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The development of traffic competences – do children need special infrastructure to be safe in traffic?

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ABSTRACT: *A lot of (visual, auditory, social, emotional, psycho-motoric, intellectual and cognitive) competences are needed for safe traffic participation. Traffic competences develop during childhood and youth and there is a close relationship to brain maturity. Based on extensive literature analysis a comprehensive tabulation of empirically based developmental milestones was developed by gathering knowledge from different disciplines (Schützhofer, Rauch, Knessl & Uhr, 2015, Schützhofer, 2017).*

These milestones of traffic competences, forming the core of this paper, are now extended and updated to answer the question of how children can be aware of the traffic environment at a certain age and what this implies for their safe traffic participation. This article forms the framework for the tabulation and focuses on the development of visual competences and hazard perception. Based on the results of the literature review, it will be discussed if there are implications for infrastructure planning as well as for traffic education. Main objective of this research is the development of recommendations for age dependent safe traffic participation that do not under- or overstrain children and give them the chance to have their own active traffic experiences within adequate and safe borders.

This traffic psychological and developmental psychological knowledge is essential in various fields. The results address policymakers, traffic managers, transport planners and technicians and help them to appreciate that children are not small adults and adaptions of the existing traffic environment are needed. They can also be a starting point for the development of traffic safety workshops for pedagogues, parents and police officers as in Austria.

KEYWORDS: *Development of traffic competences; traffic education; traffic infrastructure for children; hexagon of traffic safety work; traffic sense*

1. INTRODUCTION

Children are not small adults. Their necessary competences to be safe in traffic are still in development. Empirical findings show, that the perception of the traffic environment strongly depends on the developmental stage of the child (cf table 1). An important target of traffic and mobility education is to train children age-adequate and to help them take the first steps in traffic within safe borders that do not lead to over- or understraining. High-quality programs on traffic and mobility education therefore have to be theory-based and need continuous evaluation. Furthermore, good programs are well structured and build on each other considering that traffic and mobility education are lifelong processes. Thus, they need to begin early in kindergarten and last as long as possible. In the sense of *mobility* education, programs should continually include aspects promoting children's active and independent mobility by reflecting on the consequences of travel behavior on health and environment; this is not elaborated in this paper. According to the development of the cognitive ability of abstract thinking, good programs start with simple and concrete tasks that become slowly more complex and abstract. Also, according to this mentioned development of abstract thinking the first steps have to be made in the playroom, followed by the protective space. The last important step is the training in a real-life environment. Therefore, besides education and training, infrastructure plays an essential role for safe traffic participation of children.

2. THEORETICAL BACKGROUND

As argued in section 2.1, traffic safety work is more successful when it follows an interdisciplinary ap-

proach, a holistic understanding of traffic behavior and use of infrastructure. Safe traffic participation not only needs a lot of developed single competences, these single competences also must interplay fast and correctly (Schützhofer, 2017, Schützhofer, Rauch, Knessl & Uhr, 2015). Table 1 shows all necessary competences for safe traffic behavior of children in their development from age 3 to age 14 (cf section 2.2). Due to space constraints in this article the examples focus on visual competences and hazard perception.

2.1. Interdisciplinary traffic safety work

Traffic safety and mobility work often focuses on children and pedagogues in kindergarten or school. Sometimes parents are also involved. Because traffic participation takes place in the traffic system, it is necessary to take the whole traffic system into account, including infrastructure, traffic laws etc. and to think in a holistic and interdisciplinary way (Schützhofer et al., 2015).

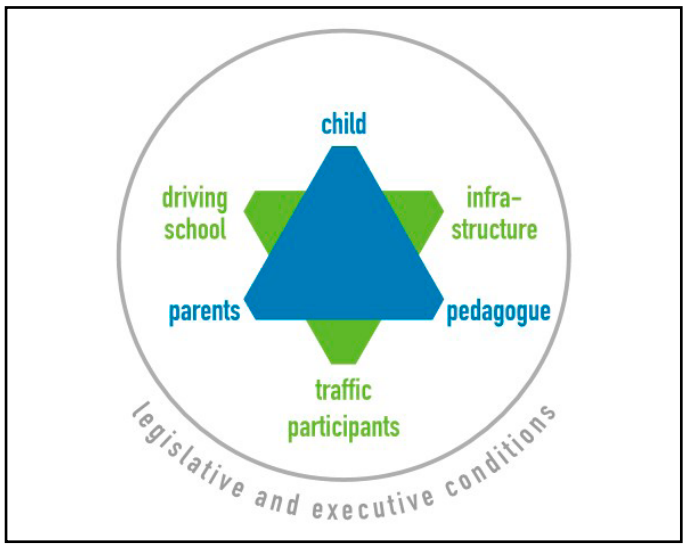

Figure 1: Hexagon of traffic safety work

As shown in figure 1, the pedagogic triangle (child – parents – pedagogue) was extended by another triangle consisting of infrastructure, other traffic participants (e.g. as role models for correct traffic behavior) and driving schools (e.g. as institutions for traffic education for adults). The two triangles are embedded in the actual legislative and executive legal framework. The more child adequate the single dimensions of the hexagon of traffic-safety-work are implemented in the traffic system the more active traffic participation of children can be observed. The safer the given infrastructure is evaluated by the parents the more children are allowed to participate actively and to walk unaccompanied in traffic (Frauendienst & Redecker, 2011, Ausserer, Röhsner & Risser, 2010). Schützhofer et al. (2016) therefore recommend checking if guidelines and regulations for traffic planners are child adequate. Traffic psychologists can here contribute with the necessary knowledge and background information and help with further education.

In Austria, for example, there are RVS guidelines for a safe school environment (RVS 03.04.14, 2003) and for child-friendly mobility (RVS 03.04.13, 2015). RVS guidelines are activity regulations with a recommended character representing the current technical standard for a defined field of action. They are based on legal, normative and further technical rules. The school environment in the RVS guidelines is defined as a radius of 250 m around the school entrance. For the broader environment the implementation of school way plans is recommended. The aim of these guidelines is the adaption of the traffic environment around schools to the needs of children. They contain a list of ratings of specific traffic-organizational and constructional measures. Besides an improvement of traffic safety, the creation of an attractive residential area is considered. Essential for technicians is also the improvement of the visibility conditions. General recommendations for measurements are pedestrian zones in front of schools, enough space in front of the school entrance or bus stops to avoid crowding, speed limits near schools, bicycle lanes, pedestrian crossings that reflect the special needs of children (cf Leden, Johansson, Rosander, Gitelman, & Gårder, 2018), kiss and go areas, and barrier free design. School way safety and traffic safety of children in general are also an important issue in the traffic safety program of the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) (bmvit, 2016).

An evaluated good practice example for an interdisciplinary approach for improving traffic safety of children is the so-called school way plans in Austria (Knowles, Schneider & Robatsch, 2016). They are developed involving children, parents, school directors, police officers, a representative of the road maintenance department and traffic safety experts. The school way plan helps parents to find the safest way to school and to detect any possible dangerous situations. The plans support the local authorities in a further step to decrease or eliminate hazards on the way to school. The school way plans are a good basis for the school way training.

Children focus on different aspects of the traffic and built environment than adults do

(Limbourg, 2008). For example, in an Austrian study, children's perceptions on the environment were collected with a smartphone application (Stark et al., 2018b). Children locate aspects in their environment that they like or dislike. More than 450 evaluations were collected and visualized in a digital map containing photos and descriptions. A categorization of their observations reveals that children focus not so much on traffic safety issues but rather on functionality aspects like (not) enough space, places to sit, waiting times or damaged local infrastructure as well as on aesthetics like for example cleanliness and roadside greenery (Figure 2). They also take notice of environmental related aspects like air quality and noise emissions in their areas of activity in the city of Vienna. They often take the traffic environment as granted and do not dare to express their wishes. Traffic infrastructure should therefore be planned and build carefully, in a way that attracts the child's attention.

2.2. Development of traffic competences – developmental milestones by means of visual competences and hazard perception

As outlined before, traffic competences develop during childhood and adolescence. In Table 1, developmental milestones of average children and their implications for safe traffic behavior are described. This takes into account that some children develop at a slower or faster rate. To use the developed competences effectively in traffic, children need age-specific traffic education and training. Without such education, the necessary traffic understanding is missing. Figure 3 demonstrates, as an example, why this is essential by means of visual competences of a 6-year-old pupil. The first photo on the left-hand side shows a typical traffic situation: A father wants to cross the street together with his six-year-old daughter. The second and third photos demonstrate that both have a completely different perspective of the situation: The adult can get a good overview resulting in a reliable information basis for safe traffic behavior. However, the child can only get an overview of parts of the situation and cannot get all relevant details for a safe crossing decision.

