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Development of speed perception in children

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Introduction

Accidents involving children are particularly tragic. According to federal road accidents statistics in 2019 every 19 minutes a child was involved in a road traffic accident [1]. Of all children under the age of 15 who were involved in an accident, around one fifth was on foot [1]. Most of them had just crossed a street [1]. Of these, 55 percent did not pay attention to the other vehicles [1].

Children usually walk when starting to move in traffic on their own. Crossing roads is therefore one of their first and most frequent challenges in road traffic. However, the cognitive and physical abilities required for this are not yet fully developed [2].

A road crossing consists of several steps, such as approaching the road, estimating the approaching vehicles and finally deciding to cross the road [3]. The children need to perceive the vehicles and estimate their speed [3]. Only if they asses driving speeds correctly and choose an appropriate moment, they can cross the road safely.

Aim of the project

The aim of the present study was to analyse the speed perception and decision behavior of children when crossing a street. This situation can be analyzed using time-to-collusion estimates (the participants are asked about the duration until a collision) or street crossing decisions (the participants decide whether they would still cross the road in front of the vehicle). Both can be investigated using a real street or a virtual representation of it.

In this study, the decision to cross the street was chosen as an indicator for speed perception and both field and laboratory experiments were conducted. The children were to decide whether to cross the road in front of a vehicle both on a real road and in a virtual representation of it. The children were aged from 5 to 14 years to investigate the development across age groups. The study also systematically varied different conditions, such as the speed or approach direction of the vehicles. In addition, cognitive and personality factors of the children were included and analyzed in connection with decision behavior.

As a result, comprehensive findings on the development of children's perception of speed and their crossing behavior are available [4]. The research report no. 72 "Development of speed perception in children" (in German) is available on the UDV website at www.udv.de.

Methodology of the study

First a field experiment was carried out, followed by a laboratory experiment. Subsequently, the children's cognitive skills were examined and related to previous results. A total of 183 children participated in the study, 95 of them girls (51.9 %). The children were between 5 and 14 years old. Table 1 gives an overview of the sample. A total of 45 children within the age group seven to eight years and 13 to 14 years participated in all three experiments. 73 children participated in both the laboratory experiment and the cognitive skills test (marked with *). In the field experiment, some children had to be excluded from the analysis retrospectively, as the eye movement recording was impaired, e.g. due to sunlight exposure.

In the early stages of the study, various characteristics of the children and parents were collected which could be relevant to their behavior in road traffic. This includes walking speed, handiness or the traffic situation in the residential area. Traffic-related personality traits, such as impulsiveness, were assessed using the Junior Temperament and Character Inventory (JTCI) [5]. Various socioeconomic data were collected as well, such as place of residence, educational level of the parents or leisure activities.

Study participants of the different age groups

Table 1

Study	Age group
Field experiment	5–6 years: N=20**/23
	7–8 years: N=20**/23
	13–14 years: N=20**/23
Laboratory experiment	5–6 years: N=38
	7–8 years: N=37*
	9–10 years: N=36
	11–12 years: N=36
	13–14 years: N=36*
Testing of cognitive skills	7–8 years: N=37*
	13–14 years: N=36*
Total sample	N=183

*= identical in study 2 and 3;
** N= complete eye movement and behavior data

Figure 1 · Field experiment: Securing the child at the roadside

Field experiment

In the first experiment, the children's crossing decisions were investigated in a field experiment. For this purpose, the children were asked to assess on a two-lane road whether they would cross the road in front of an approaching car. They were then asked about their reasons for their decisions.

Methodology

For the experiment a section of a 6.5-meter-wide road in Berlin-Adlershof was blocked. The children stood at the side of the road and were secured with a belt (Fig. 1). With this belt, the children were firmly attached to a supervisor. The cars approached from the right or left at a constant speed of 50 kilometers per hour.

