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Unfallforschung
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Safe transportation of children by bike

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1. Introduction

The number of bicycles as a proportion of total road traffic has risen considerably in recent years, in particular in connection with the Covid pandemic and above all in urban areas [RAD20]. At the same time, bicycles are increasingly being used not only as a means of transport for the cyclists themselves, but also as a way of transporting children. In addition to conventional child seats, the use of bicycle trailers and cargo bicycles is also growing.

The current study examines how safety is affected by the different methods of transporting children on bicycles – primarily consisting of child seat, bicycle trailer or cargo bicycle – and the specific risks potentially associated with the individual systems. The results presented here are taken from the research report issuing from a project undertaken in cooperation with the Berlin-based vehicle technology association, Gesellschaft für Kraftfahrzeugtechnik Berlin – GKB UG [FOB24].

2. Legal requirements

When transporting children by bicycle, it is always necessary to observe the legal requirements. Section 21, paragraph 3 of the German Road Traffic Regulations (StVO) [STV13] sets out the general regulations governing the transportation of children on bicycles. These stipulate that the person transporting the child must be at least 16 years of age. It is necessary to make sure that the child's feet cannot intrude into the spokes. In general, the age of children transported on child seats and in trailers is limited to a maximum of seven years. However, this limit does not apply to children with disabilities. A maximum of two children may be transported at any one time in a bicycle trailer. In principle, there is no requirement to use helmets or safety belts.

2.1 Cargo bicycles[1]

There are no separate regulations governing cargo bicycles. The law treats them in the same way as normal bicycles and they are therefore not subject to any special requirements. If the cargo bicycle has been "equipped for the transportation of persons" then the following provisions apply: There is no age limit for passengers. However, "special seats" must be installed for children aged under seven. However, there is no more detailed specification of "special seats" in this context. There is also no limit on the number of passengers and neither the cyclist nor the passenger(s) are required to wear a helmet. Nevertheless, standard DIN 79010 [NORMDIN 79010:2020-02] does set out certain minimum standards for cargo bicycles [BUN21]. This standard defines basic requirements relating, for example, to protection against injuries due to shearing or crushing, the chemical properties of the employed materials, protective measures concerning flammability, etc..

1 The present paper discusses both cargo bicyles (single-tracked) and tricycles (double-tracked). However, the generic term 'bicycle' is used for ease of reading.

Primarily, however, it sets out requirements relating to the employed belt systems and associated locking mechanisms. These are derived from standard DIN 15918 [NORMDIN EN 15918:2017-05], which describes the safety requirements relating to bicycle trailers used for the transportation of children. It defines the stress tests that belts and belt locks must pass undamaged.

Regulations relating to lighting equipment are set out in § 67 of the German road traffic licensing regulations (StVZO) [STV12]. However, these are no different from the regulations applicable to conventional bicycles and pedelecs.

2.2 Bicycle trailers

There are specific regulations relating to the lighting equipment to be installed on bicycle trailers. These are set out in § 67a of the German road traffic licensing regulations [STV12]. On trailers that are more than 60 cm wide, it is necessary to attach a white reflector on the front on both the left and right sides and located no more than 20 cm from the outside edge. In the case of trailers that are more than 1 m wide, it is also necessary to install a white lamp at the front left. On the rear of trailers that are more than 60 cm wide, it is necessary to install a red tail lamp on the left and, more generally, a red category "Z" reflector on both the left and right sides that are located no more than 20 cm from the outside edge. White reflector strips or two yellow spoke reflectors offset from one another by 180° must be attached to each of the wheels. These regulations apply to bicycle trailers that have been put into service as of 1st January 2018. Requirements relating to the safety of the frame structure, the belts and belt locks are defined in standard DIN EN 15918 [NORMDIN EN 15918:2017-05]. This standard describes concrete tensile strength tests for the belts and quasi-static rigidity tests for the frame.

2.3 Child seats for bicycles

DIN EN 14344 [NORMDIN EN 14344:2022-08] defines minimum requirements and test methods for bicycle child seats. This standard also describes dedicated test methods for the belts, belt locks and the rigidity of the child seat.

Although the German Road Traffic Regulations and German road traffic licensing regulations do not specifically require compliance with the standards for cargo bicycles, trailers and child seats, § 63a paragraph 3 of the road traffic licensing regulations states the following: "Bicycles and bicycle trailers may only be put into service on the public highway if they comply with the provisions of the current Regulation, the officially published notifications relating to their design, and accepted engineering practices at the time of their manufacture." [STV12] In the light of this provision, trailers and also cargo bicycles, which are considered to be bicycles under the current legislation, must comply with accepted engineering practices and therefore with the applicable standards.

3. Accident analysis

To gain an in-depth understanding of the situation regarding the transportation of children by bicycle and, in particular, the associated accident occurrence, it is essential to look closely at the accident databases and further descriptions of the accidents.

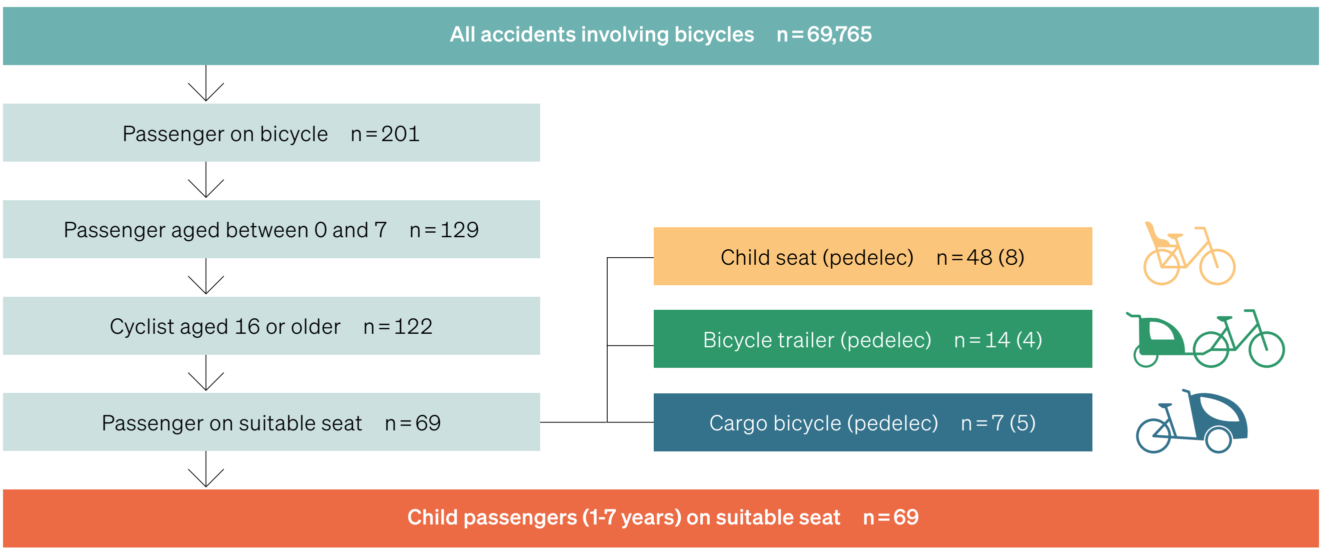
The number of cycling accidents involving injuries recorded by the police is increasing and reflects the general increase in bicycle use. In 2022, cycling accidents (n=70,496) were already 11 % above their pre-Covid level. Cycling accidents involving injuries with children as passengers were relatively infrequent but also on the increase. Compared to 2019, they increased by 45 % to n=222 in 2022. It was only thanks to luck that no child travelling as a passenger was killed in one of these cycling accidents. This upward trend in the use of bicycles and increase in the number of cycling accidents will continue.