Adults need to be aware of these facts when doing traffic education with children. In addition, transport planners have to take the smaller size and the lower eye position into account. Due to their smaller size children don´t see the same as adults. When adults are not aware of this fact, they explain traffic relevant details that the children cannot understand because they don´t see them. The child in figure 3 would have to move closer to the street or even walk onto the street to have the possibility of a full overview.

In addition to the handicap due to smaller size, depth perception and near and far accommodation are not fully developed until the age of nine. Depth perception and near and far accommodation are necessary requirements for speed and distance perception. Children up to the age of nine are therefore not able to estimate speed and distances in a satisfactory way. They compensate for this lack by interpreting light intensity for distance perception. In their speed rating bright colored cars are both faster and nearer then dark colored cars. This misinterpretation can lead to dangerous situations in traffic and must be considered. Additionally, peripheral vision must be developed during childhood and adolescence. There are different empirical findings concerning this ability, but what is

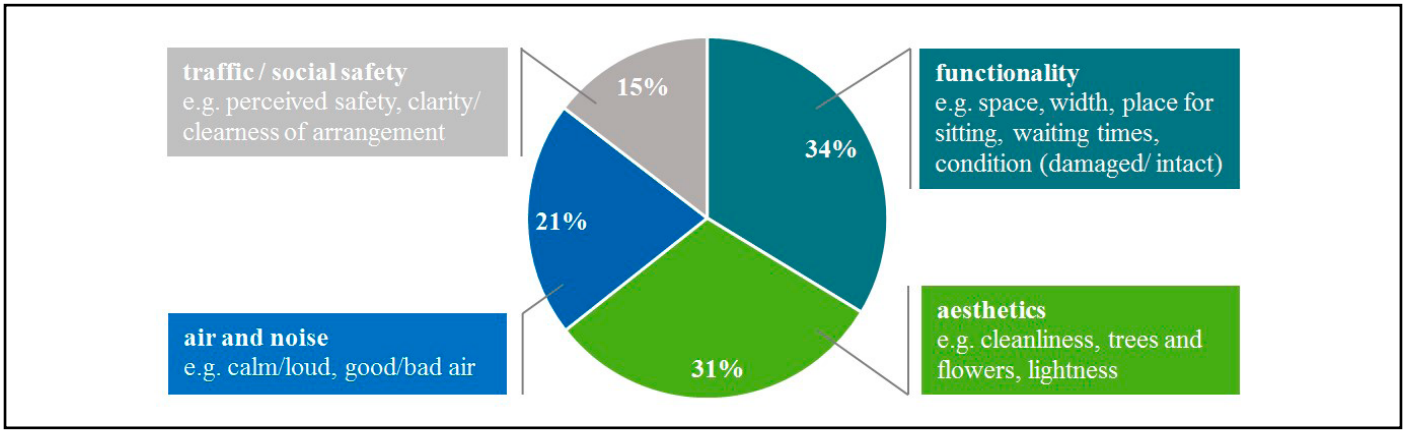

Figure 2: Categorization of aspects of traffic and built environment children evaluated with the help of a smartphone application (N=466)

Figure 3: An example of a typical traffic situation (left), adult perspective (middle), child perspective (right) (picture credits: AUVA)

known for sure is that even teenagers cannot use their peripheral vision efficiently (cf table 1).

Hazard perception is one of the most important abilities for safe traffic behavior. It is strongly connected with the development of cognitive abilities. Children up to the age of 6 have a preoperational thinking structure. Children from 6 to 12 have a concrete-operational thinking structure (Piaget, 1983). This means that they are not capable of abstract and anticipatory thinking processes. These processes are still in development. In this context it is very important that *knowledge* should not to be equated with *understanding*. Many studies have shown that children in kindergarten and in primary school had good results when they were shown pictures of traffic situations and were asked to identify what was dangerous. But when they showed them the same pictures and asked them what they could see, they mentioned numerous traffic irrelevant details before they talked about the traffic relevant ones (Limbourg & Günther, 1977 citied after Limbourg, 2008, Hill, Lewis & Dunbar, 2000). When children were asked if something can become dangerous in the situations shown here, especially the younger children failed completely but even the older ones didn´t get good results. That´s because the cognitive processes necessary for anticipating are not developed in these age groups. This means that hazard perception and hazard awareness are not fully developed until the age of ten.

Compared with adults, children have slower perception, thinking and decision processes. An awareness of hazard perception develops in three developmental stages (Limbourg, 2008, cf figure 4). Pre-school children do not have a realistic sense of hazards in traffic. They have an egocentric view of the world and magic thinking which means that they confuse reality and fantasy. Three, four or five-year-old children feed their dolls or teddys and want to put big Lego figures into a small toy car. They have the same thinking structure in traffic. For example, they believe they are super(wo)man and cars cannot harm them – that´s the logical conclusion from a child's perspective. At the age of six, children switch from the pre-operational thinking structure to the con-

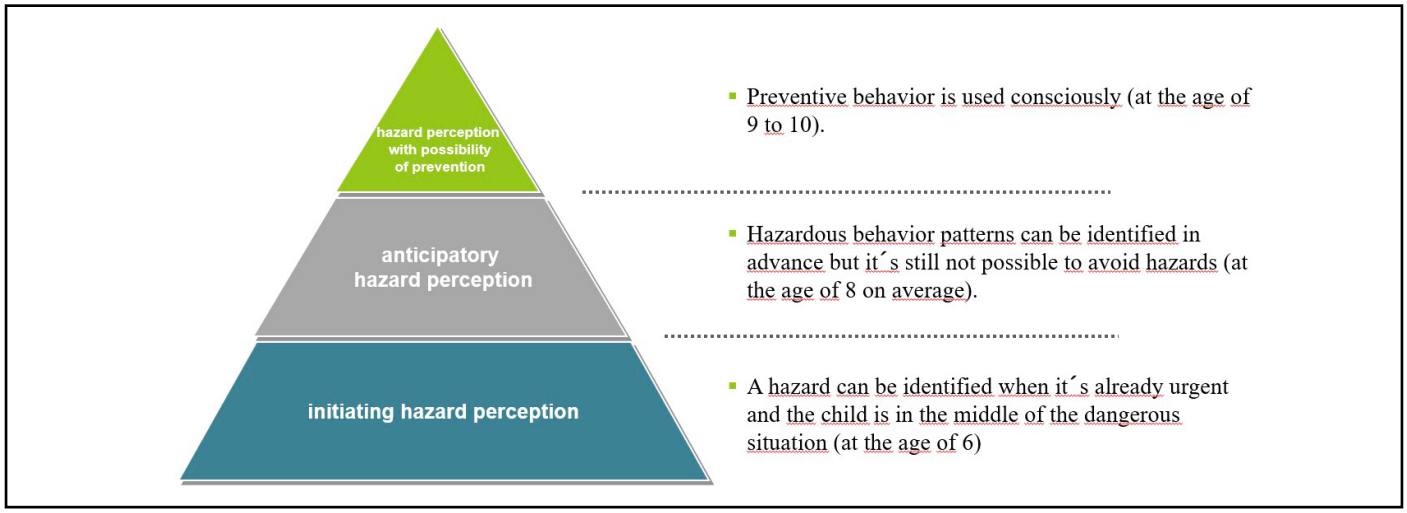

Figure 4: Development of hazard perception and safety awareness (Limbourg, 2008 translated and adapted)

crete-operational one. They can now already identify a hazard but only when they are confronted with it and are in the middle of a dangerous situation. This means that a child at the age of six realizes the danger when it´s already too late to cope with the situation. The child cycles, for example, downhill and identifies the hazard when it´s already too late for braking. It cannot realize that cycling downhill could lead to dangerous speeding. At the age of 8 on average, children can realize this in advance, but preventative behavior is not used consciously until the age of 9 to 10. Then the child can choose an alternative route and doesn´t cycle downhill, for example.

