the child seat performance and that is always based on the protection principles applicable for rearward facing seats. Hence, regulatory ambitions and change of mindset/structure is urged for, enabling technology developments in-line with real world protection needs and future transportation challenges

A concrete example is easy and preferably standardized mounting of the rearward facing child seat. Today, two main types of mountings exist for the large (toddler) rearward facing seat; ISOFIX attached and seat belt attached. Due to only two usable ISOFIX anchorages for the rearward facing seat, additional support leg and anti-rotation devices are needed. This in combination with the load limit for the ISOFIX anchorages, does not serve the needs for the rearward facing seats for toddlers. Optimal future direction should be in line with the proposed '*DELTAFIX* 3-point' in the 1990s, as shown in Figure 10. This would enable a 3-point installation without extra straps and support legs,

and could also provide confirmation of correct installation, by click-in indicators or in-vehicle information. Pending the optimal 3-point installation for rearward facing seats and upgraded load limits for the ISOFIX anchorages, the interim solution would be to make as standardized and hence easy-to-use specification of the best practice of today. This is a combination of using the seatbelt, a support leg (or leaning towards the dashboard) and tethers to the floor, preferably in front of the seat, as seen in Figures 13a-b. In line with the principles of top tether anchorages for forward facing seats, the ISO working group on Child Restraint Systems (ISO/TC22/SC36/WG2) is developing a standard for lower tether anchorages. The ambition is to provide a standardized method of attaching the lower tethers. Some cars are equipped with designated anchorages on the floor in front of the child seat position. Figure 15a shows an example of anchorages in the front seat rails for easy mounting of a child seat in the rear seat. Similar anchorages can also be found on the floor in front of the front passenger seat. However, most cars do not have designated anchorages. Figure 15b shows a vehicle where the straps are routed around the seat rails of the front seat. Alternative routings are around the seat cushion or around the recliner mechanism between the seat cushion and seat backrest. All of these are less controlled and may damage the vehicle seat. Standardized anchorages will clearly simplify the usability of the rearward facing seats, as well as minimize the misuse.

Fig 15a. Examples of pre-installed lower tether anchorages (Volvo XC90).

Fig 15b. Examples of lower tether anchorages; strapped around the seat rails.

Misuse aspects are important issues with respect to child safety in cars today, exemplified by the child seat not attached properly or the child not restrained properly in the child seat. Although having limited data on the large rearward facing seats, Lesire et al. (2016) presented different general child seat misuse factors and proposed a severity measure. Several of the severe identified misuse aspects for the forward facing seats, could be technically addressed by using a rearward facing as an example of a more technical robust solution. The low Swedish child occupant fatality data for rearward facing seats confirms the robustness of the principle design (Carlsson et al., 2013), although the Swedish parents are likely not better in tightening the harnesses and tethers than any other parent. In a frontal impact, being the most common and severe crash situation, the rearward facing seat for toddlers is not as sensitive to slack in the seat attachments nor to slack in the harness, simply because the seat shell is the main interaction with the child. With equivalent degree of harness slack, a child in a rearward facing seat is less likely to slide out of the seat as compared to when using a forward facing seat. Crash tests performed with three convertible child seats comparing the two travel modes confirmed that loose harness or tethers had no effect when rearward facing, while significant when forward facing (Manary et al. 2016). They found that the only misuse with a large effect for the rearward facing seat was incorrect belt path. This emphasizes the importance of simplifying the attachments, and to provide a support leg or lean against the dashboard, which acts to limit forward rotation.

Nowadays, most child safety experts agree that rearward facing mode is the safest alternative for infants and provide essential protection to toddlers up to 3-4 years. The arguments against rearward facing for this group are not due to safety but due to ease of use, lack of space and other comfort and usability related aspects. Going back to the initial invention by Bertil Aldman; providing a shell for distributing the loads, a good attachment to the car and a harness to keep the child in the shell, the design of future seats should target ease of use and future transportation needs, still applying the same protection principles.

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