While the federal accident statistics (DESTATIS) [STA19, STA20, STA21] provide only insufficient data concerning cycling accidents involving children, the police accident data makes it possible to perform extremely accurate analyses. This is so-called EUSKa data, which is collated and uniformly recorded by the police in the majority of the German states.

The EUSKa data records a total of 69,765 accidents (see Figure 1). These 69,765 cases form the comparison group. In 201 of these cases, at least one passenger was being transported on the bicycle. In 122 of these cases, both the cyclist and the passenger(s) were in the legally permissible age groups for the bicycle transportation of children. In 69 of these cases, a child seat, bicycle trailer or cargo bicycle was used for transport. These 69 cases form the study group, which will be compared with the comparison group defined above. Due to the relatively small number of cases

Cycling accidents with child passengers are comparatively infrequent

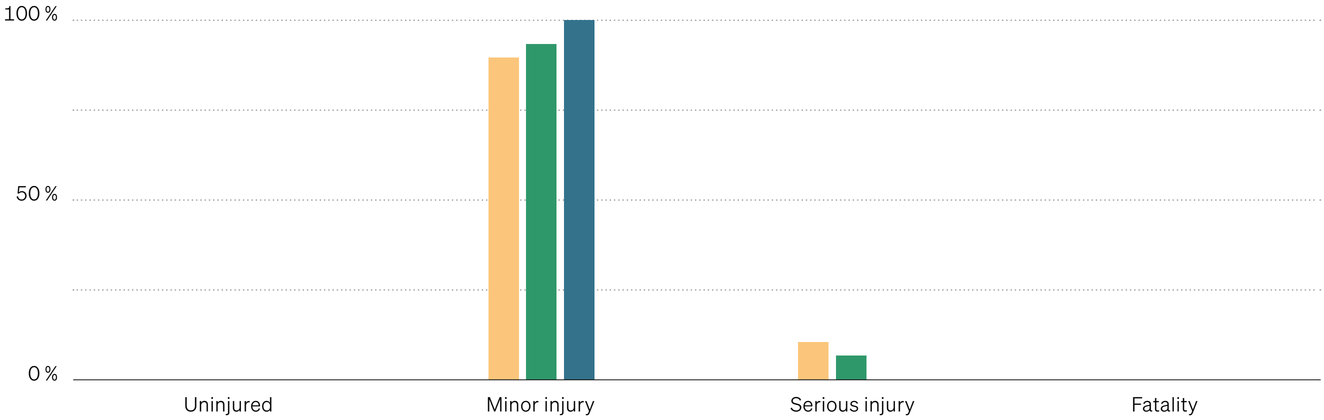
Figure 1 · Summary of the consulted police accident data (EUSKa) from eleven German states for the year 2020



in the study group, the fact that they are also included in the comparison group can be ignored. What is more, due to the comparison between the study group (n=69) and the comparison group (n=69,765), the results of this analysis are only of limited statistical validity.

The transported children suffer at least minor injuries

Figure 2 · Severity of injuries suffered by the transported children in the EUSKa accident data from eleven German states for the year 2020

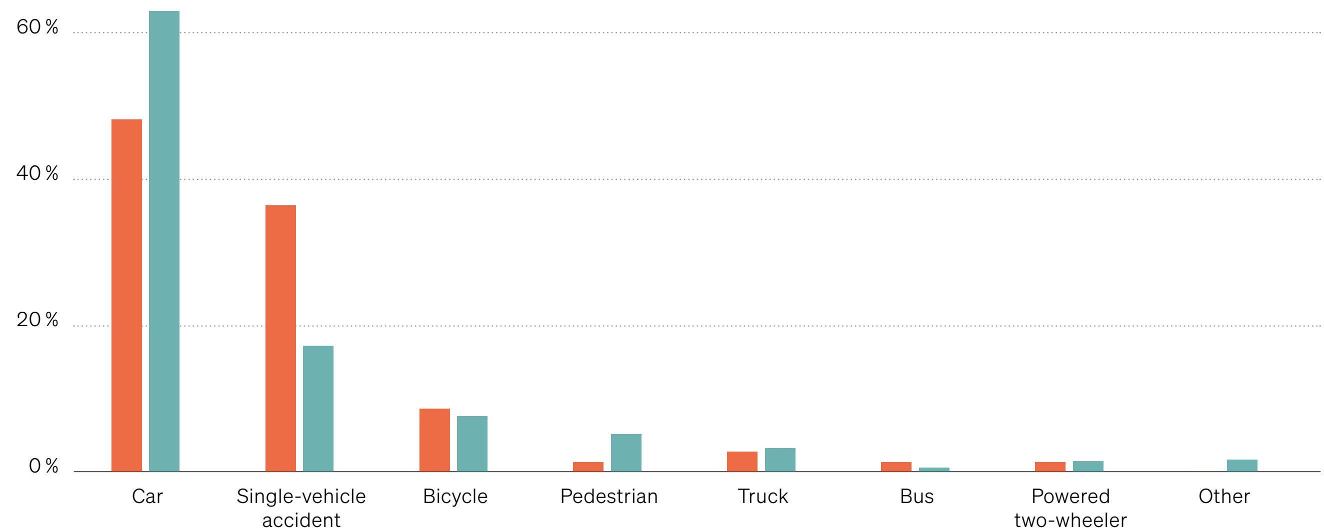


Child seat (n = 48) · Bicycle trailer (n = 14) · Cargo bicycle (n = 7)

Figure 2 indicates the severity of the injuries suffered by the transported children for the different transport methods for the year 2020. It is striking that the children always suffered at least minor injuries. No child fatalities were recorded during the period under consideration.

