Collision avoidance in road crossing

Behaviour of children with and without hemiparesis

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The research presented in this thesis was carried out at the research group ‘Perceptual motor control: development, learning and performance’ of the Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands.


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Behaviour of children with and without hemiparesis

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Chapter 1

General introduction
Introduction

Collision avoidance is such a common practice that we are hardly aware of our excellent skills. A failure due to a slight lapse of inattention or a misjudgement, however, may have vast consequences. Imagine the sky is blue with a change in the weather pending. When you look upward, you may observe numerous lines caused by all the airplanes flying over. Considering these higgledy-piggledy patterns, it is incredible that these planes never collide. Of course we know that the air-traffic control, the navigator, and the equipment aboard guarantee well-planned routes and different fly heights. However, sometimes you cannot escape from the thought that the planes are apparently on a collision course. More down to earth; isn’t it surprising how we manage to survive in traffic? Because of traffic rules, some organisation is observable in the apparent chaos that exists in urban areas. Still, each traffic participant must possess excellent anticipatory and reactive skills. Once in a while, a cyclist or running child might unexpectedly appear out of the blue. In most occasions both parties involved have a lucky escape because at least one of them is capable to adjust the speed or movement path so as to avoid a collision. These situations are very demanding for adult road users. But for less skilled individuals, like young children or physically impaired people, this is sometimes beyond their capabilities. It is these groups of road users that appear most vulnerable (e.g. Fontaine & Gourlet, 1997; Gaebler-Spira & Thornton, 2002).

This thesis examines the skill of avoiding collisions with approaching moving objects, and in particular the competences of primary-school children and children with motor impairment. Pedestrian road crossing is chosen as the point of departure. As will be explained in Chapter 2, road crossing consists of several component skills, which are all of importance to participate in traffic safely. This thesis, however, does not aim to cover road-crossing behaviour in general, but mainly focuses on three component skills. First, once the pedestrian has found a safe place to cross, he/she must decide if and when to cross the road through the flowing traffic stream. Second, the moment to start walking must be timed carefully, which should not be too late in order to avoid a collision with the successively approaching vehicle. Finally, once crossing is initiated, the spatial-temporal characteristics of locomotion (i.e. path direction and/or walking speed) must be coordinated to the spatial-temporal characteristics of the approaching vehicle(s); for example, if a vehicle accelerates or approaches more quickly than initially judged, walking speed may have to be increased. The overarching goal is to assess whether collision proneness relates to the degree to which the three component skills are mastered by children of different age or physical abilities.
The thesis is roughly arranged into two parts. Chapter 2, 3, and 4 deal with questions regarding age-related differences in behaviour of typically-developing children and adults. Chapter 5 and 6 assess collision avoidance in children with hemiparetic Cerebral Palsy (CP). The reported studies employed different experimental designs. Both parts lead off with a design in which judgements to cross or not to cross are made at a simulated road in front of an approaching bike. The judgements are analysed and considered as safe, unsafe, or cautious relative to the individual’s action capabilities. In the subsequent chapter a new design is employed that, compared to prior work, enabled a more detailed focus on the motor planning and control processes that underlie collision avoidance. In order to do so, participants manually push a doll across a small road between successively approaching toy vehicles, thereby departing from actual road-crossing behaviour. These chapters specifically focus on the timing of movement onset and the subsequent unfolding of the movement in relation to the approaching vehicles.

Theoretical background

The coupling between perception and action

According to the ecological psychology, perception and action are coupled inseparably (Gibson, 1979). This relation between perception and action is expressed by the concept of affordances. It describes the environment in terms of the possibilities for actions. Gibson defined an affordance as ‘a specific combination of the properties of its substance and its surfaces taken with reference to an animal’ (J.J. Gibson, 1977, p 67). This means that to one person the environment may afford a certain action, while for another person it does not, depending on the action capacities (e.g. Warren, 1984; 1988). The capability to navigate in-between moving objects, like in road crossing, may be considered a specific example of collision avoidance. Inter-vehicle traffic gaps of different size may or may not afford the pedestrian to cross safely, or may afford to avoid collisions with approaching vehicles. The crossability of a road depends on the temporal size of the gap and the distance to cover in relation to the locomotor abilities of the pedestrian (e.g. Lee, Young, & McLaughlin, 1984; Oudejans, Michaels, Van Dort, & Frissen, 1996b).

Long before he introduced the concept of affordances, Gibson (Gibson & Crooks, 1938) gave a field description of locomotion in a cluttered environment in terms of available and safe travel paths. He described the field of safe travel as all the possible unimpeded paths that a traffic participant at any given moment can take.
Gibson visualised the dynamics of the field of safe travel as a tongue protruding forward in front of the road user, the boundaries of which are determined by other road users, kerbs and so on (Fig. 1.1). These obstacles were considered to have a negative affordance (‘valence’) for locomoting toward, i.e. they are to be avoided. The field of safe travel itself, in contrast, does afford moving toward. Because traffic situations are continuously changing, the shape of the field of safe travel also changes continuously, elongating, contracting, widening and narrowing, resulting in changing affordances. In the case of a contracting or narrowing field of safe travel, the traffic participant must judge whether to change his/her speed and/or direction; otherwise a collision with one of the obstacles will be imminent. The safety margin that is maintained with regard to the ‘objects to-be-avoided’ represents an index of cautiousness of the road user, or the degree to which he/she is at risk of colliding with the obstacle. Chapter 3 and 5 examine the affordance crossability by scaling environmental properties, i.e. different temporal ‘traffic gaps’, to individual crossing abilities, i.e. the time needed to cross the road. The perception-action coupling is evaluated in terms of safety and accuracy of crossings for individuals of different age and physical ability.

In addition, in Chapter 3 the need of maintaining a natural coupling is examined explicitly by comparing verbal reports without crossing action to behavioural outcomes when actual crossing is required. Although previous work on road-crossing judgements was for obvious safety reasons frequently limited to verbal reports, it is questionable whether these perceptual judgements reflect what participants are doing when real crossing is required. In this thesis, all ensuing experimental chapters maintain a natural coupling between perception and a meaningful action. This not only may provide more accurate insights into perceiving whether a road affords crossing, but can also provide insight into the processes (and/or deficits) underlying movement planning and control in collision avoidance.

**The coupling between environment and movements**

Once the decision to cross is made, the continuously changing relation between actor and traffic environment, like the field of safe travel, can be described in terms of the direct relationship between environmental properties and (reactive) movements. This coupling is established at a different level than the coupling between perception and action; namely, it is not about whether the situation affords a certain action, but about the execution of the action in relation to the environment. For road crossing, this concerns movement speed and direction and the tuning to the spatial-temporal characteristics of approaching vehicles. So far, research on environment-movement
Figure 1.1. The field of safe travel for a pedestrian who wants to cross a road with one vehicle approaching; the clearance lines of the vehicle indicate negative valence and should be avoided; a) the field is open and allows the pedestrian to cross; b) the field is narrowing and the pedestrian should adjust his/her movement path or speed; c) a closed field of safe travel, the pedestrian needs to halt.

coupling in road crossing is virtually absent. However, a number of experimental studies on interceptive actions, in which arm movement or hand aperture had to be precisely adjusted in response to the spatial-temporal characteristics of an object to-be-intercepted, point to a finely attuned coupling in adults, but less so in primary school children (e.g. Davids, Kingsbury, Bennett, & Handford 2001; Peper, Bootsma, Mestre, & Bakker, 1994; Savelsbergh, Whiting, & Bootsma, 1991; Schneiber, Sveistrup,
McFadyden, McKinley, & Levin, 2002). Chapter 4 and 6 examine collision avoidance at this level, considering timing of movement onset and adjustments in movement velocity in relation to the changing positions of the objects to-be-avoided.

**Young children’s collision proneness**

Compared to adults and pre-adolescents, child pedestrians are at increased risk to be involved in traffic accidents (see Chapter 2). This underlines the importance of systematic research into children’s skills that are related to road crossing. Chapter 2 reviews children’s capacities on four component skills; namely, finding a safe place to cross, looking behaviour, perceptual judgements whether or not to cross, and the visual guidance of walking across the road. The majority of research has focussed on children’s perception of the traffic environment and knowledge of safe crossing practices. It is generally agreed that around 9 years children are aware of the difference between safe and unsafe behaviour (e.g. Ampofo-Boateng & Thomson, 1991). By contrast, the findings with respect to judgements whether or not to cross in front of an oncoming vehicle are much more ambiguous, perhaps because many studies did not maintain a natural coupling between perception and action. In addition, walking behaviour and movement control during crossing has hardly been studied, and accordingly our knowledge about this skill remains limited. It seems obvious that more research is necessary to estimate the age at which children master these component skills.

Thus far, visual-motor processes underlying collision-avoidance behaviour in children have not been studied. However, studies examiningprehension in children show that the visual control of movements still develops during primary school age. Movements become smoother, inter-joint coordination becomes more consistent while visual information is increasingly used to optimise accuracy (Kuhtz-Buschbeck, Stolze, Johnk, Boczek-Funcke, & Illert, 1998; Schneiberg et al., 2002; Smyth, Katamba, & Peacock, 2004). Likewise, studies on interceptive actions in primary school children have found that with age timing accuracy and adaptation to constraints imposed by the environment improve (Benguigui & Ripoll, 1998; Ricken, Savelsbergh, & Bennett, 2004). This may suggest that between the age of 5 and 12 years visual-motor processes for collision avoidance in children may also develop and become more accurate and attuned to the demands of the environment.

Chapter 3 and 4 aim to investigate whether the increased collision proneness of young children is associated with age-related differences in the perception of the
affordance crossability and the visual control of movements. The aim is twofold, not only do we examine what processes may limit children’s performance; we also try to delineate how they differ from the well-developed adult processes. Only after we have a thorough understanding of the processes that limit children’s safety, training programmes may be developed that improve their behaviour.

Physical impairment and collision avoidance

Besides the age differences in collision-avoidance behaviour, this thesis examines the influence of hemiparetic CP. Hemiparetic CP can be defined as a non-progressive disorder of the brain that affects one side of the body. Left hemiparesis is caused by right hemispheric damage (RHD), whereas right hemiparesis is caused by left hemispheric damage (LHD). The damage in the brain may be caused by ischaemic infarction, haemorrhage, or an interruption of the oxygen supply to the brain during pregnancy or around the time of birth. The severity of symptoms can vary widely from hardly detectable to severe impairments of the contra-lesional body side. The nature of the disorder is spastic (muscular stiffness and weakness resulting in uncontrolled jerky movements) in most cases, but can also be ataxic (poor coordination, weakness, shakiness) or choreoathetoidic (slow, involuntary movements). In addition, individuals with hemiparetic CP may experience other problems of which visual impairments may be of importance in the context of safely participating in traffic situations (Bax, 1964; Carr, Reddy, Stevens, Blair, & Love, 2005). Because of their physical (and sometimes also cognitive) impairments, individuals with hemiparetic CP may be even more vulnerable than typically-developing children.

Several studies have shown that processes related to goal-directed actions in individuals with hemiparetic CP are disturbed and result in adversely affected behaviour. Van der Meer, Van der Weel, Lee, Laing, and Lin (1995) demonstrated that as compared to healthy preterm infants, infants diagnosed with CP anticipated worse when catching moving objects. Other authors have found that children and adolescents with hemiparetic CP demonstrate an adaptive movement strategy, different from a normal movement pattern. This strategy often involves a prolonged movement time for the non-preferred hand, deficits in timing, and diminished motion stability. However, fast externally-paced movements may be flexibly adjusted to position and velocity of a moving target. In addition, planning processes are reported to be disturbed, while processes related to movement execution may be relatively spared (Mackey, Walt, & Stott, 2006; Mutsaarts, Steenbergen, & Bekkering, 2005; Mutsaarts, Steenbergen, &
Meulenbroek, 2004; Steenbergen, Van Thiel, Hulstijn, & Meulenbroek, 2000b; Van Thiel, Meulenbroek, Hulstijn, & Steenbergen, 2000).

Chapter 5 and 6 aim to investigate whether the perception of the affordance crossability in children with hemiparesis is different from that in typically-developing children, and to identify the underlying movement planning and control processes that are involved in road-crossing behaviour of children with hemiparetic CP. The chapters report studies that examine whether specific disturbances in planning and control processes are associated with the number of collisions. Because some have argued that there are differences in the type of visual-motor processes that are adversely affected between individuals with left and right hemiparesis (e.g. Steenbergen, Meulenbroek, & Rosenbaum, 2004), behaviour of the children with left and right hemiparesis are examined separately in order to identify the specific limitations for each group.

**Goals and outline of the thesis**

The present thesis examines three component skills of collision avoidance in road crossing in terms of affordances (perception-action coupling) and in terms of visual-motor processes. The purpose is to find whether there are 1) relations between age, degree of proficiency on the three component skills (i.e. visual judgements whether or not to cross, movement initiation timing, and velocity control during crossing), and the number of collisions; and 2) relations between physical impairment (LHD and RHD), degree of proficiency on the three component skills, and collision proneness.

**Chapter 2** addresses the importance of research into children’s road behaviour and describes the behaviour as consisting out of at least four component skills; namely, selecting a safe site and route, looking behaviour, perceptually judging ‘crossable’ traffic gaps, and crossing behaviour. It reviews the current literature on children’s competences to perform these components of road crossing. The importance of children actually performing the crossing action in studies on road-crossing behaviour is underlined explicitly. Furthermore, this chapter describes the outcomes of training studies that have been executed in order to improve children’s performance. Although this thesis does not address the issue experimentally, training studies are undoubtedly important so as to improve children’s road behaviour. The ensuing chapters particularly focus on the components perceptually judging traffic gaps and crossing behaviour. Because they have received little attention so far, further investigation would be useful.

**Chapter 3** examines the inseparability of perception and action in a road-crossing study by comparing verbal judgements to actual crossing behaviour.
Moreover, this chapter assesses the age differences in safety and accuracy of judgements to walk across a simulated road in front of an approaching bike in typically-developing children aged 5 to 7 years, 10 to 12 years, and adults. The outcomes are evaluated in terms of affordances, namely, is the road crossable given the individual action abilities. In addition, this chapter analyses environment-movement coupling by evaluating timing strategies in terms of the approach time of the bike.

Chapter 4 provides a more detailed description of the underlying visual-motor processes in collision avoidance. It examines children aged 5 to 7 years, 10 to 12 years, and adults, but on a task in which they manually push a doll between two consecutively approaching toy vehicles across a scale-size road. Movement initiation and in particular velocity control in relation to the continuous changing position of the approaching toy vehicles throughout the whole movement are subject to analysis. To this end, the required velocity model (RV-model) is modified (Peper et al., 1994). The outcomes are discussed in terms of separate processes thought to underlie visual planning and control of movements (Glover, 2004).

Chapter 5 assesses children with (hemiparetic) CP and compares their behaviour to the behaviour of typically-developing children. The design is comparable to that of chapter 3. In this chapter differences between children with RHD and children with LHD are explored. The study suggests that the children with RHD and LHD differ in the way they adjust their walking speed to prevent collision.

Chapter 6 adopts a design comparable to that of chapter 4 and provides a detailed description of visual-motor processes in collision avoidance of children with hemiparetic CP. We examine whether LHD and RHD is associated with differential deficits in planning and control (Glover, 2004) on the manual collision-avoidance task. Experiment 1 compares behaviour of typically-developing children to children with LHD and RHD, while Experiment 2 compares the preferred and non-preferred hand of children with LHD and RHD.

In the Epilogue the findings with respect to age differences and differences between typically-developing children and children with LHD and RHD are discussed. Applications in the field of road-crossing training programmes and rehabilitation programmes for children with hemiparetic CP are discussed.
Chapter 2

Road-crossing behaviour in young children
Introduction

It is widely acknowledged that young children are over-represented in traffic accidents. It is therefore obvious that reducing the number of child pedestrian accidents is an important research aim. Through the introduction of (additional) pedestrian facilities, specific traffic regulation and other improvements to roadway situations, the problem of children’s traffic safety may be reduced. In the end, however, such measures will only be beneficial if children’s road-crossing skills are taken into account. To this end, not only is an analysis of the pedestrian task indispensable, but it also needs to be established how the (component) skill(s) of road crossing change with age. The present chapter therefore aims to describe the age-related changes in road crossing and its component skills in 4- to 12-year-old children. Furthermore, training programmes that are directed at improving the component skills of road crossing, and that may reduce child pedestrian casualties, are reviewed. The improvements appear to be less than one would hope for, and as such we discuss whether the results from simulated environments should be generalised to actual traffic situations. We will dwell on some of the more important methodological aspects (e.g. the practice environment). Although characteristics like temperament and socialisation might explain a substantial proportion of safe or unsafe road-crossing behaviour (Plumert & Schwebel, 1997; Schwebel & Plumert, 1999; West, Train, Junger, West & Pickering, 1999), these will not be taken into account. Likewise, socio-economic and environmental characteristics are beyond the scope of this chapter. Before turning to children’s road-crossing skills, however, we start with an assessment of children’s exposure to risk situations.

