



# Children's safe routes to school: Real and perceived risks, and evidence of an incapacity-incapability space

Stefan Gössling<sup>a,b,\*</sup>, Jessica Kees<sup>a</sup>, Rafael Hologa<sup>c,d</sup>, Nils Riach<sup>c,d</sup>, Rul von Stülpnagel<sup>e</sup>

<sup>a</sup> School of Business and Economics, Linnaeus University, Kalmar 39182 Sweden

<sup>b</sup> Western Norway Research Institute, PO Box 163, Sogndal 6851, Norway

<sup>c</sup> Physical Geography, University of Freiburg, Schreiberstraße 20, Freiburg 79085, Germany

<sup>d</sup> T3 Transportation Think Tank gGmbH, Clayallee 177, Berlin 14195, Germany

<sup>e</sup> Center for Cognitive Science, Albert-Ludwigs-Universität Freiburg, Hebelstr. 10, Freiburg 79104, Germany

## ARTICLE INFO

### Keywords:

Children  
Routes to school  
Subjective traffic risks  
Transport planning  
Transport policy

## ABSTRACT

There is a general consensus that children and adolescents should ideally travel to school actively and independently. Yet, in many parts of the world, real and perceived traffic risks represent a major barrier to walking, cycling, or the use of scooters. As the perspectives of children and adolescents on perceived dangers are insufficiently understood, this quantitative-qualitative study compares injury data for 2019–2021 with questionnaires answered by school management (n=40 school managers) and focus-group interviews with students aged 6–17 (n=40) in the city of Freiburg, Germany. The triangulation indicates that a significant number of collisions and injuries in traffic appear to go unreported, and that school routes are characterized by insecurity and perceived dangers. The analysis suggests that perceptions of risk change with age, and in reflection of influences including cognitive ability and motor skills, social environment and attitudes, transport mode, and technology adoption. Results are conceptualized as an incapacity-incapability space, indicating that relative risk exposure is highest for younger children (5–9 years), and for teenagers (12–16 years). Findings have implications for the study of traffic risks, urban design and transport planning and policy.

## 1. Introduction

The way to school is one of the earliest encounters of children with transport systems. In Europe, and Germany in particular, it is common for children in many cities to travel to school independently. Children will walk, use scooters, or ride bikes; older children will also use public transport including busses, trams, and sometimes trains. Travel to school is a routine that means being confronted with traffic risks, shaping perceptions of transport systems and urban designs. These experiences influence current and, possibly, future transport behaviour. How children travel to school varies depending on transport culture, and includes a wide range of perceived personal, physical and social barriers (Lu et al. 2014; Carver et al. 2013). In a comparative study in seven European countries, factors affecting children's school mobility patterns were found to include parents' mobility choices and safety perceptions; bike ownership and commute distance; availability of public transport; and population density (Masoumi et al. 2020). Other studies have pointed to traffic situation, built environment and traffic designs, including spots

that are difficult to navigate (Chillón et al. 2015; Davison et al. 2008; Schützhofer et al. 2018; Twisk et al. 2013), as well as the age of children and their mental and physical capabilities (Meir et al. 2015; Meir and Oron-Gilad, 2020; Zeuwts et al. 2015).

Even though the relevance of perceived safety for transport mode decisions is understood (Cobb et al. 2021; Goel et al. 2021; Snelson et al. 1993), research addressing these interrelationships from the perspective of the children themselves is rare (Evenson et al. 2006; Granié 2007, 2009). To adequately consider the complexity of traffic risks, which may be real or perceived, the study compares injury data, the views of school management, and the children's own perceptions of dangers. The study is based in Freiburg, Germany, where a majority of children commutes over short distances, mostly walking, cycling or using scooters. Even though Freiburg has comparably high active transport shares (Green City Freiburg, 2022), traffic situations can be complex, as different transport modes intersect at schools (cyclists, e-scooters, busses, trams, "parent taxis"), while children have to navigate crossings, traffic lights, bus stops, parked cars, or construction sites. Their fears and

\* Corresponding author at: School of Business and Economics, Linnaeus University, Kalmar 39182 Sweden.

E-mail address: [sgo@vestforsk.no](mailto:sgo@vestforsk.no) (S. Gössling).

<https://doi.org/10.1016/j.jcmr.2024.100019>

Received 26 July 2023; Received in revised form 5 February 2024; Accepted 23 February 2024

Available online 24 February 2024

2950-1059/© 2024 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

understanding of risks is consequently of relevance for traffic planning and urban designs that can support children's independent and active travel to school.

## 2. Theoretical background

Traffic risks are usually assessed on the basis of recorded injuries, with active transport users being disproportionately more often involved in collisions (Aldred and Crossweller, 2015). This "objective" approach to risk evaluation is not equivalent to safety, as evident from studies on near misses (e.g. Aldred, 2016; Aldred and Goodman, 2018). There is also an associated issue of crashes not leading to injuries or injuries going unrecorded (Juillard et al. 2017), as well as injuries being recorded, but injury mechanisms remaining unknown (Airaksinen et al., 2020). As a study for Europe by the World Health Organization (Racioppi et al. 2004: 23) underlined, injury underreporting is significant, with for instance UK data showing that "36% of road traffic injuries are not reported to the police", and one fifth (20%) of reported crashes remaining unrecorded. This suggests that dangers in traffic cannot be accurately understood on the basis of official data on injuries alone. Even where traffic designs are collision and injury free, they may not necessarily be perceived as safe (Abadi and Hurwitz, 2018; Hull and O'Holleran, 2014; Möller and Hels, 2008; Winters et al. 2012).

Children are particularly vulnerable in traffic, as they lack motor skills to navigate traffic (Schützhofer et al. 2018), and because they do not appropriately recognize and respond to dangers (Tomoda et al. 2022). Motor skills, visual and acoustic perceptions, and cognitive capabilities develop with age, and often with considerable variability between individual children (Limbourg, 1995; Meir et al. 2015; Meir and Oron-Gilad, 2020; Zeuwts et al. 2015, 2016). Road traffic is becoming increasingly complex. Cities implement cycle lanes, add signage, implement traffic calming barriers, or legalize new transport modes such as e-scooters. This affects younger children, who can track fewer objects simultaneously (Dye & Bavelier, 2010; Kovesdi & Barton, 2013; Zeuwts et al. 2017). Awareness of traffic risks and availability to process peripheral information increases with age (Wann et al. 2011; Zeuwts et al. 2016), and 7–8-year-olds are focused on central vision, for example when crossing intersections (Jiang et al., 2021). Children 6–8 years old cannot correctly estimate the speed and distance of approaching vehicles (Joly et al. 1991; Van der Molen, 2002), and base their decisions to cross a road on the gap size between vehicles (Congiu et al. 2006; Morrongiello et al. 2016). As they also need more time to initiate a crossing (Jiang et al. 2021), this results in more collisions of 6–10 year-olds with vehicles, compared to 14 year-olds and adults (O'Neal et al. 2017). This is equally true for children on bikes, who underestimate the time required to cross a road (Plumert et al. 2004).

There are also significant, age-related differences in the processing of auditory information in traffic situations. For example, 6–9 year-old children have greater difficulties in estimating the existence, direction, and time-to-arrival of a car based on sound (Barton et al. 2013). The development of noise-reducing road surfaces and e-cars with reduced engine noise thus increases auditory risks (Brand et al. 2013; Mendonça et al. 2013). Younger children also have greater problems to stay focused (Schmidt & Funk, 2021; Schützhofer et al. 2018), and they have difficulties to understand the behaviour and limitations of others, such as a car driver's blind spots (Twisk et al. 2013).