At a signal tone, the children had to decide whether they would cross the street or not. They indicated this by taking a step forward or backward without actually walking on the street. When the children stood still, it became clear that they were unable to decide. Moreover, children partly revised their decisions. The signal tone was given at three different distances of the vehicle. If

Decisions that do not represent correct crossing behavior

Table 2

Cautious decision	Decision **against** a crossing with a large vehicle distance. The crossing would have been possible safely.
Risk decision	Decision **for** a crossing at medium vehicle distance. The crossing was just possible but was a high risk.
Wrong decision	Decision **for** a crossing with small vehicle distance. This crossing would have led to a collision.

the distance was large, a crossing would have been possible safely. If the vehicle had been at a medium distance, a crossing would have been just possible, but risky. At short distances, a crossing would have been impossible without a collision. Table 2 shows the decision options that were defined as incorrect in this study.

In addition, eye movements were recorded from 20 seconds before the signal tone until five seconds after the signal tone. The gaze behavior provides information about the attention control of the children. It was recorded which areas were fixed in the decision situations and for how long. The fixation of the relevant areas was especially considered. These "areas of interest" refer to the approaching vehicles and were determined in advance. Finally, the children were asked about the reasons for their crossing decisions.

Selected results

In most cases the children decided for or against a crossing. Only in the youngest age group (5 - 6 years) about a quarter of the children made **no decision**. Children in this age group also asked most frequently questions regarding the procedure. Seven to eight-year-old children most frequently **changed their decision**, in most cases by withdrawing a crossing decision. In real traffic, this could lead to risky situations when the children are already on the road and stop or even turn back.

About half of all children in all age groups take a **cautious decision** (Fig. 2). Thus, they decide not to cross, although a safe crossing would have been possible. It makes no difference whether the vehicle approaches from the right or the left.

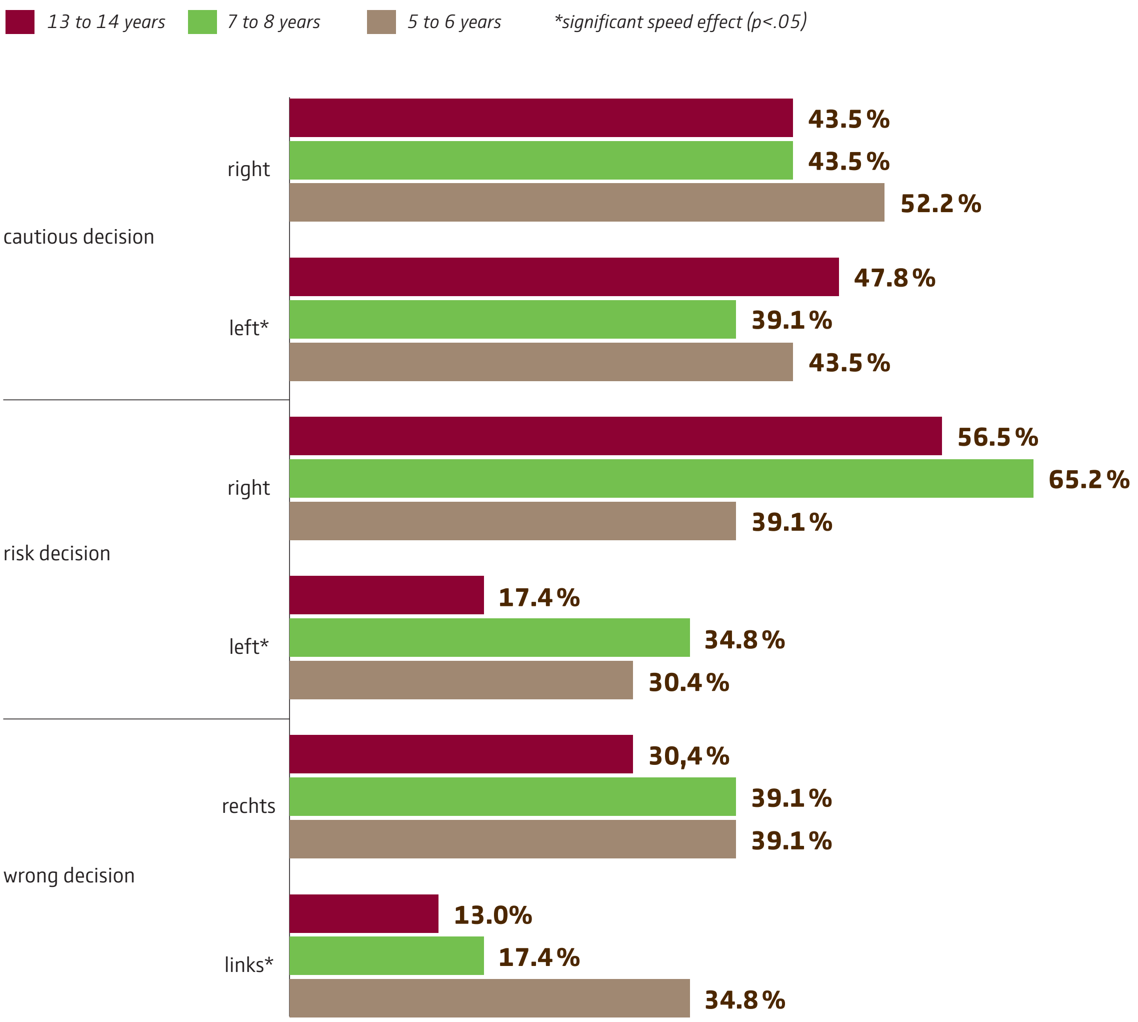
However, the **direction from which the vehicle comes** has a significant influence on the risk and wrong decisions (Fig. 2). If the vehicle came from the left, the children's decisions improved the older they were, as risk decisions and wrong decisions were made less frequently. Children between the ages of 13 and 14 made significantly fewer risk decisions (17.4 %) than younger children between the ages of five and six (30.4 %) or seven to eight years (34.8 %; p<.05). Wrong decisions were also made significantly less frequently by 13- to 14-year-olds (13 %) than by five- to six-year-olds (34.8 %) or seven- to eight-year-olds (17.4 %; p<.05). However, when approaching from the right (opposite lane), 13- to 14-year-olds still had difficulties. In more than half of the situations with medium vehicle distance, they made risk decisions, i.e. they decided to cross. Overall, risk decisions were made significantly more frequently when the vehicle came from the right than when the vehicle approached from the left (right: 53.6 %, left: 27.5 %; p<.05).

