OVERVIEW OF DESIGN SOLUTIONS FOR CHILD SEATS

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Abstract

In order to increase the child's safety when traveling in a passenger car, special child seats are used to minimize the child's injuries in a car accident. The aim of the article is to discuss the topic of design solutions for child seats. It should be noted that child seats are built in order to increase the safety of the transported child during a car accident. Child seats are crash-tested. Unfortunately, no tests related to vibration comfort are carried out. Undoubtedly, attention should be paid to the vertical vibrations that penetrate from the road surface, through the structure of the passenger car, to the seat of the child seat. Vibration comfort is particularly important in the case of long journeys. Because the current child seats on the market are adjusted only to the mass and age of the child. Choosing the right car seat is not a simple task. Not every child will feel comfortable in a seat adapted only to mass and age. The anthropometric dimensions of the child are of great importance. Therefore, more and more child seats are created that allow you to change the position of the backrest or seat in such a way as to ensure both the safety and comfort of the child during the journey.

Keywords: child seat; vibration comfort; safety

1. Introduction

In Poland and other European Union countries, transporting children in car seats is obligatory. The main task of the car seat is to ensure the safety of the child in the event of a collision or accident. In addition, the design of the seat is to ensure reduction of possible injuries that could be sustained by a child as a result of a road accident. Choosing the right car seat as well as a convenient technical solution is a difficult task for many parents [1, 6, 32]. You can find many design solutions for child seats on the market, which are adapted to the age and mass of the child. Directly to the purchase of a child seat, there is a problem with its installation in a passenger car. It is estimated that in Poland about 70% of car seats are not fastened properly. An incorrectly selected and installed child seat, instead of protecting the child from danger in a collision or accident, additionally exposes it [6, 10, 32]. Undoubtedly, the most common mistakes made

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when attaching the seat include: choosing the wrong place in the car to install the seat, loose fastening of the seat causing it to move both to the sides as well as forward and backward, too loose fastening of the child's seat belts, improperly adjusted headrest and incorrect seat angle determination [37, 38, 40] . Most scientists confirm the fact that one of the main causes of serious injuries and even death of children involved in road accidents is incorrect fastening and the placement of the child in a car seat. It should be noted that there are many types of child seats, which take into account both mass categories, assembly method, assembly direction and purpose [10, 11].

Undoubtedly, in terms of safety, the safest place to mount a car seat is the center seat of the rear seat of a passenger car. This position of the seat minimizes injuries resulting from a frontal collision and a side collision. It should also be noted that the front passenger seat is the least safe place to install a car seat, because in the event of a crash the child is exposed to additional risks due to objects that lead to the interior of the vehicle. However, in terms of the vibration comfort of the child in a child seat, it is best to fix the seat on the rear seat on the left side behind the driver. Because the rear seat in the middle is usually raised and the installation of a car seat, and if possible, can cause greater vibrations from the uneven road to the seat of the child seat [10, 11, 25]

The paper [20, 25, 27] presents an analysis of road accidents involving children. The authors found that more than half of the children involved in these accidents were incorrectly fastened in a child safety seat. On the other hand, in the works [2, 3, 5] the authors drew attention to the risk caused by improper mounting of the child seat in the car. It should be noted that any irregularities in the installation of the child seat may contribute to the increased risk of injuries to the child in a road accident. In the works [2, 9, 39] attention was paid to the installation of child seats in a passenger car in terms of vibration comfort. It should be noted that improper installation as well as an incorrectly selected child seat for the anthropometric dimensions of the child may be the cause of increased vertical vibrations from road unevenness to the seat of the child seat [8, 9, 28]. Undoubtedly, it should be noted that a motor vehicle is a complex vibrating system, which is stimulated to vibrate by many factors. Such factors include uneven road surfaces, engine performance, and the suspension system. Vibrations can be bothersome during long journeys, therefore they can cause discomfort and have a negative impact on human health. The authors [24, 28, 35] confirm the negative influence of vibrations on the human body. Moreover, it should be noted that the permissible value of vibrations acting on an adult human has been the subject of many studies. Therefore, the measurement methods as well as the maximum vibration values are legally regulated in the International Standards Organization (ISO). The permissible values of vibrations affecting the human body are included in ISO 2631-1 [22] and also in British Standards BS 6841 [4]. Unfortunately, these values apply only to an adult human, so it should be noted that there are currently no appropriate standards in the case of measurements and values affecting the child's body. Therefore, the works [31, 37, 38] propose a method of estimating the natural frequency for organs and parts of a child's body based on data collected for an adult.