The most frequently involved other road user is a car

Figure 3 · Other involved road user in the study and comparison groups in the EUSKa accident data from eleven German states for the year 2020



Child passengers on suitable seat (n = 69) · All accidents involving bicycles (n = 69,765)

For both groups, the breakdown of the other involved road users presented in Figure 3 shows that the vast majority of the accidents involved a bicycle and a car, followed by single-vehicle accidents and accidents between several bicycles. The considerably higher proportion of single-vehicle accidents in the study group is striking. This could be an initial indication of handling difficulties resulting from the altered dynamics of loaded bicycles. It is also striking that there was a considerably smaller proportion of accidents involving pedestrians in the study group. This contrasts with the generally held assumption that parents who are transporting their children will make greater use of sidewalks.

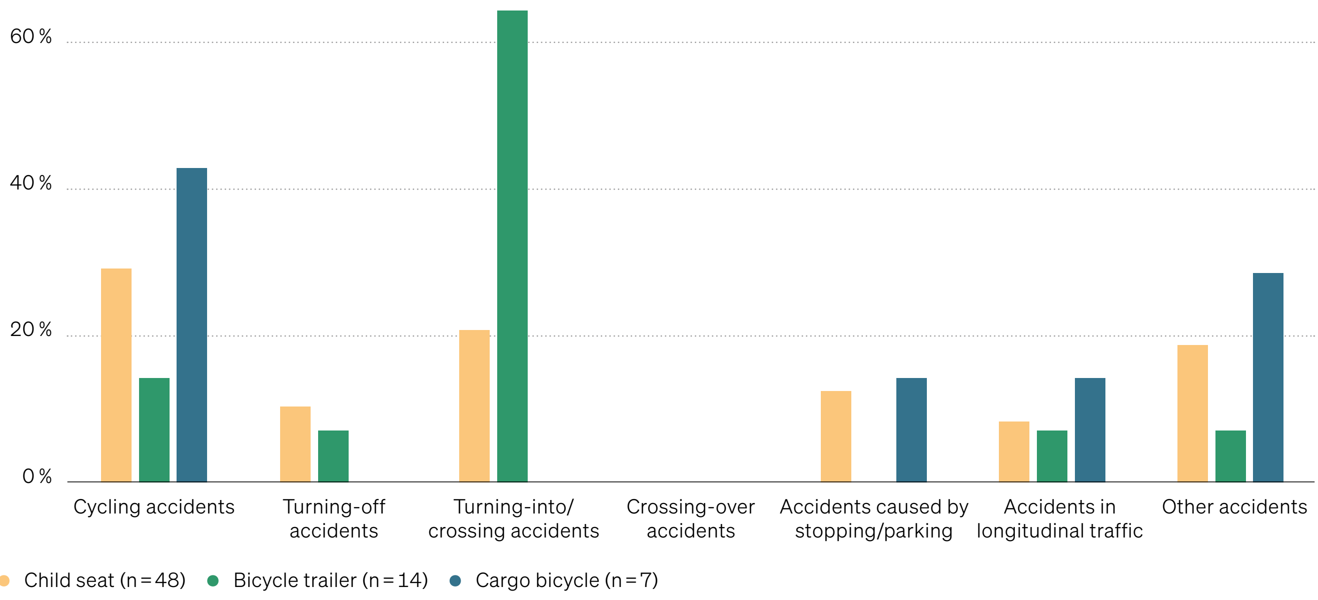
In Figure 4, alongside the cycling accidents in cases where child seats or cargo bicycles were used, the number of turning-into/crossing accidents with bicycle trailers is striking. No strong pattern emerges from an evaluation of the detailed descriptions here. However, in some cases it can be seen that the car driver initially allows the crossing cyclist to pass by, but then fails to notice the bicycle trailer, moves off again too early and collides with the trailer.

If we consider the cycling accidents by category then an almost identical picture emerges for the study and comparison groups. It can be seen that approximately 85 % of the cycling accidents are single-vehicle accidents that do not involve any other road user, while multiple parties are involved in only approximately 15 % of these accidents. This is consistent with the analysis of the accident causes associated with the different transport methods, which points to a striking level of inappropriate speeds among cargo bicycle users. This might suggest the presence of dynamic problems when riding a cargo bicycle.

To gain a more detailed understanding of the accidents that occur when transporting children by bicycle, the detailed accident descriptions of the 69 cases in the study group will be analysed below. The information obtained concerning the

In cases involving child seats and cargo bicycles, cycling accidents predominate; in the case of trailers, turning-into/crossing accidents are the most frequent

Figure 4 · Comparison of accident types for the different transport methods in the study group in the EUSKa accident data from eleven German states for the year 2020



accident scenarios supports the picture already painted above of the situations in which accidents occur depending on the transport method.

- In the case of accidents in which the child is sitting in a child seat, falls not attributable to any outside influence, e.g. weather conditions or cycling errors, predominate and account for approximately 35 % of cases. It is obvious that the higher centre of gravity and the resulting reduced stability are significant factors here.

- In the case of accidents involving bicycle trailers, two scenarios occur relatively frequently and each account for 21 % of such accidents. On the one hand, there are turning-off errors, in which a car driver turns off to the right and hits a cyclist travelling in the same direction ahead of them in longitudinal traffic. On the other, there are the turning-into/crossing scenarios, in which a car drives out from an exit and collides with the bicycle or trailer. Here, there is reason to assume that often only the bicycle, but not the trailer, is seen and that the car therefore moves off too early and hits the trailer.

- In the case of cargo bicycles, falls not preceded by any collision – that is to say, pure cycling accidents – predominate at 57 %. In such cases, the fall often occurs while negotiating a bend. The so-called dooring accidents are another major source of accidents. In these cases, the cyclist collides with a car door as it is being opened. This is usually the driver's door. Such cases account for approximately 28.5 % of the accidents involving cargo bicycles. Studies conducted by the UDV have already shown that approximately one in every 14 car/bicycle accidents (7 %) is a dooring accident. Approximately one fifth of these accidents end with the cyclist suffering serious injuries. These are mostly head and leg injuries. [UKO71].

4. User survey and user tests

A combined online survey and field study were undertaken to determine the mobility and cycling behaviour of cyclists who regularly transport children. The online survey made it possible to identify the respondents' perceived safety, individual preferences and personal objectives when transporting children by bicycle. The field study was used to identify the real-life cycling and safety-related behaviour of adults when they are transporting children. The field study made use of both observations and interviews.