When children were asked on which **criteria** their decision is based, they mention mostly speed and distance of the vehicles. Speed was cited significantly more often by children between 13 and 14 years (78.3 %) than by younger children between seven and eight years (52.2 %) and between five and six years (39.1 %; p<.05). The distance to the car was also mentioned more often by older children as a decision criterion. Other criteria such as gut feeling (18.8 %) or "rather safe decisions" (21.7 %) were mentioned less frequently.

Before a road can be crossed, both directions must be checked. However, only 53.6 percent of all children **looked at the opposite direction** from which the vehicle came. The opposite direction was observed more often when the vehicle came from the left than from the right. However, especially when approaching from the right, vehicles in the opposite direction drive on the lane closest to the child crossing the street. This result underlines that vehicles approaching from the right are a greater challenge for children.

Decision behavior depending on the approach direction of the vehicle and the age grou

Figure 2 **· Field experiment: Data in line percent; N = 69**



In summary, about half of the children in the field experiment took cautious decisions. With increasing age, they made fewer wrong and risk decisions. This is particularly evident when the vehicle approaches from the left. If vehicles approach from the right, even older children still have difficulties in making correct crossing decision. The second lane has to be included in the decision, which makes the task more complex and thus also more difficult. The speed of the vehicles is more important for older children when deciding to cross or not.

Laboratory experiment

In the second experiment, the crossing behavior of the children was investigated in a laboratory experiment, i.e. in a virtual environment. Additional age groups were included in the study. It was also considered how different speeds of approaching vehicles and different types of vehicles influence crossing behavior.

Methodology

In a computer simulation, the children were shown a street (Fig. 3). Here too, a vehicle approached from the right or left. Again, the signal tone was given when the vehicle was at a large, medium or small distance. The children then had to decide whether they would cross the road or not. They indicated this by pressing a button (arrow up = crossing, arrow down = no crossing). The decisions were defined as in the field experiment (see Tab. 2).