Risk and exposure

Recent statistics show that child pedestrians up to 15 years of age are three times more at risk than older children and adults to be involved in a fatal accident (Road Accidents Great Britain, 2000), the risk being dependent on country, socioeconomic status, age and gender (Chapman & O’Reilly, 1999). Rivara (1990) reported that casualty rates in the United States varied from 1.9 to 5.4 fatalities per 100,000 children between 5 and 9 years of age, and from 0.9 to 2.0 per 100,000 for children between 10 and 14 years of age (cf. Dhillon, Lightstone, Peek-Asa, & Kraus, 2001; Howarth, Routledge, & Repetto-Wright, 1974; Routledge, Repetto-Wright, & Howarth, 1974). Obviously, reported injury rates are higher: respectively 111 and 79 per 100,000 children between 5 and 9 years and 10 and 14 years of age (Rivara, 1990). However, in the past few decades there has been a decrease in casualty rates in 5- to 9-year-olds. Nowadays, it is
at a somewhat older age that children appear particularly at risk (Chapman & O’Reilly, 1999). This shift may be due to a decline in children’s traffic exposure. Parents have become more reluctant to allow their children to walk unaccompanied, and there has been a concomitant increase in age at which children are allowed to cross roads unaccompanied (Roberts, 1993).

Nevertheless, a consideration of children’s traffic exposure emphasises the vulnerability of young children to traffic. In most definitions exposure relates to the number of children playing in the street without supervision, frequency of encounters with a car, frequency of crossing roads each day, and mode of travel to school (e.g. Van der Molen, 1981). It appears that, dependent on country and socio-economic status (e.g. owning a car), primary school children cross between one and ten roads each day (Macpherson Roberts, & Pless, 1998; Rao, Hawkins, & Guyer, 1997; Roberts, Carlin, Bennett, et al., 1997). The number of road crossings increases with age, and this contributes to the increasing exposure to traffic (Demetre & Gaffin, 1994; Howarth et al., 1974; Routledge et al., 1974; Rao et al., 1997; Stevenson, 1996). For instance, Rivara and co-workers (Rivara, Bergman, & Drake, 1989) report that 3 per cent to 33 per cent of kindergarten school children walk to school unaccompanied, whereas this increases to 15 per cent to 69 per cent of children in the fourth grade. On their way to school, the younger children in particular are accompanied by a parent, whereas on their way back home, children tend to walk with peers. When children play outdoors, they are more likely to walk than when going to school (Towner, Jarvis, Walsh, & Aynsley-Green, 1994). Importantly, it has been found that, within an age group, increased exposure is accompanied by increased risk, whereas with age groups, the risk relative to exposure decreases (Howarth et al., 1974; Macpherson et al., 1998; Routledge et al., 1974). The decline in the relative rate of children’s traffic accidents suggests, among other things, an increase in road-crossing skill with age. These age-related changes will be considered in the next section.

**Road-crossing skills**

The pedestrian road-crossing task can be divided into many component skills (Foot, Tolmie, Thomson, McLaren, & Whelan, 1999; Thomson, Tolmie, Foot, & McLaren, 1996; Van der Molen, Rothengatter, & Vinjé, 1981; Vinjé, 1981). In the present chapter we restrict ourselves to only four of these component skills. First, pedestrians have to find a safe site and a safe route to cross. Before they actually cross the road, pedestrians have to detect the presence of traffic, which involves strategic looking behaviour.
Subsequently, the pedestrian requires information about the time available to cross the road; that is, the pedestrian must visually judge whether a traffic gap is ‘crossable’. Finally, after having judged that a traffic gap is safe, pedestrians’ crossing behaviour (e.g. movement time and path) should be consistent and adapted to the situation. In order to determine at what age these component skills are properly developed, the remainder of this section reviews the development of these four component skills of the road-crossing task. It needs to be emphasised beforehand that possessing well-developed component skills does not guarantee safe road-crossing behaviour, although it may provide an indication of what may be expected of a child at a particular age (cf. West et al., 1999).

Select a safe site and a safe route
A child must select a safe site and route to cross. That is, a child should be able to distinguish safe places from dangerous places and situations where crossing should not be attempted. A safe site to cross is usually considered a place that provides an unobstructed view of oncoming vehicles. In contrast, locations where visibility is restricted, such as at bends or near parked cars, and complex situations, such as junctions where traffic might arrive from a number of directions, are considered dangerous. However, there are some conflicting opinions: Rothengatter (1984) argues that quiet streets are particular dangerous for younger children, and Grayson (1981) argues that crossing from the offside of a parked vehicle reduces the distance to be walked and that vehicle speed is lowest at junctions.

At what age are children able to select a safe site to cross a road? To answer this question, Ampofo-Boateng and Thomson (1991) presented children between 5 and 11 years of age with a tabletop traffic simulation and photographs of road situations, and took the children to real-world sites. They found that, on the one hand, in all the three testing situations the 5- to 7-year-olds frequently recognised dangerous situations (e.g. crossing between parked cars, at junction, or near a hedge) to be safe ones. Identifying safe places, on the other hand, was much better. Their judgements appeared to rely almost exclusively on the visible presence of vehicles that were nearby. Their judgements were based on a rule of thumb ‘don’t cross if you see cars, do cross if you don’t’, whether the view was blocked or not. The young children also tended to prefer the shortest route to the destination as the safest (see also Ampofo-Boateng, Thomson, Grieve, et al., 1993; Thomson, Ampofo-Boateng, Lee, et al., 1998; Thomson, Ampofo-Boateng, Pitcairn, et al., 1992). Only at 9 years of age did children start to correctly recognise the dangerous sites; for example, those where vehicles might be hidden from
view. These findings thus confirmed earlier observations of Demetre & Gaffin (1984), who took children to a real-world site and found that 8-year-olds, but not 6-year-olds, identified the place with a clear view (i.e. without parked cars) as the safest site to cross. Moreover, children who had experience with crossing a road unaccompanied were much more likely to select a site that provided a clear view.

In short, these findings and others (e.g. Whitebread & Neilson, 2000) strongly suggest that children’s ability to select safe sites to cross a road is not appropriately developed before 9 years of age. The ability appears strongly related to experience. These findings are consistent with figures that about 40 to 70 per cent of 5- to 6-year-old children’s accidents involve attempts to cross near parked cars, compared with about 20 per cent of 13- to 14-year-olds’ accidents (Van der Molen, 1981). It appears that at the age of 9 years children are increasingly aware that the visibility of oncoming traffic may be obstructed. It is important to note, however, that in none of these studies children were actually required to cross the road.

**Looking behaviour**

After having selected a place to cross, the child, before making a decision to cross, has to detect whether any traffic is approaching. Obviously, visual search strategies are highly dependent on the road traffic situation and the moment-to-moment changes of that situation. However, when standing (or walking and running) at the kerbside, every visual search strategy should contain looking left–right–left before crossing the road. Limbourg and Gerber (1981) found in an actual road-crossing task that only about 10 per cent of the 3- to 7-year-old children stopped at the kerb before crossing the road, and that about 20 per cent of these children looked left and right before crossing. In a recent study, Zeedyk, Wallace, & Spry (2002) confirmed these observations. Five- and 6-year-olds were asked to cross a road at a T-junction at which there was an approaching car, and between parked cars. Road-crossing behaviour was extremely poor. More than half of the children failed to stop before proceeding from the kerb onto the road. Looking before proceeding was exhibited by no more than about 30 per cent of the children, and when looking did occur it was as likely to be in the inappropriate as in the appropriate direction. Strikingly, at the T-junction only 7 per cent of the children looked for oncoming traffic. Also, looking whilst crossing the road occurred more often when children crossed from between parked cars. Rivara, Booth, Bergman, Rogers, & Weiss (1991) also examined somewhat older children. Remarkably, they found that at 7 to 9 years of age children stopped even less often at the kerb than children of 5 and 6 years of age (25 per cent and 50 per cent respectively). Looking left–right–left before
crossing the road was observed in about 25 per cent of the children and did not change with age. Likewise, the percentage of children (15 per cent) who kept looking for traffic while crossing did not change with age. From these studies, all of which observed children actually crossing a road, it can be concluded that looking behaviour is poor in 3- to 6- year-old children. They do not stop at the kerb, they do not look left–right–left to detect traffic, and looking during crossing is virtually absent. Moreover, it appears that even at 9 years of age, children do not perform much better. At what age children do, or whether they should, consistently stop at the kerb and look left–right–left before proceeding onto the road remains to be established. Nevertheless, one recent study (Whitebread & Neilson, 2000), which used three television screens that showed the views to the left, centre and right along a road, suggests that even 11-year-old children have not fully attained adult looking performance. The authors investigated the visual search strategies adopted by children of primary school age and their relation to the development of general performance as a pedestrian. Children were required to detect information from video presentations and make a decision about when it was safe to cross the road. Eye and head movements were measured. It was found that 4- and 5-year-old children had less but longer fixations, and often had problems of keeping attention on one of the screens. The oldest children fixated more frequently and for shorter durations, but did not reach the frequency of switching attention demonstrated by the adults. Children at 10 and 11 years of age and adults performed a ‘last-minute’ check of all three directions before deciding the road was safe to cross. Whitebread and Neilson showed that the visual search characteristics were related (within age groups) with component road-crossing skills (i.e. selecting a safe site, detecting dangerous vehicles, and identifying safe crossing times). While there were large individual differences, perhaps implying that exposure is an important determinant, this study suggests that a shift in visual search strategy occurs certainly not before the age of 7–8 years, and even at the age of 11 adult looking behaviour is not yet fully acquired.

**Visually judging ‘crossable’ traffic gaps**

When a child has detected an oncoming vehicle, it must judge whether, and if so when, it is safe to cross the road in front of the vehicle. That is, the child must visually judge whether a traffic gap is ‘crossable’. Only when the time-to-arrival of an approaching vehicle is longer than the time needed to reach the far kerb can the child cross the road safely. Hence, the child must perceive the size of gaps not in any abstract or absolute terms but in terms of the time it will take to walk across the road (Lee, Young, & McLaughlin, 1984). In this respect, a consideration of the child’s conception of speed...
(Cross & Mehegan, 1988) may distort the investigator’s view of young children’s difficulties in judging whether a traffic gap is crossable. A prediction motion task, as used by Hoffmann, Payne, & Prescott (1980), may be the more suitable methodology. In this study, 5- to 10-year-old children were shown movie film clips of vehicles approaching with speeds between 27 and 55 kph. The clips terminated when the vehicle was at a distance of 20, 60 or 100m from the camera position. The children’s task was to press a key when they thought that the vehicle would have passed their location beside the road. It was found that all children underestimated time to arrival, but this underestimation decreased with age, and performance comparable to adults was reached at about 12 years of age. Nevertheless, there were large variations within each age group, and even among the 5- to 6-year-olds there were children who performed in the adult range. Underestimating a vehicle’s time to arrival does not necessarily mean, however, that children’s crossability judgements are cautious, because it remains unknown from this study how they estimate the time to cross the road.

Lee and co-workers (Demetre, Lee, Pitcairn, et al., 1992; Lee et al., 1984; Young & Lee, 1987) described a simple, safe method involving normal traffic where 5- to 10- year-old children’s road crossing was investigated in a roadside simulation task. The method comprised a pretend road, which the child was told to cross as if crossing the adjacent road in the face of oncoming vehicles. The children were generally more cautious than the adults, which may indicate that adults accepted smaller gaps (cf. Pitcairn & Edlmann, 2000). For instance, 5-year-olds rejected almost half of the gaps of adequate duration. The number of missed opportunities decreased with age (see also Whitebread & Neilson, 2000; but see Pitcairn & Edlmann, 2000). Though children were overcautious, they did occasionally accept unsafe, too short gaps. The proportion of children that accepted tight fits was sometimes (Lee et al., 1984), but not always (Demetre et al., 1992; Young & Lee, 1987; see also Pitcairn & Edlmann, 2000) found to decrease with age. Finally, it was stressed that, with an increase in age, an increasing number of children performed in the adult range, suggesting that even the youngest children could be trained to an adequate level (see the section about training programmes). These findings suggest that young children are not as accurate as adults in judging whether or not a road is crossable. Rather than a general inability in visually timing per se, the relative inaccuracy may reflect a compensatory strategy of setting a wider safety margin (Demetre et al., 1992; Lee et al., 1984). Because the oncoming vehicle’s speed was not controlled, it cannot be excluded that younger children were using distance instead of time to arrival, as was assumed by Lee and co-workers, to decide whether a traffic gap was crossable. Assuming that traffic speeds under 30 mph
were overrepresented (see Connelly, Conaglen, Parsonson, & Isler, 1998), a decision based on distance would also lead to rejecting larger (in time) gaps, and consequently rejecting more gaps.

In their study, Connelly et al. (1998) measured the vehicle’s actual speed and distance with a laser speed and distance recording device. Primary school children said ‘Yes, yes, …’ repeatedly until the approaching vehicle reached a point at which they would no longer be prepared to cross in front of it, at which moment they said ‘No’. This was the signal to measure the vehicle’s speed and distance. Overall, children were setting similar distance thresholds regardless of the vehicle’s approach speed, although judgements were inconsistent, particularly those of the 5- and 6-year-olds. This resulted in safe (i.e. taking the pre-determined crossing time into account) judgements for the lower speeds (< 55 kph), but also an increasing number of risky judgements for the higher speeds (> 56 kph) in particular for the 5- to 9-year-olds. At the highest speeds it was only the 11- to 12-year-olds who made safe decisions. Connelly also calculated the remaining distance and time between the front of the vehicle and the child at the moment the child would have arrived at the centre of the road, had they begun to walk just as they said ‘No’. Both the remaining distance and time decreased with the vehicle’s approach speed, underlining the finding that judgements were safest for the lowest speeds. Hence, primary school children appear generally overcautious, which is in agreement with the conclusion of Lee and co-workers. However, at higher vehicle speeds, judgements of whether a traffic gap is safe to cross become increasingly risky. Hence, the observation in most studies that the percentage of missed opportunity decreases with age might be caused by a shift from a distance to time strategy instead of setting narrower safety margins (cf. Demetre et al., 1992). However, Connelly et al. (1998) suggested that even adults primarily rely on distance.

In sum, most authors agree that visual timing judgements of the crossability of traffic gaps change between 5 and 12 years of age. Remarkably, the judgements of the youngest children are the most cautious. It remains unclear, however, what induces the change in the children’s ability to judge traffic gaps visually.

Crossing behaviour
With respect to crossing behaviour, a few developmental trends can be identified. The most frequent child pedestrian accident occurs when dashing out on the road, the percentage of which decreases with age (Van der Molen, 1981; Van Schagen & Rothengatter, 1997). Zeedyk et al. (2002) is the only experimental study that examined this issue by having children actually cross a road. They reported that, at a T-junction
with a moving car, 75 per cent of the 5- and 6-year-olds were either running or skipping across the road, and that when crossing between parked cars half of the children demonstrated this behaviour. Moreover, Limbourg and Gerber (1981) found that children between 3 and 7 years of age crossed the street diagonally instead of at a right angle (see also Ampofo-Boateng & Thomson, 1991). Likewise, the crossing times reported from the pretend road simulation studies tended to decrease with age. Also the inconsistency of the crossing times decreased with age (Lee et al., 1984; Young & Lee, 1987). Some of the observed inconsistency may be due to children attempting to adapt their crossing speed to the time available to cross: the shorter the time, the faster the children tended to walk (Young & Lee, 1987). This ability to adapt walking while crossing warrants much research. In this respect, it is characteristic that only between 15 per cent and 40 per cent of the primary school children are reported to look while crossing the street (Rivara et al., 1991; Zeedyk et al., 2002). Finally, the pretend road simulation studies showed that the time between making a judgement and starting to cross a road systematically decreased with age. Likewise, the inconsistency of this starting delay decreased, indicating that with increasing age children hesitated less before crossing (Lee et al., 1984).

To summarise, there is convincing evidence that the four component skills of road crossing improve during the primary school years. It appears that at 9 years of age children are increasingly aware that the visibility of oncoming traffic may be obstructed, and hence are able to select a safe site and route to cross. In contrast, although looking behaviour is suggested to improve from 7 and 8 years of age, even the 11-year-olds did not perform in the adult range. The ability to visually time crossing also undergoes changes between 5 and 12 years of age. Encouragingly, however, the youngest children appear more cautious. Although it is clear that the youngest children, in particular, often run, other developmental changes in crossing behaviour remain blurred. Because of obvious reasons, the developmental changes of the component skills are to a greater or lesser extent derived from simulation or laboratory studies instead of actual road-crossing behaviour. Hence, it is difficult to compare the developmental rates of the component skills. Nevertheless, it appears that looking behaviour is the most likely candidate as a rate limiter (cf. Thelen & Smith, 1994) for the development of road-crossing skill. As such, training or education programmes that are directed at improving children’s looking behaviour (i.e. stopping at the line of vision, looking left–right–left, looking while crossing) might have the largest impact on their safety. Fortunately, there is a real possibility that children might be trained to adequate levels in looking behaviour, and also in selecting a safe site, visual timing, and
crossing behaviour. Almost every single study reported that some of the younger children performed like adults. Although the majority of the studies did not report the children’s traffic exposure, it seems reasonable to suggest that experience is an important contributor in the children’s ability to cross a road safely. The next section, therefore, reviews the attempts that were undertaken to improve children’s road-crossing skills.

Training programmes
The ultimate goal of training programmes and safety education is a decline in the number of children involved in traffic accidents. However, very large numbers of children would need to be trained before an impact on accident rates would be measurable (Rivara et al., 1991). Therefore, researchers have chosen to evaluate the effects of training programmes on (the components of) road-crossing skill or knowledge of that skill. Firm conclusions about the effectiveness of a training programme can only be drawn from methodologically sound studies. These involve at least a comparison between an intervention and a control group and the verification of long-term effects of the intervention (cf. Duperrex, Bunn, & Roberts, 2002a). Unfortunately, it is often considered undesirable to deny some children a training programme, and hence most studies have compared different forms of intervention. With this in mind, the effectiveness of training programmes that have attempted to improve children’s ability to select a safe site and route, to look appropriately, to detect crossable gaps, and to actual cross the road, is evaluated.