Even young children can identify traffic dangers, but cognitive abilities to recognize risks develop between 6 and 14 years (Granié 2007). Children aged 6–8 have been found to ignore even basic traffic rules, such as to stop before crossing a road (Morrongiello and Kiriakou, 2006). They do not seek eye contact with drivers, a behavior allowing for non-verbal communication. Children are, depending on how tall they are, also limited in their perceptions, as bonnets or other car parts block views. Awareness of the risks implied in obscured views is insufficiently developed in younger children aged 7–9 years (Lehtonen et al. 2017; Meir et al. 2015). Younger children's knowledge of traffic rules and risks

"should thus not to be equated with understanding" (Schützhofer et al. 2018: 6). Traffic danger awareness is a result of maturity and experience (Vansteenkiste et al. 2016). This changes with older age, as adolescents, and boys more than girls, show an increased tendency for rule violations (Granié 2007, 2009).

Parents have a strong influence on their children's behavior in traffic, as they are the earliest educators on traffic dangers. Parents also influence the perceptions of children (Nevelsteen et al. 2012; van den Berg, 2020). Where safety cultures exist, this can have a positive effect on safety (Morrongiello et al. 2008), although parents are not necessarily role models in their actual traffic behaviors (Cloutier et al. 2017; Morrongiello & Barton, 2009; Zeedyk & Kelly, 2003). Parental supervision of children declines with age and is replaced by peer influence, including views on traffic risks and behavior (Darvell et al. 2015; Morrongiello et al. 2019). In particular teenagers (aged 13–16) will engage in riskier traffic behaviors in the company of peers, specifically boys (Gardner and Steinberg, 2005). Peers thus influence behavioral norms, and increase traffic risks when children travel together (Koekemoer et al. 2017).

Active travel to school consequently involves risks that depend on various factors, such as safety culture, peers, transport mode forms (walking, cycling, scooter-riding), traffic density and speed, built environment, parked cars, safety infrastructure such as crossings, as well as cognitive ability and motor skills (Hwang et al. 2017; Lu et al. 2014; Masoumi et al. 2020; Nevelsteen et al. 2012; Rothman et al. 2014; Rothman et al. 2017; Scheiner et al. 2019; van den Berg et al. 2020). It is less clear how the children themselves perceive traffic risks. Evidence from a survey in Germany (Landeshauptstadt Stuttgart 2006) suggests that they consider some infrastructures as safe, such as pavements (see also Amieur et al. 2022) and others as unsafe (riding bikes on shared roads, cycle tracks in bad shape). Children note careless drivers; cars parked on cycle tracks or pavements; construction and road maintenance sites; and they feel less safe in situations involving high vehicle traffic volumes and speeds (Landeshauptstadt Stuttgart 2006).

German children's perceptions of risks are aligned with actual risks. Germany is a country with 11.9 million children up to 15 years old (Destatis, 2023). In 2022, 51 children were killed in traffic collisions, and 25,800 children involved in injuries. As highlighted by the Federal Office of Statistics (2023), 6–14-year-olds are disproportionately often injured on weekday mornings between 7 and 8 am, this is, on the way to school. The period accounts for 14% of all collisions, followed by another 11% of injuries occurring between 3 and 4 pm, i.e. when many children return home. The way to school is thus characterized by considerable risk for children, and thus represents an opportunity to reduce injury numbers.

In light of these considerations, the primary goal of this paper is to juxtapose injury statistics with the insights and viewpoints of both school managers and children. This comparative analysis is used to conceptualize the extent of risk exposure concerning various factors, including age, social environment, attitudes, technology adoption, cognitive abilities, and motor skills. The paper also contributes to a more comprehensive understanding of traffic risk exposure, thereby enabling a discussion of urban designs, transport planning and policy.

## 3. Methodology

The study investigates the perspectives of school management and school children in Freiburg, Germany, as questionnaires (school management) and focus group interviews (school children) presuppose a locational focus. Two age groups are distinguished, i.e. "children" (age range 6–10, primary school), and "adolescents" (age range 11–17, secondary school). To assess objective (reported injuries) and subjective (school management and children's views) traffic risks, the project combines a quantitative/qualitative approach in a convergent parallel design (Bryman, 2016), evaluating:

- 1) Injury data related to traffic of children on the way to school (quantitative; descriptive statistics);
- 2) The perceptions of school representatives (n=40) of the traffic situation characterizing their schools (quantitative [descriptive statistics]; qualitative);
- 3) Focus group interviews with (n=40) children in primary schools (classes 1–4; age range 6–11) and secondary schools (classes 5–12; age range 11–17) (qualitative).

Injury data for primary schools was compiled and made available specifically for the city of Freiburg by Unfallkasse Baden-Württemberg ([www.ukbw.de](http://www.ukbw.de)), a regional insurer registering all injuries that have required a visit to an emergency room or physician. Data covers the period from 2019 to 2021 (three years) but is available only for primary schools in Freiburg. A total of n=96 injuries were recorded for school routes.

School management views of children's travel risks appear to have been rarely addressed (Price et al. 2011). For this research, assessments by school management were sought from all schools in Freiburg (N=64). The request for data was sent to principals in November 2021, in co-operation with the city of Freiburg's school board ("Schulamt"). The city provided emails for all schools, informed schools about the project, and encouraged participation in the project. Also due to the ongoing COVID-19 situation, information was collected through a questionnaire focused on children/adolescent's use of transport modes (estimates), traffic conflicts and risks, reported injuries, as well as measures carried out to improve traffic safety. Schools were provided with a link to an electronic form, in which school management (principals or vice-principals) were asked to enter information regarding the transport modes used by children/adolescents, traffic risks and conflicts, injury occurrence, as well as preventive measures taken by schools to increase traffic safety. For example, questions were formulated as this: "If there are traffic conflicts, could you describe these? Does the school try to increase the safety of school routes?"

Despite the pressure put by the pandemic on managers, the response rate was high, with 63% (n=40) of schools answering the questionnaire. Data was summarized in a document distinguishing primary and secondary schools, and evaluated using descriptive statistics, along with a thematic analysis of written comments. To validate findings, two researchers independently assessed the data (Bryman, 2016). There were no discrepancies to report. It is acknowledged that some of the data provided by school management, for instance in regard to transport mode shares, is indicative. Schools in Freiburg however seem to have a very good understanding of how children/adolescents travel, and some schools even carry out surveys.

The main empirical part of the project focused on the perspectives of school children/adolescents, whose views complement injury data as well as school management perspectives on traffic risks. Out of the 64 schools in Freiburg, only three principals agreed to organize focus group interviews. This can be explained with the considerable administrative burdens implied, i.e. to secure written parental consent for participation of the children/adolescents in interviews; to organize an interview-day and a room for interviews; and to interrupt classes for groups of children/adolescents to participate in the interviews. All interviews were carried out by two researchers. They were organized as focus group interviews to reduce feelings of potential intimidation among children/adolescents and to make the talks more inspirational through the exchange of perspectives among the children/adolescents. Focus groups contained two, three or four children/adolescents, and were organized at two primary schools (including a total of seven focus groups, with n=16 children aged 6–10) and one secondary school (seven focus groups, with n=23 adolescents aged 10–17). Of the n=39 students interviewed, 20 were male and 19 female. Children/adolescents were interviewed in February, April and May 2022. Focus group interviews were organized by teachers who selected children/adolescents volunteering for the task and thus represent a convenience sample. While this

may have influenced the pool of children/adolescents interviewed, there was no evidence to suggest that the children/adolescents held specific or homogenous views.

All students only had a general idea of the focus group interview context ("travel to school") as the purpose of the study was only communicated in general terms. Interviews lasted between 9:01 minutes and 18:52 minutes and were recorded. Anonymity was ensured by noting only age, gender, and the respective students' first name for communication during the interview. Interviews comprised broad questions regarding way to school (length, mode of transport used), traffic situation encountered, and infrastructural or traffic changes that would improve the way to school. The issue of traffic dangers was not raised by the researchers, though noted and elaborated on when raised by children/adolescents. While children/adolescents discussed personal perspectives, the focus group format also allowed for an exchange of viewpoints and reflections between children/adolescents. Important points raised by the children/adolescents were also recorded as field notes.