In this experiment speeds of the vehicles were varied. They approached at 30, 50 or 60 kilometers per hour. In addition, there was one condition where they accelerated from 20 to 50 kilometers per hour. These speeds were chosen because they correspond to real road traffic and are part of the children's everyday lives. The type of vehicle was also varied and included not only cars but also trucks. Again, decision-making behavior and eye movements were recorded. In addition, the reaction time was recorded. It is defined as the time from when the signal sounds until the children press a button.

Figure 3 **·** Laboratory experiment: test person during the experiment

Selected results

The results on crossing behavior of the children confirm the findings from the field experiment. Once again, the decisions improve with increasing age. Again, the **direction from which the vehicle is coming** plays an important role. If the vehicle comes from the left, a significant improvement in decisions can already be seen at the age of seven to eight years, as fewer wrong decisions are made (Fig. 4). When the vehicle approaches from the right, more than half of the children make wrong decisions, even in the age group of 13 to 14.

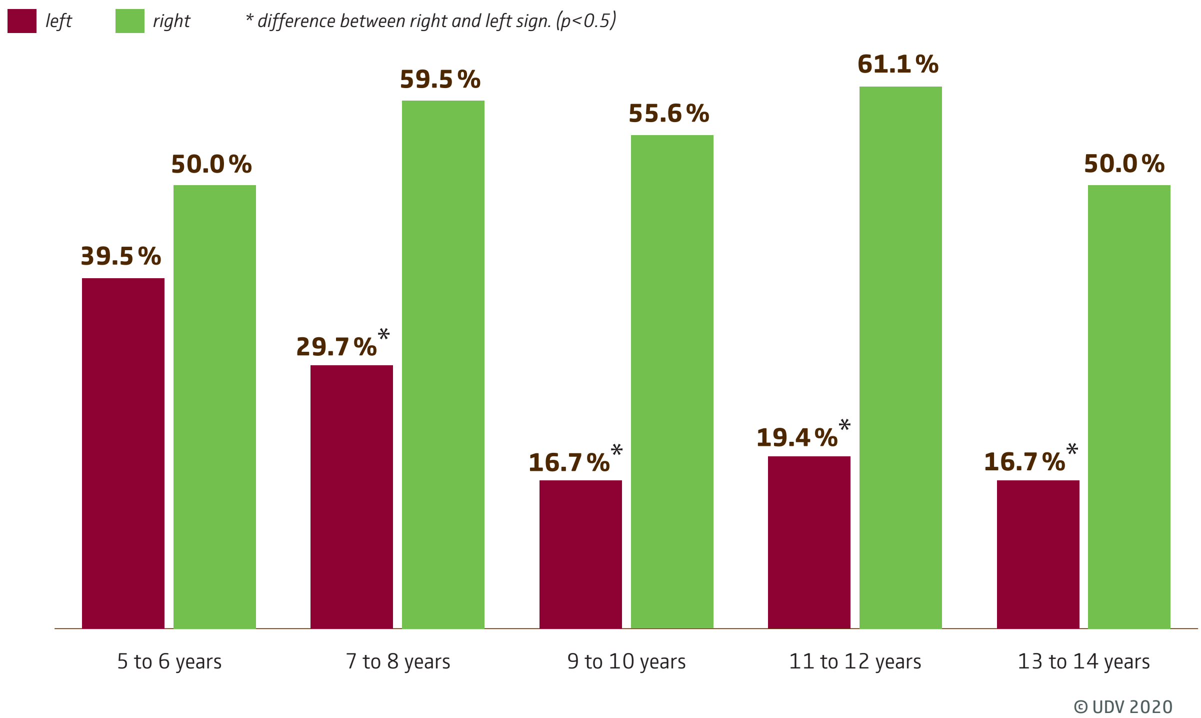
The **speed of** approaching vehicles also influences the children's decision-making behavior. At 30 kilometers per hour, children show the highest willingness to cross the road. Here, 62 percent of the decisions for a crossing are made (instead of against). This is significantly more than at higher speeds (50 km/h: 48.8 %, 60 km/h: 47.3 %, acceleration to 50 km/h: 48.9 %; p<.05). However, this does not yet say anything about the appropriateness of the decisions. Although children make correct decisions to cross the road significantly more often at 30 km per hour if the vehicle was at large distance (75.1 %; Fig. 5) they also make significantly more risk (63.7 %) and wrong (47.3 %) decisions (vehicles at medium and small distances) than at higher speeds. The significantly higher willingness of children to cross a road is accompanied by more correct crossing decisions as well as more wrong decisions and, above all, more risk decisions.