3. IMPLICATIONS FOR CITY AND TRANSPORT PLANNERS

From a child's perspective, the public space is not only a space in which to move, but is also a space to live, to meet and to play. It should be pointed out that children want to explore their environment actively. They clearly rate walking as well as the use of a bicycle or scooter as their favorite travel modes (Stark et al., 2018a). Knowledge of children's different perception of the traffic environment should not lead to restrictions to their active and independent mobility. Moreover, the idiosyncrasies of children due to developmental processes should be considered in infrastructure planning. In particular, the design and dimensions of traffic areas must be adapted to children's requirements and abilities. Thus, ideally, public space should be designed in such a way that persons with not fully developed traffic competences can fulfill their mobility needs at the best possible rate. In this respect, it could be unreliable to relate recommendations to specific age classes. It may be better to strive for child-friendly traffic environments using a low as possible stage of development as a yardstick. The following recommendations are based on what is actually seen or perceived through the eyes of a child. No claim is made that this is a complete list, but it should provide examples of implications for city and transport planners.

Generously sized sidewalks extended into the road in special areas help to give an improved overview. A better overview is also given when vision is not obstructed by (large) cars, advertising hoardings, large plants, etc. at junctions, (zebra) crossings or near schools (cf figure 3). In this regard, a careful revision of existing guidelines is recommended, for example regarding adequate clearance gauge requirements. Due to the longer time demands of children e.g. for gap choices, large-scale speed reduction measurements like speed limits or speed bumps for motorized transport and pedestrian islands are as helpful for children as longer green signal phases on traffic lights. As mentioned before, speed reductions should be accompanied by measures on road alignment such as roadway swiveling.

Other organizational measures such as pedestrian zones or temporary car-free zones around schools at the beginning and end of lessons are recommended. Parents escorting their child to school by car should not be allowed to drive close to the school building (kiss and go). This should also refer to teaching staff except for disabled persons. In this regard, as one example, the City of Bregenz (province Vorarlberg, Austria) can be mentioned. In the vicinity of a school strict restrictions have been implemented for safe and active travel for children. Traffic bans for motorized transport (except for residents and suppliers) apply from 07:15 a.m. to 5 p.m. on working days. Bus and tram stops as well as spacious bicycle stands are sited close to the school; parking spaces are limited. In addition, job tickets for public transport and incentives for active mobility are offered for the teachers. There are also other individual examples that have already been implemented in some Austrian provinces (Salzburg, Styria). As a pilot test, also Vienna is going to implement a temporary driving ban starting in September 2018 at one school between 07:45 to 08:15 a.m.

Another very important issue is the logical structure of infrastructure. For the child´s better understanding bicycle lanes, for example, must not only be clearly marked but also continuously. When they are interrupted by a junction the child doesn´t know how to go on. Children need a logical (at best self-explaining) structure for safe orientation in the traffic system.

It should be pointed out, that residents and parents should be involved when implementing measures in the school environment to enhance the acceptance of regulations.

4. CONCLUSION AND DISCUSSION

Depending on age, children don´t have the full set of necessary traffic competences or it is not fully developed (cf table 1). Due to these facts they need more time in traffic situations for perception, getting an

overview, information processing, making decisions (e.g. gap-choices) and starting actions (e.g. crossing the street or starting to cycle). Especially due to children´s longer time demand and their smaller size infrastructure that is ideal for adults isn't always the optimum for children. Interdisciplinary traffic safety work can help to find the optimum traffic environment for all users. As described before, the development of school way plans in Austria is a good practice example. School way plans need regular reworking and should be accompanied by effective and determined awareness programs for parents. However, if hazard zones are identified, every effort must be made to improve the built environment in terms of traffic safety.

As outlined before, existing guidelines for a safe school environment and for child-friendly mobility in Austria (RVS) are good practice examples for inclusive urban planning and are a first step in raising awareness regarding children's requirements. These guidelines should also be considered for the immediate catchment area of kindergartens. It should be noted that practical implementations based on such regulations need to be evaluated carefully. In a next step such regulations should be transformed into more binding legal instruments.

It can also be concluded that it is necessary to make adults aware of the child's age dependent traffic competences. This would help to sensitize road users to this vulnerable group so that they are able to understand and appreciate exactly how children may react and the reasons why. In this context, Table 1 can serve as a basis because it gives a comprehensive overview especially concerning single competences. For safe traffic behavior a fast and correct interplay between the numerous single competences is essential. However, single competences develop at different speeds. As such, it is necessary to have a holistic and systemic approach and to investigate how theory based and age specific traffic education as well as child adequate infrastructure can help to compensate for the missing single competences. A lot of research is already done, but further research is still needed - especially with an interdisciplinary approach. This research could also be fruitful for a better understanding of self-explaining infrastructure, the redundancy of existing traffic signs or the need for new helpful signs or signals.

To sum up, depending on the local structural conditions special infrastructure for children may be necessary. Child adapted infrastructure helps to improve traffic safety of children and enables them, for example, to perceive all the relevant details to make a safe crossing decision. As a positive side effect, a child adapted infrastructure often tends to make traffic conditions also safer for people with special needs such as the disabled, wheelchair users and the elderly.

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Table 1: TRAFFIC SKILLS AND THEIR FOUNDATIONS