All files, including the audio files were later on evaluated in a comparative thematic analysis (Bryman, 2016) to ensure all elements of relevance had been considered. More specifically, we followed an axial coding procedure, in which we identified themes mentioned by students (e.g. "parent concerns influence children's behaviour") created categories summarizing similar themes (e.g. "social environment and attitudes"), and then connected these categories (e.g. Strauss and Corbin, 1990). To validate the process and the findings, the data was again independently evaluated in a parallel assessment by two researchers. There were only minor disparities that were deliberated upon and resolved, while the process also allowed to add individual observations. Results are distinguished for primary and secondary schools and organized as themes also underlying the conceptualization (Fig. 2; social environment & attitudes; transport modes & technology; cognitive abilities; motor skills).

The study has several limitations, with the primary concerns being the geographical scope and the restricted number of children interviewed. The use of focus groups involving only two children may have limited the depth of exchanges. Considering the significance of the study's findings, there is a need for its replication, possibly in a manner that allows for a more representative interpretation.

## 4. Results

### 4.1. Reported injuries

Injury data for primary schools includes a total of n=96 injuries recorded for children aged 6–11, between 2019 and 2021. Even though this is an insufficient basis for generalizations beyond the local context, data does suggest that a large share of injuries are self-injuries (79%; n=76), i.e. smaller children experience motor skill deficits, compounded by issues of being distracted or inattentive. The 'sequence of events' leading to such injuries is described in insurance reports as "running and stumbling", "tumbling from scooter", or "falling from bike", along with a generic assessment of the injury cause, which may for example include "lack of motor skills", "tussle and play", or "weather conditions". Available data is consequently insufficiently detailed to assess the role of infrastructure designs (e.g., narrow boardwalks) or other influential factors (e.g., limited visibility due to parked cars).

Other traffic participants are involved in only one in five injuries (19%, n=18). Here, the car is the most relevant cause of injuries (n=10). In four cases, collisions involve a cyclist, a pedestrian in another three, and a tram in one. The data also suggests that injury frequency increases between ages 6–9, to then fall when children become older. Given the low number of observations, this is indicative. Data shows that grazes and wounds represent the most prevalent injuries (n=16), followed by bone fractures (n=15), tooth fractures (n=13) and cranial bruises (n=14) - the latter sometimes in combination with tooth fractures.

Again, it is unclear whether this is representative of school route injuries more generally.

Regarding transport modes, data reveals that scooters are involved in most injuries ( $n=41$ ), followed by walking ( $n=33$ ) and cycling ( $n=16$ ). As the share of kilometers travelled with each transport mode is unknown, this does not imply a hierarchy of transport mode risks. Scooters, for example, are frequently used by smaller children for school travel. Many children also walk to school, specifically when living nearby. In regard to bicycle-related injuries it is important to know that children in Germany have to pass a bicycle test at the age of 10 (in fourth grade) and are only then encouraged to cycle to school.

Overall, the available injury data is of limited value for the evaluation of traffic risks, as case numbers are low, while descriptions of circumstances leading to injury remain unclear. The high share of self-injury confirms insufficiently developed motor skills, including sense of balance, and cognitive issues (inattentiveness, inability to understand risks). Whether self-injuries are caused or compounded by traffic infrastructure designs remains uncertain, as descriptions of injury circumstances do only sometimes refer to the built environment (e.g., “scooter caught on pavement”). Injury data nevertheless suggests that way-to-school injuries are not rare, and sometimes even have grave consequences (fractures and trauma). A preliminary insight from this analysis is thus the desirability of more detailed injury reports.

#### 4.2. School management perspectives on traffic risks

School management perspectives are distinguished for primary (representing about 5000 students in this study) and secondary schools (about 9800 students). According to managers, walking (50%), and scooters (19%) are the most prevalent transport modes in primary school. Ten percent of the children use bicycles, while trams and busses are used by 3% each. School management suggests that a significant share of the children, 15%, are brought to school by their parents in private cars. There is a notable change in secondary school, where the bicycle becomes the most important transport mode (25%), followed by trams (24%), busses (20%), and trains (14%). Walking declines to 9%, and “parent taxis” to 5%. While only indicative, these changes can be explained with a significant increase in travel distances to secondary schools, and greater independence of the children. The bicycle gains popularity as distances of several kilometers can be easily covered, while the children have also gained motor skills. However, those with longer travel distances are reliant on trams, busses and sometimes trains.

In regard to traffic risks, 34 out of 40 schools reported conflicts. Primary schools associate most risks with traffic behavior and infrastructure. Children have problems to navigate high-traffic roads; safety

risks arise out of parent taxis and the behavior of other traffic participants. The ignorance of traffic rules was also highlighted. Infrastructure risks are mentioned in referral to the design of pedestrian walks and cycle lanes, as well as crossings. In comparison, secondary schools report most risks as being related to car drivers not adhering to traffic rules; the organization of public transport; the character of pedestrian walks, cycle tracks and crossings; and students’ inappropriate (risky) traffic behavior.

To better understand the relevance of individual aspects, a related question addressed pre-determined traffic risks on a Likert scale from 1 (no problem) to 5 (a significant problem) (Fig. 1). Responses suggest that the management of primary and secondary schools (sometimes) differs in their perceptions of individual risks, though primary schools are generally considered more exposed. Of specific interest is that both the management in primary and secondary schools see the behavior of parents as the most significant traffic problem, though the assessment does not allow for an analysis of the type of behavior referred to. In primary schools, this is followed by a lack of crossings, limited visibility and overview of the traffic situation, for instance because of parked cars, and “parent taxis”. Traffic density, missing traffic lights, short green phases at traffic lights, and missing speed controls are also mentioned. Notably, the management in primary schools rates all of the nine traffic risks higher than 2.5, the average Likert-scale value. The situation is somewhat different in secondary schools, where parent taxis, traffic density, lack of crossings, short green phases, and lack of traffic lights are relevant issues, indicating that risks decline as well as shift.

School management also reported on injuries. Of the 40 schools that had answered the questionnaire, 28 schools reported a total of  $n=49$  injuries for a single month, November 2021 (when the questionnaires had been sent to managers). Of these,  $n=30$  happened at primary schools, involving seven seriously injured children, five of these in collisions with cars. Injury incidences recorded by primary schools in just one month ( $n=30$ ) consequently seem high in comparison to the 96 injuries reported to the insurer over the three-year period 2019–2021. Notably, five of the injuries occurring in November 2021 involved seriously injured children/adolescents in collisions with cars. Yet, only ten such car collisions appear in the insurer statistic over the three-year period. While no statistical conclusions can be drawn from this, data nevertheless suggests that a significant number of traffic injuries go unreported.

Finally, more than half of the schools ( $n=22$ ) have sought to improve traffic safety. This includes informing parents, discussions of travel-to-school plans, parent initiatives, traffic education, or initiatives to slow down traffic or to achieve changes in infrastructure designs in discussions with city representatives. Regarding the latter, schools had

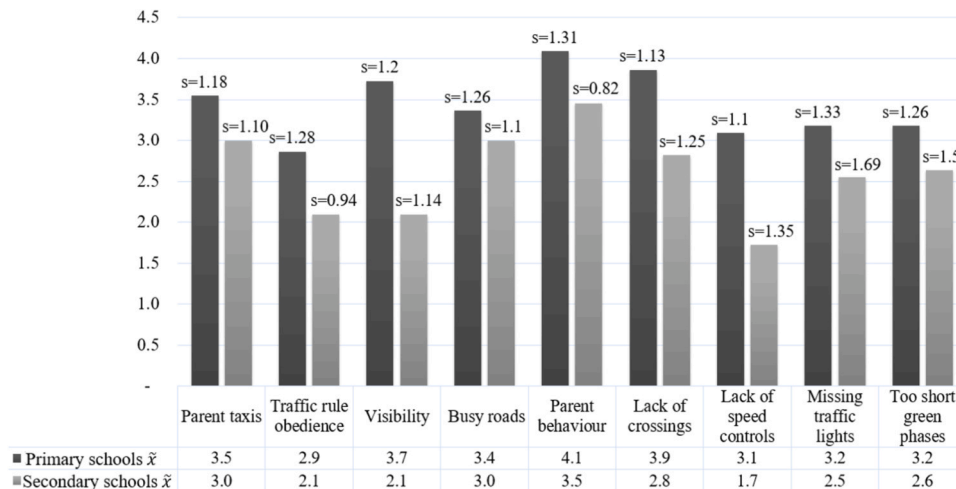


Fig. 1. Primary and secondary schools’ managers’ traffic risk ratings.



submitted ideas focused on crossings, pavements and cycle tracks, bus and tram connections, speed limits, limitations of motorized individual transport, or educational measures. While such initiatives apparently had limited success, results underline that school management in many schools is aware of traffic risks and proactively engaged in improving traffic safety.