The **type of vehicle** was also varied (car vs. truck). When a truck approaches, all age groups make significantly more cautious decisions (45.3 %, car: 32.7 %; p<.05) and fewer risk decisions (45.1 %, car: 55 %; p<.05). However, there was no significant difference in the number of wrong decisions between cars (38.7 %) and trucks (42.3 %).

The **reaction time** decreases with increasing age of the children (Fig. 6). Thus, older children make their decis-

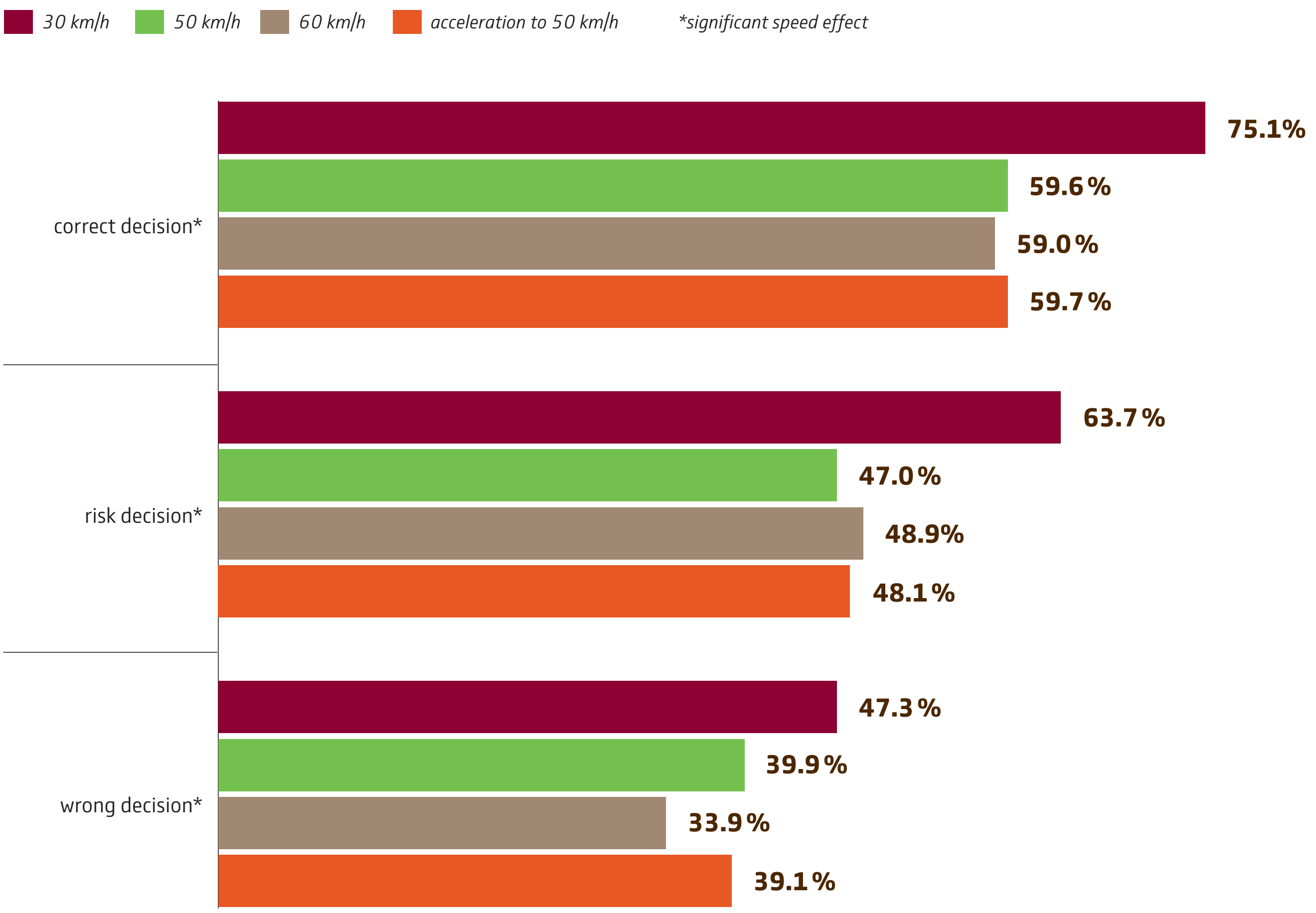
Wrong decisions depending on the approach direction and age group of the children