	MOTOR SKILLS			VISUAL PERCEPTION				
Age	Gross motor skills	Hand motor control / finger dexterity	Effects in traffic	Perception of colour / light and dark	Visual acuity and accommodation	Peripheral vision	Depth perception and spatial perception	Effects in traffic
up to 3 years:	**3 years:** hopping off a step with both feet, with reliable balance control (Michaelis & Niemann, 1999) **3 years:** running with swinging arms (Michaelis & Niemann, 1999) **3 years:** moving around obstacles (Michaelis & Niemann, 1999) **3 years:** clear acceleration when running, greater agility and dexterity; walking backwards, walking on tiptoe, dancing to music, balancing on narrow beams (Schneider & Lindenberger, 2012) **3-4 years:** climbing stairs with alternating legs and descending stairs with one leading leg; jumps and hops with flexible upper body; throws and catches ball with slight involvement of the upper body; ball is still clamped against chest; steers tricycle; pedals (Berk, 2011) **3 years:** walking backwards, standing on tiptoe (Schneider & Lindenberger, 2012)	**3 years:** child can turn individual pages of a book (Michaelis & Niemann, 1999) **3 years:** child can use precise three-finger pinch grip (thumb-index finger-middle finger) to manipulate small objects (Michaelis & Niemann, 1999) **3-4 years:** undoing and doing up buttons; eating without help; using scissors; copying circles and vertical lines; drawings of people consisting of a circle for the head and lines for the limbs (Berk, 2011)	**3 years:** considered purely from the perspective of motor skills development processes, the child can perform simple riding manoeuvres on a bicycle (getting on and off, braking, riding in a straight line, riding around corners) (Pfafferott, 1994) **from approx. 3 years:** child can complete simple manoeuvres in terms of motor skills on a bicycle (Basner & De Marees, 1993)	**4 months:** child sees colours like an adult (Kellmann & Arterberry, 2006) **3 years:** colour perception (50-85%) (Van der Molen, 2002)	**6 months:** visual acuity comparable to that of an adult (Slater, 2001)	**2-3 years:** visual field (field of vision) corresponds to the size of an adult's (Dobson, Brown, Harvey, & Narter, 1998), but cannot yet be used equally well, due to cognitive mechanisms (e.g. attention) (Martin, 2010)	**3-4 months:** infants can recognise three-dimensional shapes (Kraebel, West, & Gerhardstein, 2007). **from 4 months onwards:** depth perception is possible (Pieper, 1990) **between 5-7 months:** development of the ability to process depth information in two-dimensional images (Pieper, 1990)	
4 years	**4 years:** child can ride a tricycle or similar safely in a focused manner (Michaelis & Niemann, 1999) **4 years:** pedalling and steering at the same time (Michaelis & Niemann, 1999) **4 years:** hopping forward on both legs approx. 30-50 cm from a standing start, with reliable balance control (Michaelis & Niemann, 1999) **4-5 years:** children find it difficult to interrupt their actions, only 33% of the 4 to 5-year-old children needed less than 1 second to interrupt their action (cranking toy cars attached by string over a long plank using a hand crank) in response to a signal (Limbourg, 1995) **up to 5 years:** children rely greatly on visual information and lose their balance when they close their eyes (Bremner, Lewkowicz, & Spence, 2012)	**4 years:** holding a pencil correctly (with 3 fingers) (Michaelis & Niemann, 1999) **4 years:** child draws and comments on objective things; draws people consisting of a circle for the head and lines for the limbs (Michaelis & Niemann, 1999)	**4-5 years:** riding a bicycle/scooter is possible, as the child has a sense of balance (Limbourg, Höpfner, & Niebling, 1977; Limbourg, 2008; Klöck & Schorer, 2011)				**< 5 years:** no distinction between stopped and moving vehicles is possible (Limbourg, 1995)	**4 years:** children can find their way in a maze using simple maps; reference stimuli such as trees, roofs or buildings are more important than verbal explanations on the map (Blades & Spencer, 1985) **4-5 years:** children cross the road quickly and without prior orientation (Limbourg, 1976) **4-5 years:** only 11% can correctly estimate speeds (Günther & Limbourg, 1977)
5 years	**5 years:** climbing and descending stairs safely and without holding on, alternating leading leg (Michaelis & Niemann, 1999) **5 years:** catching larger balls (diameter approx. 20 cm) with hands, arms and body, when they are thrown from a distance of 2 m (Michaelis & Niemann, 1999) **from 5 years onwards:** balance has developed further; standing on one leg, rolling and catching balls (Schneider & Lindenberger, 2012) **5 years:** children with an average amount of training can master simple manoeuvres on a bicycle (riding in a straight line, cornering, etc.)(Weber et al., 2005)	**5 years:** child can cut along a straight line using safety scissors (Michaelis & Niemann, 1999) **5 years:** child can write individual letters, numbers, names in large letters (also still laterally inverted) (Michaelis & Niemann, 1999) **5 years:** child paints and draws easily recognisable images (Michaelis & Niemann, 1999) **5-6 years:** shapes such as circles, triangles or crosses can be copied (Michaelis & Niemann, 1999) **approx. 6 years:** only one hand should be used when painting (Balster, 1998)	**4-6 years:** improvement in motor skills and fewer accidents after coordination training (Kambas et al., 2004) **5-6 years:** children stop at the side of the road 50% of the time (Savelsbergh, Davids, van der Kamp, & Bennett, 2003) **from 5 years onwards:** balance has developed further. Prerequisite for riding scooters and bicycles is in place (Schneider & Lindenberger, 2012) **5 years:** children can master simple manoeuvres on a bicycle (riding in a straight line, cornering, etc.) (Weber et al., 2005) **5-13 years:** only slight performance improvement when riding between two boundary lines on a bicycle between 5-13 years, performance only increases rapidly from 14 years (Arnberg et al., 1978)	**5 years:** colour perception (>85%) (Van der Molen, 2002) **5 years:** child recognises and names basic colours (blue, green, yellow, red, black, white) (Michaelis & Niemann, 1999; Kellmann & Arterberry, 2006) **5 years:** ability to distinguish brightness and colour continues to develop up to 5 years of age, but distinguishing between red and green is not a problem, brighter whiteish light is perceived as closer than dark, coloured light (Limbourg, 2008)	**5 years:** limited accommodation in the sense of restricted near-far perception (Warwitz, 2009) **5 years:** visual acuity matures at 5 at the earliest; some studies find adult levels for the first time in teenagers (Leat et al., 2009)		**5 years:** perspective depth perception is developing (Warwitz, 2009) **5 years:** adequate estimate of speed (only 50-85%) (Van der Molen, 2002) **5 years:** adequate estimate of distances (only < 50%) (Van der Molen, 2002) **5 years:** concept of speed and distance is mastered (Siegler & Richards, 1979) **5 years:** adequate movement perception (Van der Molen) (>85%) (Michaelis & Niemann, 1999)	**5-6 years:** safe behaviour in traffic is still weak (stopping on the pavement in good time, looking out for approaching traffic, looking in the wrong direction) (Zeedyk, Wallace, & Spry, 2002) **5-6 years:** decisions taken by children when crossing the road in connection with time gaps in the flow of traffic and the speed of approaching cars: children make dangerous decisions, as the absolute spatial size of the gap is used as the basis for the decision and not the speed (Connelly, Conaglen, Parsonson, & Isler, 1998) **5-7 years:** children decide whether to cross the road based only on whether they can see cars from their position, further information such as confusing crossing points, visual obstructions or complex crossings is not taken into account (Ampofo-Boateng & Thomson, 1991) **5-11 years:** children focus on irrelevant features of the situation that have nothing to do with road traffic (Tolmie et al., 2005)