Training to select a safe site
Most children under 9 years of age are poor at judging a safe place to cross the road (e.g. Ampofo-Boateng & Thomson, 1991). In a series of studies Thomson and Ampofo-Boateng (Ampofo-Boateng et al., 1993; Thomson et al., 1992, 1998), therefore, examined the effectiveness of roadside training in a real road environment and training using a tabletop scale model, or a combination of both. The 5-year-old children were either trained individually or in small groups by parents or highly qualified teachers. The six training sessions of half an hour were aimed at recognising dangerous sites and routes, and emphasised the importance of the visibility of vehicles. The training did not consist of drills, but attempted to improve the children’s conceptual understanding. Roadside pre-tests, post-tests and follow up tests at about two and eight months after termination of the training were conducted. The children indicated the safe route by
pointing and describing it, though they were never asked to actually walk across the road. It was found that both the roadside and the tabletop training led the children to select safer routes and sites (Ampofo-Boateng et al., 1993; Thomson et al., 1992, 1998). In one study (Ampofo-Boateng et al., 1993), the trained children even performed like 11-year-old control participants. The latter training effect slightly deteriorated after a few months (Ampofo-Boateng et al., 1993), which was not the case in the other studies (Thomson et al., 1992, 1998). The authors concluded that in 5-year-olds, training substantially improves the ability to select safe sites and routes, and that these beneficial effects last at least as long as two months after the training has been terminated.

Notwithstanding these promising results, there is still the unexamined assumption in these studies that there is an automatic transfer from knowledge of perception (i.e. being able to point and describe the safest route) to roadside behaviour (i.e. actually walk across the road). Zeedyk, Wallace, Carcary, Jones, & Larter (2001) report two studies in which they attempted to address this point. The first study involved training 4- and 5-year-old children to identify safe and dangerous sites. A tabletop model, a board game and a set of illustrations were used. Knowledge was assessed after one week and after six months. Control children were only tested once. The small but significant increase in knowledge, which was brought about after a single 20-minute training session, was retained over six months. All interventions were equally effective. In the second study, Zeedyk et al. (2001) examined whether the same children were able to apply their knowledge to real traffic situations by conspicuously filming the children’s road crossings that were made in the midst of completing a ‘treasure trail’. The majority of children crossed the road at dangerous locations (e.g. between parked cars, or at a junction). No differences were found between the intervention and control group. That is, the greater knowledge of the trained group did not result in safer road-crossing behaviour.

To conclude, it has been shown that even 5-year-olds can acquire knowledge or can learn to identify what constitutes a safe site or route to walk across the road. Although these findings appear encouraging, it remains to be demonstrated that this leads to safer road-crossing behaviour. This lack of convincing intervention effects may be due to either the young age of the children (i.e. only 5-year-olds were trained), or perhaps more likely, to inherent limitations in the transfer of (perceptual) knowledge into action (cf. Goodale & Humphrey, 1998).
Training looking behaviour

In the previous section we argued that children’s looking behaviour might be a rate limiting parameter in learning to cross a road safely. From the four component skills discussed here, children’s ability to look satisfactorily seems to change at the slowest pace. Nevertheless, attempts to train children’s looking behaviour are rather scarce. We found two such studies (Limbourg & Gerber, 1981; Rivara et al., 1991). In both studies, children were conspicuously filmed while actually walking across the road before and after the training programme. The training programme of Limbourg and Gerber (1981) consisted of a film and a brochure that instructed parents to practice their 3- to 7-year-old children directly in real traffic situations. Parents were asked to analyse the own child’s crossing behaviour and to demonstrate and explain correct behaviour. Correct behaviour comprised, among other, stopping at the kerb and looking left and right. In their final experiment the authors reported dramatic improvements in both stopping at the kerb (10 per cent vs. 80 per cent) and looking left and right (20 per cent vs. 70 per cent). The two control groups, however, performed also better during the post-test, albeit to a lesser degree (i.e. stopping at the kerb 10 per cent vs. 30 per cent, and looking left and right 20 per cent vs. 35 per cent). They also reported, but did not further substantiate the claim, that the improvements were dependent on age and training frequency, and that looking behaviour deteriorated in a follow-up test after four months in all groups, but was still better in the experimental groups than in the control groups. Rivara et al. (1991) also used a school training programme that included role-playing, real traffic environments, and theoretical instructions (e.g. the children were taught to make eye contact with the driver). Important limitations of the study were that it did not involve a control group and that there was no verification of the long-term effects. No improvement in stopping at the kerb was found, and the proportion of children who were looking left–right–left before crossing increased, but only after the parents were involved in the training. Finally there was a two- to threefold increase in the number of children who looked during crossing. In sum, these studies seem to indicate that children’s looking behaviour can be trained. However, the findings need validation before we can draw firm conclusions.

Training visually judging ‘crossable’ traffic gaps

Young and Lee (1987) used the pretend road method to train children to visually judge whether or not traffic gaps are crossable. Five-year-olds were given nine to twelve sessions spread over six to twelve weeks of guided practice on the pretend road. The children received two types of feedback: i) they could see whether they reached the
pretend kerb before the vehicle had passed the crossing line, and ii) the trainer reprimanded them if they behaved recklessly or urged them to watch more carefully if they were wasting large gaps. The 5-year-olds in this study performed very well on a single lane. They showed almost no tight fits (unlike their peers in Lee et al.’s 1984 study) throughout all the sessions. Moreover, the number of missed opportunities was less than the 7- and 9-year-olds (Lee et al., 1984), and reached almost adult standard in two training sessions. On a two-way road, however, the children missed many more opportunities than the adults, and training only slightly reduced the number of missed opportunities. Demetre, Lee, Grieve et al. (1993) aimed to extend these findings. The 5-year-old children received six training sessions on a two-way pretend road or on a two-step task. The study included a 14-week and a long-term follow-up assessment (i.e. at six months). Both training programmes resulted in a reduction of the proportion of tight fits and missed opportunities committed by the children. These training effects did not appear very robust. After 14 weeks, reductions of tight fits were only found on the pretend road simulation, whereas reductions in missed opportunities were only present in the two-step task. The long-term follow-up failed to demonstrate any difference from the control group. In sum, although training on the pretend road revealed some promising short-term effects on visual timing skills, these improvements were not retained very long.

Training crossing behaviour
Limbourg and Gerber (1981) reported that after supervised practising in real traffic environments, there was an increase in the number of children who stopped at the kerb before crossing (but see Rivara et al., 1991), which might indicate that fewer children would run across the road. The pretend road simulation training did not reveal systematic effects on crossing time (i.e. sometimes crossing time decreased, sometimes it increased, and sometimes it became more consistent) and the effects were not retained in the follow-up assessments. Likewise, the changes in time taken between making a judgement and starting to walk across (i.e. a decrease in starting delay and its inconsistency) the pretend road were no longer present four weeks after the termination of training (Demetre et al., 1993; Young & Lee, 1987). Finally, Limbourg and Gerber (1981) found that an increasing number of children crossed at a right angle after their behavioural training programme.
The necessity to train the road-crossing action

It is now well established that action is inseparable from perception, and that perception is inseparable from action (e.g. Gibson, 1979). Moreover, perception in action is dissociated from perception in knowledge (Goodale & Humphrey, 1998). A major implication of this is that action can only be learned in the context in which it occurs, for example, crossing a road in a real traffic environment. Training on a real road has not been applied frequently because it can be dangerous for children. However, even mimicking the action as closely as possible either visually (e.g. learning to identify safe sites at the roadside) or motorically (e.g. practising on the pretend road) may not be sufficient for improvements in children’s road-crossing behaviour to occur. At least, that is the rather discouraging conclusion that emerges from the summary of the effectiveness of training programmes for children’s component skills of road crossing. Even the pretend-road studies did not succeed in bringing about long-term training effects. In fact, only Limbourg and Gerber (1981) reported an improvement in looking behaviour (i.e. stopping at the kerb, and looking left and right) of 3- to 7-year-old children in a follow-up assessment. Although the study appeared methodologically sound, the authors did not report any detail of the long-term training results. Notwithstanding this limitation, it is perhaps no coincidence that the training programme required the children to practice actual walking across the road (obviously, with supervision). There are also a few more studies that suggest that practising the act of road crossing is indispensable for a training programme to be successful. Unfortunately, these studies report a total score instead of separate scores for the component skills of road crossing. For example, Yeaton and Bailey (1978) found an increase of the overall road-crossing score that included waiting at the kerb, looking left and right, watching the vehicle distance, walking, and looking while crossing, even one year after termination of the training programme. Rothengatter (1984) had children practice road crossing in real traffic environments under parental supervision, and found that at the three month follow-up assessment, 4- to 6-year-olds’ road-crossing performance (as indicated by a sum score based on elements like stopping at the kerb, looking left and right, and speed and angle of crossing) was improved without concomitant improvements in traffic knowledge. In other words, there was no transfer between roadside behaviour and traffic knowledge. These findings underline the putative dissociation between perception in action and perception in knowledge, particularly with respect to road-crossing behaviour. Young children therefore require practice; safe road-crossing behaviour is learned by doing (cf. Rothengatter, 1984). In this context, the findings of Ampofo-Boateng, Thomson and co-workers with 5-year-
olds who learned to perceptually distinguish dangerous sites and routes from safe ones should be interpreted with great care. The authors did not assess the children’s ability during actual road crossing. Practice involving showing and explaining to children the real traffic environment does not automatically transfer to actual road-crossing behaviour (Zeedyk et al., 2001).

In conclusion, the review suggests that training programmes in road-crossing behaviour may enhance safety if, and only if, children actually practice the behaviour itself. It is the degree of exposure to traffic that appears to be one of the most important determinants of safe road-crossing behaviour in young children. As several studies have shown, parents are capable of achieving improvements in their children’s road-crossing behaviour (e.g. Limbourg & Gerber, 1981; Rivara et al., 1991; Rothengatter, 1984). The disadvantage is that with parental training programmes it is difficult to assess relevant issues like the nature of the verbal instructions (e.g. explicit or implicit learning; see Masters, Law, & Maxwell, 2002) and the type of feedback (e.g. knowledge of performance or results) or its frequency. Furthermore, it is perhaps fruitful to examine the additional effects of training by means of video or virtual reality (see Plumert, 2003). However, we should be careful not to throw the baby out with the bath water. It is curious to find that most training efforts so far have been directed at 5-year-old children (e.g. Ampofo-Boateng et al., 1992; Demetre et al., 1993; Rothengatter, 1984; Thomson et al., 1992, 1998; Young & Lee, 1987; Zeedyk et al., 2001). We cannot be sure that the lack of transfer from increasing traffic knowledge to road-crossing behaviour in these young children is not due to the very young age of the participants. Perhaps in older children an increase in traffic knowledge transfers better to roadside behaviour. This is particularly important, because it is the older age group that is allowed to walk unaccompanied. A study of Van Schagen and Rothengatter (1997) suggests that cognitive training of road-crossing skills might be beneficial in 6- and 7-year olds. They compared three groups of children who received a classroom cognitive instruction, a roadside behavioural training or a combination of both. Compared to the control group, all three interventions led to improved knowledge and road-crossing behaviour on an intersection. It is unknown, however, what aspects of road crossing were tested, and whether these effects were retained over longer periods.
Chapter 3

Visual timing and adaptive behaviour in a road-crossing simulation study
Abstract

In this road-crossing simulation study, we assessed participant’s ability to visually judge whether or not they could cross a road, and their adaptive walking behaviour. To this end, participants were presented with a road inside the laboratory on which a bike approached with different velocities from different distances. Eight children aged 5 to 7 years, ten children aged 10 to 12 years, and ten adults were asked both to verbally judge whether they could cross the road, and to actually walk across the road if possible. The results indicated that the verbal judgements were not similar to judgements to actually cross the road. With respect to safety and accuracy of judgements, groups did not differ from each other, although the youngest group tended to be more cautious. All groups appeared to use a strategy to cross the road based both on the distance and the velocity of the approaching bike. Young children waited longer on the kerb before crossing the road than older children and adults. All groups adjusted their crossing time to the time-to-arrival of the bike. These findings are discussed in relation to the ecological psychological approach and the putative dissociation between vision for perception (i.e. verbal judgement) and vision for action (i.e. actual crossing).

Visual timing and adaptive behaviour in road crossing

Introduction

Road safety research in children is important since pedestrian accidents are a prominent cause of death for children. Studies that examined the relations between accident risk, exposure, and age suggest that in particular young inexperienced children are at risk when exposed to traffic situations (Howarth, Routledge, & Repetto-Wright, 1974; Macpherson, Roberts, & Pless, 1998; Routledge, Repetto-Wright, & Howarth, 1974). This is supported by accident statistics, which report that in the year 2000 in Great Britain about one third of all killed and seriously injured pedestrians were children up to 15 years, of which 107 children were killed, while 3,119 were seriously injured (Road Accidents Great Britain, 2000).

Road crossing consists of several components. Among others, a child needs to find a safe place to cross a road, s/he must look in the right direction to detect approaching traffic, combine information from different directions, visually judge whether there is sufficient time remaining to cross before a vehicle arrives, and while crossing s/he must continuously adapt locomotion behaviour to changes in the traffic situation. Furthermore, safety of road-crossing behaviour also depends on the child’s attentional skills and proneness to take risks (e.g. Foot, Tolmie, Thomson, McLaren, & Whelan, 1999; Te Velde, Van der Kamp, & Savelsbergh, 2003b; Van der Molen, Rothengatter, & Vinjé, 1981). This study will focus on visual judgements as to whether there is sufficient time to cross a single-lane road and on walking behaviour during crossing. These two components are of particular interest, because in order to behave safely, children have to scale moment-to-moment changes in the traffic situation to their own (changing) action abilities (e.g. walking speed). To this end, approaching time of traffic must not be perceived in absolute terms, but in terms of time the pedestrian needs to reach the far kerb (Lee, Young, & McLaughlin, 1984).

According to the ecological approach to perception and action (Gibson, 1979), the most valid way to examine visual timing skill is asking participants to actually cross a road, because it maintains the natural coupling between visual information and action. There is ample evidence that visual information is inseparable from the timing and the control of action. Accordingly, verbal or button press perceptual judgements as to whether there is sufficient time to cross a road are expected to be less accurate than judgements to actually cross, because information and movement are de-coupled (see Bootsma, 1989, and Cornus, Montagne, & Laurent, 1999).

Nevertheless, a substantial part of the research on visual timing in the context of road-crossing behaviour presented participants with 2-dimensional simulations of traffic and asked for verbal judgements or a button press to indicate how long the
participants thought it would take for a vehicle to reach them (e.g. Hancock & Manser, 1997; Hoffmann, Payne, & Prescott, 1980; Manser & Hancock, 1996; McLeod & Ross, 1983; Schiff & Detwiler, 1979; Schiff & Oldak, 1990; Schiff, Oldak, & Shah, 1992). Judgements generally showed an underestimation of time-to-contact, and from these findings conclusions were drawn that participants would have crossed the road safely if they were to cross the road. In these studies, however, outcome measures were not related to individual physical or action abilities.

Perception of own physical or action abilities was taken into account in studies that asked for participants’ estimates about the boundaries of what would be within and what would be beyond their physical abilities (e.g. Plumert, 1995). Connelly, Conaglen, Parsonson, and Isler (1998), asking children to verbally judge when they could not cross in front of an approaching vehicle anymore, found that children were able to judge their action capacities safely at vehicle approaching velocities lower than 60 kph. However, at vehicle approaching velocities above 60 kph, 5- to 6- and 8- to 9-year-old children, in particular, made unsafe judgements, whereas children aged 11 to 12 years were still able to make safe judgements about their abilities. Yet, both time-to-contact estimates and estimates about the boundaries of physical abilities might not represent what children would actually do.

Still, there are studies that assess children’s judgements about whether or not they would cross a road with flowing traffic. In this respect, Pitcairn and Edlmann (2000) required adults and children to press a button to indicate when they would cross a road that was displayed on two video screens. The authors observed that children behaved very similar to adults, but children demonstrated longer starting delays, made fewer crossings, and made fewer safe decisions than adults. But as mentioned before, the fact that participants had to press a button instead of actually crossing the road might have influenced the outcomes.

Recently, Simpson, Johnson, and Richardson (2003) examined children’s and adults’ road-crossing judgements in a virtual environment. Participants were asked to actually walk across a virtual road when they thought it was safe, with the view of the road changing according to the participant’s movements, providing an accurate depiction of the road from the participant’s perspective. This way, participants were examined in a coupled situation, in which judgements were scaled to individual walking capacities. Although the results appeared to suggest that the youngest children (5- to 9-years-old) showed the highest incidence of tight fits and/or collisions, the statistical analysis revealed no significant differences between children of different ages and adults on the percentage of collisions, tight fits, or rejected gaps. A drawback of this
study, however, was that due to the novel equipment stereovision could not be accomplished yet, and the horizontal field-of-view was restricted. Furthermore, the authors reported that the collision rate was somewhat overestimated, probably due to the absence of direct risk.