Moreover, in the works [7, 12, 33] attention was paid to the issues of ergonomic comfort of child seats. The authors drew attention to the pressure of the child's body on the seat and backrest of the seat. The result of the work of these authors is a model that

allows the manufacturers of the car seat to choose the right materials as well as the angle of the backrest to the child's body. However, the authors of the works [21, 34] pointed to the modification of the dimensions of the backrest and the base of the car seat. The authors believe that adjusting the dimensions of the seat to the anthropometric dimensions of the child increases safety in a road accident.

2. Child seats' mass categories

Child seats available on the Polish market must comply with the European regulation ECE 44. According to the European regulation ECE R44, there are five basic categories of car seats [29, 30]:

- Group 0 – below 10 kg (up to approx. 9 months),
- Group 0 + – below 13 kg (up to approx. 18 months),
- Group I – 9–18 kg (approx. 8 months – 4 years),
- Group II – 15–25 kg (approx. 4–12 years),
- Group III – 22–36 kg (approx. 8–12 years).

A group 0 restraint system shall keep the child in the rearward facing position. The seats are secured with a standard adult safety belt or IsoFix [29, 30]. In order to be transported safely and in accordance with the provisions of Regulation No 129 of the Economic Commission for Europe and the United Nations, a child under 15 months of age may only be transported in a rearward-facing restraint [28]. In this way, you can minimize the possible risk of injury in a car accident or in the event of heavy braking. The seat presented below is one of the group 0 seats installed in the car directly using the Isofix system without the use of an additional attachment (Figure.1). The seat should be installed using the IsoFIx and the Top Tether type top tether or using the three-point seat belt. The fastening system has been certified according to Regulation No. 44 of the Economic Commission for Europe and the United Nations. The ISOFIX system allows for a safe, secure and error-free mounting of the seat in the car. The seat is installed in the car facing backwards. It is possible to install the seat on the rear seat of the vehicle and on the front passenger seat after making sure that the airbags have been deactivated [26].

Fig. 1. Group 0 child seat [26]

Group 0+ restraints are in the mass category 0kg to 13 kg. They ensure safety for the baby's delicate spine. A child seat in this category can be mounted with car belts or a special Isofix base. The Isofix system is easier and safer of these two methods of installation. The child is fastened in the seat with the 3-point (Figure. 2a) or 5-point inner belts (Figure 2b). The 5-point seat belts are safer and more common [30, 26]. Figure 2 shows children's seats with three-point and five-point seat belts. Which can be fastened with standard seat belts or the Isofix system. Car seats for children up to 13 kg are most often equipped with additional elements, including a special reduction insert, a pillow or a roller, which are designed to reduce the surface of the seat, thanks to which the child is safer and more comfortable. The position of the child in the restraints is adapted to the shape of the child while lying down, so that it is the healthiest for his spine [17, 23, 30].

(a) (b)

Fig. 2. Group 0+ car seats [16]; (a) 5-point restraint belts, (b) 3-point restraint belts

Group I restraints are designed for children from 9 kg to 18 kg, they can be fastened with car belts as well as with the Isofix system. Child seats belonging to this mass category can be installed in both directions of travel. The child in the restraints is most often secured with five-point seat belts and an additional torso protection. The seats in this category are most often equipped with an adjustment of the headrest, backrest and height of the belts or covers, so that the child is as well protected as possible and feels safe. The seat presented in Figure 3 is intended for children from 9 kg to 18 kg. It has been adapted to be mounted in a vehicle with seat belts as well as with K-FIX connectors compatible with the Isofix system. The seat is equipped with an additional reduction insert, which allows it to be optimally adapted to the current size of the child. It makes it possible to change both the height and the width of the restraint. The device is equipped with an adjustable footrest and headrest, which allows it to be adapted to the constantly developing child. The seat has elements that absorb energy during an impact, it is a very key element ensuring the safety of the transported child. The Kiddy Abosrber system used ensures that some of the energy is absorbed during an impact. The seat for category I meets all the requirements of the ECE-R44-04 approval [16, 17, 18].

Fig. 3. Group I restraint [18]

Child seats from group II are designed for children weighing from 15 kg to 25 kg. These types of devices are characterized by a classic form, they are much larger than the previous ones and more durable. They ensure the safety and comfort of the child. They are equipped with comfortable armrests, contoured backrest and the possibility of adjusting the headrest. Some of the car seats in this mass category have internal belts, but this is rare. The seats are attached to the vehicle with straps or with Isofix connectors [18, 26, 30].