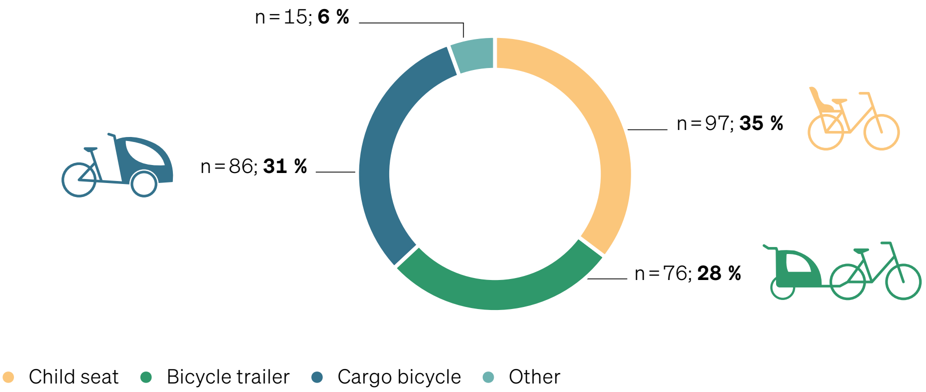
4.1 Online survey

The online survey was launched on 2nd July 2022 and ended on 19th February 2023. The raw dataset consisted of n=274 complete datasets from individuals who either transport or could transport children by bicycle.

The results regarding the most frequently used form of transport revealed by the survey are shown in Figure 5.

Bicycle with child seat is the most frequent solution

Figure 5 · Most frequently used method of transporting children



Overall, there were no significant differences between the transport methods in terms of the criteria determining the decision to purchase the equipment. Respondents to the survey primarily justified their decision in terms of the functionality and quality of the equipment, its ease of use, safety in road traffic, and comfort for the transported children.

It was found that cargo bicycles are used particularly intensively for transporting children when compared to bicycle trailers and bicycle child seats: While 60 % of cargo bicycle users transport children at least five times per week, the corresponding proportion for bicycle trailer users is approximately 43 % and that for child seat users just under 40 %. The most important reasons given for using all of the transport methods are journeys to take children to and fetch them from kindergarten or school, excursions and children's leisure activities. The purpose of using the different transport methods also differs significantly: In the case of cargo bicycles, child transport is relatively frequently combined with the accomplishment of everyday tasks, shopping and journeys to the cyclist's own place of work.

Overall, and for all the transport methods, respondents favour routes where there is a structural demarcation from the motorized traffic, that containing separate cycle lanes or are identified as cycling roads, whereas proximity to motorized traffic (in particular when this travels at high speeds) and pedestrians tends to be avoided.

Almost half of the respondents are able to report at least one critical situation that has arisen while transporting children by bicycle. In the current survey, the frequency or type of critical situations do not depend to any significant level on the respondent's sex or choice of transport method. The most frequent critical situations relate to small (side) distances to the motorized traffic, single-vehicle accidents (falls, tipping over, etc.), crossing road users (e.g. failure to observe the rules relating to the right of way) and turning-off manoeuvres.

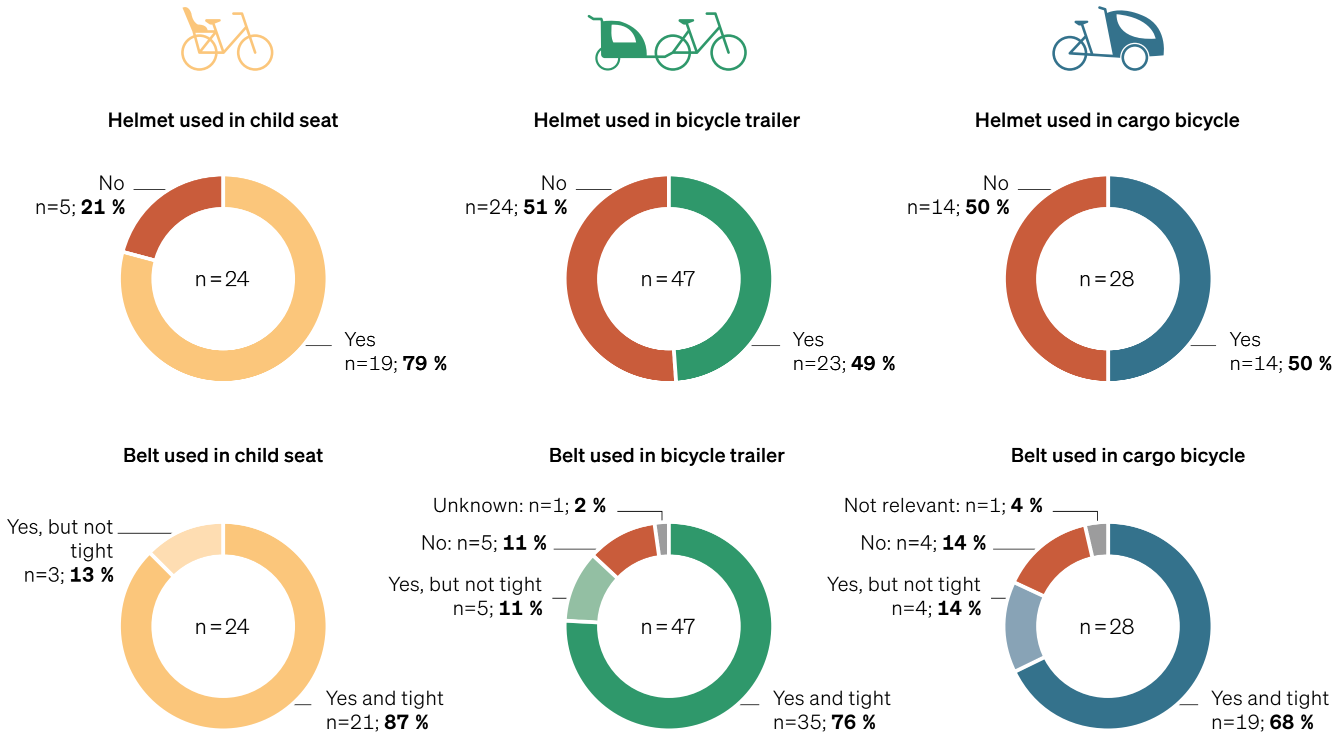
4.2 Field study

In order to compare the subjective data obtained by means of the online survey with the actual behaviour of individuals transporting children by bicycle, the survey was accompanied by a field study consisting of a safety check (documented by recording the observed behaviours) and an interview (following semi-standardized guidelines). The field study was conducted at various locations in the public road network and only involved adults who were transporting their children.

The total sample consisted of n=101 persons, consisting of 54 female (53.5 %) and 47 male (46.5 %) adults who were transporting one or more children by bicycle.

Helmets and belts are primarily used in combination with a child seat

Figure 6 · Use of helmets and belts by the transported children as a function of transport method



There was a significant difference in helmet usage depending on the transport method. This was not the case for safety belt usage. It is noticeable that helmets were worn most frequently by children in a child seat

(see Figure 6). However, even here, the child did not wear a helmet in approximately one fifth of the observed transport situations, a finding which is consistent with the results of the online survey. A child helmet was worn in half of all the observed situations involving a bicycle trailer or cargo bicycle, while correct belt usage was observed in two thirds (cargo bicycle) and three quarters (trailer) of all cases, respectively. A little under half of the adults themselves wore a helmet (n=47 or 46,5 %). However, adult helmet usage did not depend to any significant level on the chosen transport method.