Figure 4 **· Laboratory experiment: speed 50 km/h; N = 183**



Correct decision (large distance), risk and wrong decisions (medium and small distance) depending on the speed of the vehicle

Figure 5 · Laboratory experiment: N=183



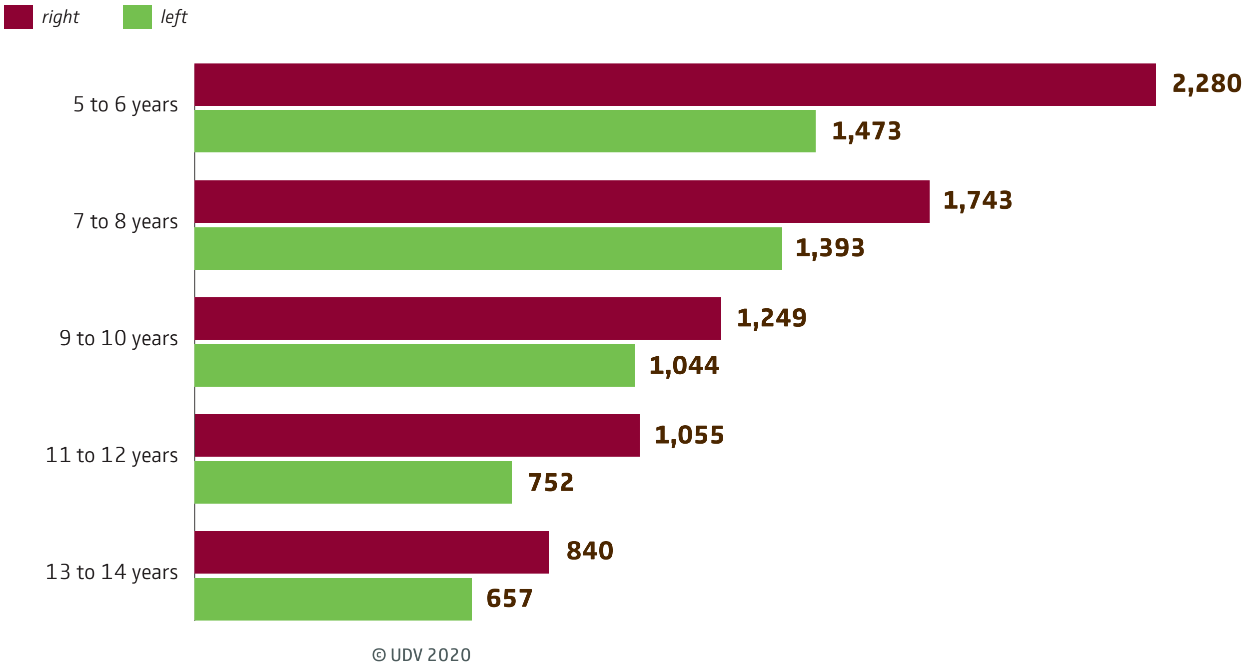
ions significantly faster (r = -.378, p<.05). Younger children process the necessary information more slowly and need longer to implement the decision motorically. Here, too, a difference between the directions from which the vehicle approaches is apparent. When approaching from the right, the reaction time is higher, i.e. the decision takes longer (Fig. 6). The younger the children are, the greater the differences (r = -.23, p<.05). Younger children up to ten years also need longer to decide against a crossing than for it. However, the reaction time is not related to the quality of the decision. Shorter reaction times are not associated with more correct decisions.