Lee and co-workers examined adults’ and 5- to 10-year-old children’s visual timing skills on a ‘pretend road’ (Demetre, Lee, Grieve, et al., 1993; Demetre, Lee, Pitcairn, et al., 1992; Lee et al., 1984; Young & Lee, 1987). In this pretend road task, participants were asked to walk across a path that ran adjacent to a real road, pretending that the traffic on the real road was driving on this path. Adults were examined both on the pretend road and on a real road and were found to behave comparably on the pretend road and on the real road. It remains unknown whether this is also the case for children as they were only examined on the pretend road. On the pretend road, young children made a few more unsafe errors, but clearly missed more opportunities (i.e. they erred on the safe side) than older children and adults. These effects decreased with age (Lee et al., 1984). Demetre et al. (1992) also compared children’s performance on the pretend road task to their performance on a ‘two-step’ task and a ‘shout’ task along side the real road. Five-year-old children were asked to take only two steps or shout when they thought the situation to be safe. Children missed fewer opportunities to cross in the ‘two-step’ and the ‘shout’ tasks than when walking across the pretend road. Though this seems a naturally coupled road-crossing situation, perhaps the changed visual angle in which the traffic was seen and the discrepancy between the location where the traffic moved and the scene of the action influenced the detection of the visual information about the approaching vehicles in the pretend road situations.

From the studies that assessed children’s abilities to judge whether or not to cross a road, only the pretend road studies (Lee and colleagues) and the virtual environment study (Simpson et al., 2003) maintained a coupling between perception and a relevant action. Yet, these studies only assessed visual timing for the moment that participants made a judgement, while not merely this moment, but also the whole crossing action presumably yields valuable information about how participants safely cross a road.

Regarding walking behaviour, Zeedyk, Wallace, and Spry (2002) reported that young children were often running across the road instead of walking. Lee et al. (1984) and Young and Lee (1987), in the pretend road task, observed that young children’s crossing times were less consistent than older children’s and adults’ crossing times and argued that a consistent crossing time would be beneficial. However, walking behaviour has not yet been assessed in relation to the available time. Yet, adjusting walking speed
to the available time might increase the safety margin and compensate an unsafe decision to cross. Hence, inconsistent crossing time may also be considered as advantageous (Te Velde, Savelbergh, Barela, & Van der Kamp, 2003a).

The aim of the present study is to further contribute to the knowledge on adults’ and children’s capacities to time their actions in relation to a moving vehicle in a road-crossing situation. To this aim, safety and accuracy of adults’, 10- to 12-year-old children’s, and 5- to 7-year-old children’s actual judgements about the crossability of a road (i.e. walk across the road if possible) are examined. In separate tasks adults and children are also required to give verbal judgements about the crossability of a road, which allows us to directly compare the two tasks (actual performance vs. verbal judgements), and examine whether verbal reports, which is one of the most easily applicable methods in road safety research and training programmes, may represent actual behaviour. Second, the analyses on actual road-crossing performance for different age groups may increase the understanding in how visual timing develops over age. Third, it is possible to gain insight as to whether children and adults are able to adjust walking behaviour to the available time. However, to ensure safety of the participants, concessions with respect to traffic speed and the number of vehicles had to be made.

**Methods**

**Design**

This study examined road-crossing judgements of adults, 10- to 12-year-old children, and 5- to 7-year-old children, on two tasks, namely a performance task (i.e. actually walk across a road if possible) and a verbal judgement task, which was carried out twice, once before and once after the performance task. Both verbal judgement tasks were identical but in the analyses considered as separate tasks, because in the first verbal judgement task participants did not have the experience of actually performing the task, whereas in the second verbal judgement task participants did have this experience. In each task a motor-controlled bike slowly approached 16 times. At the time participants made their decision, the bike could be approaching from one of four starting distances (2.3, 4.3, 6.3, or 8.3 m) and at one of two approaching velocities (for adults 1.3 or 1.8 m/s, for children 0.9 or 1.3 m/s; the different velocities for adults and children allowed all groups to cross on an equal number of trials, which facilitated later analyses), resulting in eight different approaching times for each group throughout each task. Each of the distance-velocity combinations was presented twice. Judgements
whether or not to cross were noted for all 48 trials, and kerb delays and crossing times of participants were measured during the performance task. These variables were used to determine the safety and accuracy of judgements, the timing strategies that participants may have used, and the extent to which crossing time was adjusted to the available time to cross the road (and accordingly, the ability to compensate for unsafe decisions).

Participants
Thirty participants were included in this study: ten adults (\(M = 25.8, \ SD = 3.9\) years), ten older children (\(M = 11.0, \ SD = 0.8\) years), and ten younger children. Of the latter group, two children (1 boy, 1 girl) did not follow the instructions of the experimenter, and therefore were excluded from the analyses. Hence, the young children’s group consists of only eight participants (\(M = 6.7, \ SD = 1.0\) years). Gender was equally distributed within all groups. Prior to the initiation of the experiment a written informed consent form was obtained from adult participants and children’s parents.

Apparatus
In the laboratory, an experimental road, 20 meters long and three meters wide, was created. At one end, designated as the crosswalk, wooden platforms represented the kerbsides. The participants started the experiment from one kerbside, where they gave verbal judgements and where they started to walk across the road to the other kerb. The starting position for participants was marked directly at the kerbside. Figure 3.1 shows the simulated road and the kerbsides.

The experimental vehicle was a bicycle that approached in the ‘far lane’ from the right side as seen from the participants’ perspective. A frame connected to a cable, at a height of 2.5 m above the road, supported it. The cable-and-bike system was moved by an electric engine, which was placed at the beginning of the road. The engine could be switched on and off manually, could be reversed, and was able to produce a constant velocity of the cable and bike up to a maximum of 1.8 m/s.

A device that gave a starting signal was designed, one part of which was positioned at one of the four starting distances. As the bike passed this part, it displaced a moving arm, which then switched on a lamp that was placed on the left side of the participant, and simultaneously caused a movement in an infrared emitting marker that was attached to the device’s second part. The lamp switching on was the signal for participants to look towards the bike and to judge whether or not to cross the road. The movement of the marker was registered and used for calculations.
Figure 3.1. Experimental set-up, including the road, the kerbsides (sidewalk), the bike, the OPTOTRAK camera, the video camera, and the starting device.
An OPTOTRAK-system registered the three-dimensional position of both a marker on the participants’ back and the marker on the starting-device at a sampling rate of 100 Hz. A video camera recorded the participants’ behaviour, the bike, and the trial numbers. This camera was placed on a tripod next to the OPTOTRAK-camera.

**Procedure**

Prior to the experiment, an OPTOTRAK-marker was attached to the participant’s back. Subsequently, one of the experimenters gave an explanation and a demonstration of the tasks. If necessary, this was repeated until the tasks were understood. Participants were asked to walk at normal pace. In order to become familiar with the road-crossing task, participants crossed the road twice without the approaching bike.

During the experiment, participants stood at the edge of the road on the kerbside, looking at the lamp on their left side. The bike was placed at the beginning of the road, on their right side, and then started moving towards the crosswalk. OPTOTRAK-data were only registered in the performance task and collection started before the bike passed the first part of the starting-device. When the bike hit the device’s moving arm, the light switched on and participants were allowed to look at the bike. In both verbal judgement tasks they immediately told the experimenter whether or not they could cross the road. The bike stopped after participants had given their verbal judgement, and was reversed to the starting position. In the performance task the participants were required to cross the road if possible. The bike stopped at the end of the road, after it had passed the crosswalk, then reversed to the beginning of the road, and the first part of the starting device was positioned at the next starting-position. Trials were blocked on speed and starting distance of the bike and randomised across participants.

**Data analysis**

All trials were scored according to whether or not participants judged to cross the road. OPTOTRAK-data were used to calculate kerb delay and crossing time. *Kerb delay* was defined as the time the participant spent on the kerb after the starting signal until the first step on the road. *Crossing time* was defined as the time between the first step on the road and lifting the last foot off of the road. These variables were calculated for all trials where participants crossed the road.

Judgements were defined as unsafe when participants decided to cross the road in front of the approaching bike when time-to-arrival of the bike was shorter than individual mean crossing time (time-to-arrival was defined as the bike’s arrival time at
the moment the participant stepped on the road; individual mean crossing time is assumed to be the participant’s indication of his/her action-capacities). Judgements were defined inaccurate (i.e. missed opportunity) when participants decided not to cross the road in front of the bike when there was sufficient time to cross (i.e. approaching time of the bike was longer than the sum of individual mean kerb delay and individual mean crossing time). All other decisions were regarded correct. This implies that no safety margins were taken into account, which may be considered risky in normal life, but here it was assessed whether participants were able to relate approaching time of the bike to their own capacities, and therefore minimal safety margins were also defined as safe.

For each participant, crossing behaviour (i.e. crossing or not crossing) was expressed as a function of the approach times of the bike. Onto each data set the best possible logistic function, represented by the following equation,

\[ y = \frac{1}{1 + e^{k(c-t)}} \]  (3.1)

was fitted to determine the transition point at which behaviour changed from not crossing to crossing. In equation 3.1 \( t \) is the approach time of the bike; \( k \) is the slope at point \( c \), which is the approach time of the bike at which the transition from not crossing to crossing occurs (see Oudejans, Michaels, Van Dort, & Frissen, 1996b).

Participants’ timing strategies were examined by determining the effect of approaching distance and velocity of the bicycle on their judgements to cross in front of it. Participants should be able to cross the road more often for the longer approaching distances than for the shorter approaching distances (i.e. distance effect) and more often for the slowly approaching bike than for the ‘fast’ approaching bike (i.e. velocity effect). Accordingly, a distance effect in combination with a velocity effect on number of crossings indicates that participants used a strategy based both on distance and on velocity of the approaching bike (that reflects a time strategy), whereas a distance effect in the absence of a velocity effect on the number of crossings indicates that participants used a distance strategy. Alternatively, a velocity effect in the absence of a distance effect on the number of crossings indicates that participants used a velocity strategy. Timing strategies were examined for each group separately. Prior to these analyses, the expected distance and velocity effects were also calculated on the basis of participants’ actual kerb delays and crossing times.

To examine participants’ abilities to adjust behaviour to the available time, and thus the ability to compensate for unsafe decisions by increasing walking speed, the
relationships between kerb delay and approaching time of the bike and between crossing time and time-to-arrival of the approaching bicycle was assessed. To this end, the individual linear relationships of individual kerb delay as a function of the approaching time of the bike, and the individual linear relationships of crossing times as a function of time-to-arrival of the bike were calculated.

Statistical Analysis
The intra-individual means of percentages crossings, unsafe errors, and unnecessarily rejected gaps were submitted to an analysis of variance (ANOVA) with repeated measures on task (first verbal judgement vs. performance vs. second verbal judgement). Then, the three groups were compared on the intra-individual means of percentages crossings, unsafe errors, and unnecessarily rejected gaps for only the performance task by submitting these variables to a univariate ANOVA. The transition points from not crossing to crossing were also submitted to a univariate ANOVA. Because timing strategies were assessed for each group separately, non-parametric tests were used. In order to verify whether participants crossed more often for longer approaching distances and more often for the slowly than for the ‘fast’ approaching bike, individual numbers of crossings for each of the four approaching distances were submitted to Friedman tests and individual numbers of crossings for each of the two approaching velocities were submitted to Wilcoxon Rank tests. Subsequently, groups were compared on the intra-individual means and standard deviations of the kerb delays and crossing times, which were submitted to a univariate ANOVA. In order to assess the linear relationship of kerb delay and approaching time and the linear relationship of crossing time and time-to-arrival, slopes and intercepts of the individual linear regressions, and Fisher Z-transformations of the correlation coefficients were submitted to univariate ANOVA’s. For all ANOVA’s, Greenhouse-Geisser adjustments of the p-values are reported in cases where violations of the sphericity assumption occurred (i.e., for ε smaller than 1.0). Post-hoc comparisons were conducted with Tukey’s HSD test (p<.05).

Results
Verbal judgements vs. performance
A repeated measures ANOVA revealed a significant task effect on the percentages of crossings, $F(2, 54) = 5.87, p < 0.01, \eta^2_p = 0.18$. A post hoc Tukey HSD-test indicated that participants judged the road significantly more often crossable in the second verbal
judgement task than in the performance task (p < 0.05), whereas no differences on the percentages of crossing judgements were found between the two verbal judgement tasks and between the first verbal judgement task and the performance task. Based on participants’ behaviour in the performance task (i.e. kerb delays and crossing times), percentages of unsafe judgements (percentage unsafe judgements divided by percentage crossings) and missed opportunities (percentage missed opportunities divided by percentage non-crossings) were determined for all three tasks (note that there were no measurements on kerb delays and crossing times in the verbal judgement tasks). A repeated measures ANOVA revealed a significant task effect on the percentages of unsafe judgements, F(2, 54) = 11.89, p < 0.01, \( \eta^2_p = 0.31 \). Post-hoc test indicated that participants judged the ‘crossability’ more often unsafely in both verbal judgement tasks than in the performance task, whereas no differences were found on the percentages of unsafe judgements between both verbal judgement tasks. The percentages of missed opportunities were comparable for the three tasks, F(2, 54) = 1.47, p = 0.24, \( \eta^2_p = 0.06 \). Means and standard deviations of the percentages of crossings, unsafe errors, and missed opportunities for the different tasks are given in Table 3.1.

Table 3.1. Means (and standard deviations) of percentages of crossings, unsafe judgements and missed opportunities in the first verbal judgement task, the performance task, and the second verbal judgement task.

<table>
<thead>
<tr>
<th></th>
<th>% crossings</th>
<th>% unsafe</th>
<th>% missed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st judgment</td>
<td>62.3 (17.8)</td>
<td>17.2 (11.4)</td>
<td>17.3 (18.2)</td>
</tr>
<tr>
<td>Performance</td>
<td>56.5 (13.4)</td>
<td>7.3 (9.7)</td>
<td>12.8 (15.7)</td>
</tr>
<tr>
<td>2nd judgement</td>
<td>66.8 (17.9)</td>
<td>17.3 (13.0)</td>
<td>11.5 (16.6)</td>
</tr>
</tbody>
</table>

\(^1\) based on actual kerb delays and mean crossing times in the performance task
\(^2\) based on mean kerb delays and mean crossing times in the performance task

Visual timing in the performance task
A univariate ANOVA revealed that the percentages of crossings in the performance task were comparable for the three age groups, F(2, 27) = 0.71, p = 0.50, \( \eta^2_p = 0.05 \) (note that the velocities of the bike were faster, and hence approaching times were shorter, for adults than for children). The percentages of unsafe crossings and missed opportunities for each group were comparable for the three age groups, F(2, 27) = 1.63,
p = 0.22, \eta_p^2 = 0.12 and F(2, 27) = 2.09, p = 0.15, \eta_p^2 = 0.14 respectively. However, as can be deduced from Table 3.2, there was a tendency for the youngest group to be more cautious than the other two groups, but this tendency failed to reach the significance level.

A group effect on approach times of the bike at which transitions from not crossing to crossing occurred was found, F(2, 27) = 4.89, p < 0.05, \eta_p^2 = 0.28. Approaching times at which the transitions occurred were smaller (p < 0.05) for adults (M = 3.17 s., SD = 0.22) than for young children (M = 4.69 s., SD = 1.71); transition points for older children (M = 4.05 s., SD = 0.81) did not differ from either adults’ or young children’s transition points.

Based on adults’ and children’s kerb delays, it was expected that participants crossed the road significantly more often with increasing distance of the bike, and more often for the slowly approaching bike than for the ‘fast’ approaching bike. Three Friedman tests, executed separately for the different groups, revealed in all cases significant distance effects at the p < 0.01 level (\chi^2 = 26.23 for adults, \chi^2 = 28.70 for 10- to 12-year-old children, and \chi^2 = 22.75 for 5- to 7-year-old children). Three Wilcoxon Rank tests, executed separately for the different tasks and groups, revealed in all cases significant velocity effects (Z = -2.43, p < 0.05 for adults, Z = -2.88, p < 0.01 for 10- to 12-year-old children, and Z = -2.39, p < 0.05 for 5- to 7-year-old children). This indicates that all groups appeared to have used a strategy based on both the distance and the velocity of the approaching bike.
Adaptive behaviour in the performance task

A univariate ANOVA revealed a significant effect for kerb delays, $F(2, 27) = 17.79, p < 0.01, \eta^2 = 0.59$. Post-hoc Tukey HSD-test indicated that adults’ kerb delays were shorter than older children’s kerb delays, which in turn were shorter than young children’s kerb delays. Univariate ANOVA’s on the slopes, intercepts and the correlation coefficients of the individual linear regressions of kerb delay and approaching time of the bicycle yielded only a significant difference on intercept between the three age groups, $F(2, 26) = 3.41, p = 0.05, \eta^2 = 0.22$. Post hoc comparison showed that the intercept was higher for young children than for adults.

A univariate ANOVA did not reveal a significant effect for crossing time, $F(2, 27) = 1.23, p = 0.31, \eta^2 = 0.09$. Univariate ANOVA’s on the slopes, intercepts and the correlation coefficients of the individual linear regressions of crossing time and time-to-arrival of the bicycle also yielded no significant differences between the three age groups. Adults compensated 4 of the 11 unsafe decisions, 10- to 12-year-old children 2 of the 6 unsafe decisions, and 5- to 7-year-old children 1 of the 4 unsafe decisions by increasing walking speed. Means and standard deviations of kerb delays and crossing times, and means and standard deviations of the slopes and intercepts of the linear regression equations for kerb delay and crossing time are depicted in Table 3.3.

Table 3.3. Means (and standard deviations) of kerb delays and crossing times, and means (and standard deviations) of intercepts and slopes of the individual linear relationships of kerb delay (kd) as a function of approaching time, and crossing time (ct) as a function of time-to-arrival for adults, 10- to 12-year-old children, and 5- to 7-year-old children in the performance task.