School management views indicate that a considerable number of injuries may not be reported to insurers. They reveal that parent behaviour is considered a main barrier to traffic safety. They also show that primary schools feel more exposed to traffic risks than secondary schools, reporting higher injury rates than secondary schools, and that such risks involve traffic density, infrastructure designs (missing traffic lights), behaviour (parents, students, other traffic participants), as well as transport planning and designs (short green phases, lack of traffic controls, lack of traffic lights and crossings). Given that most children/adolescents walk to primary schools while most injuries involve scooters, the relevance of transport mode choices is indirectly highlighted. Further research is however needed to confirm that scooters are unsafe transport modes.

#### 4.3. Children/adolescents' perspectives on traffic dangers

Interviews with focus groups in primary and secondary schools reveal further insights. Primary school children report risks related to infrastructure, the organization of traffic, the reckless behaviour of other traffic participants, and negative traffic experiences leading to injuries. Children also talked about transport system changes that might improve safety. Both crossings and construction sites were mentioned by children as causing anxieties. Children were adamant to underline that crossings are problematic because automobilists may or may not stop, while construction sites force children to reconsider routines and find alternative ways. Traffic risks also arise out of cars or busses overtaking or passing by too closely; limited visibility in traffic because of parked cars and in particular larger vehicles; and complex traffic situations.

Children report that they often feel overlooked in traffic and endangered by car drivers ignoring traffic rules. For instance, drivers would not stop for waiting children at crossings, or run red lights. It is also of interest that children's perceptions are affected by views and experiences of peers and family: parents talking about their own traffic collisions, injured friends, hit-and-run occurrences, or parental restrictions of bicycle use out of safety concerns. Leaving home late for school was mentioned by several children as a stressor, sometimes forcing them to use a scooter or bicycle to still make it to school in time. In line with this, missed busses, along with bad weather and appointments in town (e.g., to see a doctor), were mentioned as reasons for "parent taxis".

Traffic lights were perceived as safe to cross roads, though overall views of traffic organization were negative. Children felt that the traffic system dictated behaviour, and exposed them to traffic dangers. They reported to be overlooked by other traffic participants, not only drivers, and to be treated unfairly regarding priorities such as waiting times at traffic lights. A preliminary finding of this research is also that while younger children - first and second grade - where still capable of imagining a different, 'better' transport system to make travel to school safer (fewer cars, 'play street' designs), older children seemed to accept the system as given.

Focus group interviews conducted in secondary schools mirror those in primary schools, though the higher age of the respondents reflects on changes in transport mode use, motor skills, cognitive abilities, and more 'mature' perspectives on the design and organization of traffic. Adolescents expressed greater awareness of dangers, such as slippery roads or elevated pavements, constructions sites, or poor visibility due to parked vehicles. They also reflected on themselves in traffic, for instance when cycling in groups and thus provoking automobilists. Perceived traffic risks include drivers ignoring traffic rules such as mandated stops at crossings to let students pass, or regulation that

prohibits parking on pavements. Risks also include dense traffic, unclear traffic situations, dark roads, or long waiting times at traffic lights, with short green phases. Adolescents reported that wearing bicycle helmets is considered a nuisance, pointing out that parents would not wear helmets.

Forms of 'transport rebellion' are notable from the age of 12 years. This includes to no longer wear helmets, or to ignore red traffic lights when waiting times are considered excessive. Forms of rebellion may also include other aspects, such as to ride without lights or in ways that deliberately block road space for car drivers. Students also discussed crash experiences, as well as minor injuries and frequent near misses. Acceptance of the traffic system as a given appears to manifest itself with higher age: the dominating role of the car in traffic, as well as the anticipation of collisions are examples.

In summary, focus group interviews illustrate the different dimensions in which traffic safety is negotiated, with some notable, if preliminary findings. Crossings, a key element in urban planning and designs, are mentioned frequently as unsafe by students in the entire age range, notably unprompted. Crossings create fears as children feel overlooked, and uncertain whether a driver will stop. Specifically, from the perspective of small children, approaching cars are becoming increasingly more intimidating, as their mass increases. Car fronts resemble faces that for a range of models are perceived to express aggression and dominance. This creates ambiguous traffic situations, in which children may avoid eye contact – important to establish an understanding as to whether the child will cross the road –, though this was not discussed. Crossings, in this view, represent an ambiguous traffic infrastructure element. Another element are construction sites, an infrastructural 'design' mentioned more frequently by children. Such sites are usually erected in ways that will allow pedestrians to pass around. While transport planners will find new routings self-evident, these may be a challenge for smaller children.

Another general finding refers to differential speeds, specifically where different transport modes meet. Where speeds are aligned, also giving priority to cyclists, conflicts – and injuries – can be reduced. Speed is also relevant at crossings, where large cars rushing towards waiting children will be perceived as a threat, creating uncertainty. Speed-related risks however also accompany the progression in transport mode use, i.e. from walking to scooter and bicycle. Risks can be amplified when children have to rush to school because they are late. Speed consequently has relevance in very different traffic contexts.

## 5. Discussion

This research demonstrates the usefulness of a comparative approach to the analysis of traffic safety risks, here recorded injuries, school management views, and the perspectives of children/adolescents. The triangulation results in several relevant findings. First, there is evidence that recorded injury numbers seem low in comparison to school management reports. More research is needed to confirm this finding, also in comparison to national injury data (Destatis, 2023), but this may mean that public injury data – often considered to objectively reflect on traffic dangers – is inadequate to evaluate traffic risks. Another finding is that virtually all children/adolescents highlight traffic situations in which they do not feel secure, revealing that perceived safety on the way to school is fundamentally different from public risk perspectives based on injury data. Children/adolescents experience small injuries and near-misses, and they consider many daily traffic situations to be dangerous. Often, this may include situations believed to be safe by adults. For example, school management asks for more crossings to increase safety, i.e., a traffic design that is highly problematic for children/adolescents and confirming findings by Scheiner et al. (2019). All of this is relevant, because experiences in traffic shape risk perceptions, and are likely to have repercussions for transport mode choices later in life.

Focus group interviews with children and adolescents allow for

conceptualization, as risks and risk perceptions change with age, and in conjunction with social (identity, attitudes), technological (transport mode, technology use), and neurological (cognitive ability, motor skills) developments. With growing age, children/adolescents appear to move through different stages, which may be termed “parental control & advice”, “early independence”, “safety-oriented behaviour”, “risk taking”, and “individual safety profile”. These are illustrated in Fig. 2, which generalizes traffic situations, omitting that relative risks may be seasonal (dark mornings/evenings) or situational (heavy rain, ice or snow). The conceptualization is based on the findings in this study, but it is also aligned with research as presented in the introduction.

*Parental control & advice* is an early childhood stage (approximately 0–5 years), in which children are virtually always under supervision of their parents or others. Motor skills begin to develop, and mobilities evolve through stages of crawling, walking, tricycling, to scooter use and cycling. Cognitively, small children travel in a “bubble”, i.e. they are largely unaware of traffic dangers and risks. This earliest phase is followed by a stage of *early independence*, in which children begin to make their own decisions, and travel to school by themselves. In this period, which may comprise ages 6–9, children move at growing speeds (walk – scooter – cycle), and are influenced by parents and others in their views of traffic dangers and their understanding of the transport system. As cognitive abilities and motor skills still have to develop, risk exposure is high, and potentially reflected in a larger number of self-injuries.