The **eye gaze behavior** of the children is also not related to the quality of the crossing decisions. Longer fixations of the relevant areas do not lead to more correct crossing decisions.

In summary, the influence of the approach direction of the vehicle can also be seen in laboratory experiments. If vehicles come from the right, even older children still have problems estimating the speed and crossing the road safely. Only at a lower speed of 30 kilometers per hour the majority of children decide to cross the road. They make more correct decisions at 30 kilometers per hour compared to higher speeds, but also more wrong

Reaction time (in milliseconds) as a function of age of children and approach direction of the vehicle

Figure 6 · Laboratory experiment: n=183; significant age effect (p<.05)



and risky decisions. The younger the children are, the more time they need to make their decision. However, faster reaction times and more effective gaze behavior do not lead to better crossing decisions.

Testing of cognitive skills

In the third part of the study, possible relations between the children's cognitive skills and street crossing behavior were investigated. For this purpose, attention performance as well as hazard perception were assessed and correlated with previous results.

Methodology

A total of 73 children from two age groups participated in this testing (see Tab. 1). The seven- to eight-year-old children were included because they are particularly at risk with school entry and increasing mobility [1]. The 13- to 14-year-olds were included because previous research suggests that traffic-related skills should be fully developed at this age [6, 7]. The following aspects of **attention performance** were assessed using the standardized, computer-based test procedures TAP (test battery for attention testing; 13- to 14-year-olds [8]) and KiTAP (test battery for attention testing for children; seven to eight-year-olds [9]):

- **Distractibility**: Ability to maintain attention even during distractions and in complex situations
- **Alertness**: State of wakefulness and readiness to respond to demands
- **Flexibility**: Ability to flexibly direct attention to relevant requirements
- **Control of impulsive behavior**: Suppression of inadequate behavioral impulses to show adequate behavior and react appropriately
- **Divided attention**: Ability to pay attention to several things at once

Performance was recorded in the form of response time, errors and omissions. Since different test material suitable for the respective age group was used, the results are presented separately by age group. Within the age groups, the children were divided into two groups (above vs. below average) based on the group mean and compared with each other.

In addition, **hazard perception** was examined with the help of video sequences of three different, potentially critical traffic situations. The children looked at them from a bird's eye view and assessed how dangerous the situations are, what aspects of them are actually dangerous and how corresponding dangers could be avoided in the future.

- **Crossing at crosswalk**: A child crosses the road at normal speed.
- **Crossing at a bus stop**: A child crosses the roadway in front of a bus without paying attention to the traffic or taking into account the limited visibility. An approaching vehicle can just barely brake.
- **Unsecured crossing of a street**: A child runs across the street between parked vehicles. An approaching vehicle can just barely brake.

Selected results

Overall, the **attention performanc**e of all children was within the norm for each respective age group. There were only few correlations between attention performance and crossing behavior in the expected direction. For example, in the field experiment in the group of seven to eight-year-olds, the less distractible children and the children with better divided attention performance made more correct decisions to cross a road at a large vehicle distance (less distractible: 85.7 %, more distractible: 44.4 %, $p<.05$). The risk and wrong decisions did not differ, however.

Traffic-related **hazard perception** of the children was examined using the three crossing situations "crosswalk", "bus stop" and "street". The perceived danger was rated significantly differently by the children on a scale from 1 (not dangerous at all) to 5 (very dangerous). The video sequence "street" was rated as the most dangerous ($M = 4.46$), followed by the scene "bus stop" ($M = 3.75$) and "crosswalk" ($M = 1.55$). Thus, children already show differentiated hazard perception at the age of seven to eight years. Compared to the seven to eight-year-olds, the 13- to 14-year-olds also made even more sensible suggestions for preventing the dangers (Tab. 3). While seven- to eight-year-olds more often reproduce general, learned traffic rules, such as waiting until the vehicle has passed by, 13- to 14-year-olds tended to look for alternative solutions such as crosswalks. This shows that older children have preventive hazard perception [10] and can adapt their behavior to the situation.