<table>
<thead>
<tr>
<th></th>
<th>kerb delay</th>
<th>intercept kd</th>
<th>slope kd</th>
<th>crossing time</th>
<th>intercept ct</th>
<th>slope ct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td>0.68 (0.08)</td>
<td>0.56 (0.22)</td>
<td>0.03 (0.04)</td>
<td>2.63 (0.30)</td>
<td>2.30 (0.43)</td>
<td>0.08 (0.08)</td>
</tr>
<tr>
<td>10-12 years</td>
<td>0.89 (0.14)</td>
<td>0.74 (0.22)</td>
<td>0.02 (0.03)</td>
<td>2.80 (0.24)</td>
<td>2.42 (0.34)</td>
<td>0.06 (0.05)</td>
</tr>
<tr>
<td>5-7 years</td>
<td>1.19 (0.29)</td>
<td>0.81 (0.22)</td>
<td>0.05 (0.03)</td>
<td>2.85 (0.42)</td>
<td>2.42 (0.43)</td>
<td>0.09 (0.09)</td>
</tr>
</tbody>
</table>

Discussion

This study examined actual crossing of a (simulated) road in front of an approaching vehicle in children (i.e. situation involving risk), and directly compared this with a verbal judgement task. As pointed out in the introduction, estimates about time-to-
arrival of an approaching object or estimates about own physical or action abilities may not fully represent road-crossing judgements. The comparisons on the percentages of crossings and safety and accuracy of judgements between the performance task (actual crossing) and the verbal judgements gave direct measurements as to whether verbal judgements may represent actual visual timing. The results indicated an overestimation of the percentage of crossings in the second verbal judgement task in comparison to the performance task. Subsequently, the results suggested an overestimation of unsafe judgements in both verbal judgement tasks in comparison to the performance task (note that in the verbal judgement tasks judgements could not be really unsafe, because participants did not cross). Accordingly, there appeared to be no ‘transfer of knowledge’ from the performance task to the second verbal judgement task; judgements were as unsafe as in the first verbal judgement task. These findings support the notion that verbal judgements do not represent actual crossing behaviour. Therefore, in order to assess road crossing in a valid manner, the action component appears to be essential and should not be ignored.

The importance of testing in a naturally coupled situation (i.e. including a relevant action) instead of asking for verbal reports might be underlined by a theory on the processing of visual information for perception and action (Milner & Goodale, 1995). According to this theory, two anatomically distinct visual systems in the cortex exist: a dorsal stream which processes visual information necessary for the control of actions, which often cannot be verbalised, and a ventral stream which processes information necessary to recognise objects or events, which often can be verbalised. This theory is supported, among others, by studies in which participants estimated distances either verbally or by walking or reaching blindfolded. These studies revealed better estimates while walking or reaching blindfolded than when verbally judging; moreover, outcomes were not systematically related to each other and there appeared to be no transfer of the calibration in the action task to the perception task, which indicates a different use of information (e.g. Pagano, Grutzmacher, & Jenkins, 2001; Rogers, Andre, & Brown, 2003). Based on this theory, which fits with the ecological approach (cf. Michaels, 2000; Van der Kamp, Savelsbergh, & Rosengren, 2001), the two tasks in the present experiment may have tapped two different visual systems. Given that it is the performance task that taps the system that is normally involved in visual timing behaviour, this task is presumed to resemble natural road crossing more closely than the verbal judgement tasks.

In the performance task, we did not find significant effects with respect to percentages of crossings, and safety and accuracy of judgements among the different
age groups. We only observed a tendency for young children to be more cautious. Nonetheless, a group effect on the transition point from not crossing to crossing together with comparable crossing times for all groups strengthen this observation that young children seem to be more cautious. Young children being more prudent on visual timing would be in agreement with the studies on the pretend road (Lee et al., 1984; Young & Lee, 1987; Demetre et al., 1992). Perhaps the scaling of properties of the approaching bike in relation to their own action capacities is not yet as accurately calibrated as in older children and adults. Fortunately, the results tend to go in the direction of more cautious behaviour in young children.

With respect to the timing strategies, it is important to note that even the young children appeared to make their judgements based both on distance and on velocity of the approaching bike. This is not in line with previous studies that argue that participants, and in particular young children, merely use distance to time their judgements (Connelly et al., 1998; Hancock & Manser, 1997; Manser & Hancock, 1996; McLeod & Ross, 1983; Schiff & Oldak, 1990; Schiff et al., 1992; Simpson et al., 2003). However, none of these studies examined participants in a situation in which perception and action were naturally coupled and in which participants could have used binocular information (stereovision), whereas in our study this was the case. Further research is needed to examine which visual information children exactly use to time their actions. Still, the use of information specifying time-to-contact to time an action by young children seems conceivable, since even infants seem able to do so when intercepting moving objects (see Van der Meer, Van der Weel, & Lee, 1994; Van Hof, Van der Kamp, & Savelsbergh, 2004).

Regarding adaptive behaviour, the analyses on kerb delays indicated that young children spent more time on the kerb than older children, who in turn spent more time on the kerb than adults. It seems plausible that young children in general need more time to attend to the most adequate information, because they have less experience in visual timing in the context of road crossing than older children and adults. Groups did not differ on crossing times, and all groups appeared to increase their walking speed when less time was available to cross the road, as indicated by positive relationships between crossing time and time-to-arrival of the bike. Therefore, in contrast to the explanation that an inconsistency in crossing time is not preferable (Young & Lee, 1987; Lee et al., 1984), we would like to argue that inconsistency in the sense of adjustments in walking speed to the available time may be functional. Because participants increased walking speed for short approaching times of the bicycle, some of the potentially unsafe judgements were compensated.
In conclusion, this study has shown that verbal judgements do not seem to fully represent actual road-crossing behaviour. Theoretical argumentation based on the ecological approach to perception and action and the theory of distinct visual systems for perception and action supported this finding. Moreover, asking participants to actually walk across a road in front of an approaching object enabled us to examine how adults and children timed and adapted their actions to the changing environment. This way, timing strategies and adjustments in crossing times provided us with new understanding regarding the development of road-crossing behaviour in children. Namely, children used a strategy to time their actions based on distance as well as on velocity of an approaching vehicle and they seemed able to tune their actions to the available time. Therefore even young children’s movements were adequately coupled to visual information in this simulated traffic situation. So far these abilities have not been assessed yet, because previous studies merely examined the moment that the (often verbal) judgements were made, whereas the total action was not taken into consideration. One drawback of the present study is the relatively slow velocity of the bike; however, in order to guarantee children’s safety higher approach speeds were not acceptable. Nevertheless, based on the findings of the present study, in which participants’ attention was directed to the approaching bike, and in which participants actually crossed the road in front this bike, the higher risk for young children to become involved in a traffic accident does not seem to be due to a generally poor capacity to visually time walking in front of a moving vehicle, or to a lack of adaptive behaviour. Future research might establish the exact visual information that adults and children use to visually time road crossing. In this respect, visual search and calibration of actions to this information also deserves more precise investigation. It goes without saying that an all-embracing conclusion on children’s road-crossing skill cannot be based solely on visual timing evidence for different age groups, but should comprise knowledge from a wide range of behavioural studies.
Chapter 4

Control of movement velocity in a dynamic collision-avoidance task
Abstract

We investigated age-related differences in a dynamic collision avoidance task that resembles pedestrian road crossing. Five- to 7-year-old children, 10- to 12-year-old children, and adults were instructed to push a doll across a scale-size road between two toy vehicles, which approached one after the other. We analysed the number of attempted crossings, the number of collisions, movement onset times and movement velocity control. The youngest children attempted to cross less often, but collided more frequently than the adults. This age effect could be attributed to differences in the way the children and adults controlled movement velocity. The youngest children attained the velocity that was required for safe travel too late, particularly when the gaps between the toy vehicles were small. Age differences in movement onset strategies were less clear-cut. The findings are discussed within a framework that proposes distinct roles of vision in action planning and action production.

Introduction

This study considers age-related differences in collision-avoidance behaviour. Since child pedestrians are over-represented in traffic accidents, the majority of research on collision-avoidance behaviour in primary school children has addressed road crossing (e.g. Connelly, Conaglen, Parsonson, & Isler, 1998; Demetre, Lee, Pitcairn, Grieve, Thomson, & Ampofo-Boateng, 1992; Lee, Young, & McLaughlin, 1984; Plumert, Keary, & Cremer, 2004; Thomson, Tolmie, Foot, Whelan, Sarvary, & Morrison, 2005). This work has provided important insights into children’s behavioural and cognitive limitations that hamper collision avoidance or safe crossing; however, a description of the young children’s ability to avoid collisions in terms of movement control is still lacking (Te Velde, Van der Kamp, & Savelsbergh, 2003b). Hence, we aim to provide a description of age-related differences in collision avoidance behaviour among primary school children couched in terms of movement control. For obvious safety reasons, children cannot actually cross a road during an experimental session. We therefore used a scale-size road-crossing simulation. The task requires would-be pedestrians to push a doll across a scale-size road in-between perpendicularly approaching objects without colliding into them. Akin to real road crossing, would-be pedestrians must perceive whether or not the road is safe to cross. If deemed safe, the time of onset and velocity of the movement must be tuned to the motion of the objects to-be-avoided.

Investigations into children’s perception and action in road crossing have yielded somewhat ambiguous outcomes. Traffic statistics show that primary school children’s accident rate is relatively high compared to adults (e.g. UK Department for Transport, Scottish Executive & National Assembly for Wales, 2005). However, a series of experimental studies in which road crossing was simulated in various ways found that even 5-year-olds rarely crossed traffic gaps that were too small (Demetre et al., 1992; Lee et al., 1984; Te Velde, Van der Kamp, Barela, & Savelsbergh, 2005; Thomson et al., 2005). In contrast, young children were observed to choose either larger (Demetre et al., 1992; Lee et al., 1984; Te Velde et al, 2005) or same (Plumert et al., 2004) size gaps as adults; by tending to miss more opportunities to cross, the young children seem to ‘err’ on the safe side. This is not entirely in line with the higher collision rate among children in traffic statistics.

Obviously, perceiving and choosing safe gaps is not the sole determinant for avoiding collisions with moving vehicles. It is also pertinent that the production of the subsequent action is attuned to the motion of the vehicles to-be-avoided. In this respect, experimental investigations revealed that young children start crossing somewhat later and time less consistently than adults and older children (Lee et al., 1984; Plumert,
2004; Te Velde et al., 2005; Thomson et al., 2005). Early movement onset leaves more time for crossing, whereas a late initiation may increase the risk on a collision. It must be taken into account, however, that the younger children chose relatively large inter-vehicle gaps. Hence, later movement onset does not necessarily imply that these children acted more risky than adults. In addition, it is still largely unclear what the basis of movement initiation is. There are several candidate variables such as a fixed distance or time of the vehicle from the crosswalk (e.g. Connelly et al., 1998; Lee et al., 1984; cf. Te Velde et al., 2005). Moreover, the movement onset hypotheses tend to overlook that during crossing movement speed can be adjusted continuously. A major reason for this negligence may have been methodological. There is a dearth of studies that measured the spatial-temporal characteristics of pedestrian crossing. Some have reported that crossing times of children and adults are comparable (Lee et al., 1984; Thomson et al., 2005), but they did not take the vehicle’s motion into account (but see Plumert et al., 2004). Te Velde et al. (2005) observed that both young children’s and adults’ maximum movement speed was higher when there is less time available to reach the far kerb. They did not provide evidence to show whether the modulation of movement speed was sufficiently large to avoid collisions. It remains unknown therefore whether the increased collision proneness among younger children as compared to older children and adults is associated with age-related differences in velocity control. By using a scale-size road-crossing simulation, we aimed to assess whether there are age-related differences in velocity control during collision-avoidance behaviour.

This study compares collision behaviour in terms of the momentarily velocity needed to safely push a small doll in-between two moving toy vehicles. To this end, we modified the required velocity model that was introduced to describe how individuals continuously attune movement speed to intercept a moving object (Peper, Bootsma, Mestre, & Bakker, 1994; see also Dessing, Bullock, Peper, & Beek, 2002; Montagne, Fraisse, Ripoll, & Laurent, 2000). This model described a catcher’s lateral (i.e. left-right) hand movements to catch balls that approach from different oblique directions and that pass by at different lateral distances. A catcher must, to get the hand to the right place at the right time, continuously match hand velocity to the momentary required velocity. The momentary required hand velocity is specified by the current lateral distance between the ball and the hand, and the current time remaining for the ball to pass the participant. By moving their hand at the currently (and continuously changing) required velocity, the participant ensures that the lateral ball-hand distance is reduced to zero in the remaining time. Typically, the required lateral hand velocity is
attained well before interception occurs. Subsequent adjustments in hand velocity are then adequately geared to the (ever changing) required velocity, resulting in successful interception.

To make the required velocity description relevant to collision avoidance behaviour, the difference in constraints on interception and collision avoidance must be considered. First, unlike interception, collision avoidance requires that the actor controls movement velocity in such a manner that the moving vehicle and the actor do not reach the place where their paths intersect at the same time. Hence, the actor should ensure that the difference between the time the moving vehicle would reach the intersection point and the time the actor would reach that point (based on the actor’s current position and velocity) is not equal to zero; it should be higher than zero to pass in front of the second vehicle (i.e. lower velocity boundary) and lower than zero when intending to pass behind the first vehicle (i.e. upper velocity boundary). Otherwise a collision is inevitable. Second, unlike interception tasks, there is not one optimal velocity for collision avoidance. To the contrary, there is a region or range of velocities above the lower velocity boundary (in relation to the second vehicle) and below the upper velocity boundary (in relation to the first vehicle) that ensures collision avoidance. Any velocity within this range of safe velocities will do. To safely navigate in-between the two moving objects, the region of required velocities must be attained before the actor enters the collision area. Thereafter, velocity adjustments are only needed when a passing beyond one of the velocity boundaries is imminent (see Fajen, 2005).

In the present study, we used a collision-avoidance task to examine age-related differences in collision avoidance. Five- to 7-year-old children, 10- to 12-year-old children and adults were instructed to push a doll across a scale-size road between two toy vehicles that approached one after the other. We examined the number of attempted crossings, the number of collisions, movement initiation times, and movement velocity control. We were particularly interested to see whether age-related differences in collision rate could be attributed to age-related differences in the way movement velocity is regulated. We expected that a higher frequency of collisions would be associated with a participant’s inclination to attain the required velocity (too) close to the collision area.
Methods

Participants
Twelve adults (mean age = 27.1 years, range 23.8–31.4 years), 14 pre-adolescent children (mean age = 11.1 years, range 10.0–13.0 years), and 20 young children (mean age = 6.6 years, range 5.2–8.0 years) participated in the study. Bootstrap simulations on the number of crossings for each participant were performed to determine the number of participants for each group. This method shows that adding more participants would not result in a 5% or more reduction of the between-subject variance within groups (Hoozemans, Burdorf, Van der Beek, Frings-Dresen, & Mathiassen, 2001). Gender was equally distributed within groups. All participants reported normal or corrected to normal vision. Written informed consent was obtained from participants or their parents prior to the experiment. The experiment was approved by the ethical committee of the Vrije Universiteit Medical Centre and participants were treated in accordance with the Declaration of Helsinki.

Task and Apparatus
Participants manually pushed a doll between two consecutively approaching toy cars on a scale-size road, which was painted on an elongated table (Fig. 4.1). The road was 6 m long and 0.25 m wide and had kerbs (0.05 m wide) on both sides. The doll (Playmobil®, 0.035 m wide) was attached to a rod that extended underneath the table through a slot in the table. By grasping and moving the rod underneath the table the participants could move the doll as if it walked across the road. Two toy vehicles (length 0.15 m, width 0.065 m) were placed on two supports that were moved by two mechanically driven conveyer belts (length 3 m each, width 0.05 m), which were sequentially positioned under the tabletop. A second slot in the table exactly in the middle of the road, through which the supports slid while resting on the conveyer belts, made it look as if the two vehicles were driving along the road. Approximately 0.02 m was left clear between the two conveyer belts to make space for the rod on which the doll was attached to cross the vehicles’ track.

A potentiometer connected to the rod collected position data of the doll. Two Opto Switches (comprising an infrared source and an integrated photo detector) were positioned underneath the kerbs along the road at 1.75 m before and after the intersection with the doll’s track. The light beams of these Opto Switches were interrupted when the supports on which the vehicles were positioned passed. This provided the moments the vehicles were at 1.75 m before and after the intersection point. Together with the known velocity of the vehicles, these measures were used to
calculate the moment the vehicles crossed the doll’s track. Data of the potentiometer and Opto Switches were synchronised and collected at a sampling rate of 500 Hz (Labview, National Instruments). A video camera was placed in front of the participants to record their behaviour.