The seat presented in Figure 4 below, with the R44-04 certificate, is intended for the transport of children from mass group II. The restraint is equipped with a headrest adjustable in eleven steps. Reinforced armrests protect the hips and allow older children to sit comfortably. The method of mounting the seat can be done using car belts as well as Seatfix connector compatible with the Isofix system. Advanced side protection in the event of a side collision absorbs energy, which further increases the safety of the child while traveling in the car. Additional elements of the seat are also seat belt guides marked in red, which facilitates proper assembly [18, 36].

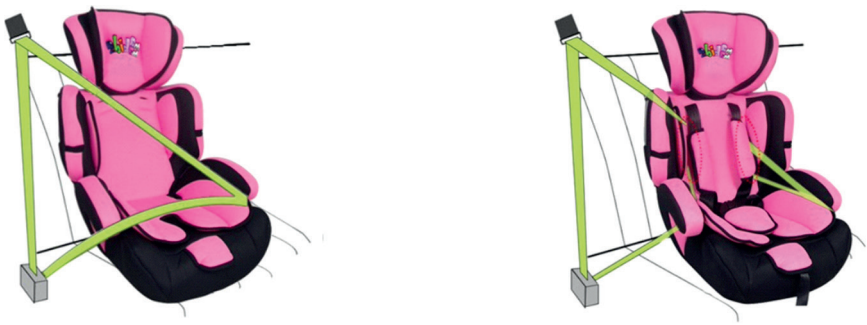
Fig. 4. The seat is intended for children from group II [18]

Group III restraints intended for children weighing from 22kg to 36kg are the last mass category in accordance with the provisions of Regulation No. 44 of the Economic Commission for Europe and the United Nations. They are characterized by a classic form and are more durable than the previous category. Restraint systems of the last mass category are intended for children up to the age of 12, i.e. until the child can ride without a seat. The child in the seat is secured with the car seat belts. The seats are attached to the vehicle with straps or with Isofix connectors [16, 17]. The restraint system shown in Figure 5 below allows for the safe and comfortable transport of children weighing 22kg to 36kg. The seat is equipped with the ISOCATCH system, which makes it possible to mount the seat using Isofix connectors, it can also be mounted with car belts, which makes it universal. The restraint has been equipped with additional armrests, thanks to which the transported child will sit more comfortably, which is especially important during a longer journey [15, 16, 17].

Fig. 5. Graco Connext restraint [15]

3. Design solutions for child seats

The oldest and most popular type of fastening of restraint systems in vehicles are seat belts, which can be mounted in two ways. The first and most common method of securing the seat is the so-called braiding, which is characterized by the belt being guided through the lap section, while the chest part is guided through the backrest of the restraint. It is presented in Figure 6 (a). The authors of the article [26] presented the correct way to assemble this type of seat. The second method of assembly is shown in Figure 6 (b). The assembly consists in leading the car belts through the base of the seat in places designated by the manufacturer, they are most often marked with red elements. In many cases of restraints, this involves an additional tilting or disassembly of the seat from the base of the seat for proper assembly. Please note that in any installation the car belt should run smoothly and must not be twisted. Installation by means of seat belts is intended for all mass groups provided that the restraint systems have been appropriately approved in accordance with the Regulations of the Economic Commission for Europe and the United Nations. The following two methods of mounting the restraint systems are presented [26, 36].



(a) (b)

Fig. 6. The method of mounting the restraint devices with car belts [26]; (a) braiding, (b) base assembly

An equally popular system for attaching restraint systems in vehicles is the Isofix bracket shown in Figure 7. This type of technical solution was proposed in 1991, and it became the standard in 1995 [36]. The Isofix system is designed to attach the restraint systems to the vehicle seats.

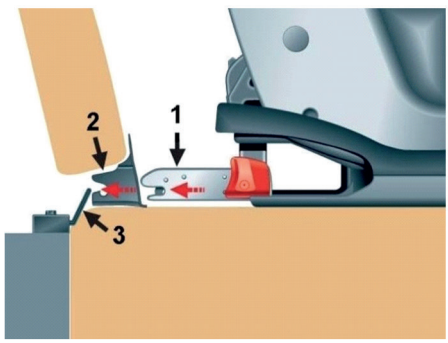


Fig. 7. Isofix restraint attachment system [24]