Bicycle trailers exhibited the most defects coded in connection with the safety check (faulty or missing rear lamps, detached reflectors, a twisted frame, torn off safety strap). This transport method was the subject of criticism in one fifth of cases. There were reports of a risk of tipping when a child seat is used.

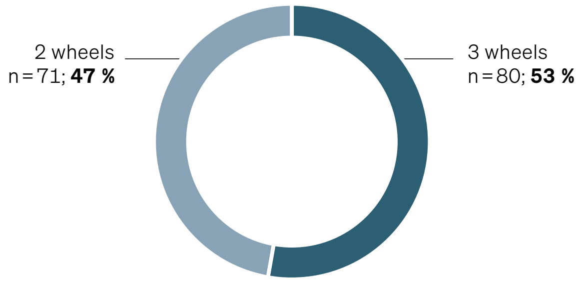
5. Field research in Berlin

Statistical research was conducted in Berlin in 2023 in order to make it possible to go beyond the constraints of the online survey and field interviews and evaluate the general behaviour of users when transporting children by bicycle. The focus here was placed on the frequency of use of the different transport methods and users' safety-related behaviour [FOB24].

According to the observations made, the child seat was the most frequently used method, accounting for 53 % of the total. At 37 %, cargo bicycles were also seen considerably more frequently than trailers, which accounted for only 10 % of the observed cases of child transportation.

More stable tricycles are more frequently used to transport children

Figure 7 · Ratio of single-tracked to double-tracked cargo bicycles



Approximately 53 % of the observed cargo bicycles were double-tracked (see Figure 7). This confirms the observations described above that the more stable tricycles are the slightly more popular variant, in particular when it comes to transporting children. Further details relating, for example, to the level of helmet use and the drive type can be found in the research report [FOB24].

6. Studies of active and passive safety

Two complementary approaches to examining active safety were pursued in parallel:

→ A measurement bicycle was constructed to record all the dynamic variables affecting the handling of the bicycle types examined here

→ A cycling dynamics simulation capable of mirroring the behaviour of all the examined transport concepts was developed

Selected crash tests were first performed in order to permit an in-depth study of passive safety, that is to say protection in the event of an accident. On the basis of these tests, it was then possible to develop detailed FEM simulation models for all the transport concepts.

6.1 Studies of cycling dynamics

A measurement bicycle to which a trailer and child seat could be attached was constructed in order to capture data relating to the real-life cycling dynamics. A cargo bicycle was also constructed for the same purpose The measurement bicycle had the following components:

- Force sensors to measure the braking force
- Potentiometer to record the steering angle
- Hall sensor to measure the speed
- Raspberry Pi to record the data and the three-axis orientation (yaw, pitch and roll) and angular acceleration

6.1.1 Studied cycling manoeuvres

The following cycling manoeuvres were undertaken by test subjects for all three transport methods:

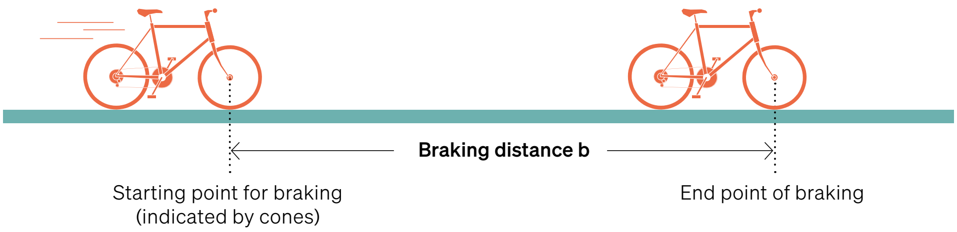
Emergency braking: Emergency braking on level ground was performed from a starting speed of 20 km/h for the various transport methods. The braking deceleration and braking distance and the lateral stability of the bicycle were evaluated (see Figure 8).

Slalom travel: This manoeuvre provided information about the bicycles' dynamic cornering behaviour and ease-of-handling in the case of frequent changes of direction. The slalom trajectory can be seen in the diagram in Figure 9.

Circular travel with increasing speed: The test subject started by cycling at low speed and increased this continuously until it was no longer possible to ride stably around the predefined circular route (see Figure 10).

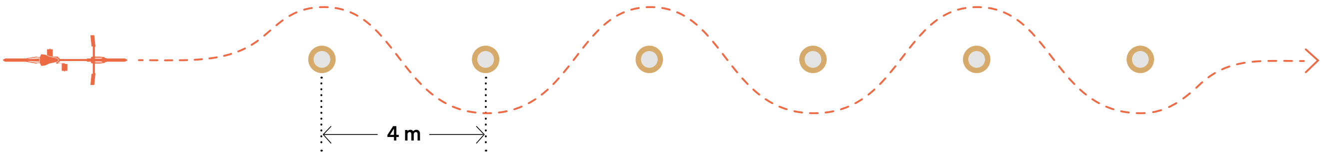
Manoeuvre 1: Emergency braking

Figure 8 · Schematic representation of the emergency braking manoeuvre



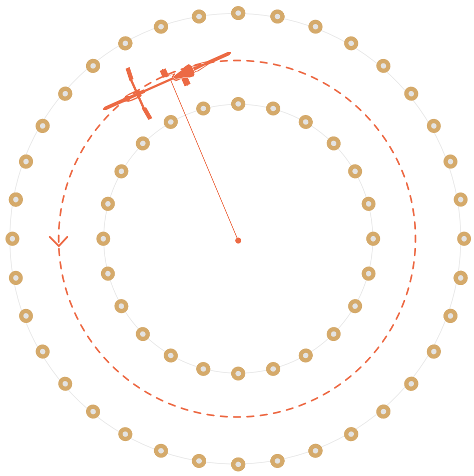
Manoeuvre 2: Slalom travel

Figure 9 · Schematic representation of the slalom manoeuvre



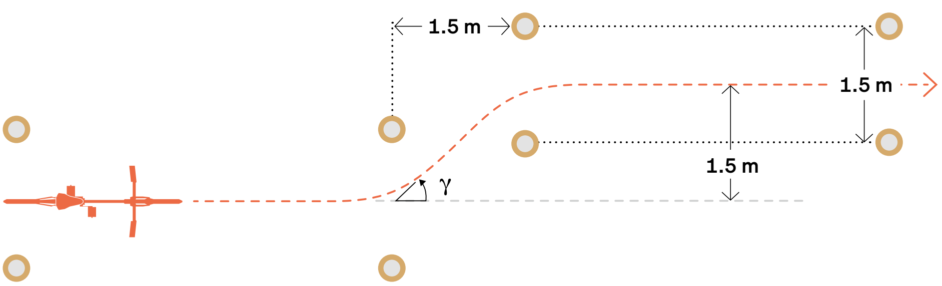
Manoeuvre 3: Circular travel with increasing speed

Figure 10 · Schematic representation of the circular travel manoeuvre



Manoeuvre 4: Evasive action

Figure 11 · Schematic representation of the evasive action manoeuvre



Evasive action: The test subject cycled straight ahead with no lateral movement at a speed of 20 km/h. Cones positioned at a predefined point made it necessary to take evasive action comparable to that required in a dooring situation (see Figure 11). The form of this evasive action resembled a rapid change of lane. The aim of these tests was to assess the stability of the system when taking evasive action.