![Figure 4.1. Picture of the experimental setup; the child is sitting in front of the table and pushes the doll between the two approaching vehicles.](image)

**Procedure and Design**

Prior to the experiment, the participants pushed the doll across the road without the approaching vehicles at a comfortable and at maximum movement speeds in order to become familiar with the doll’s ‘movement abilities’. Then they were instructed to move the doll across the road between the two approaching toy vehicles without colliding into either vehicle. If they thought that crossing between the two vehicles was impossible, they had to cross the road after both vehicles had passed. In the case that a collision occurred, participants were politely reminded not to collide and to pretend that they were crossing the road themselves. Each participant performed 36 trials with a total duration of approximately 30 minutes. The vehicles approached alternately from the left and right sides. Three constant vehicle speeds (0.50, 0.75, and 1.00 m/s) and three inter-vehicle distances (0.15, 0.30, and 0.45 m) were used. Each of these nine conditions was repeated four times randomly within two blocks, but was always repeated in two successive trials.
Dependent variables and data analyses

Crossings and Collisions

The percentage of crossings was determined by dividing the number of trials in which the participants attempted to push the doll between the vehicles by the total number of trials, multiplied by 100. The percentage of collisions was determined by dividing the number of collisions by the number of crossings, multiplied by 100. The individual means of these variables were submitted to a 3 (group: 5- to 7-year-olds vs. 10- to 12-year-olds vs. adults) x 3 (vehicle velocity: 0.50 vs. 0.75 vs. 1.00 m/s) x 3 (inter-vehicle distance: 0.15 vs. 0.30 vs. 0.45 m) ANOVA with repeated measures on the last two factors. For the percentage of collisions the factor 'vehicle' (first vs. second) was added. In the case the sphericity assumption was violated (i.e. for $\epsilon < 1.0$) Greenhouse-Geisser adjustments of the p-values are reported. Post hoc comparisons were performed using Tukey HSD test ($p < 0.05$).

Movement Time (MT) and Peak Velocity (PV)

MT and PV were determined for each attempted crossing between the vehicles. MT was defined as the time between movement onset of the doll and the moment it reached the far kerb. PV was defined as the doll’s maximum velocity before it reached the far kerb. Univariate ANOVAs were used to compare the MT’s and PV’s for the different age-groups.

Movement onset (TTI₁ and TTI₂)

The onset of the doll’s movement was defined as the moment that the movement velocity exceeded 5% of the peak velocity and expressed in terms of the boundaries of the inter-vehicle gap, i.e. the rear of the first and the front of the second vehicle. TTI₁ is the time between the moment the first vehicle’s rear intersects the doll’s track and the moment of movement onset; TTI₂ is the time between the moment the second vehicle’s front intersects the doll’s track and the moment of movement onset. TTI₁ and TTI₂ were only determined when participants attempted to push the doll between the vehicles. To compare differences between groups, the individual means of TTI₁ and TTI₂ were submitted to univariate ANOVA’s. Following earlier work from Lee and Redish (1981), we reasoned that if one of these variables is constant over conditions (i.e. inter-vehicle time gaps), then this would suggest a timing strategy that is consistent with movement onset being based on the time available before the vehicle is at the intersection point. We therefore calculated the linear regressions of TTI₁ and TTI₂ as a function of inter-vehicle time gap for each participant, and tested for each age-group
separately whether the resultant slopes and Fisher-Z transformed correlation coefficients differed from zero.

Required Velocity
The derivation of the indices for the control of movement velocity deserves some additional explanation. The doll must gain sufficient velocity to avoid a collision with the second vehicle (i.e. lower velocity boundary). At the same time, velocity must not become too high to avoid a collision with the first vehicle (i.e. upper velocity boundary). It is pertinent for collision avoidance that movement velocity remains within the two velocity boundaries when the doll reaches the collision area and until after it has cleared it. The dimensions of the vehicles (0.065 m) and the doll (0.035 m) determine the physical boundaries of the collision area. Figure 4.2 provides a schematic representation of the collision area (hatched). It is located between 0.10 and 0.20 m from the doll’s starting position.

To establish when the doll moves within the boundaries of required velocity, the predicted position where the doll would be at the moment the vehicles cross the doll’s track (providing that the doll’s velocity remains unchanged) was determined throughout the whole movement by using the following formula (see Peper et al., 1994),

\[ xp(t) = x_{doll}(t) - (v_{doll}(t) \times ti_{vehicle}(t)). \]  

In Equation (4.1) \( xp(t) \) is the predicted difference between the doll’s position and the vehicles’ track at the moment a vehicle would cross the doll’s track given the doll’s current position and velocity and the vehicle’s current time remaining before it intersects the doll’s track; \( x_{doll}(t) \) is the current distance between the doll and the vehicle’s track (negative until the intersection is reached, and then positive); \( v_{doll}(t) \) is the current velocity of the doll; \( ti_{vehicle}(t) \) is the vehicle’s current time remaining before it intersects the doll’s track (positive until the intersection point is reached, and then negative). For safe travel, \( v_{doll}(t) \) must be controlled in such a way that the resulting \( xp(t) \) falls outside the collision area at the moment the vehicle would cross the intersection point. Given the dimensions of the collision area (Fig. 4.2), the doll is on a non-collision course when the predicted difference of the doll with respect to the first vehicle, \( xp_1(t) \), is smaller than -0.05 and when the predicted difference of the doll with respect to the second vehicle, \( xp_2(t) \), is larger than 0.05. The doll is on a collision course when these criteria are not met. To avoid a collision, a velocity within the velocity
Figure 4.2. Schematic representation of the doll (circle), the vehicles (squares v1 and v2), the doll’s track ($x_{doll}$ from the starting position at -0.15 m to the far kerb at 0.15 m), the vehicle’s track (at $x_{doll} = 0.00$ m), and the collision area (hatched).
Control of movement velocity in collision avoidance

boundaries is required at the moment the doll enters the collision area at the latest (i.e. at $x_{doll}(t) = -0.05$ m). It must be maintained until the collision area is cleared (i.e. at $x_{doll}(t) = 0.05$ m).

We used two indices for the control of movement velocity. First, we determined the position of the doll (i.e. $x_{doll}(t)$) at the moments the lower and upper boundaries of required velocity were reached. These are denoted with $xrv_{low}$ and $xrv_{up}$, respectively. $xrv_{low}$ is reached the moment that $xp_2(t) > 0.05$. To avoid collision, the lower boundary of required velocity must be attained before the doll enters the collision area (i.e. $xrv_{low} < -0.05$ m). The nearer to the collision area the required velocity is attained, the more likely a collision with the second vehicle becomes. $xrv_{up}$ is reached when $xp_1(t) < -0.05$. To avoid colliding into the first vehicle, the upper velocity boundary must not be reached before the collision area is cleared (i.e. $xrv_{up} > 0.05$ m). Secondly, we determined the $xp(t)$ (i.e. the predicted difference or safety margin) with respect to both vehicles at the moment the doll crossed the intersection, $xp_1$ and $xp_2$. The bigger the margin, the less likely a collision is. The validity of the required velocity description was established by calculating the percentage of non-collision trials that met the four criteria that were set with respect to boundary values of $xrv_{low}$, $xrv_{up}$, $xp_1$, and $xp_2$. Finally, to reveal differences in velocity control between groups, linear regressions of $xrv_{low}$, $xrv_{up}$, $xp_1$, and $xp_2$ as a function of inter-vehicle time gap were calculated for each participant. The resultant intercepts, slopes, and Fisher-Z transformed correlation coefficients were submitted to univariate ANOVA’s.

Results
Crossings and collisions

Adults and pre-adolescent children crossed significantly more often between the two vehicles than young children (F(2, 43) = 5.54, p < 0.01, $\eta_p^2 = 0.21$, Table 4.1). The lower the vehicles’ speed (F(2, 86) = 57.21, p < 0.01, $\eta_p^2 = 0.57$) and the larger inter-vehicle distance (F(2, 86) = 80.49, p < 0.01, $\eta_p^2 = 0.66$), the more crossings were made. Significant interactions of vehicle speed x inter-vehicle distance (F(4, 172) = 3.51, p < 0.05, $\eta_p^2 = 0.08$) and group x vehicle speed x inter-vehicle distance (F(8, 172) = 2.25, p < 0.05, $\eta_p^2 = 0.10$) revealed that the younger children made fewer crossings in situations of intermediate difficulty (i.e. combinations of speed and inter-vehicle distance conditions that resulted in time gaps between 0.30 and 0.45 s). By contrast, all groups crossed rather frequently in the easy conditions (i.e. time gaps > 0.45 s) but less so in the difficult conditions (i.e. time gaps < 0.3 s).
Young children collided more often than adults ($F(2, 43) = 6.40, p < 0.01, \eta_p^2 = 0.23$, Table 4.1). Most of the younger children’s collisions occurred with the second vehicle for conditions with the 0.15 m inter-vehicle distance. A similar pattern, but to a lesser degree was found for the pre-adolescent children, but not among the adults. These effects were revealed by significant effects of vehicle ($F(1,43) = 12.58, p < 0.01, \eta_p^2 = 0.23$), inter-vehicle-distance ($F(2, 86) = 23.85, p < 0.01, \eta_p^2 = 0.36$), vehicle x group ($F(2, 43) = 5.15, p < 0.05, \eta_p^2 = 0.19$), vehicle x inter-vehicle distance ($F(2, 86) = 13.65, p < 0.01, \eta_p^2 = 0.24$), and vehicle x inter-vehicle distance x group ($F(4, 86) = 2.99, p < 0.05, \eta_p^2 = 0.12$).

Table 4.1. Means (and standard deviations) of percentages of crossings and collisions for adults, 10- to 12-year-old children, and 5- to 7-year-old children.

<table>
<thead>
<tr>
<th></th>
<th>Crossings</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td>79.9 (14.8)</td>
<td>3.4 (3.8)</td>
</tr>
<tr>
<td>10-12 years</td>
<td>75.8 (20.8)</td>
<td>8.7 (6.4)</td>
</tr>
<tr>
<td>5-7 years</td>
<td>53.9 (29.9)</td>
<td>15.5 (12.9)</td>
</tr>
</tbody>
</table>

**Kinematic analyses**

The kinematic analyses include the 1115 trials in which participants crossed between the two vehicles, either safely or unsafely. However, the participants did not perform according to the instruction in 31 trials (e.g. starting too early or halfway across the road). These trials were discarded from further analyses. One child in the young children’s group contributed only one trial to the regression analyses and was therefore excluded from the analyses.

**Movement time (MT) and Peak velocity (PV)**

MT did not differ between the groups ($F(2, 44) = 0.39$). To further examine whether MT was related to the time available to clear the collision area, individual MT’s were regressed against the time remaining before the second vehicle crosses the doll’s track at the moment of movement onset (i.e. TTI$_2$). Univariate ANOVAs comparing the three groups showed that regression coefficients were significantly higher for adults than for pre-adolescents, which in turn were higher than for young children ($F(2, 44) = 21.59, p < 0.01, \eta_p^2 = 0.51$). The slope of the linear regression was significantly steeper and the
intercept significantly smaller for adults and pre-adolescent children than for young children ($F(2, 44) = 11.15, p < 0.01, \eta_p^2 = 0.35$ and $F(2, 44) = 23.04, p < 0.01, \eta_p^2 = 0.52$, respectively). This indicates that each group moved faster when less time was available; however, the influence of available time on MT was weaker for the young children (Fig. 4.3).

PV was smaller for young children than for the other groups ($F(2, 44) = 4.85, p < 0.05, \eta_p^2 = 0.18$). Regression analyses of PV as a function of TTI$_2$ revealed significantly higher regression coefficients for adults than for pre-adolescents, which in turn were higher than for young children ($F(2, 44) = 23.12, p < 0.01, \eta_p^2 = 0.52$). Additionally, the slope of the linear regression was significantly steeper ($F(2, 44) = 17.26, p < 0.01, \eta_p^2 = 0.45$) and the intercept significantly larger ($F(2, 44) = 14.64, p < 0.01, \eta_p^2 = 0.41$) for adults and pre-adolescents than for young children. Consistent with the outcomes of the MT analyses, this indicates that each group reached higher maximum velocities when less time was available, and that the influence of available time on PV increased with age (Fig. 4.4).

![Figure 4.3. Linear regressions of movement time (MT) as a function of TTI$_2$; solid line: adults; dashed line: 10- to 12-year-old children; dotted line: 5- to 7-year-old children.](image-url)
Figure 4.4. Linear regressions of peak velocity (PV) as a function of TTI\textsubscript{1}; solid line: adults; dashed line: 10- to 12-year-old children; dotted line: 5- to 7-year-old children.

**Movement onset**

Movement onset times TTI\textsubscript{1} and TTI\textsubscript{2} did not differ between the groups (F(2, 44) = 1.85, F(2, 44) = 1.05, respectively). Linear regressions of TTI\textsubscript{1} and TTI\textsubscript{2} as a function of inter-vehicle time gap indicated that in adults TTI\textsubscript{1} and TTI\textsubscript{2} at movement onset were not constant over inter-vehicle time gaps (i.e. slopes and correlation coefficients differed significantly from zero). However, TTI\textsubscript{1} at movement onset for the pre-adolescents (i.e. the slopes did not differ from zero, t(13)= 0.96) and young children (i.e. slopes [t(18) = 0.01]) and correlation coefficients [t(18) = -0.01] did not differ from zero) was associated with the inter-vehicle time gap (Fig. 4.5). Hence, the children’s movement onset is not inconsistent with a timing strategy based on the first vehicle.

**Required Velocity**

The four criteria with respect to the boundaries of required velocity for crossing the road without colliding (i.e. \(x_{rv_{low}} < -0.05\) m, \(x_{rv_{up}} > 0.05\) m, \(x_{p_1} < -0.05\) m, and \(x_{p_2} > 0.05\) m, see Methods) were met in 92\%, 95\%, and 95\% of the successful trials for the young children, the pre-adolescents, and adults respectively. For the remaining successful trials, either one or two of the criteria were not met. Yet, the participants managed to avoid a collision albeit with a very small safety margin. There was not a
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Figure 4.5. Linear regressions of $\text{TTL}_1$ (dashed lines) and $\text{TTL}_2$ (solid lines) as a function of the inter-vehicle time gap; a) adults, b) 10- to 12-year-old children, c) 5- to 7-year-old children.
Figure 4.6. Typical example of the velocity profile $v_{doll}(t)$ as a function of $x_{doll}(t)$ (upper panel) and the course of $xp_1(t)$ as a function of the doll on the road for a safe crossing. $xp_1(t)$ (middle panel) remains smaller than -0.05 m until the doll reaches 0.05 m. $xp_2(t)$ (lower panel) exceeds 0.05 m before the doll reaches -0.05 m. The horizontal lines reflect the safety thresholds. The hatched areas reflect the collision areas.
Figure 4.7. Typical example of the velocity profile $v_{\text{doll}}(t)$ as a function of $x_{\text{doll}}(t)$ (upper panel) and the course of $x_p(t)$ as a function of the doll on the road for an unsafe crossing. $x_p(t)$ (middle panel) remains smaller than $-0.05$ m until the doll reaches $0.05$ m. However, $x_p(t)$ (lower panel) does not exceed $0.05$ m before the doll reaches $-0.05$ m. The doll collides with the second vehicle. The horizontal lines reflect the safety thresholds; the hatched areas reflect the collision areas.
single trial for which all criteria were met but still resulted in a collision. The required velocity analysis thus provides a good description of the present task.

Figure 4.6 shows an example of the doll’s speed (i.e. \( v_{doll}(t) \)), and the predicted difference between the doll’s position and the point of intersection with the vehicles’ track at the moment the vehicle would cross the intersection point (i.e. \( x_{p1}(t) \) and \( x_{p2}(t) \)) as a function of the position of the doll on the road (i.e. \( x_{doll} \)) for a trial in which both vehicles were avoided. The velocity required for safe crossing was attained before the collision (hatched) area was reached (i.e. the requirements of \( x_{p1} < -0.05 \) m and \( x_{p2} > 0.05 \) m) and maintained until the area was cleared. Figure 4.7 shows a trial in which the doll collided with the second vehicle. As can be seen, the velocity that would result in safely avoiding the second vehicle (i.e. \( x_{p2} > 0.05 \) m) was not reached before the doll entered the collision area.

Figure 4.8a depicts for each age group the doll’s position at the moment the lower boundary of required velocity (i.e. \( x_{rv\_low} \)) was reached in relation to the inter-vehicle time gap. Generally speaking, the velocity required to not collide with the second vehicle (i.e. \( x_{rv\_low} \)) was reached later for smaller inter-vehicle gaps. This relationship, however, differed between the age groups (i.e. the slope from the linear regressions of \( x_{rv\_low} \) as a function of the inter-vehicle time gap was steeper for young children than for adults, \( F(2, 42) = 3.65, p<.05, \eta_p^2 = 0.15 \)). For the smallest time gap, the young children only attained the required velocity after they had entered the collision area, implying that a collision was imminent (i.e. a significant effect of group was found for the intercept (\( F(2, 42) = 3.57, p<.05, \eta_p^2 = 0.15 \)).

The predicted difference between the doll’s position and the intersection point at the moment the second vehicle would reach the intersection point (i.e. \( x_{p2} \)) became smaller (i.e. the predicted safety margin is smaller) the smaller the inter-vehicle time gap (Fig. 4.9a). The time gap, had a larger effect on the youngest group than on the adults, as was attested by significant effects of group on the slope and correlation coefficient of the linear regression of \( x_{p2} \) as a function of the inter-vehicle time gap (\( F(2, 42) = 8.22, p<.01, \eta_p^2 = 0.28 \), and \( F(2, 42) = 6.31, p<.01, \eta_p^2 = 0.23 \), respectively). For the smallest time gap the predicted difference, \( x_{p2} \), was approximately zero for the young children. That is, unlike the pre-adolescents and adults, the young children were on a collision course with the second vehicle. This was statistically confirmed by a main effect of group on intercept (\( F(2, 42) = 25.98, p<.01, \eta_p^2 = 0.55 \)).