Video scene „street“: suggestions for prevention by age group

Table 3 · N=73; *significant differences between age groups (p<.05)

Suggestions	7-8 years	13-14 years
Right-left orientation	75.7 %	61.1 %
Wait until car has passed*	48.6 %	19.4 %
Look and wait when car comes	24.3 %	36.1 %
No running	35.1 %	33.3 %
Use traffic lights/ pedestrian crossing*	29.7 %	55.6 %
No crossing the road between parked cars*	5.4 %	22.2 %

In the field experiment, there was no relation between children's hazard perception and their decision-making behavior. In the laboratory experiment, the decisions varied depending on the approach direction of the vehicles. If the vehicle came from the left, children with higher scores on hazard perception made fewer risk decisions.

In summary, higher skills in attention performance and hazard perception of children do not necessarily lead to better crossing decisions in road traffic. Children's hazard perception and attention skills are necessary but not sufficient for better speed perception and safe road crossings.

Influence of traffic competence

There are hardly any correlations between crossing behavior and variables that describe the children's previous experiences in traffic (e.g., residential area, choice of transport). However, children who frequently or always move alone as pedestrians make fewer wrong and risk decisions in the laboratory experiment. This effect is limited to seven- to ten-year-olds and is strongest among seven- to eight-year-olds.

Summary

The results of the present study show that the ability of children to cross a road safely improves with age. Speed perception and estimation becomes more accurate. However, this development does not end at the age of 14, as assumed by previous research. Even children aged between 13 and 14 years still have considerable problems, especially when vehicles approach from the right. Taking two lanes into account is obviously more difficult and, in some cases, too difficult for the children. This is also illustrated by longer reaction times.

Different speeds of approaching vehicles also influence the perception and crossing decisions of children. It is only at low speeds of 30 kilometers per hour that children begin to trust themselves to make decisions and cross the road for the most part. However, these crossings are not necessarily safe. In addition to the correct ones, the number of wrong and risk decisions also increases compared to higher speeds.

The eye movements and reaction times of children also improve with age but are no guarantee for better crossing decisions. Although they are prerequisites for safe traffic participation, they can only be implemented with sufficient experience in decision-making behavior. The attention performance and the hazard perception are already developed in children at an early age but are also not necessarily associated with better crossing decisions.

Recommendations

The results support **speed limits of no more than 30 kilometers per hour in urban residential and leisure areas** where many children are expected to walk. Children gain their first independent experiences at low speeds. Their willingness to cross a street independently and thus their learning opportunities decrease with higher speeds. At the same time, vehicles can react faster at low speeds and compensate for the children's mistakes.

Children should be made aware of the dangers of road traffic from an early age to **build up an appropriate hazard perception** step by step. **Crossing a road** should be trained as **often and realistically** as possible taking children's age into account. Although children are able to perceive vehicles speed it is not yet routine. Routine behavior (e.g. automatically stopping at the side of the road), however, saves cognitive resources, which are then available for higher demands (e.g. vehicle approaching from the right). To develop routines, children have to practice in real traffic. They should be accompanied and supported by adults. This includes, for example, letting the children make independent crossing decisions, discussing them afterwards and only taking corrective action if necessary.

As older children still have considerable problems **safe pedestrian crossings** should be set up not only in front of kindergartens or elementary school, but also **in front of secondary schools** and the roads leading to them.

In **future research** speed perception of children for speeds below 30 kilometers per hour should be investigated in order to determine at what speed children can make sufficiently correct crossing decisions. Children over 14 years of age should also be included in order to investigate their further development.

There is a need to better understand how children mentally represent crossing situations, i.e. how they are depicted in their heads. Such a mental model allows a child to organize and use the knowledge about this situation in his/her mind. Only if we know these mental models and the process of building them up, we may be able to facilitate this process.

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