Table 1: TRAFFIC SKILLS AND THEIR FOUNDATIONS

	ACOUSTIC PERCEPTION		COGNITIVE DEVELOPMENT					
Age	General hearing ability, directional hearing and noise differentiation	Effects in traffic	Attentiveness (selective, duration, divided, distractibility)	Ability to adopt other perspectives	Thinking	Social and emotional competence	Hazard perception	Effects in traffic
up to 3 years:	**6 months:** threshold values for general hearing ability are reached at approx. 6 months (Tharpe & Ashmead, 2001) **3-4 years:** hearing ability reduced by 7-10 decibels (cars heard later) (Pieper, 1990)		**2-6 years:** selective attention develops slowly in the first 2 years of life, with significant developmental gains up to approx. the 6th year of life (Garon, Bryson, & Smith, 2008) **3 years:** child plays in a focused and in-depth manner: "make believe" games, games with cars, dolls, building blocks, Playmobil, etc. (Michaelis & Niemann, 1999) **up to approx. 4 years:** attention is exclusively controlled by environmental stimuli. Children are hardly able to pay attention in the manner necessary for their safety (Limbourg, 1995)	**3-6 years:** egocentric adoption of perspective in the sense of "I see the car, therefore the car sees me!"; differences between him/herself and others are perceived, but not differences to his/her own social perspective (Piaget, 1983) **3-7 years:** stage of subjective interests (Warwitz, 2009)	**2-6 years:** pre-operational stage (Piaget, 1983) **2-4 years:** descriptive-situational and causal thinking (an event has a cause), self-centred perception and thinking. Egocentrism is based on the reactions of adults (Böttcher, 2005)	**2-4 years:** impulsive and need-based actions take place without fine control and without insight into social rules (Böttcher, 2005) **3 years:** playing together with other children for at least 5 minutes (Michaelis & Niemann, 1999) **3 years:** child can stay with people known to him/her for several hours, and also stay outside the house without a caregiver (Michaelis & Niemann, 1999) **3 years:** imitates adult activities in role play; would like to help with household activities (Michaelis & Niemann, 1999)	**3-4 years:** only very vague basic understanding that traffic can be dangerous (Briem & Bengtsson, 2000)	**3-4 years:** only very vague basic understanding that traffic can be dangerous; children only had dolls use the zebra crossing by chance, and hardly looked and waited before they crossed the road (Briem & Bengtsson, 2000) **3-7 years:** children are often emotionally engaged in the process of riding a bicycle. Mixing of reality and fantasy, bicycle is viewed as a horse for example. This leads to distraction and poor hazard perception (Walter, Achermann Stürmer, Scaramuzza, Niemann, & Cavegn, 2012)
4 years	**4-5 years:** acoustic perception/location (>85%) (Van der Molen, 2002)		**4-5 years:** high level of distractibility due to irrelevant stimuli (Pasto & Burack, 1997) **4-5 years:** children pay less attention to oncoming traffic than older children (Barton & Schwebel, 2007) **4-5 years:** attention is more focused on things that are not relevant to traffic (Günther & Limbourg, 1977)	**from 4 years onwards:** children begin to understand meta-representations of the world by developing theories about what others think or know (theory of mind). These theories make it easier for them to predict the behaviour of others (Premack & Woodruf, 1978) **4-5 years:** children can deduce that someone sees something they cannot themselves see (Flavell, 1992) **4-6 years:** children understand that their perception of the world can differ from that of others and also that there can be incorrect beliefs (Wimmer & Perner, 1983)	**4 years:** child asks "W" questions (Michaelis & Niemann, 1999) **4 years:** child distinguishes and names identical objects of different sizes, and is able to differentiate these (for example large and small apples) (Michaelis & Niemann, 1999) **4 years:** children are already showing the beginnings of successful inhibition in inhibition tasks that are simple (e.g. only inhibiting response) and more complex (e.g. inhibiting response and displaying alternative response) (Bjorklund, 2005). **4-6 years:** more integrated thinking (details move into the background), purposeful thinking, events are conceivable, symbolic thinking, extension of knowledge through visual acquisition (Böttcher, 2005) **< 5 years:** children are only able to sort objects by one criterion (Brooks, Hanauer, Padowska, & Rosman, 2003)	**4-6 years:** child can carry out requested actions, basic understanding of the rules of games, but the use of these is variable (Böttcher, 2005) **4 years:** start of games with rules (board games) (Michaelis & Niemann, 1999) **4 years:** child is ready to share (Michaelis & Niemann, 1999) **4 years:** child is generally able to regulate his/her emotions concerning everyday events him/herself, certain tolerance to sadness, disappointment, joy, fear, anticipation, stress (Michaelis & Niemann, 1999) **4 years:** child knows that he/she is a boy or girl and behaves accordingly (Michaelis & Niemann, 1999)	**4-5 years:** children have only a very rudimentary concept of danger, with situations being recognised as dangerous more readily than objects (Hill, Lewis, & Dunbar, 2000) **4-5 years:** visual obstructions are not perceived as dangers by children of this age (Thompson, 1997) **4-5 years:** children are able to identify dangerous situations and accidents, but do not understand the cause of the accident or how to avoid danger (Hargreaves & Davies, 1996)	**4-5 years:** children cross the road quickly and without prior orientation (Limbourg, 1976)
5 years	**5 years:** "slow hearing" with regard to registration, identification, classification, unreliable discrimination, inaccurate localisation (Finlayson, 1972) **5 years:** directional hearing is facilitated by looking in the relevant direction (Warwitz, 2009) **5-10 years:** Depending on the pitch (frequency), children attain the hearing threshold of adults between the ages of 5 and 10. Prior to this, noises are only heard clearly from a higher frequency (Werner & Marean, 1996)	**5 years:** the speed of loud cars is overestimated, quiet cars are perceived as slower, which makes control perception necessary (Warwitz, 2009) **5 years:** children are poor at identifying oncoming vehicles or those driving away from them using acoustic signals, meaning that no directional hearing is possible (Pfeffer & Barnecutt, 1996)	**5 years:** if you ask a child to focus only on the road traffic, he or she will do so for 15 minutes at most. Longer periods of deliberate attention place excessive demands on the child (Walter et al., 2013). **from approx. 5 years onwards:** children develop systematic strategies for attention (Limbourg, 2008) **5 years:** deterioration of performance when processing tasks concerning the ability to distinguish visually due to minor acoustic distraction; children made more frequent mistakes and strayed away from the task (Higgins & Turnure, 1984) **5-7 years:** attention can be more consciously controlled, but distractibility as a result of environmental stimuli is still present (Limbourg, 1997; 2008)		**5 years:** 5-year-olds need approximately twice as long as adults to make a decision as a pedestrian (Schieber & Thompson, 1996) **from 5 years onwards:** children can sort objects by 2 criteria, e.g. cards by colour and shape (Brooks et al., 2003) **5-8 years:** children have more difficulties choosing safe routes to cross the road than older children (Schwebel et al., 2012)	**5 years:** child can share toys and sweets fairly between him/herself and others (Michaelis & Niemann, 1999) **5 years:** Child invites other children, is invited (Michaelis & Niemann, 1999) **5 years:** occasionally still looks for close physical contact: when tired, exhausted, ill and similar (Michaelis & Niemann, 1999) **5 years:** Child can report on embarrassing, frustrating, unpleasant incidents (Michaelis & Niemann, 1999) **5 years:** Children play a lot of role-playing games (including with other children), dress up as heroes, role models (Michaelis & Niemann, 1999)	**5 years:** Targeted individual training (better than group training) can improve the safety strategies (selection of safe route) in 5-year-old children (Thompson, 1997) **5 years:** dangerous situation creates vague feeling of fear that paralyses or leads to panicky behavioural outbreaks (Warwitz, 2009; Piaget, 1983) **5 years:** children can generally recognise danger; their weakness lies in transferring and applying their knowledge (Dunbar, Lewis, & Hill, 1999) **5-6 years:** beginning consciousness of risk (Limbourg, 2001) **5-6 years:** Term "accident" is falsely equated with injury (near-misses are not classified as danger) (Rollett, 1993) **5-6 years:** Compared to 7-8-year-olds, children take more risks when crossing the road and accept smaller gaps between cars, which increases the risk of a collision (Barton & Schwebel, 2007) **5-7 years:** have low capacity to detect dangers when crossing the road (Ampofo-Boateng & Thompson, 1991) **5-7 years:** the most direct route is also seen as the safest route when crossing the road, lack of awareness for dangers originating from obstacles at the side of the road or other visual restrictions (Ampofo-Boateng et al., 1993)	**from approx. 5 years onwards:** children can be educated using pedestrian training based on the psychology of learning (Funk, Hecht, Nebel, & Stumpf, 2013) **5 years:** compared to 3-4-year-olds, they have a better basic understanding of the fact that traffic can be dangerous. Children made dolls use the zebra crossing more often, but still paid little attention to the traffic. They had problems explaining their actions. More than 50% believe that they can see better at night with a reflector and that a helmet prevents them from falling (Briem & Bengtsson, 2000) **5 years:** laboratory-based training on crossing the road does not result in any long-term, significant change in actual behaviour when it comes to real traffic (Young & Lee, 1987) **5 years:** detection of a safe crossing place after training (50-85%) (Van der Molen, 2002) **5-7 years:** When assessing safe places to cross roads, children focus on whether or not there are any cars travelling there. They either wait a very long time to cross or choose places after corners, hilltops, bridges, etc. from which it is scarcely possible to see cars. I.e. decisions are taken based only on whether cars can be seen from the selected location, without taking other information such as confusing crossing points, visual obstructions or complex crossings into consideration (Ampofo-Boateng & Thomson, 1991) **5-11 years:** children between 5 and 11 years of age tend to concentrate on other things (e.g. play areas, dogs), if they are not expressly instructed to pay attention to the traffic during the study (Percer, 2009).