The third stage, *safety-oriented behaviour*, is characterized by growing abilities to understand and evaluate traffic risks, as well as evolving routines and experience of moving in traffic. A growing awareness of dangers, advice from parents, peers and police help rationalizing these risks. For example, children in German primary schools have to pass a bicycle test in fourth grade (at the age of about 10). This “bicycle licensure” (Fahrradführerschein) is a semi-formal confirmation of cycle ability. Police visit primary schools to issue cycle “licenses”, for which theoretical and practical tests have to be passed. They also remind children that they should not cycle on their own before they have passed

the test. To be “licensed” has no legal implications, but it creates notions of safety for children and parents, and is thus, ultimately, motivating (Renninger et al. 2022). The test also raises awareness of traffic rules and legislation, as well as the consequences of misbehavior in traffic.

Changes in the socio-technological environment characterize adolescents between the ages of about 12 and 16. Risk exposure increases, also because of active *risk-taking*. In this stage, technology distractions such as in-ear speakers, smartphone use, or “trendier” bicycles without fixed lights imply new risks. At this stage, adolescents are increasingly influenced by peers, while parent views lose relevance. Parents, however, are often poor role models. This may be one factor explaining why teenagers refuse to wear helmets, run red lights, or cycle irresponsibly, though these behaviors may also be interpreted as forms of rebellion against society (Gössling, 2017). Risk taking may also be a form of a challenge to impress peers, or to question the system of automobility – for instance, by “occupying” street space in groups of cyclists. Findings such as these are generally confirmed by research finding adolescents (aged 13–16) engaging in riskier traffic behaviors in the company of peers, specifically boys (Gardner and Steinberg, 2005; Granié 2007, 2009). While growing motor skills help to handle risks, they do not offset dangers: The severity of injuries increases for children/adolescents 6–15 years travelling with peers (Koekemoer et al. 2017). In comparison to early independence, which is characterized by an incapacity space (lack of awareness and motor skills), risk-taking may be considered an incapability space, in which traffic safety risks are consciously or unconsciously ignored, or challenges even actively sought.

However, peers may also influence behavioral norms positively (Darvell et al., 2015; Morrongiello et al., 2019), and at the age of about 16, risk exposure may thus increase or decrease, depending on *individual safety profiles*. Driving licensure in particular may change perspectives on traffic, as teenagers can start to take theory lessons at the age of 16. They may learn about risks and rules, and they may start to see traffic from the perspective of the driver. From the age of 18 onwards, the car is theoretically accessible as a transport mode. In comparison to their earlier experience, young drivers may feel more protected in a car, and

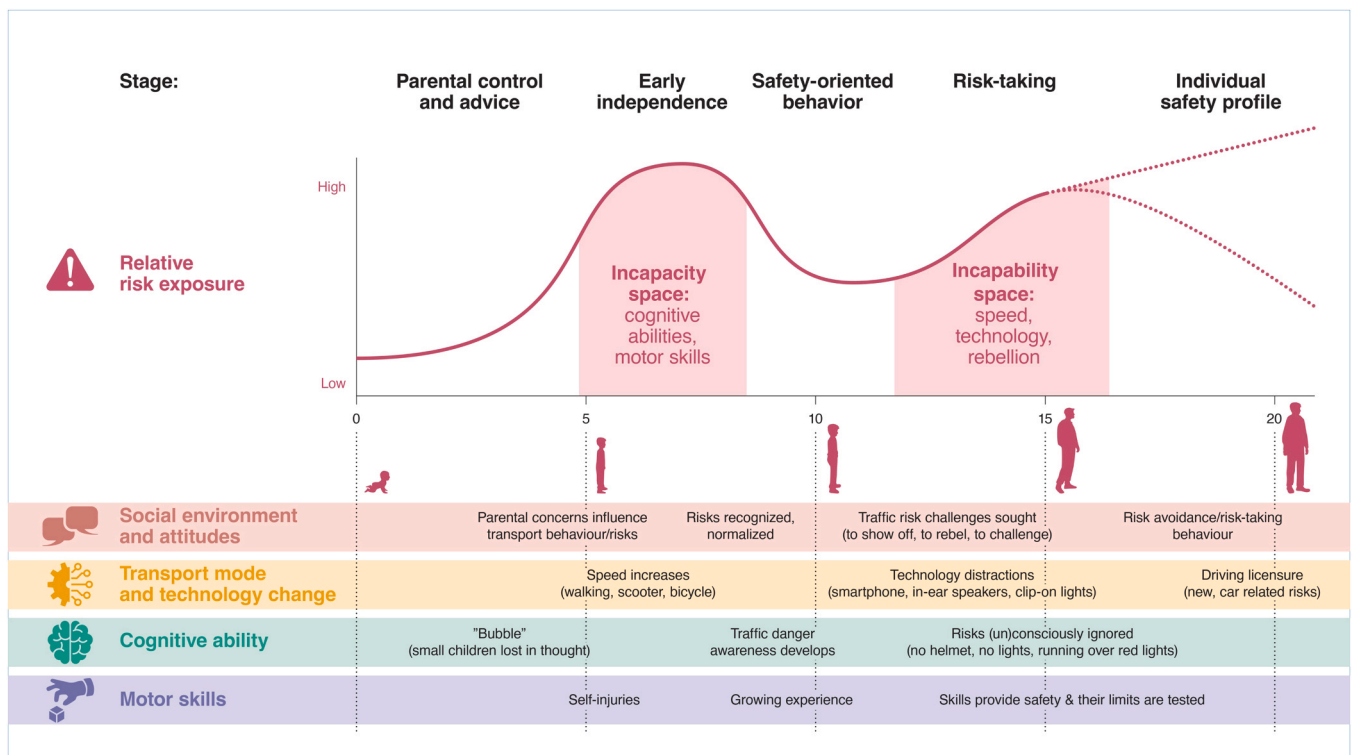


Fig. 2. Risk exposure and the incapability-incapacity space.

they may also be able to reflect on their earlier roles as for example cyclists, and drive more carefully. It is equally possible that the car becomes a means of rebellion or source of excitement (Gössling, 2017), with a corresponding increase in injuries. Young drivers aged 18–24 are a crash-prone age group in Germany, and disproportionately often – in two thirds of cases involving this age-group – responsible for the collision (Destatis 2021). Traffic risks consequently decline or increase with age in this phase, depending on personality and transport culture identity. This suggests that there is a non-linear development process with risky behaviors as well as risk-avoidance at different stages.

Overall, findings confirm earlier research, outlining traffic risks and safety perceptions related to the children themselves (age, parents' fears), built environment, and traffic characteristics including speeds, vehicle size, irregular parking, or driver behavior (Amiour et al. 2022; Cloutier et al. 2017, 2021; Scheiner et al. 2019). Novel insights of this research highlight the importance of distinguishing observed risks from the anxieties and fears of children. Findings also underline the importance of understanding risk-exposure in the context of age, and stages of risk-avoidance and risk-seeking. To increase the share of children travelling independently and actively to school (Waygood et al. 2017), there is a need to think ways-to-school in interrelated dimensions of infrastructure (built environment and motorized transport system), legislation and rule control, the transport modes used by students, their motoric and cognitive skills, as well as their experiences and attitudes. While results thus support calls for improvements in infrastructure (Ragland et al. 2014; Tomoda et al. 2022) – here specifically irregular parked cars and reduced visibility, rule ignorance by car drivers, “parent taxis”, missing traffic lights, short green phases at traffic lights, and missing speed controls – they also underline the need to consider a wide range of other factors affecting safety and safety perceptions, and, ultimately, way-to-school behavior. A specifically relevant insight is that older children appear to lose their capability of imagining children-friendlier urban infrastructures, pointing to a role for younger children in traffic planning procedures. A notable omission in this research is the role of gender (Renninger et al. 2022), which may call for further distinctions in children's safety needs.