6.1.2 Summary of the cycling tests

The child seat is the most versatile of the three systems tested and is the one whose in-journey behaviour most closely resembles cycling without any child passenger. The results of the real-life tests of cycling dynamics show that although it is permissible to transport a child weighing 22 kg on a bicycle child seat, this is not to be recommended. The resulting instability leads to a high risk of falls or of the bicycle tipping over, in particular when changing direction and after stopping. The test subjects found it almost impossible to keep the system upright once it had started to tip over.

The test subjects found that the bicycle trailer inspired confidence and was pleasant to use. In tight bends or in situations where sudden evasive action is necessary, the cornering behaviour of the trailer can lead to collisions with objects which riders would only be able to avoid without the trailer. What is more, in the case of emergency braking manoeuvres, the trailer may jack-knife and enter the path of oncoming traffic or intrude into adjacent lanes, potentially resulting in serious accidents.

The three-wheeled cargo bicycle proved to be the most stable of the three tested methods of transport. It achieves similar braking distances to a conventional bicycle without child passenger. However, in tight bends and on abrupt changes of direction, the cargo bicycle reaches its dynamic limits due to a risk of tipping.

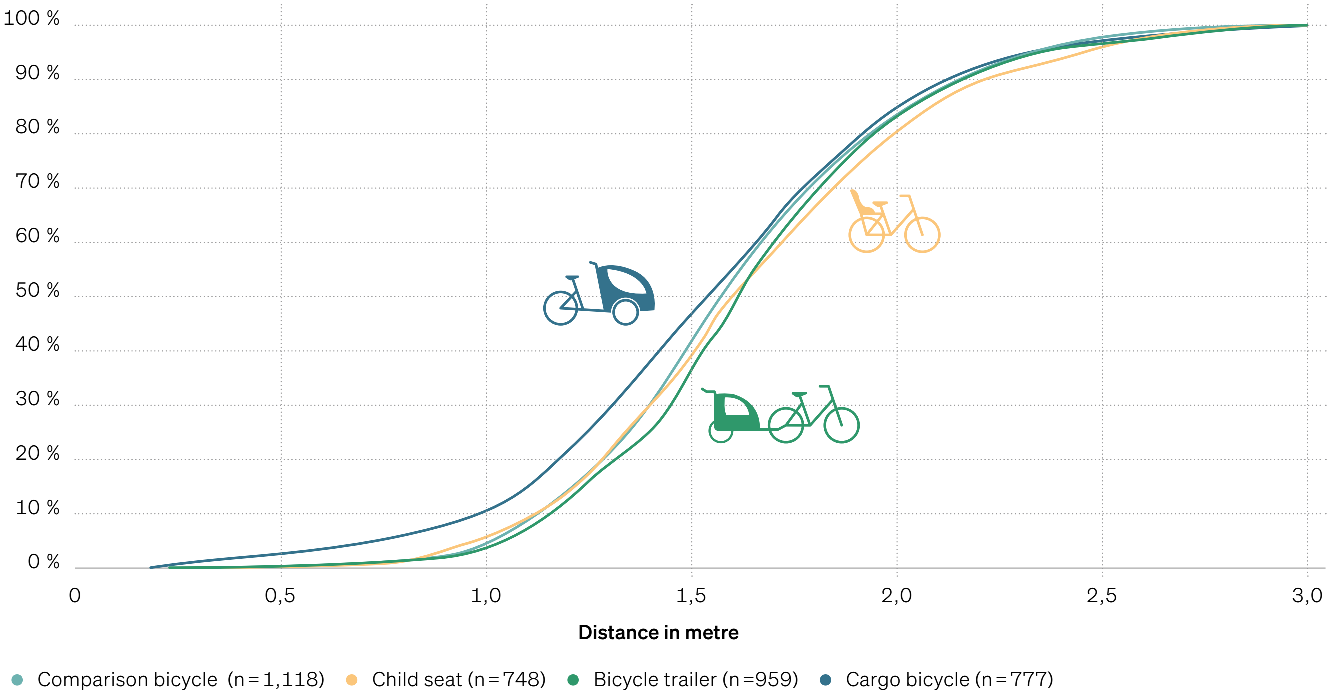
6.1.3 Study of overtaking clearance

The study also included a field test which measured the clearance between bicycle and overtaking vehicle during overtaking manoeuvres. Observations were made for all three methods of child transport. The measurements were made on a route through Berlin city centre This route was 10.5 km long and included 31 roads with widths of between 6 m and 15 m. Of the 31 roads, 20 were main roads and eleven were secondary roads.

It was found that at 40 %, a considerable proportion of the overtaking manoeuvres failed to respect the statutory minimum clearance of 1.50 m (see Figure 12).

In 40 % of all overtaking manoeuvres, the distance to the bicycle was less than 1.50 m

Figure 12 · Overtaking clearances as a function of bicycle type



6.2 Studies of passive safety

The information obtained regarding accident occurrence made it possible to identify relevant accident scenarios for the different transport methods. These were simulated by means of crash tests (see Table 1) and FEM simulations (see Figure 14):

Accident scenarios

Table 1 · Accident scenarios simulated by means of crash tests

Child seat	• Tipping over from the vertical with child seat and child • Collision of cyclist (10 km/h) with car door that is opened unexpectedly (dooring) • Car turning off to left (12 km/h) collides with bicycle with child seat that is travelling straight ahead (8 km/h)
Bicycle trailer	• Collision of cyclist (10 km/h) with car door that is opened unexpectedly (dooring) • Car drives into stationary trailer • Car turning off to left (10 km/h) collides with bicycle with trailer that is travelling straight ahead (7 km/h) and crashes into the trailer
Cargo bicycle	• Collision of cyclist (10 km/h) with car door that is opened unexpectedly (dooring) • Car turning off to left (7 km/h) collides with cargo bicycle that is travelling straight ahead (7 km/h) and crashes into the transport box

6.2.1 Crash tests

In the crash tests, a non-instrumentalized dummy that was representative of an average man in terms of size and weight was used on the bicycle or cargo bicycle. In addition, a fully-instrumentalized Q6 dummy [HUM93] that was representative of a 6-year-old child was placed in the corresponding transport equipment and secured there using the supplied safety belts (see Figure 14 for an example in the cargo bicycle). The ensuing loads were measured and evaluated based on the limit values set out in the European New Car Assessment Programme (Euro NCAP) [EUR23] and Regulation no. 129 of the United Nations Economic Commission for Europe (UNECE) [WIR14].