Table 1: TRAFFIC SKILLS AND THEIR FOUNDATIONS

	MOTOR SKILLS			VISUAL PERCEPTION					ACOUSTIC PERCEPTION	
Age	Gross motor skills	Hand motor control / finger dexterity	Effects in traffic	Perception of colour / light and dark	Visual acuity and accommodation	Peripheral vision	Depth perception and spatial perception	Effects in traffic	General hearing ability, directional hearing and noise differentiation	Effects in traffic
6 years	**6 years:** stopping as a pedestrian (>85%) (Van der Molen, 2002) **6 years:** at least 5 sec. standing on one leg (Michaelis & Niemann, 1999) **6 years:** hopping on one leg (Michaelis & Niemann, 1999) **6 years:** motor development shows significant increase in learning capacity (Limbourg, 2008) **6 years:** catching a ball (Michaelis & Niemann, 1999) **6 years:** riding a bicycle (Michaelis & Niemann, 1999) **6 years:** overestimation of physical abilities when performing physical exercises (Plumert, 1995)		**6 years:** once they have started movement patterns, children are frequently unable to interrupt or control them promptly. They would not come to an abrupt halt even if it were necessary (Brück, 2009) **6 years:** while 8-year-olds already make use of learning effects in their self-assessment regarding their vertical reach and their judgment is therefore more accurate, this is not yet possible for 6-year-olds; they still tend to overestimate (Plumert, 1995).		**5-6 years:** visual acuity values correspond to those of adult test subjects (Lai, Wang, & Hsu, 2011) **6 years:** visual acuity and sensitivity to contrast are comparable to what is found in adults (Ellemberg, Lewis, Liu, & Maurer, 1999).	**6-7 years:** peripheral vision is 70% developed, objects approaching from the side are outside the field of vision for a long time (Walter, Achermann Stürmer, Scaramuzza, Niemann, & Cavegn, 2013) **6 - 8 years:** children in this age group need longer to react to optical stimuli in their peripheral field of vision than 11-year-olds and adults (David, Foot, Chapman, & Sheehy, 1986).	**6 years:** adequate estimation of distances (50-85%) (Van der Molen, 2002) **6-7 years:** difficulties in interpreting the speed and direction of moving objects/ vehicles (Joly, Foggin & Pless, 1991) **6-7 years:** adequate understanding of spatial relations (50-85%) (Van der Molen, 2002)	**6-7 years:** only 32% are able to estimate speeds correctly (Günther & Limbourg, 1977) **6-7 years:** when crossing the road, children principally oriented themselves on the edge of the pavement, then ran across the road without additional orientation (Limbourg 1976)	**6 years:** still uncertainty with noise localisation, noises are only correctly attributed from in front or behind (Dordel & Kunz, 2005)	**from 6 years onwards:** hearing ability fully developed, but not yet regularly drawn on in traffic (Finlayson, 1972)
7 years	**6-7 years:** stopping actions after they have been started is possible, but is linked to guidance (Limbourg, 1976) **6-7 years:** 63% of the 6 to 7-year-old children needed less than 1 second to interrupt their action (cranking toy cars attached by string over a long plank using a hand crank) in response to a signal (Limbourg, 1995) **6-7 years:** posture in balance tasks is 3-6 times more unstable compared to adults, due to children's higher centre of mass. Children have only 15% of the capability of 25-year-old adults (Basner & de Marées, 1993) **7-8 years:** developmental leap in psychomotor skills with a significant improvement in performance (Arnberg, Ohlsson, Westerberg, & Öström, 1978)		**7-8 years:** better performance in terms of balance regulation following increased cycle training or increased bicycle use (Basner & De Marees, 1993) **Primary school age:** children with motor impairments are not able to master whole basic requirements when it comes to cycling. This affects safely staying in lane while looking sideways or backwards, above all when combined with intended changes of direction and the indication of these (including to the right) (Günther & Degener, 2009)			**from 7 years onwards:** peripheral perception required for stimuli encountered in traffic is fully developed (Schwebel, Davis, & O'Neal, 2012)	**7-8 years:** improvement regarding visual search strategies in traffic (Whitebread & Neilson, 2000) **7-8 years:** improvement in gaze behaviour, more frequent directional changes in visual attention and reduced gaze duration in one direction lead to an improvement in collecting information from various directions (Whitebread & Neilson, 2000).	**from 7 years onwards:** peripheral perception required for stimuli encountered in traffic is fully developed (Schwebel et al., 2012) **< 7-8 years:** children younger than 7-8 years tend to be less efficient in their visual search and to ignore disturbing information. They also perform more poorly in pedestrian crossing tasks (Barton, 2006) **7-8 years:** the move to an effective application of visual search abilities appears to take place at the age of 7-8 years (Whitebread & Neilson, 2000). **7-8 years:** when cycling, 7 to 8-year-olds focus more on central vision, in order to maintain their balance on the bicycle, while less attention is paid to information relevant to traffic in the peripheral area (Ellis, 2014) **7-10 years:** unfavourable visual search strategies (Tapiro, Oron-Gilad, & Parmet, 2016): surroundings are scanned in a hectic manner using more frequent and shorter fixations		
8 years	**8 years:** child can master difficult manoeuvres on a bicycle (riding a slalom, stabilising the bicycle while riding slowly, etc.) (Pfafferott, 1994) **8 years:** children are able to estimate physical abilities more accurately when performing physical exercises (Plumert, 1995) **8 years:** cycling without wobbling when stopping (>85%) (Michaelis & Niemann, 1999) **8-9 years:** 91% of the 8 to 9-year-old children needed less than 1 second to interrupt their action (cranking toy cars attached by string over a long plank using a hand crank) in response to a signal (Limbourg, 1995) **8-10 years:** on average, children required 0.8 seconds of reaction time, 10-year-olds required 0.6 second and adults only 0.4 seconds (Hoffmann, Martin, & Schilling, 2003)		**8-9 years:** children cross the road at normal walking speed and orientate themselves by the various areas of the road (pavement, edge of pavement, line of sight) (Limbourg, 1976)	**> 8 years:** contrast sensitivity develops fully between 8 and 19 years of age (Leat, Yadav, & Irving, 2009)		**8 years:** for 8-year-olds, central vision is predominantly important in order to maintain balance in a stable manner. In comparison, for 6-year-olds and/ or 10-year-olds, central and peripheral vision is equally important for stable postural control (Nougier, Bard, Fleury, & Teasdale, 1998). **8-9 years:** peripheral perception (>85%) (Van der Molen, 2002)	**8-9 years:** understanding of spatial relationships (>85%) (Van der Molen, 2002) **8-9 years:** adequate estimation of distances (>85%) (Van der Molen, 2002)	**up to 8 years:** children had problems looking in a different direction to the direction of travel. If they did try to do so, they had great difficulties in keeping their balance (Küting, Boigs, & Winkler, 1979) **8-9 years:** only 43% of the children were able to estimate speeds correctly (Günther & Limbourg, 1977) **< 9 years:** when deciding whether to cross the road, children principally take visual stimuli into consideration, i.e. whether or not a car is visible (Ampofo-Boateng & Thompson, 1989)	**from 8 years onwards:** adequate interpretation of sound impressions (Wildner et al., 2009) **from 8-9 years onwards:** directional hearing functions (Pfeffer & Barnecutt, 1996) **8-9 years:** due to the greater negative impact of reflecting sounds, directional hearing in a real-world road setting appears only to be fully developed from the age of 8-9 years (Barton, Lew, Kovesdi, Cottrell, & Ulrich, 2013).	**8 years:** hearing is regularly called on in traffic (Finlayson, 1972) **8 years:** less than 50% of the vehicle sounds (driving away vs. approaching) could be correctly recognised (Pfeffer & Barnecutt, 1996).
9 years	**from 9 years onwards:** significant improvement in cycling one-handed (Basner and De Marées, 1993) **9-10 years:** motor skills for cycling, such as maintaining balance, braking, steering, staying in lane or keeping to a line in corners, are developed (Limbourg, 1997)						**9 years:** depth-of-field perception is fully developed (Limbourg, 2008) **9-10 years:** adequate estimation of speeds (>85%) (Michaelis & Niemann, 1999)		**from 9 years onwards:** signal direction is recognised (Wildner et al., 2009)	