## 6. Conclusions

Results of the triangulation of perspectives on traffic risks including injury reports, school management views and data, as well as the perceptions of children and adolescents provide new insights: One relevant finding is that injury data appears to underreport collisions and injuries, and thus represents a poor basis for transport safety planning. However, this finding is based on reports by school managers, and needs to be confirmed in further studies. Such data could then also be compared to national injury data suggesting that a large share of injuries occur on the way to school. It is evident that near misses are not reported in any statistic, even though they may have considerable importance for safety perceptions of children; even this requiring further study. Interviews with children/adolescents suggest that traffic density, rule ignorance (by automobilists), reduced visibility (parked cars), infrastructure designs prioritizing motorized transport, and ambiguous traffic situations influence perspectives on traffic safety negatively. Crossings in particular, one of the most common traffic design elements in Germany, create fears. This has repercussions for the independence of children in traffic, and likely longer-term perceptions of risks that influence future transport mode choices.

To illustrate the development of risk exposure with age, the paper presents a conceptualization distinguishing five risk stages. While small children rarely travel unsupervised, their early independence is associated with high risk exposure, as children lack cognitive abilities and motor skills. Risks decline when children/adolescents become older (9–12 years) and begin to develop a traffic safety awareness while gaining motor skills and collecting experience in traffic. Risks again increase when teenagers start to use technologies, such as in-ear

speakers while cycling, or refuse to wear helmets. Adolescents may even seek out traffic dangers to impress others or to rebel against the transport system or society more generally.

These findings have relevance for the planning and design of transport infrastructure and transport policies, specifically in the context of safe routes to school. If the ambition is to make a greater number of children and adolescents to walk, cycle or scooter to school, subjective safety perceptions must be taken more seriously. Barriers seem implied in the inappropriate behaviour of parents and other traffic participants, specifically car drivers. There is a need for transport planners to consider unreported injuries and near misses, and to understand the implications of specific design elements for children, such as crossings or construction sites. Enforcement of traffic rules has specific relevance near schools, and more far-reaching measures, such as the limitation of motorized traffic near schools – including entirely car-free environments –, need to be considered. Underlying changes in the transport system need to be addressed as well, such as changes in car mass and fear-inducing car designs, which are not in the interest of society – responsibility for these developments lies with the national government. Urban speeds should be reduced, and overall motorized vehicle numbers be reduced to distribute available road space more adequately, possibly separating active transport users from other traffic. While this study is focused on Germany and its specific traffic situation, it illustrates a complexity of necessary changes that likely has relevance even elsewhere.

## CRedit authorship contribution statement

**Rafael Hologa:** Resources, Formal analysis. **Nils Riach:** Resources, Formal analysis. **Rul von Stülpnagel:** Validation, Resources, Formal analysis. **Stefan Gössling:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jessica Kees:** Visualization, Project administration, Investigation, Formal analysis, Data curation, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data Availability

Data will be made available on request.

## Acknowledgement

We gratefully acknowledge the support by Schulamt Freiburg, as well as the school management at Loretoschule, Rieselfeld, and Dr. Gunter Karrasch at Theodor-Heuss-Gymnasium, who helped to set up the interviews with children. We are also grateful for the provision of data on traffic injuries by Jannis Rolli at Unfallkasse Baden-Württemberg.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jcmr.2024.100019](https://doi.org/10.1016/j.jcmr.2024.100019).

## References

- Abadi, M.G., Hurwitz, D.S., 2018. Bicyclist's perceived level of comfort in dense urban environments: how do ambient traffic, engineering treatments, and bicyclist characteristics relate? *Sustain. Cities Soc.* 40, 101–109.
- Airaksinen, N.K., Handolin, L.E., Heinänen, M.T., 2020. Severe traffic injuries in the Helsinki trauma registry between 2009–2018. *Injury* 51 (12), 2946–2952. <https://doi.org/10.1016/j.injury.2020.09.025>.