In sum, the younger children attained the velocity required to avoid collision with the second vehicle relatively late and maintained smaller safety margins. They
Figure 4.8. Linear regressions of $x_{rv, low}$ (a) and $x_{rv, up}$ (b) as a function of the inter-vehicle time gap. Solid lines: adults; dashed lines: 10- to 12-year-old children; dotted lines: 5- to 7-year-old children.
Figure 4.9. Linear regressions of $x_{p1_i}$ (a) and $x_{p2_i}$ (b) as a function of the inter-vehicle time gap. Solid lines: adults; dashed lines: 10- to 12-year-old children; dotted lines: 5- to 7-year-old children.
were therefore more likely to collide. This is particularly true for the smallest time gap, but the young children also tended to move nearer to the boundaries of safe travel for the intermediate inter-vehicle time gaps. Hence, a similar small mistake or inaccuracy in young children is more likely to result in a collision than in pre-adolescents and adults. These conclusions are in agreement with the findings for the percentage of collisions.

In line with the small amount of collisions with the first vehicle, the analysis for the upper boundary velocity (i.e. \( xrv_{up} \)) did not indicate any substantial risk for collision (Fig. 4.8b). The upper velocity boundary (i.e. \( xrv_{up} > 0.05 \text{ m} \)) was never breached; not even for the smallest time-gap did the groups approach the maximal velocity allowed for safe travel. Univariate ANOVA’s on the slope and intercept from linear regression of \( xrv_{up} \) as a function of the inter-vehicle time gap did not yield group effects. The analysis with regard to the predicted difference, \( xp_1 \), underlines that none of the groups appeared to behave structurally unsafe in relation to the first vehicle. That is, the regression lines for \( xp_1 \) as a function of inter-vehicle gap did not approach the unsafe areas, not even for the shortest time-gaps. However, ANOVAs did reveal significant effects of group for the slope (\( F(2, 42) = 3.61, p<.05, \eta^2_p = 0.15 \)) and the correlation coefficient (\( F(2, 42) = 7.13, p<.01, \eta^2_p = 0.25 \)), indicating that pre-adolescents took larger safety margins for the longer time gaps (Fig. 4.9b).

Discussion

We examined age-related differences in collision avoidance in a task that resembled pedestrian road crossing. Five- to 7-year-old children attempted to cross less frequently than pre-adolescents and adults in particular for the intermediate time-pressure conditions (see also Demetre et al., 1992; Lee et al., 1984; Te Velde et al., 2005). Despite fewer attempts, the younger children did collide more frequently mostly with the second of two vehicles. Hence, 5- to 7-year-old children’s perceptions and actions in collision-avoidance situations are not attuned as they are at later ages. Although the younger children’s judgements were a little more cautious than that of pre-adolescents and adults, they still accepted inter-vehicle gaps that were beyond their action capabilities. With respect to the latter, previous work on collision-avoidance behaviour hinted that primary school children may be less capable to adjust their movements to the spatial and temporal properties of the objects to-be-avoided. For example, investigators have suggested that young children wait longer before they start moving (Lee et al., 1984; Plumert et al., 2004; Te Velde et al., 2005; Thomson et al., 2005).
But, and this is probably due to methodological reasons, few genuine advances have been made in understanding how the action unfolds after onset. The present research provides the first systematic description of age-related differences in collision avoidance couched in terms of control of movement. It shows that the younger children are less capable to adjust movement velocity to the motion of the objects to-be-avoided.

Our analyses of the control of movement velocity during collision avoidance is based on the principle that the children need to perceive the temporal gap available, and continuously gear their movement velocity on the basis of the available time and the distance they need to cover to reach safety (cf. Peper et al., 2004). Adjustments in movement velocity are required until it is sufficiently high to avoid collision. We found that for the smaller inter-vehicle gaps the 5- to 7-year-olds attained the velocity required to safely cross in front of the second of two moving objects later (and sometimes too late) than the older children and adults. They also had smaller (and sometimes too small) safety margins than the 10- to 12-year-olds and adults. Because the younger children barely moved fast enough (and sometimes not at all) to avoid collision when they entered the collision area, a small error by these children is more likely to result in a collision (i.e. to breach the velocity boundaries for safe travel) than it would among pre-adolescents and adults who take larger safety margins. Such an error may, for instance, be due to a lapse in attention (distraction), which occurs more often in young children (e.g. Dunbar, Hill, & Lewis, 1991).

It might seem that our description of collision avoidance in terms of required velocity is an overly complicated way of saying that young children moved too slowly which caused collisions. A simple comparison of the children’s maximal velocity suggests just that; the 5- to 7-year-old children moved slower than the older children and adults. Even so, a description in terms of required velocity offers better-quality insight than a comparison of maximum velocity. We found, for instance, that the younger children crossed less often at intermediate inter-vehicle time gaps. This leads to an overrepresentation of crossings with low time pressure among young children compared to the other groups (the number of crossings for the small time gaps was low in all groups). It is a basic finding in interceptive actions that participants reach lower maximum velocities when more time is available to execute the action (e.g. Brouwer, Brenner, & Smeets, 2000; Caljouw, Van der Kamp, & Savelbergh, 2004; Tresilian, Oliver, & Caroll, 2003). Likewise, we observed that all groups showed a lower maximum velocity for larger inter-vehicle time gaps. Hence, the younger children may have moved slower because they chose to cross larger gaps. This shows that an examination of maximum velocity in itself is insufficient. Instead, it is critical to
analyse whether the children’s movement velocity is sufficiently high, not in terms of absolute maximums, but in terms of reaching the velocity required to reach safety at the right time. Our analysis shows that the younger children tend to attain that required velocity late (and sometimes too late). The present data do not directly explain why the young children did not attain the required velocity at the right time. It must be caused by either using the wrong information about the time available or by using it in the wrong way. The latter alternative might include an inability to generate high movement velocities in very short time. The use of a paradigm where vision is occluded at different times combined with a range of vehicle speeds (and accelerations) should in principle be able to reveal what information the children use and whether this changes with age. The understanding of possible age-related differences in movement initiation strategies may also benefit from such a paradigm. The findings of the present study were not straightforward in that respect. There were no age-related differences in movement onset time. However, since there is a relatively high proportion of crossing for the larger inter-vehicle time gaps, it cannot be ruled out that the younger children in fact initiate a little later than the older children and the adults. This might also explain that the children could have based movement onset on the first vehicle, whereas such a strategy must be ruled out for the adults.

Research over the last ten years has accumulated many evidences for the existence of two separate but interacting visual systems (e.g. Glover, 2004; Milner & Goodale, 1995; Rossetti & Pisella, 2002). Although the precise functions of these two visual systems are hotly debated, there is a broad consensus that on the one hand a perceptual system is involved in planning or preparing the action. It obtains visual information to make out what the environment affords for action, choose the goals for action, select an appropriate action mode, and perhaps pre-plan the movement kinematics (e.g. Glover, 2004; cf. Goodale & Milner, 2004). Neuroanatomically, this perceptual system is mediated by the ventral stream. On the other hand, there is an action system that exploits visual information for the fast and online control of the movement. It is supported by the dorsal stream. Within this two-visual systems framework, the 5- to 7-year-olds’ poorer ability to regulate velocity during collision avoidance behaviour indicates that in early childhood the action system is still undergoing development. Numerous studies examining young children’s visual control of the spatial-temporal characteristics of arm and hand movements in relation to the properties of an object to-be-grasped also point to an action system that, although functional, still continues to develop during childhood (e.g. Kuhtz-Buschbeck, Stolze, Johnk, Boczek-Funcke & Illert, 1998). This might be a major constraint on the young
children’s ability to safely avoid collisions with moving objects. In addition, within the two-visual system framework collision-avoidance behaviour is subject to an interaction between the perceptual and action systems. Children must also acquire visual information to perceptually judge whether a gap can be crossed. As we argued, 5- to 7-year-old children’s judgements were not as well attuned to their action capabilities as later during development. It seems that the young children insufficiently accounted for their poor ability to control movement velocity when deciding to cross. This suggests that, at least with respect to collision avoidance behaviour, not only the action system per se, but also its interaction with the perceptual system awaits further development in the younger children (see also Hanisch, Konczak, & Dohle, 2001).

It goes without saying that the experimental task is distinct from real road crossing both in terms of perception (e.g. stationary versus moving point of observation) and action (i.e. arm movements versus locomotion). Notwithstanding these differences, they both are collision-avoidance situations that involve a perceptual judgement to act and require the time of movement onset and velocity of the movement to be tuned to the motion of the objects. In this respect a comparison is legitimate, and strengthened by the observation that both in real road crossing and in the present experimental task young children are more vulnerable, particularly when time pressures are relatively high (e.g. Plumert et al., 2004; Thomson et al., 2005). Two different but closely related points come to the fore. First, the present findings suggest that age-related differences in collision proneness in road crossing cannot merely be understood in terms of the sizes of the gaps accepted to cross. The age-related differences in the quality of velocity control indicate that also the production of the action itself may be a significant contributor to young children’s enhanced vulnerability to collisions. This implies that when considering road safety programmes, the attuning of young children’s movements to moving objects should be emphasized in order to improve velocity control. Moreover, if practice in a safe simulation situation would generalise to road behaviour, then that would have important consequences for road safety education. Tutoring children in crossing rules is not enough. Road crossing is a dynamic situation that requires action skills. Hence, the young children’s poorer ability to adjust movement velocity to the motion of approaching vehicles needs the teachers’ attention as well. Second, the present findings also makes clear that in order to gain a deeper understanding of the young children’s road-crossing skill, it is imperative to have participants actually act to avoid moving objects. Paradigms in which participants only make perceptual or verbal judgements (e.g. Connelly et al., 1998; Whitebread & Neilson, 2000) can be considered a starting point at best.
Chapter 5

Safety in road crossing of children with cerebral palsy
Abstract

Children with Cerebral Palsy (CP) are regularly confronted with their physical constraints during locomotion. Because abnormalities in motor control are often related to perceptual deficits, this study questioned whether children with CP were able to walk across a road as safely as typically-developing peers. Ten children with CP and 10 typically-developing children aged 4 to 14 years were asked to cross a simulated road if they felt the situation was safe. With respect to safety and accuracy of crossings, children with CP behaved comparably to typically-developing children. However, perusal of children’s individual crossing behaviour showed large differences within the CP-group. In contrast to children with damage to the left hemisphere, the children with damage to the right hemisphere made unsafe decisions and did not compensate for them by increasing walking speed. The differences in unsafe behaviour and in the ability to compensate for it within the group of children with CP might be related to damage to specific regions that are involved in the processing of spatial or temporal information.

Introduction

Children with Cerebral Palsy (CP) regularly experience difficulties in activities that for typically-developing children are just habitual. They are often delayed in learning to walk (Crenna, 1998), and in childhood they are not able to walk as fast as their typically-developing counterparts (Leonard, Hirschfeld, & Forssbergh, 1991; Norlin & Odenrick, 1986). Fortunately, by using splints to support spastic or paralysed legs and by modifying bikes, children with disabilities have the opportunity to move independently. However, although these and other adjustments have improved impaired locomotion, it is questionable whether children with CP can participate in traffic as safely as their typically-developing peers. It has been observed that diplegic children were less able to increase walking speed than typically-developing peers when they were required to do so (Abel & Damiano, 1996). This might cause dangerous situations when crossing busy roads. Moreover, abnormalities in motor control are often related to perceptual deficits, which may complicate the perception of temporal and spatial properties of the environment (e.g. Savelsbergh, Douwes Dekker, Vermeer, & Hopkins, 1998), and hence, can be an additional impediment for safely crossing roads by children with disabilities.

In order to cross a road safely, one must be able to perceive the time-to-arrival of approaching traffic. According to the ecological approach to visual perception and action (Gibson, 1979), temporal information is directly specified in the optic array at the eye, provided that velocity of the approaching object and the observer is constant (Lee, 1976). If one attempts to cross a road safely, the perceived approaching time of the oncoming traffic has to be longer than the time it takes to reach the far kerb (Lee, Young, & McLaughlin, 1984). Accordingly, the temporal information of approaching traffic has to be related to the pedestrian’s own walking speed (Gibson, 1979; Demetre, Lee, Pitcairn, et al., 1992). Presumably, action-scaled information that relates temporal information of oncoming vehicles to the pedestrian’s own walking speed is used to determine whether a situation affords crossing. The aim of the present study is to examine whether children with CP have the capacity to perceive safe traffic gaps in the context of actual road crossing. To perceive safe gaps, they need to be able to perceive information that specifies time-to-arrival of approaching traffic, and secondly, the time-to-arrival of traffic has to be specified in terms of their own (constrained) walking abilities.

Furthermore, the mutual relationship of perception and action (Gibson, 1979) implies that perception of relevant information is enhanced by action, which gives online information about one’s walking speed. This, in turn, guides and constrains
further action. Several studies have validated this importance of self-motion for accurate perception in various tasks by adults (Oudejans, Michaels, Bakker, & Dolné, 1996a; Cornus, Montagne, & Laurent, 1999). Furthermore, Savelsbergh et al. (1998) found that children with CP were able to make more accurate judgements whether an aperture afforded passing through while locomoting than while standing still. These judgements when locomoting did not differ from judgements of typically-developing peers. During road crossing, Oudejans, Michaels, Van Dort, & Frissen (1996b) demonstrated that adults were able to make more accurate decisions about whether a road afforded crossing while locomoting as compared to standing still on the kerbside. The effect of self-motion or locomotion while deciding to cross a road has yet to be assessed in children, but these observations suggest that children might also benefit from locomotion.

Several researchers (Lee et al., 1984; Demetre et al., 1992; Connelly, Conaglen, Parsonson, & Isler, 1998) have investigated typically-developing children who were required to make judgements about whether it was safe for them to cross the road in front of approaching traffic. They found that children aged five years were already able to make reliable judgements, however, all children were likely to be cautious. But younger children, in particular, also made dangerous judgements, which would have resulted in accidents. For fast moving traffic, this effect became even more pronounced. With increasing age, children were able to make more accurate decisions.

Thus far, no road-crossing experiments where children with CP were required to actually cross the road have been carried out. However, especially children with CP of a mild to moderate severity strive to behave just as their typically-developing peers, and many of them want to go to school without help of their parents. The aim of this study was to assess the basic capacity of these children to make safe decisions about crossing a single-lane road, and furthermore, whether there are any differences to typically-developing children. To this end, we used a simulated road on which one slowly approaching bike was moving at different speeds, and where children were required to judge whether or not to cross while standing still and while walking on the kerbside. They were asked to cross the road if they thought the situation was safe. In doing so, the basic capacity of children with CP to perceive and act according to temporal information in relation to their own abilities, required for safe participation in traffic, was examined in a natural, but safe manner.
Method

Participants
Twenty children were included in the study, ten children with CP (two girls and eight boys; mean age 9.3 years) between 4 and 14 years old, and ten typically-developing children (four girls and six boys, mean age 9.1 years) between 6 and 12 years old, that served as the control group (see Table 5.1). The mean age and leg-length did not differ between the two groups. Mean absolute difference in age of matched children was 1 year (SD = 0.85). The children with CP were recruited from a school for children with disabilities, ‘Centro de Reabilitação Infantil “Princesa Vitória”’ in Rio Claro (Brazil). The control children were recruited from the sport-facilities of the university in Rio Claro. The functional inclusion criterion was the ability to walk independently. Children with visual, hearing, or walking problems (not due to CP) that could not be corrected were excluded. Additional exclusion criteria for the CP-group were moderate to severe mental retardation, ataxia, chorea-athetosis, hemi-neglect and other medical problems not associated with CP that could influence walking-speed. All participating children with CP were diagnosed with spastic hemiplegia or diplegia of mild to moderate severity. Prior to the initiation of the experiment, an informed consent form was signed by a parent or caretaker.

Apparatus
In the laboratory, an experimental road, 20 meters long and three meters wide, was created. At one end, designated as the crosswalk, wooden platforms were placed on both sides of the road; these platforms represented the kerbsides. The children started the experiment from one kerbside and walked across the road to the kerb on the other side. Figure 3.1 (see Chapter 3) shows the simulated road and the kerbsides. Two starting-positions for children were marked: the first one, directly at the kerbside, was used to examine walking across the road from an initial standing position, the second one, at two meters from the kerbside, was used to examine walking across the road from a locomoting posture.