The measured values were the accelerations at the head, chest and pelvis, applied force and bending moment at the neck, as well as the Head Injury Criterion (HIC).

Figure 13 · Cargo bicycle with crashtest dummies

6.2.2 Summary of the findings

An accident occurring while a bicycle child seat is being used generally leads to the bicycle tipping over and therefore to a fall from a height of approximately 1.5 m. This brings with it a high risk of injury, in particular when the bicycle tips over from an almost vertical starting position. Because the child is restrained in the seat by the safety belts, he or she inevitably tips over with the bicycle and crashes onto the roadway The child seat provides virtually no protection against contact with the roadway or other party involved in the collision. The side protection at head height does not usually prevent direct contact with the roadway.

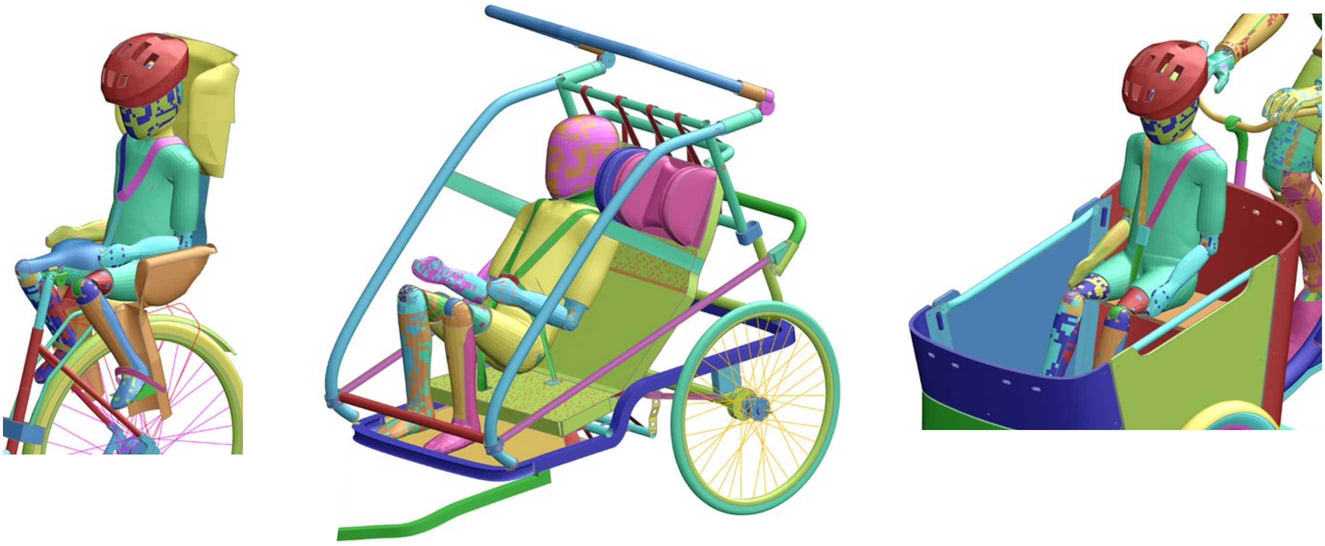
The crash tests showed that bicycle trailers provide good all-round protection. The rigid outer frame forms an integral passenger compartment and protects the occupant from contact with the roadway. However, if there are two occupants then there may be some interaction between them.

The rigid wooden box on the cargo bicycle also provides occupants with a good level of protection in the scenarios tested here. Here again, interaction between multiple occupants is possible. Clearly, the model tested here is not optimally designed for transporting children. There is also no protection at the level of the occupants' heads. In the event of an accident, it is also possible for the adult cyclist to be propelled into the transport box and/or against the children sitting in the direction of travel. The rebound following a collision can also cause the back of the head of children sitting in the direction of travel to impact against the handlebar or the cyclist's hand.

6.2.3 Computer simulation

In addition to the crash tests, simulations were run to replicate individual accident scenarios and the resulting load characteristics. To determine representative values, three models were constructed using the finite element method (FEM) and were calculated using the LS-DYNA solver for selected crash scenarios (see Figure 14

Figure 14 · FEM simulation models of the three transport methods



and Table 2). The “rigid wall” scenario represents a collision with an infrastructure object or the front of a vehicle.

Simulated accident scenarios

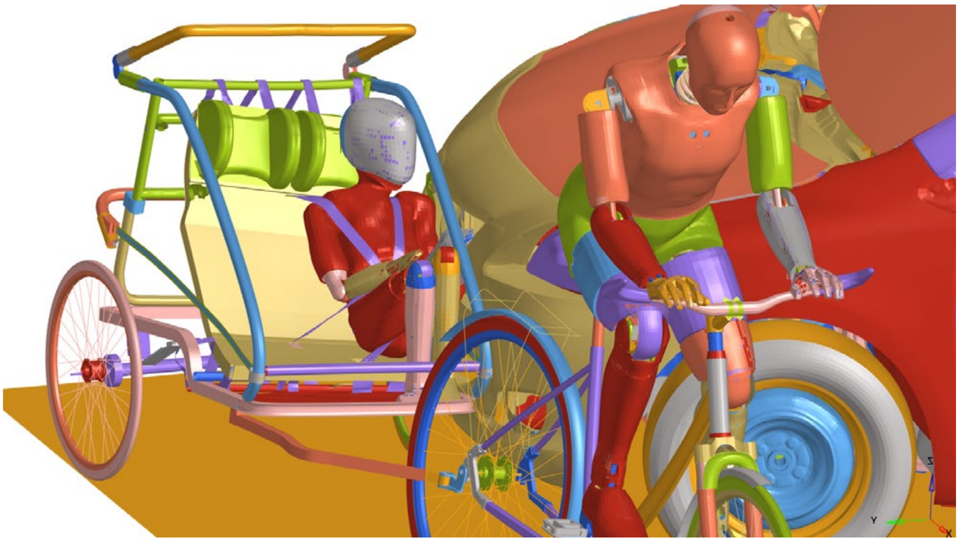
Table 2 · Accident scenarios replicated using the FEM simulation

Scenario	V_{car}	$V_{bicycle}$	Transport method
Dooring with door opening angle 60°	0 km/h	25 km/h	All
Turning off left with collision angle 70°	30 km/h	25 km/h	All
Rigid wall with collision angle 5°	–	25 km/h	All
Tipping with helmet	–	–	Child seat
Tipping without helmet	–	–	Child seat

Through this virtual replication of the previously conducted crash tests, it was possible to compare the kinematics of the dummies and bicycles in the simulation with those in the real-life test and in this way develop a valid simulation model.