Table 1: TRAFFIC SKILLS AND THEIR FOUNDATIONS

	COGNITIVE DEVELOPMENT					
Age	**Attentiveness (selective, duration, divided, distractibility)**	**Ability to adopt other perspectives**	**Thinking**	**Social and emotional competence**	**Hazard perception**	**Effects in traffic**
6 years	**6 years:** children in traffic direct their attention to relevant stimuli just as frequently as irrelevant stimuli (Tolmie et al., 2005) **6-8 years:** children have a system of paying attention that functions comparably well to that of an adult (Ristic, 2009). **6-10 years:** performance improves significantly in tasks where unimportant stimuli are incorporated into the task and a test is carried out to see how focused the child remains on the important aspects (Gómez-Pérez & Ostrosky-Solís, 2006)	**6 years:** children already have a kind of "theory of mind" (Cox, 1991) **6-8 years** (Limbourg, 2008) **or 6-7 years** (Piaget, 1983)**:** subjective adoption of perspective: The child is able to understand that another person also has his/her own perspective, based on his/her own thinking. This may be similar to one's own perspectives or not. The child is only ever able to concentrate on one perspective. However, he or she understands that other people's actions, just like his or her own, are partly determined by thoughts and feelings, and knows the difference between intentional and unintentional actions.	**6-8 years:** simple strategies for drawing conclusions, acquisition of systematic, ready-to-use knowledge begins, if-then thinking: naming of causes based on practical experience (Böttcher, 2005) **6-12 years:** concrete-operational stage (Piaget, 1983)	**6-8 years:** learning social norms and rules, switch between non-binding use and very close monitoring in shared play (Böttcher, 2005) **from 6 years onwards:** children are more motivated to complete tasks on their own, explore their own limits and those of the group (Kellmann & Arterberry, 2006) **from 6 years onwards:** children become increasingly independent of caregivers (Kellmann & Arterberry, 2006)	**< 6 years:** the speed of an approaching car is perceived as a greater potential risk factor compared to its distance (Rosenbloom, Nemrodov, Ben-Eliyahu, & Eldror, 2008) **6-7 years:** children can recognise accidents, dangerous situations and preventative measures more comprehensively than younger children. They begin to recognise their role as possible cause of a situation (Hargreaves & Davies, 1996) **6-7 years:** detection of a safe crossing place without training (<50%) (Michaelis & Niemann, 1999) **6-8 years:** accident risk increases continually (Richter, Gruner, Rollow, & Schneiders, 2006) **6-9 years:** inexperience and lack of knowledge are the main causes of accidents (Schneider, 2001) **6-17 years:** fearful children have just as many accidents as very lively, extroverted children; boys are involved in accidents more frequently than girls (Richter, Schlag, & Schupp, 2006)	**6 years:** children are more easily distracted by irrelevant stimuli than older children (Barton & Morongiello, 2011) **6 years:** children know that a helmet cannot prevent a fall, can distinguish between "falling" and "being injured", and understand that reflectors contribute to their own visibility. However, there is mostly still no understanding of reciprocal communication between children and other traffic participants at a zebra crossing (Briem & Bengtsson, 2000) **6-7 years:** while safe road behaviour at lights and zebra crossings is learned somewhat earlier, crossing the road at unregulated points and those with restricted visibility is still very difficult for 6 to 7-year-old children (Limbourg, 2010) **6-14 years:** children have the highest risk of having an accident as cyclists in traffic, a medium risk as pedestrians and a low risk as car passengers and train/bus users (Richter et al., 2006)
7 years	**7-8 years:** easy stimulation/distraction during processing of a task led to fewer mistakes; there were indications that the ability to gain an overview of the situation decreased as noise levels increased (Higgins & Turnure, 1984)	**7 years:** there is a consciousness that people make assumptions about other people's assumptions, and that these can be incorrect. If a child is aware of the existence of incorrect second order beliefs, he or she can draw conclusions as to the reasons for these (Astington, Pelletier, & Homer, 2002)	**7 years:** distinction between left and right possible (Limbourg & Senckel, 1976)		**7-8 years:** hazard perception is based on the existence of certain objects (e.g. a large car), while the object's surroundings are ignored (Underwood, Dillon, Farnsworth, & Twiner, 2007) **7-8 years:** while hazard perception is still rather idiosyncratic and self-centred at the age of 7-8, in older children (11-12 years) this changes to a more global perspective on traffic events (Underwood et al., 2007) **7-9 years:** children react less often to potential dangers (Meir, Oron-Gilad, & Parmet, 2015a, 2015b)	**7-8 years:** when organizing images of traffic situations based on their own safety criteria, 7 to 8-year-olds demonstrate a very individual, special perspective compared to the overall, integrated perspective of the older children (Underwood et al., 2007) **7-9 years:** children can be trained in hazard perception as pedestrians: children who had undergone training recognised possible dangers related to a restricted field of vision more often than those in the control group (Meir et al., 2015a) **7-9 years:** 7 to 9-year-old children recognised fewer situations (restricted field of vision due to parked cars) as dangerous compared to older children and adults (Meir, et al., 2015b) **7-10 years:** 7 to 9-year-old children and 9 to 10-year-old children recognised fewer situations (restricted field of vision due to a bend in the road) as dangerous compared to adults; 10 to 13-year-olds scored significantly better here than 7 to 9-year olds (Meir et al., 2015b) **7-10 years:** in a virtual study, it was possible to show that children increase their speed when crossing the road as soon as the traffic conditions become more risky (Morrongiello, Corbett, Milanovic, Pyne, & Vierich, 2015) **7-11 years:** the ability to predict the driver's intention correctly improves significantly with increasing age (Foot et al., 2006) **7-13 years:** In both 7 to 13-year-old children and adults, crossing the road is negatively affected by mobile phone communication. Influence of age: adults scored significantly better, followed by 11 to 13-year-olds. 7 to 8-year-old children had the worst score. Differences were apparent above all in maintaining a safe distance from approaching cars (measured by the time that passes until arrival of the next car after crossing the road): this safety distance increased from the 7 to 8-year-olds, through the 9 to 10-year-olds to the 11 to 13-year-olds and adults. 7 to 8-year-olds demonstrated the worst behaviour in this regard, with their safety distance being significantly less than that of all other age groups (Tapiro, et al., 2016) **7-13 years:** virtual study with 7 to 13-year-olds (7 to 9-year-olds, 9 to 10-year-olds, 10 to 13-year-olds) and adults: with increasing age and increasing experience, the attention paid to possible dangers rises and the ability to anticipate forthcoming events when crossing the road improves (Meir, Parmet, & Oron-Gilad, 2013)
8 years	**8 years:** in comparison with 11-year-olds, 8-year-olds have more difficulties in coordinating and controlling the focus of their attention (Irwin-Chase & Burns, 2000) **from 8 years onwards:** concentration is possible for a relatively long period of time (Limbourg, 1997) **>8 years:** children are less skilled at directing their attention to relevant information than older children (Miller & Weiss, 1981; Welsh, Pennington, & Groisser, 1991; Trick & Enns, 1998) **8-9 years:** selective attention is developed (Tabibi & Pfeffer, 2003)	**8-10 years:** subjective adoption of perspective: child can place him/herself in the position of someone else and knows that the other person can do the same (Limbourg, 2008). The child knows that, in principle, everyone can reflect on the behaviour of other people. Children of this age are able to form chains of perspectives. For example: "I know that the other person knows that I know…"	**8-9 years:** it is not the shortest route that is selected, but rather the safest (Günther & Limbourg, 1977) **8-10/11 years:** development of theoretical and simple deductive thinking, thought processes are uncoupled from concrete objects, causal thinking: cause and effect relationships, ascertaining of complex structures and understanding of proportions (Böttcher, 2005)	**8-10/11 years:** binding norms and rules determine social behaviour; change of rules when those involved agree (Böttcher, 2005)	**approx. 8 years:** forward-looking awareness of risk develops (Limbourg, 2001) **approx. 8 years:** children are increasingly competent at putting a reflective, less impulsive style of behaviour into practice, and this is reflected in safety-conscious actions (Rollett, 1993) **8-10 years:** boys demonstrate more risky behaviour than girls of the same age (Walesa, 1975) **8-11 years:** children can recognise dangers in relation to their perspective and that of the adults. They can distinguish between coping and avoidance strategies when dealing with dangers (Hargreaves & Davies, 1996)	**8 years:** children can control their attention to some extent. They can distinguish between relevant, irrelevant and neutral stimuli. These stimuli may facilitate paying attention in a selective manner or hinder it (Pearson & Lane, 1990). **8-9 years:** up to the age of approximately 8, children's behaviour as pedestrians is risky and not very reliable. Even older children (8 to 9 years) can sometimes still be distracted and then cease to exhibit safe road behaviour. Both as pedestrians and cyclists, boys are more at risk than girls, due to their leisure activities and their greater willingness to take risks (Limbourg, 2010). **8-9 years:** detection of a safe crossing place without training (50-85%) (Michaelis & Niemann, 1999)
9 years					**< 9 years:** children show a low awareness of possible dangers when crossing the road (Oron-Gilad, Meir, Tapiro, & Borowsky, 2011) **9 years:** speed and distance are evaluated separately as potential risk factors, but not in combination; risks are evaluated in the same way for children as for adults (Rosenbloom et al., 2008) **9-10 years:** preventative risk awareness is present (Limbourg, 2001) **9-10 years:** perception and anticipation of risks (>85%) (Michaelis & Niemann, 1999)	**9-10 years:** older children, who are more cautious, are also more resistant to distracting information than younger children (Dunbar, Hill & Lewis, 2001; Tabibi & Pfeffer, 2003). **9-13 years:** 9 to 13-year-olds cross roads (in a virtual study) more hesitantly than experienced adults (Meir, et al., 2013)

Table 1: TRAFFIC SKILLS AND THEIR FOUNDATIONS

	MOTOR SKILLS			VISUAL PERCEPTION				
Age	Gross motor skills	Hand motor control / finger dexterity	Effects in traffic	Perception of colour / light and dark	Visual acuity and accommodation	Peripheral vision	Depth perception and spatial perception	Effects in traffic
10 years	**from 10 years onwards:** significant improvement in cycling through gates (Arnberg et al., 1978) **10 years:** cycling without wobbling when slowing down, when riding in a straight line, when looking back, when riding one-handed (hand signals) (>85%) (Michaelis & Niemann, 1999)					**10-12 years:** identical performance to adults in standard tests of peripheral perception (Martin, 2010)	**10-14 years:** improvement of the ability to adjust their own behaviour in relation to other objects (Plumert, Kearney, Cremer, Recker, & Strutt, 2011; Stevens, Plumert, Cremer, & Kearney, 2013)	**< 10 years:** children often choose smaller gaps between approaching cars than older children and adults. When leaving the road, 6, 8 and 10-year-olds had significantly less time and more collisions with cars than 14-year-olds and adults (O'Neal et al., 2018) **10-12 years:** (with bicycles) Children had problems estimating the speed of vehicles (how long it would take until vehicles reached the crossing line) (Plumert, Kearney & Cremer, 2004); children underestimated the time that they would need to reach the other side, but overestimated their ability to get their bicycle moving (Plumert et al., 2004; Schwebel & Plumert, 1999); from the time of the decision, children needed longer to initiate the movement (entering the intersection) than adults (Plumert et al., 2004; Pitcairn & Edlmann, 2000) **10-11 years:** when crossing the road, children have not only noticed the current road situation, but have also anticipated what will happen in a few seconds (Whitebread & Neilson, 2000)
11 years							**11 years:** visual search strategies/skills in traffic comparable to those of adults (Whitebread & Neilson, 2000)	**from 11 years onwards:** when cycling, children demonstrated a significant improvement with visual orientation to the rear (Arnberg et al., 1978)
12 years			**12 years:** children more frequently choose safe gaps to cross the road than 5-year-olds (Plumert, Kearney, & Cremer, 2007) **12 years:** the main skills for safe cycling are largely fully developed between the ages of 11 and 12 (Zweuts, Vansteenkiste, Cardon, & Lenoir, 2016).			**up to 12 years:** field of vision approximately one third smaller than in adults (Wildner, Heissenhuber, & Kuhn, 2009) **from 12-14 years:** field of vision the same size as in adults (Berger, 1992)	**12 years:** performance in estimating the speed of approaching vehicles is comparable to that of adults (Hoffmann, Payne, & Prescott, 1980)	**<12 years:** compared with adults, children have insufficient skills to adequately estimate the speeds of approaching vehicles when crossing a busy road (Wann, Poulter, & Purcell, 2011).
13 years	**13 years:** cycling without wobbling when slowing down (>85%) (Michaelis & Niemann, 1999) **13-14 years:** further developmental leap in psychomotor skills – significant performance improvement in motor skills (Arnberg et al., 1978) **13-14 years:** all skills (motor and cognitive) necessary for safe cycling are developed (Limbourg, 2003; Borgert & Henke, 1997) **13-15 years:** on their bicycles, children can master difficult, often unforeseeable and unknown situations in real-world traffic (Basner & de Marées, 1993)		**5-13 years:** only slight performance improvement in cycling between 2 boundary lines between 5 and 13 years of age; performance only improves rapidly from 14 years of age onwards (Arnberg et al., 1978)					
14 years-18 years	**14 years:** reaction time reaches adult level (Bächli-Bietry, 1998; Uhr 2015)					**14 years:** peripheral vision not yet fully developed (Schützhofer, 2017) **15 years:** significant performance decline in peripheral vision due to puberty (Schützhofer, 2017)		**14 years:** the timing of stepping onto the road improves with increasing age and reaches the level of an adult at the age of 14 (O'Neal et al., 2018).