The device consists of two holders (3) permanently attached to the vehicle structure. Another element of this type of solution are guides (2), which facilitate the installation of the seat, which are usually made of plastic. The last element of this type of solution are Isofix latches, which prevent incorrect installation of the seat in the vehicle. The latches (1) are permanently integrated with the restraint or with the base to which the child seat is successively mounted. The Isofix solution eliminated many problems related to the incorrect installation of restraints, which means that the child will be better protected during a collision. It also provides better results in crash tests, although it does not

prevent rotation of the restraints [16, 27, 28]. A well-known technical solution supporting the Isofix system, whose task is to stabilize the restraint system, is the leg shown in Figure 8. It is most often used in rearward-facing seats, but is also found in forward-facing and side-facing seats. The task of this type of technical solutions is to absorb the impact force, which is transferred to the vehicle chassis. Additional tasks are to stabilize and eliminate unnecessary movements of the child restraint in the vehicle [16, 28].

Fig. 8. Leg stabilizing the holding device [16]

For proper assembly, the stabilizing legs have a telescopic height adjustment to fit the height of the sofa. In order for the stabilizing leg to be correctly mounted, remember not to mount it on the storage compartments, because it may collapse during a road collision. The Top Tether technical solution also supports the Isofix system, the task of which is to protect the child restraint systems against excessive movement in the event of a collision. This type of solution is shown in Figure 9. Each car seat equipped with the additional Top Tether solution should be absolutely fastened in accordance with the instruction manual. When installing this type of device, remember about the correct installation location and the tension of the Top Tether belt [16].

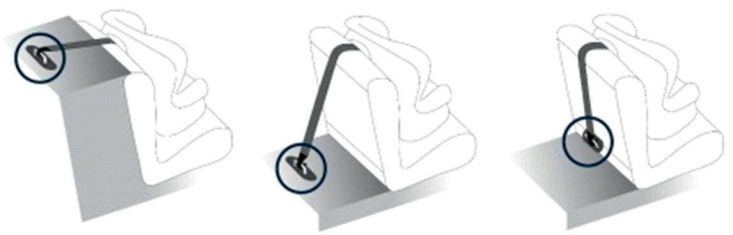


Fig. 9. Top Tether [16]

The main attachment points for the Top Tether belt are located successively in the luggage compartment, at the rear of the seat or at the top of the vehicle behind the passenger seats. This type of solution is a very important element of passive safety. It prevents the restraint from moving forward excessively and is responsible for absorbing part of the impact force in a collision [15, 16, 17]. A special base that provides 360 ° movement in any direction is responsible for this type of possibility. This type of solution is intended for children up to 4 years of age or a maximum of 18kg. It should also be remembered that children under 15 months of age should absolutely be transported rearward facing. This type of restraint is most suitable for putting a child in and out of the vehicle. They facilitate this procedure to a large extent. This type of restraint is equipped with an angle adjustment of the entire seat with respect to the plane of the couch [16, 17]. The seat shown in Figure 10 below belongs to the group of swivel seats that allow a full 360 ° movement. The seat is equipped with an Isofix fastening system and a stabilizing element in the form of a leg. The restraint is equipped with an additional tilt plane adjustment system, which ensures the correct positioning of the seat, optimizing the risk of injuries in an accident. The restraint is made of the highest quality materials, and additional elements protecting the child against side impact have been used, whose task is to absorb energy. The seat has the ECE 44-04 certificate in accordance with the requirements of the regulations of the European Economic Commission and the United Nations [16, 17, 18].

Fig. 10. holding device 360 ° [16]

Technical solutions of the Travel System type combine the functions of a vehicle restraint, a baby carrier and an element compatible with the frame of a pram. This type of solution is very universal, allowing for ergonomic movement with the child during short journeys. The mounting system for restraints both in the vehicle and in prams is very diverse. In many cases, it allows the installation of the restraint using an additional Isofix base, which increases its stability and the certainty of correct installation of this type of devices. An example of a Travel System restraint is the child seat shown in Figure 11, combining all the above-mentioned functions. The seat has ECE 44-04 approval, which meets the requirements for car seats from groups 0 and 0+, and the regulations of the European Economic Commission and the United Nations. The seat

presented below is mounted in the vehicle using the Isofix system and the stabilizing leg [16, 29, 30].

Fig. 11. Travel System 3 in 1 restraint [16]

An innovative technical solution developed in recent years is a seat with a torso cover, whose task is to replace the internal belts of the seat. This type of solution is intended for children in group I. The airbag-shaped torso protection is shown in Figure 12. The most important task of the torso protection is to keep the child in the driving position. Additional tasks are to protect parts of the torso and head in a road collision, and to absorb some of the forces acting on the child in a frontal collision thanks to its soft structure. The adjustable guard replaces the three-point and five-point seat belts [14, 23]]. This type of restraint is most often equipped with seat backrest adjustment elements and with additional side impact protection systems that absorb energy. The authors of the article [23] conduct simulation studies aimed at improving this type of technical solutions.