The results of the simulation for the bicycle trailer show that the child dummy is well protected by the aluminium frame in the event of a head-on collision. In the case of a side collision due to a turning-off accident (Vcar = 30km/h), the dummy is exposed to high loads. These are due to the low seat height of the Q6 dummy in the trailer and therefore the impact height of the vehicle (see Figure 15).

Figure 15 · AbbCar/vehicle turning-off configuration: Seat height of Q6 dummy in the trailer and impact height of vehicle



The kinematics in the case of the child seat are very different. In this case, the child dummy is sitting higher up and is not directly at impact height in the event of a turning-off accident. The Q6 slides over the vehicle's bonnet and is not exposed to any forces above the limit values. However, in other configurations, this raised seat position proved to be a disadvantage. In the real-life tests, tipping over as a result of an accident resulted in very high loads at the head. In the case of impact against a rigid wall, the loads at the head are only just below the specified limit value. These are due to the contact of the Q6 head with the back of the adult dummy.

The situation is worse in the case of the cargo bicycle. The values for the neck and chest loads in the rigid wall scenario are high for this transport method. This is indicated by the fact that the inertia of the guiding adult dummy causes it to move forward forcefully into the wooden box occupied by the Q6 and to come to rest against the head of this. In this cargo bicycle model, the low belt connection of the shoulder belts and the very advanced position of the lap belt are another disadvantage because, in the scenario in which a car turns off to the left, the dummy slips through the lap belt and, in the head-on impact scenarios, the Q6 dummy is seen to move forward by a considerable amount.

7. Recommendations

All these transport concepts differ from the situation of a conventional bicycle in many ways, some of which are absolutely fundamental. It is therefore essential for users, who are in most cases the child's parents, to consider the question of which transport method is the most suitable in the light of their own circumstances. Once this general decision has been made, it is necessary to test the selected transport method prior to any purchase. As the results of this study show, each of the concepts has its own specific characteristics, which take some time to get used to. A new bicycle should therefore be extensively tested before being used to transport children. It is particularly important to practice critical situations such as taking sudden evasive action or braking hard. It is vital that users continue to familiarize themselves with the specific possibilities for securing the child at the bicycle and make use of these during every journey. This also includes using a helmet.

In particular, manufacturers of bicycles, child seats and bicycle trailers should make sure that their products are safe and offer children the best possible protection. This includes providing suitable places for children where they can be secured in such a way that, in the event of an accident, they remain at the bicycle or in the trailer and, if possible, are protected against contact with any object or the other party involved in the collision. At the same time, parents should be given comprehensive, easily understandable information on how to use the chosen transport method at the time of purchase. This information should describe the sizes, weights and age groups for which the system is suited in an easy and comprehensible way. It should also point out the need to use belts and helmets.

To permit future safety assessments based on reliable accident statistics, it is vital that the police record the various forms of transport in their road accident reports.

7.1 Child seats for bicycles

Using a child seat on a bicycle means that the centre of gravity of the overall system is shifted considerably upwards. This effect increases, the heavier the child is. This leads to a considerable loss of stability, in particular during longer journeys. This should be borne in mind, and users should adopt a correspondingly defensive cycling behaviour. This effect is amplified when moving off and coming to a stop, meaning that the risk of falling is particularly high at these times. It is therefore also necessary to be particularly careful when placing the child in or taking him or her out of the child seat. When doing so, it is essential to make sure that the bicycle is in a secure upright position. The stands generally installed on bicycles are not suitable for this and should be replaced by so-called “double-legged” stands.

The studies of bicycle dynamics also showed that it is almost impossible to control the bicycle safely when transporting children at the upper limit of the weight range, usually 22 kg. Relative to the bicycle, the dynamic effect of the child seat is so large that it is very difficult to control the bicycle even in less critical conditions. It is vital that the legislature considers adapting the weight limit here.

In general, the introduction of child seat approval tests that verify the basic requirements for child protection is to be recommended. In addition to requirements placed on the belt system, it would also be possible to check the load limits by using suitable dummies in fall tests. The crash tests and simulations performed in this project showed that the head area is at particularly high risk. Optimization of the side protection would therefore be welcome while, for some child seat models that provide almost no lateral protection, it is an urgent necessity.

7.2 Bicycle trailers

It was found that in some situations, low trailers are not seen at all or are not easily seen by car drivers.

Instead of simple battery-powered lamps, a system with its own power supply via a hub dynamo would seem to be a good solution. The flag should also be subject to requirements in terms of its strength and durability. Once again, it was found that this was often missing from the trailer because it had become lost or broken. One solution might take the form of permanently fixed telescopic flags.

The study also shows that the trailer plays a critical role in emergency braking manoeuvres. If the towing bicycle is not travelling in a completely straight line, the trailer continues to push it from behind and skews out the rear wheel. In the worst case scenario, the bicycle rider loses balance and falls. As a result, a separate brake at the trailer, operated by means of an overrun mechanism for example, is urgently recommended.

7.3 Cargo bicycles

For users, the cargo bicycle represents the biggest change when compared to a normal bicycle. Here, it is especially important to familiarize oneself with the product and to test its behaviour, including in more extreme situations and in particular when cornering. In addition to securing the child or children correctly, it is also important to secure any other load elements correctly.

Even though cargo bicycles are formally considered to be bicycles, they can now have a weight of several hundred kilograms and assume imposing dimensions. It is therefore essential to clarify the conditions under which cargo bicycles should be subject to the same standards as bicycles or whether special regulations should apply. These considerations apply equally to cargo bicycles that are used to transport children.

The legislature must clearly define the requirements placed on cargo bicycles used to transport children in terms of the technical systems and child restraint mechanisms, as well as the protective effect that must be deployed in the event of a crash. Compliance with these requirements should then be verified by means of appropriate approval tests.

The manufacturers of cargo bicycles must pay particular attention to child safety. Seats designed with safety in mind and that provide a high level of protection in the event of an accident are required. This also includes a robust belt system, padded rods and edges in areas that the child's head can strike against, as well as a type of roll bar that protects the child if the cyclist himself or herself is propelled forwards over the handlebar or the child's upper body risks leaving the box.

Efforts must also be made to improve dynamic behaviour during travel. Above all, cargo bicycles must be made more stable during cornering and they must not tip over. To this end, the requirements set out in DIN 79010 should be made considerably more stringent.

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