Table 1: TRAFFIC SKILLS AND THEIR FOUNDATIONS

	ACOUSTIC PERCEPTION		COGNITIVE DEVELOPMENT					
Age	General hearing ability, directional hearing and noise differentiation	Effects in traffic	Attentiveness (selective, duration, divided, distractibility)	Ability to adopt other perspectives	Thinking	Social and emotional competence	Hazard perception	Effects in traffic
10 years	**10 years:** auditory perception first reaches the level of an adult at the age of approximately 10 (Johnson, Hannon, & Amso, 2005; Werner & Gray, 1998). Younger children, in particular, are less able than adults to recognise auditory stimuli at higher frequencies (Werner & Gray, 1998)			**10-12 years:** reciprocal adoption of perspective: children can now step away from a two-person interaction and place themselves in the position of a third person (Limbourg, 2008)		**10-11 years:** understanding of ambivalent emotions (Schneider & Lindenberger, 2012)	**10-11 years:** the frequency of rarer accidents (e.g. drowning) is overestimated, while the frequency of more common accidents (e.g. bicycle accidents) is underestimated; children are subject to the optimism bias: they estimate the chance of having an accident themselves, compared to their peers, as generally less likely (Joshi, MacLean, & Stevens, 2018) **10-11 years:** hazard perception among cyclists: children demonstrate inefficient gaze behaviour, a later focus on danger and slower reactions to danger than adolescents (Zeuwts, Vansteenkiste, Deconinck, Cardon, & Lenoir, 2017) **10-12 years:** detection of a safe crossing place without training (>85%) (Michaelis & Niemann, 1999)	**up to 10 years:** when crossing, children focus on distance and not on the speed of the vehicles. As a result, they always choose the same size of gap, irrespective of the situation (Walter et al., 2012) **< 10 years:** children often choose smaller gaps between approaching cars than older children and adults. When leaving the road, 6, 8 and 10-year-olds had significantly less time and more collisions with cars than 14-year-olds and adults (O'Neal et al., 2018) **10-11 years:** crossing the road while talking on the telephone leads to significantly more risk-taking (Schwebel et al., 2012) **10-11 years:** it is first at the age of approximately 10 to 11 that cognitive abilities for cycling are developed to the extent that children are able to meet the requirements regarding road traffic, at least when in an emotionally neutral mood and without any peer-group influence (Uhr et al., 2017). **10-11 years:** the ability to recognise safe and dangerous road crossing points and to distinguish between them is present; compared to adults, children still need more time to recognise these (Tabibi & Pfeffer, 2003) **10-14 years:** children still allow themselves to be distracted on the road, particularly by social interactions with their peers (Walter et al., 2013)
11 years	**11 years:** were able to correctly identify 60% of vehicle noises (driving away vs. approaching) (Pfeffer & Barnecutt, 1996)						**11 years:** children can estimate risks when crossing the road (Ampofo-Boateng & Thomson, 1991)	**11 years:** children are able to make adequately safe estimates to cross the road safely (Ampofo-Boateng & Thomson, 1991).
12 years			**up to 12 years:** it is difficult for the child to process multiple characteristics of a situation simultaneously (Schieber & Thompson, 1996) **12-13 years:** when working on a task, it was easier for children to adjust to the distraction/sound level (acoustic stimulus), and in this process the children were able to focus/concentrate more intensively on the task than in the "quiet" conditions (Higgins & Turnure, 1984)		**12-14 years:** shifting/task switching as components of executive functions is successful even in complex situations where it is necessary to switch between mental states, actions or tasks (Best, Miller, & Jones, 2009; Best & Miller, 2010)		**11-12 years:** perception of complex traffic situations takes place both effectively and in full (Pettit & Janks, 1996)	**Executive functions:** adolescents are able to estimate risks in a rational manner with similar accuracy to adults, yet they still behave in a more risky fashion as their behaviour is more strongly controlled by rewards (recognition of their peers) (Konrad, Firk, & Uhlhaas, 2013)
13 years			**13-14 years:** attention and concentration fully developed (Dordel & Kunz, 2005) **13-14 years:** all skills (motor and cognitive) necessary for safe cycling are developed (Limbourg, 2003; Borgert & Henke, 1997) **13-14 years:** development of attention is not complete until around 13-14 years of age (Limbourg, 1997)			**13-16 years:** taking risks and making risky decisions decreases with increasing age (3 age groups: 13-16 years, 18-22 years, adults from 24 years). For younger age groups (13-16 years and 18-22 years), the presence of a peer group leads to riskier behaviour and riskier decisions than is the case with adults (Gardner & Steinberg, 2005).		**13-14 years:** the willingness to comply with rules and to behave in a risk-aware manner falls significantly, while the peer group's influence on risk behaviour in traffic increases (Schützhofer, 2017)
14 years-18 years			**up to 14 years:** speed of perception not yet fully developed (Schützhofer, 2017) **up to 15 years:** resistance to distraction is not yet fully developed (Van der Molen, 2002) **15 years:** significant performance decline in speed of perception due to puberty (Schützhofer, 2017)		**Adolescence:** the limbic system (responsible for reward) develops rapidly, while the prefrontal cortex (control centre) only develops gradually (Uhr, 2015; Steinberg, 2008; Luna et al., 2001). This may result in risky and spontaneous behaviour (Schützhofer, Rauch, & Banse, 2017).	**14 years:** neuronal circuits for affect regulation are still developing during adolescence and have not yet reached adult levels (Passarotti, Sweeney, & Pavuluri, 2009) **14-16 years:** children and adolescents are often in the "conformist stage". Adaptation in line with the peer group is important. (Crone, 2011; Westenberg & Gjerde, 1999; Schützhofer, 2017) **14-15 years:** young people in the conformist phase of adolescence are significantly less willing to abide by rules and norms than 11 to 13-year-olds or 16 to 18-year-olds (Schützhofer, 2017). **16 years:** individuality and tolerance become more important, the "self-confident stage" begins (Crone, 2011; Westenberg & Gjerde, 1999)	**14-17 years:** accidents are increasingly caused by conscious rule violations (Schneider, 2001)	**14 years:** the time at which to enter the road between two moving cars improves constantly over the course of development and reaches the level of an adult at the age of 14 (simulation study on crossing the road) (O'Neal et al., 2018) **14-15 years:** risk appetite in road traffic reaches its peak and then falls with increasing age (Schützhofer, 2017) **Up to 15 years:** in children up to 15 years of age, the percentage of perception errors among cyclists (particularly incorrect focus of attention) and, connected to this, the failure to observe details relevant to traffic, is higher than among older cyclists (Platho, Paulenz, & Kolrep, 2016) **16 years:** the peer group loses its relevance; behaviour in line with the rules in traffic once again reaches the level of 12 to 13-year-olds (Schützhofer, 2017)

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