- Aldred, R., 2016. Cycling near misses: their frequency, impact, and prevention. *Transp. Res. Part A Policy Pract.* 90, 69–83. <https://doi.org/10.1016/j.tra.2016.04.016>.
- Aldred, R., Crossweller, S., 2015. Investigating the rates and impacts of near misses and related incidents among UK cyclists. *J. Transp. Health* 2 (3), 379–393.
- Aldred, R., Goodman, A., 2018. Predictors of the frequency and subjective experience of cycling near misses: findings from the first two years of the UK near Miss project. *Accid. Anal. Prev.* 110, 161–170. <https://doi.org/10.1016/j.aap.2017.09.015>.
- Amiour, Y., Waygood, E.O.D., van den Berg, P.E., 2022. Objective and perceived traffic safety for children: a systematic literature review of traffic and built environment characteristics related to safe travel. *Int. J. Environ. Res. Public Health* 19 (5), 2641. <https://doi.org/10.1016/j.ijerph.2022.12.040>.
- Barton, B.K., Lew, R., Kovesdi, C., Cottrell, N.D., Ulrich, T., 2013. Developmental differences in auditory detection and localization of approaching vehicles. *Accid. Anal. Prev.* 53, 1–8. <https://doi.org/10.1016/j.aap.2012.12.040>.
- Brand, S., Petri, M., Haas, P., Krettek, C., Haasper, C., 2013. Hybrid and electric low-noise cars cause an increase in traffic accidents involving vulnerable road users in urban areas. *Int. J. Inj. Control Saf. Promot.* 20 (4), 339–341. <https://doi.org/10.1080/17457300.2012.733714>.
- Bryman, A., 2016. *Social Research Methods*. Oxford University Press.
- Carver, A., Watson, B., Shaw, B., Hillman, M., 2013. A comparison study of children's independent mobility in England and Australia. *Child. Geogr.* 11 (4), 461–475.
- Chillón, P., Panter, J., Corder, K., Jones, A.P., Van Sluijs, E.M.F., 2015. A longitudinal study of the distance that young people walk to school. *Health Place* 31, 133–137. <https://doi.org/10.1016/j.healthplace.2014.10.013>.
- Cloutier, M.S., Beaulieu, E., Fridman, L., Macpherson, A.K., Hagel, B.E., Howard, A.W., Rothman, L., 2021. State-of-the-art review: preventing child and youth pedestrian motor vehicle collisions: critical issues and future directions. *Inj. Prev.* 27 (1), 77–84.
- Cloutier, M.-S., Lachapelle, U., d'Amours-Ouellet, A.-A., Bergeron, J., Lord, S., Torres, J., 2017. Outta my way! Individual and environmental correlates of interactions between pedestrians and vehicles during street crossings. *Accid. Anal. Prev.* 104, 36–45.
- Cobb, D.P., Jashami, H., Hurwitz, D.S., 2021. Bicyclists' behavioral and physiological responses to varying roadway conditions and bicycle infrastructure. *Transp. Res. Part F Traffic Psychol. Behav.* 80, 172–188.
- Congiu, M., Whelan, M., Oxley, J., D'Elia, A., & Charlton, J. (2006). Crossing Roads Safely: An Experimental Study of Age and Gender Differences in Gap Selection by Child Pedestrians. Proceedings of the Australasian Road Safety Research, Policing and Education Conference, 10. [https://www.safetylit.org/citations/index.php?fuseaction=citations.viewdetails&citationids\[j\]=citjournalarticle.368736.38](https://www.safetylit.org/citations/index.php?fuseaction=citations.viewdetails&citationids[j]=citjournalarticle.368736.38).
- Darvell, M., Freeman, J., Rakotonirainy, A., 2015. The psychological underpinnings of young pedestrians' deliberate rule-breaking behaviour at pedestrian railway crossings: a cross-sectional study utilising the theory of planned behaviour. *Road. Transp. Res.* 24 (3), 14–23. <https://doi.org/10.3316/informit.817339414191013>.
- Davison, J.K., Werder, J.L., Lawson, C.T., 2008. Peer reviewed: children's active commuting to school: current knowledge and future directions. *Prev. Chronic Dis.* 5 (3). <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2483568/>.
- van den Berg, P., Waygood, E.O.D., van de Craats, I., Kemperman, A., 2020. Factors affecting parental safety perception, satisfaction with school travel and mood in primary school children in the Netherlands. *J. Transp. Health* 16, 100837.
- Destatis (2023). 25800 Kinder im Jahr 2022 im Straßenverkehr verunglückt [25,800 children involved in collisions in traffic in 2022]. Available: [https://www.destatis.de/DE/Presse/Pressemitteilungen/Zahl-der-Woche/PD23\\_33.p002.html](https://www.destatis.de/DE/Presse/Pressemitteilungen/Zahl-der-Woche/PD23_33.p002.html).
- Destatis (2023). Unfälle von 18- bis 24-jährigen im Straßenverkehr 2020 [Collisions involving 18-24 year olds in traffic, 2020]. Available: [https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Verkehrsunfaelle\\_inhalt.html#\\_2kzl6cm5u](https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Verkehrsunfaelle_inhalt.html#_2kzl6cm5u).
- Dye, M.W.G., Bavelier, D., 2010. Differential development of visual attention skills in school-age children. *Vis. Res.* 50 (4), 452–459. <https://doi.org/10.1016/j.visres.2009.10.010>.
- Evenson, K.R., Birnbaum, A.S., Bedimo-Rung, A.L., Sallis, J.F., Voorhees, C.C., Ring, K., Elder, J.P., 2006. Girls' perception of physical environmental factors and transportation: reliability and association with physical activity and active transport to school. *Int. J. Behav. Nutr. Phys. Act.* 3 (1), 1–16. <https://doi.org/10.1186/1479-5868-3-28>.
- Gardner, M., Steinberg, L., 2005. Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: an experimental study. *Dev. Psychol.* 625–635. <https://doi.org/10.1037/0012-1649.41.4.625>.
- Goel, R., Goodman, A., Aldred, R., Nakamura, R., Tatah, L., Garcia, L.M.T., Zapata-Diomed, B., de Sa, T.H., Tiwari, G., de Nazelle, A., Tainio, M., Buehler, R., Götschi, T., Woodcock, J., 2021. Cycling behaviour in 17 countries across 6 continents: Levels of cycling, who cycles, for what purpose, and how far? *Transp. Res.* 1–24. <https://doi.org/10.1080/01441647.2021.1915898>.
- Gössling, S., 2017. Police perspectives on road safety and transport politics in Germany. *Sustainability* 9 (10), 1771. <https://doi.org/10.3390/su9101771>.
- Granié, M.-A., 2007. Gender differences in preschool children's declared and behavioral compliance with pedestrian rules. *Transp. Res. Part F Traffic Psychol. Behav.* 10 (5), 371–382. <https://doi.org/10.1016/j.tra.2007.02.002>.
- Granié, M.-A., 2009. Effects of gender, sex-stereotype conformity, age and internalization on risk-taking among adolescent pedestrians. *Saf. Sci.* 47 (9), 1277–1283. <https://doi.org/10.1016/j.ssci.2009.03.010>.
- Green City Freiburg (2022). Mobility and Transport. Available: <https://greencity.freiburg.de/pb/Len/1592917.html>. Accessed 1 December 2022.
- Hull, A., O'Holleran, C., 2014. Bicycle infrastructure: can good design encourage cycling? *Urban Plan. Transp. Res.* 2 (1), 369–406.
- Hwang, J., Joh, K., Woo, A., 2017. Social Inequalities in Child Pedestrian Traffic Injuries: differences in neighborhood built environments near schools in Austin, TX, USA. *J. Transp. Health* 6, 40–49. <https://doi.org/10.1016/j.jth.2017.05.003>.
- Jiang, K., Wang, Y., Feng, Z., Sze, N.N., Yu, Z., Cui, J., 2021. Exploring the crossing behaviours and visual attention allocation of children in primary school in an outdoor road environment. *Cogn., Technol. Work* 23 (3), 587–604. <https://doi.org/10.1007/s10111-020-00640-1>.
- Joly, M.-F., Foggini, P.M., Barry Pless, I., 1991. Geographical and socio-ecological variations of traffic accidents among children. *Soc. Sci. Med.* 33 (7), 765–769. [https://doi.org/10.1016/0277-9536\(91\)90375-M](https://doi.org/10.1016/0277-9536(91)90375-M).
- Juillard, C., Ngamby, M.K., Monono, M.E., Mballa, G.A.E., Dicker, R.A., Stevens, K.A., Hyder, A.A., 2017. Exploring data sources for road traffic injury in cameroon: collection and completeness of police records, newspaper reports, and a hospital trauma registry. *Surgery* 162 (6), S24–S31. <https://doi.org/10.1016/j.surg.2017.01.025>.
- Koekemoer, K., Van Gesselien, M., Van Niekerk, A., Govender, R., Van As, A.B., 2017. Child pedestrian safety knowledge, behaviour and road injury in cape town, South africa. *Accid. Anal. Prev.* 99, 202–209. <https://doi.org/10.1016/j.aap.2016.11.020>.
- Kovesdi, C.R., Barton, B.K., 2013. The role of non-verbal working memory in pedestrian visual search. *Transp. Res. Part F Traffic Psychol. Behav.* 19, 31–39. <https://doi.org/10.1016/j.trf.2013.03.005>.
- Lehtonen, E., Sahlberg, H., Rovamo, E., Summala, H., 2017. Learning game for training child bicyclists' situation awareness. *Accid. Anal. Prev.* 105, 72–83. <https://doi.org/10.1016/j.aap.2016.07.036>.
- Limbourg, M. (1995). Kinder im Straßenverkehr. Gesundheitsschutz in Schule und Beruf, (4). Gemeindeunfallversicherungsverband (GUVV). <https://trid.trb.org/view/992324>.
- Lu, W., McKyer, E.L.J., Lee, C., Goodson, P., Ory, M.G., Wang, S., 2014. Perceived barriers to children's active commuting to school: a systematic review of empirical, methodological and theoretical evidence. *Int. J. Behav. Nutr. Phys. Act.* 11 (1), 1–20. <https://doi.org/10.1186/s12966-014-0140-x>.
- Masoumi, H., Rooijen, M.V., Sierpiński, G., 2020. Children's independent mobility to school in seven European countries: a multinomial logit model. *Int. J. Environ. Res. Public Health* 17 (23), 9149.
- Meir, A., Oron-Gilad, T., 2020. Understanding complex traffic road scenes: the case of Child-Pedestrians' hazard perception. *J. Saf. Res.* 72, 111–126. <https://doi.org/10.1016/j.jsr.2019.12.014>.
- Meir, A., Oron-Gilad, T., Parmet, Y., 2015. Are child-pedestrians able to identify hazardous traffic situations? measuring their abilities in a virtual reality environment. *Saf. Sci.* 80, 33–40. <https://doi.org/10.1016/j.ssci.2015.07.007>.
- Mendonça, C., Freitas, E., Ferreira, J.P., Raimundo, I.D., Santos, J.A., 2013. Noise Abatement and Traffic Safety: the Trade-off of Quieter Engines and Pavements on Vehicle Detection. *Accid. Anal. Prev.* 51, 11–17. <https://doi.org/10.1016/j.aap.2012.10.018>.
- Møller, M., Hels, T., 2008. Cyclists' perception of risk in roundabouts. *Accid. Anal. Prev.* 40 (3), 1055–1062. <https://doi.org/10.1016/j.aap.2007.10.013>.
- Morrongio, B.A., Barton, B.K., 2009. Child pedestrian safety: parental supervision, modeling behaviors, and beliefs about child pedestrian competence. *Accid. Anal. Prev.* 41 (5), 1040–1046. <https://doi.org/10.1016/j.aap.2009.06.017>.
- Morrongio, B.A., Kiriakou, S., 2006. Evaluation of the effectiveness of single-session school-based programmes to increase children's seat belt and pedestrian safety knowledge and self-reported behaviours. *Int. J. Inj. Control Saf. Promot.* 13 (1), 15–25. <https://doi.org/10.1080/17457300500151770>.
- Morrongio, B.A., Klemencic, N., Corbett, M., 2008. Interactions between child behavior patterns and parent supervision: implications for children's risk of unintentional injury. *Child Dev.* 79 (3), 627–638. <https://doi.org/10.1111/j.1467-8624.2008.01147.x>.
- Morrongio, B.A., Corbett, M., Milanovic, M., Beer, J., 2016. Using a virtual environment to examine how children cross streets: advancing our understanding of how injury risk arises. *J. Pediatr. Psychol.* 41 (2), 265–275. <https://doi.org/10.1093/jpepsy/jsv078>.
- Morrongio, B.A., Seasons, M., McAuley, K., Koutsoulianos, S., 2019. Child pedestrian behaviors: influence of peer social norms and correspondence between self-reports and crossing behaviors. *J. Saf. Res.* 68, 197–201. <https://doi.org/10.1016/j.jsr.2018.12.014>.
- Nevelsteen, K., Steenberghen, T., Van Rompaey, A., Uyttersprot, L., 2012. Controlling factors of the parental safety perception on children's travel mode choice. *Accid. Anal. Prev.* 45, 39–49. <https://doi.org/10.1016/j.aap.2011.11.007>.
- O'Neal, E., Jiang, Y., Franzen, L., Rahimian, P., Yon, J., Kearney, J., Plumert, J., 2017. Changes in perception-action tuning over long time scales: how children and adults perceive and act on dynamic affordances when crossing roads. *J. Exp. Psychol. Hum. Percept. Perform.* 44. <https://doi.org/10.1037/xhp0000378>.
- Plumert, J.M., Kearney, J.K., Cremer, J.F., 2004. Children's perception of gap affordances: bicycling across traffic-filled intersections in an immersive virtual environment. *Child Dev.* 75 (4), 1243–1253. <https://doi.org/10.1111/j.1467-8624.2004.00736.x>.
- Price, A.E., Pluto, D.M., Ogoussan, O., Banda, J.A., 2011. School administrators' perceptions of factors that influence children's active travel to school. *J. Sch. Health* 81 (12), 741–748. <https://doi.org/10.1111/j.1746-1561.2011.00653.x>.
- Racioppi, F., Eriksson, L., Tingvall, C., Villaveces, A., 2004. Preventing Road Traffic Injury: A Public Health Perspective for Europe. World Health Organization. <https://apps.who.int/iris/handle/10665/107554> (Regional Office for Europe).
- Ragland, D.R., Pande, S., Bigham, J., & Cooper, J.F. (2014). Ten Years Later: Examining the Long-Term Impact of the California Safe Routes to School Program. *UC Berkeley: Safe Transportation Research & Education Center*. Available: <https://escholarship.org/uc/item/8m59g6vx>.
- Renninger, D., Kelsa, A., Reimers, A.K., Marzi, I., Beck, F., Engels, E.S., Demetriou, Y., 2022. Motivation and active travel in adolescent girls and boys in Germany—findings from the ARRIVE study. *Transp. Res. Part F* 90, 425–437.