Fig. 12. Seat with trunk protection [16]

The company's restraint system presented above is ECE 44-04 certified in accordance with the regulations of the European Economic Commission and the United Nations. The seat is equipped with an Isofix connector. When the child is in group II or III, the seat can be converted into an ordinary seat secured with car belts. The Smart Kid Belt technical solution presented in Figure 13 is one of the newest design alternatives for child seats, recommended for children aged 5 to 12 years or in the mass range from 15kg to 36kg. Thanks to this solution, children from groups II and III can be safely transported by replacing child seats or pads. Smart Kid Bet has been tested by many research centers dealing with child safety [17, 18].

Fig. 13. Technical solution Smart Kid Belt [18]

Smart Kid Belt has ECE 44—04 approval in accordance with the requirements for group II and III car seats, in accordance with the regulations of the Economic Commission for Europe and the United Nations. The device ensures a good positioning of the lap belt section and smoothly adjusts the shoulder section to the child's height. The technical solution enables easy and quick installation and the possibility of using it in any vehicle [17, 18]. There are many restraint systems on the market designed for disabled children aged 15kg and over. In this group, many children have problems with taking a seat on their own, not keeping their head upright or not stabilizing their head, these are the main difficulties for disabled children and their carers. This type of car seat is most often equipped with five-point belts integrated with the seat, locking wedges to ensure the correct position of the child and additional air circulation systems to prevent excessive sweating of the child. In the article [13, 15], the authors presented the methods of cooling this type of seat. To ensure safety, the seats are equipped with deep headrests, adjustable in height, absorbers in the event of a side collision and seat belt guides. In addition, the devices also are fitted with airbags and bucket-shaped elements that provide additional stability while driving in the area of the head, torso, hips and legs. The car seats shown in Figure 14 are one of the products that use the most important technical solutions to ensure the safe transport of a disabled child.

Fig. 14. Restraint system for children with disabilities [13]

The seat of this type has the ECE 44-04 certificate in accordance with the requirements of the regulations of the European Economic Commission and the United Nations. In addition to standard options in this type of devices, it can be equipped with footrests shown in Figure 15, smooth adjustment of the angle of inclination and an Isofix adapter, which allows for easy installation. A "Kick-Back" headrest with patented bending points, the task of which is to adjust it to the child's head was also used [13].

(a) (b) (c)

Fig. 15. Additional equipment of the restraint;
(a) footrest, (b) tilt adjustment, (c) Isofix adapter [13]

The travel cot shown in Figure 16, also referred to as a carrycot, is rarely used as a restraint system in vehicles. These types of solutions have been designed for the youngest, whose health condition does not allow them to be transported in standard restraint systems. Travel cots are equipped with various configurations of child restraint

belts that allow the child to be placed in any position. Restraint systems of this design shall only be mounted on the rear bench, head towards the center of the vehicle. They are equipped with additional elements regulating the inclination of the cot, whose task is to eliminate sofa unevenness, as well as elements responsible for the child's safety during a collision. The mounting of the restraint is done using the seat belts. Travel cots have been adapted to transport children mass from 2kg to about 16kg and height up to 74cm. A restraint of this type is shown below [19].

Fig. 16. Travel cot used as a car seat [19]

4. Conclusions

Child seats are manufactured to increase the safety of a child transported in a passenger car. The car seats are designed to keep the child from falling out of the seat and the car during a car accident. There is a wide variety of child seats on the market today. Technical solutions used in this type of devices are to facilitate the process of installing a child seat in a car.

The manufactured child seats are adjusted to the mass and age of the child [29, 30, 40]. Unfortunately, choosing a child seat is not that simple, there are dimensions of the child. Therefore, in order to be able to choose the correct child's seat, it is necessary to take into account its height and the circumferences of individual parts of the child's body.

In addition, it should be noted that children are not able to judge whether someone is doing well or badly in a given seat. Therefore, it is difficult to assess whether the child feels comfortable in the seat. Undoubtedly, the scope of assessment of child seats should be extended to include the assessment of vibration comfort. The transmitted vibrations from the child seat can be harmful to the child. Especially when the journey takes several hours. The article is the basis for further considerations on the vibration comfort of child seats.

5. References

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