- Rothman, L., Macarthur, C., To, T., Buliung, R., Howard, A., 2014. Motor vehicle-pedestrian collisions and walking to school: the role of the built environment. *Pediatrics* 133 (5), 776–784. <https://doi.org/10.1542/peds.2013-2317>.
- Rothman, L., Howard, A., Buliung, R., Macarthur, C., Richmond, S.A., Macpherson, A., 2017. School environments and social risk factors for child pedestrian-motor vehicle collisions: a case-control study. *Accid. Anal. Prev.* 98, 252–258. <https://doi.org/10.1016/j.aap.2016.10.017>.
- Scheiner, J., Huber, O., Lohmüller, S., 2019. Children's independent travel to and from primary school: evidence from a suburban town in Germany. *Transp. Res. Part A* 120, 116–131.
- Schmidt, J., & Funk, W. (2021). Stand der Wissenschaft: Kinder im Straßenverkehr (Berichte Der Bundesanstalt Für Straßenwesen). Bundesanstalt für Straßenwesen. [https://bast.opus.hbz-nrw.de/opus45-bast/frontdoor/deliver/index/docId/2472/file/M306\\_Kinder\\_im\\_Stra%C3%9fenverkehr\\_barrFrei.pdf](https://bast.opus.hbz-nrw.de/opus45-bast/frontdoor/deliver/index/docId/2472/file/M306_Kinder_im_Stra%C3%9fenverkehr_barrFrei.pdf).
- Schützhofer, B., Rauch, J., Stark, J., 2018. The development of traffic competences—do children need special infrastructure to be safe in traffic? *Trans. Transp. Sci.* 9 (2), 3–17. <https://doi.org/10.5507/tots.2018.011>.
- Snelson, A., Lawson, S.D., Morris, B., 1993. Cycling motorists. How to encourage them. *Traffic Eng. Control* 34 (11), 555–559.
- Strauss, A., Corbin, J., 1990. Basics of qualitative research. Sage Publications.
- Tomoda, M., Uno, H., Hashimoto, S., Yoshiki, S., Ujihara, T., 2022. Analysis on the impact of traffic safety measures on children's gaze behavior and their safety awareness at residential road intersections in Japan. *Saf. Sci.* 150, 105706.
- Twisk, D., Vlakveld, W., Mesken, J., Shope, J.T., Kok, G., 2013. Inexperience and risky decisions of young adolescents, as pedestrians and cyclists, in interactions with lorries, and the effects of competency versus awareness education. *Accid. Anal. Prev.* 55, 219–225. <https://doi.org/10.1016/j.aap.2013.02.038>.
- Van der Molen, H.H., 2002. Young pedestrians and young cyclists. *Hum. Factors Highw. Eng.* (<https://trid.trb.org/view/708886>).
- Vansteenkiste, P., Zeuwts, L., Cardon, G., Lenoir, M., 2016. A hazard-perception test for cycling children: an exploratory study. *Transp. Res. Part F Traffic Psychol. Behav.* 41, 182–194. <https://doi.org/10.1016/j.trf.2016.05.001>.
- Wann, J.P., Poulter, D.R., Purcell, C., 2011. Reduced sensitivity to visual looming inflates the risk posed by speeding vehicles when children try to cross the road. *Psychol. Sci.* 22 (4), 429–434. <https://doi.org/10.1177/0956797611400917>.
- Waygood, E.O.D., Friman, M., Olsson, L.E., Taniguchi, A., 2017. Transport and child well-being: an integrative review. *Travel Behav. Soc.* 9, 32–49.
- Winters, M., Babul, S., Becker, H.J., Brubacher, J.R., Chipman, M., Crompton, P., Teschke, K., 2012. Safe cycling: how do risk perceptions compare with observed risk? *Can. J. Public Health* 103 (3), S42–S47. <https://doi.org/10.1007/BF03403834>.
- Zeedyk, M.S., Kelly, L., 2003. Behavioural observations of adult-child pairs at pedestrian crossings. *Accid. Anal. Prev.* 35 (5), 771–776. [https://doi.org/10.1016/S0001-4575\(02\)00086-6](https://doi.org/10.1016/S0001-4575(02)00086-6).
- Zeuwts, L., Ducheyne, F., Vansteenkiste, P., D'Hondt, E., Cardon, G., Lenoir, M., 2015. Associations between cycling skill, general motor competence and body mass index in 9-year-old children. *Ergonomics* 58 (1), 160–171. <https://doi.org/10.1080/00140139.2014.961971>.
- Zeuwts, L., Vansteenkiste, P., Cardon, G., Lenoir, M., 2016. Development of cycling skills in 7- to 12-year-old children. *Traffic Inj. Prev.* 17 (7), 736–742. <https://doi.org/10.1080/15389588.2016.1143553>.
- Zeuwts, L., Vansteenkiste, P., Deconinck, F.J.A., Cardon, G., Lenoir, M., 2017. Hazard perception in young cyclists and adult cyclists. *Accid. Anal. Prev.* 105, 64–71. <https://doi.org/10.1016/j.aap.2016.04.034>.