The experimental vehicle was a bicycle that approached in the ‘far lane’ from the right side as seen from the child’s perspective. A frame connected to a cable, at a height of 2.5 meters above the road, supported it. This cable was wrapped around pulleys at both the beginning and the end of the road. An engine, placed at the beginning of the road, rotated the pulley. This engine could be switched on and off manually, could be reversed, and was able to produce a constant velocity of the cable and bike up to a maximum of 1.8 m/s. Time and distance to reach constant velocity and
Table 5.1. Age (years), gender, leg-length (m), disorder, lesion side, and severity of the children in the Cerebral Palsy-group; age, gender and leg-length (m) of the children in the control group

<table>
<thead>
<tr>
<th>Child</th>
<th>Age</th>
<th>Gender</th>
<th>Leg-length</th>
<th>Disorder</th>
<th>Lesion Side</th>
<th>Severity</th>
<th>Age</th>
<th>Gender</th>
<th>Leg-length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.3</td>
<td>F</td>
<td>0.61</td>
<td>Hemi</td>
<td>Left</td>
<td>Mild</td>
<td>6.1</td>
<td>F</td>
<td>0.67</td>
</tr>
<tr>
<td>2</td>
<td>7.0</td>
<td>M</td>
<td>0.69</td>
<td>Hemi</td>
<td>Right</td>
<td>Mild</td>
<td>6.9</td>
<td>F</td>
<td>0.71</td>
</tr>
<tr>
<td>3</td>
<td>7.7</td>
<td>M</td>
<td>0.71</td>
<td>Dip</td>
<td></td>
<td>Moderate</td>
<td>7.7</td>
<td>F</td>
<td>*</td>
</tr>
<tr>
<td>4</td>
<td>8.0</td>
<td>M</td>
<td>0.76</td>
<td>Hemi</td>
<td>Right</td>
<td>Mild</td>
<td>7.3</td>
<td>M</td>
<td>0.74</td>
</tr>
<tr>
<td>5</td>
<td>8.2</td>
<td>M</td>
<td>0.69</td>
<td>Hemi</td>
<td>Right</td>
<td>Mild/Moderate</td>
<td>7.9</td>
<td>M</td>
<td>0.66</td>
</tr>
<tr>
<td>6</td>
<td>9.3</td>
<td>M</td>
<td>0.72</td>
<td>Hemi</td>
<td>Right</td>
<td>Mild</td>
<td>11.2</td>
<td>M</td>
<td>0.83</td>
</tr>
<tr>
<td>7</td>
<td>9.6</td>
<td>M</td>
<td>0.70</td>
<td>Hemi</td>
<td>Left</td>
<td>Mild</td>
<td>11.0</td>
<td>M</td>
<td>0.91</td>
</tr>
<tr>
<td>8</td>
<td>10.6</td>
<td>M</td>
<td>0.77</td>
<td>Hemi</td>
<td>Right</td>
<td>Mild</td>
<td>11.4</td>
<td>M</td>
<td>0.84</td>
</tr>
<tr>
<td>9</td>
<td>11.9</td>
<td>F</td>
<td>0.83</td>
<td>Hemi</td>
<td>Left</td>
<td>Mild</td>
<td>11.4</td>
<td>F</td>
<td>0.82</td>
</tr>
<tr>
<td>10</td>
<td>14.7</td>
<td>M</td>
<td>0.95</td>
<td>Hemi</td>
<td>Right</td>
<td>Mild</td>
<td>12.2</td>
<td>M</td>
<td>0.85</td>
</tr>
</tbody>
</table>

M = male, F = female, Hemi = hemiparetic, Dip = diplegic, * missing data

to stop the bike were determined after a pilot-study. The bike had side-wheels to ensure stability. In addition, a device that gave a starting signal was designed and one part of it was placed at the starting position of the bike. As the bike passed this part, it displaced a moving arm, which then switched on a lamp that was placed on the left side of the child, and simultaneously caused a movement in an OPTOTRAK marker that was attached to the device’s second part. This was the signal to start looking towards the bike and to judge whether or not to cross the road. The distance from crosswalk to the starting device’s moving arm was defined as the bike’s starting distance.

An OPTOTRAK-system registered the three-dimensional position of both a marker on the children’s back and the marker on the starting-device at a sampling rate of 100 Hz. A video camera recorded the children’s behaviour, the bike, and trial numbers. The camera was placed on a tripod next to the OPTOTRAK-camera.
Procedure and design

Before the experiment started, an OPTOTRAK-marker was attached to the child’s back. Subsequently, one of the experimenters gave an explanation and a demonstration of both conditions. If necessary, this was repeated until the child understood the task. The experimenter also instructed the child to walk at normal pace. A pre-test was then performed during which the child crossed the road four times without oncoming bike: two times from the starting point at the kerbside and two times from the starting point at two meters from the edge of the road. Following the pre-test, the experiment was started, with the standing and locomoting conditions randomly assigned, but counterbalanced between subjects.

For the standing condition, children stood at the edge of the road on the kerbside, looking at the lamp on their left side. The bike was placed at the beginning of the road, on their right side, and then started moving towards the crosswalk. OPTOTRAK-data collection started before the bike passed the location where the first part of the starting-device was positioned. When the bike hit the arm of the device’s first part, the light switched on and children were allowed to look at the bike. For the standing condition, they were required to cross the road when possible. For the locomoting condition, children stood at two meters from the kerbside. They started walking immediately when the light switched on and were required to cross the road when possible. They were told to halt when it was not possible to cross the road safely. The bike stopped when it had passed the crosswalk, and was then reversed to the beginning of the road and the device’s first part was positioned on the next starting-position. For both conditions, children completed eight trials.

Approaching time of the bicycle was manipulated by i) changing starting-distance of the bike and ii) changing velocity of the bike. Starting-distances between the front-wheel of the bike and the crosswalk were 2.3, 4.3, 6.3 and 8.3 meters; velocities of the bike were 0.9 and 1.3 m/s. This resulted in eight different approaching times for each child throughout each condition. The velocities and distances were determined after a pilot study, in which kerb delays and crossing times of typically-developing children were obtained. Accordingly, on the standing condition approximately 5 trials would be within and 3 trials beyond children’s abilities to cross, whereas on the locomoting condition approximately 3 trials would be within and 5 trials beyond their abilities to cross. Starting positions were presented in ascending and in descending order, first for one velocity and afterwards for the other velocity of the bike. Children executed two conditions: 1) deciding whether or not to cross in front of the approaching
bike while standing still on the kerbside, and 2) deciding whether or not to cross in front of the oncoming bike while locomoting on the kerbside.

**Data analysis and dependent variables**

All trials were scored according to whether or not children crossed the road. OPTOTRAK-data were used to calculate kerb delay, time-to-arrival, and crossing time. 

*Kerb delay* was defined as the time the child spent on the kerb after the starting signal until the first step on the road. *Time-to-arrival* was defined as the bike’s arrival time at the moment the child stepped on the road; that is the bike’s approaching time minus the child’s kerb delay. *Crossing time* was defined as the time between the first step on the road and lifting the last foot off of the road. These variables were calculated for all trials where children crossed the road.

In order to examine safety and accuracy of decisions, approaching times of the bike were scaled to (mean) kerb delays and individual (mean) crossing times. To determine safety of decisions, the percentages of unsafe crossings and *crossing ratios* for unsafe decisions were calculated; that is, the ratios of time-to-arrival and crossing time. *Unsafe crossing* was defined as crossing when the time-to-arrival minus kerb delay was shorter than individual mean crossing time (i.e. an overestimation of ability). All other crossings were regarded as safe. This implies that no safety margins were taken into account, which may be considered risky in normal life. However, this study assessed whether children were able to scale time-to-arrival of the approaching bike to their own capacities, and therefore minimal safety margins were also defined as safe. In order to examine the accuracy of crossings, the percentages of unnecessarily rejected gaps were determined (i.e. errors on the safe side), and *rejection ratios* for rejected gaps were calculated; that is, the ratios of approaching time of the bike, and the sum of mean kerb delay and mean crossing time. *Unnecessarily rejecting gaps* was defined as deciding not to cross the road in front of the bike when approaching time of the bike was longer than the sum of individual mean kerb delay and individual mean crossing time. In these situations there appeared to be sufficient time to cross the road safely, but children decided not to cross (i.e. underestimation of ability). All other rejected gaps were regarded as correctly rejected.

Crossing time was subject to a 2 (group: CP vs. Control) by 2 (test: Pre-test vs. Experiment) by 2 (condition: Standing vs. Locomoting) ANOVA with repeated measures on the last two factors. Percentage of crossings, kerb delay, time-to-arrival, and safety and accuracy of decisions were subject to a 2 (group: CP vs. Control) by 2
Results

Children with CP vs. Control Children
Children crossed more often in the standing condition than in the locomoting condition, \( F(1, 18) = 48.32, p < 0.01, \eta^2_p = 0.73 \). The children with CP crossed on 56% of the standing trials and on 33% of the locomoting trials; the control children crossed on 56% of the standing trials and on 30% of the locomoting trials. The ANOVA yielded no group effects.

Children spent more time on the kerb after the starting signal in the locomoting condition than in the standing condition, \( F(1, 18) = 480.54, p < 0.01, \eta^2_p = 0.96 \). Mean kerb delay in the standing condition was 1.02 s. (SD = 0.35), and in the locomoting condition 2.90 s. (SD = 0.36). This difference was presumably due to the two meters walking on the kerb in the locomoting condition, and may explain why fewer crossings were made in this condition.

There were two main effects regarding crossing time. Children crossed faster during the experimental situation than during the pre-test, \( F(1, 18) = 19.34, p < 0.01, \eta^2_p = 0.52 \), and children crossed faster in the locomoting condition than in the standing condition, \( F(1, 18) = 8.42, p < 0.01, \eta^2_p = 0.32 \). An interaction effect, \( F(1, 18)=11.70, p < 0.01, \eta^2_p = 0.39 \), indicated that children crossed faster in the locomoting condition (M = 3.06 s., SD = 0.36) than in the standing condition (M = 3.45 s., SD = 0.52) during the pre-test, whereas during the experimental situations crossing times for both conditions were comparable (M = 2.90 s., SD = 0.33 in the standing and M = 2.91 s., SD = 0.39 in the locomoting condition). The ANOVA yielded no significant group effects.

Mean time-to-arrival of the approaching bike when children crossed the road was shorter in the locomoting condition than in the standing condition, \( F(1, 18) = 11.82, p < 0.01, \eta^2_p = 0.40 \). In the standing condition mean time-to-arrival of the bike when children crossed the road was 5.59 s. (SD = 0.73). In the locomoting condition this was 5.03 s. (SD = 0.97). This difference was presumably due to the longer kerb delays.

The percentages of unsafe decisions and the accompanying crossing ratios did not differ between the groups or conditions. Table 5.2 shows the number of safe and unsafe decisions, and the mean crossing ratios for both safe and unsafe crossings. This table demonstrates that the children with CP made unsafe decisions in both the standing
and the locomoting condition, whereas the control children only made unsafe decisions in the locomoting condition. For the control group two of the youngest children made unsafe decisions, whereas for the CP-group unsafe decisions were not related to age.

The percentages of unnecessarily rejected gaps were comparable for groups and conditions. The accompanying rejection ratios yielded a main effect for condition, $F(1, 7) = 10.59, p < 0.05, \eta^2_p = 0.60$; rejection ratios were larger relative to children’s own abilities in the standing condition than in the locomoting condition. Table 5.2 shows the number of correctly and unnecessarily rejected gaps and rejection ratios.

Table 5.2. Number of safe and unsafe decisions to cross and correctly and unnecessarily rejected gaps; means (and standard deviations) of crossing ratios and rejection ratios; for the children with Cerebral Palsy (CP) and the control children in the standing and locomoting conditions.

<table>
<thead>
<tr>
<th></th>
<th>Safe accepted</th>
<th>Unsafe accepted</th>
<th>Correctly rejected</th>
<th>Unnecessarily rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number &amp; Ratio</td>
<td>Number &amp; Ratio</td>
<td>Number &amp; Ratio</td>
<td>Number &amp; Ratio</td>
</tr>
<tr>
<td>CP stand</td>
<td>40 2.06 (0.57)</td>
<td>5 0.65 (0.19)</td>
<td>26 0.64 (0.18)</td>
<td>9 1.22 (0.15)</td>
</tr>
<tr>
<td>CP locomote</td>
<td>22 1.77 (0.51)</td>
<td>4 0.72 (0.15)</td>
<td>45 0.57 (0.21)</td>
<td>9 1.09 (0.05)</td>
</tr>
<tr>
<td>Control stand</td>
<td>45 1.91 (0.59)</td>
<td>0 -</td>
<td>30 0.65 (0.18)</td>
<td>5 1.26 (0.15)</td>
</tr>
<tr>
<td>Control locomote</td>
<td>21 1.85 (0.50)</td>
<td>3 0.75 (0.15)</td>
<td>49 0.61 (0.23)</td>
<td>7 1.14 (0.09)</td>
</tr>
</tbody>
</table>

Summarising, these results demonstrate that the ten children with CP as a group behaved comparably to their typically-developing peers in this road-crossing simulation. Still, although not significant, from Table 5.2 it can be deduced that the children with CP made more unsafe decisions (nine) than the typically-developing children (three). Because of the serious consequences that these decisions might have, it was necessary to further analyse the data of the children with CP. Perusal of the individual data of children with CP suggested that location of the lesion might influence behaviour. It was mainly the children with right hemispheric damage who seemed to make unsafe decisions. To further examine this suggestion, the CP-group was divided into two subgroups: i) children with damage to the right hemisphere (RHD) including three hemiparetic and one diplegic child and ii) six children with a damage in only the left hemisphere (LHD). Because of the small sample sizes within the CP-group, nonparametric Kruskal-Wallis tests, followed by Mann-Whitney U tests to examine
differences between (pooled) groups, were used to determine whether the children with
RHD and the children with LHD differed from each other and the controls on
percentages of crossings, kerb delay, crossing time, time-to-arrival, and safety and
accuracy of decisions.

Children with RHD vs. Children with LHD and Control Children
A Kruskal-Wallis test yielded significant chi-squares for percentages of crossings, $\chi^2 = 8.55$, $p < 0.05$, and time-to-arrival, $\chi^2 = 7.00$, $p < 0.05$. Significant differences with
respect to the percentages of crossings were found both when the children with RHD
were compared to the pooled data of the children with LHD and the controls, and when
the children with LHD were compared to the pooled data of the children with RHD and
the controls. The children with RHD crossed on 59% of 64 trials, the control children
on 43% of 160 trials, and the children with LHD only on 34% of 96 trials. The children
with RHD crossed for shorter time-to-arrivals of the approaching bike ($M = 4.4 s., SD = 0.6$) than the pooled group of the children with LHD ($M = 5.8 s., SD = 0.5$) and the
controls ($M = 5.4 s., SD = 0.7$). The children with LHD did not differ when compared
to the pooled data of the children with RHD and the controls. Regarding kerb delay and
crossing time no group effects were observed.

A Kruskal-Wallis test yielded a significant chi-square for percentages of unsafe
decisions, $\chi^2 = 6.63$, $p < 0.05$. The children with RHD made significantly more unsafe
decisions (12.5% of 64 trials) when compared to the pooled group of the children with
LHD (1% of 96 trials) and the controls (2% of 160 trials). The percentages of
unnecessarily rejected gaps did not differ statistically between the groups. Table 5.3
gives the number of safe and unsafe crossings and the accompanying mean crossing
ratios, and the number of correctly and unnecessarily rejected gaps and the
accompanying rejection ratios of the children with LHD and RHD. Because of the
small amount of data on crossing and rejection ratios, these were not statistically tested
for differences. In addition, further inspection of the data revealed that two of the four
children with RHD accepted unsafe gaps, while also rejecting safe gaps. This
inconsistent behaviour was not observed for the children with LHD.

For all (sub)groups some risky or unsafe gaps were accepted; however, by
walking faster children might compensate for these decisions. In order to test children’s
ability to adapt crossing behaviour to the bike’s arrival time, the relation of crossing
time and time-to-arrival of the oncoming bicycle was assessed. First, crossing times
were scaled to individual mean crossing time and time-to-arrivals were scaled to
individual mean time-to-arrival of the approaching bike when children crossed the road.
In doing so, correlations were not influenced by different children within one group spending more or less time on the kerb or walking at a different speed. Pearson’s correlation coefficients were calculated for ratios of crossing time and ratios of time-to-arrival of the bike. Correlation coefficients were significant for the LHD-subgroup, \( R(24) = 0.84, p < 0.01 \) and \( R(9) = 0.71, p < 0.05 \) for the standing and locomoting condition, respectively. For the RHD-group, on the other hand, correlation coefficients were low, \( R(21) = 0.35, p = 0.06 \) and \( R(17) = 0.38, p = 0.07 \) for the standing and locomoting condition. The control group also showed a low correlation, namely \( R(45) = 0.38, p < 0.01 \) and \( R(24) = 0.33, p = 0.06 \) for the standing and locomoting condition. These correlations demonstrate that the children with LHD adapted crossing time to time-to-arrival of the bike, whereas the children with RHD did not clearly adapt crossing behaviour. The one child with LHD who made an unsafe decision, was able to compensate for it by increasing walking speed and arrived at the far kerb before the bike reached the crosswalk. For the RHD-group only two unsafe decisions were compensated; six times the bike was stopped in order to avoid a collision. Only one unsafe decision for the control group was compensated, with the bike stopped twice.

<table>
<thead>
<tr>
<th>Safe accepted</th>
<th>Unsafe accepted</th>
<th>Correctly rejected</th>
<th>Unnecessarily rejected</th>
</tr>
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<td>Number &amp; Ratio</td>
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<td>9    1.77 (0.40)</td>
<td>0  -</td>
<td>32  0.59 (0.22)</td>
</tr>
</tbody>
</table>

**Discussion**

It turned out that when road crossing was assessed in relation to children’s own walking abilities, in general, the children with CP performed as safely as the children without disabilities. This is in line with Savelsbergh et al. (1998) who found that children with CP were able to make similar decisions when scaled to their own abilities as typically-
developing children when a task was actually performed. However, unlike Savelsbergh’s study, decisions in the present study concerned safety of children and each unsafe decision might be vitally important. Therefore, decisions of children with CP were individually analysed. After making a distinction between children with left and right hemispheric lesions (LHD and RHD), the interesting observation was made that almost exclusively children with RHD had difficulties in safely crossing the road. This subgroup made more unsafe decisions than the children with LHD or typically-developing peers. Furthermore, they sometimes crossed the road when there was not sufficient time to cross safely, while they also remained on the kerbside when gaps were safe to cross. This inconsistent behaviour was not observed in the other subgroup or in the typically-developing group. Moreover, crossing time was not related to time-to-arrival of the oncoming bike. This means that these children did not compensate for risky or unsafe decisions by walking faster. An explanation might be that these children were not able to perceive time-to-arrival of the bike accurately and therefore did not adjust crossing time (i.e. they did not see that they were crossing unsafely). Children with LHD, on the other hand, were able to make safe decisions and did not differ on this from typically-developing children. In addition, these children adjusted crossing time to time-to-arrival of the oncoming bike. As for the children with RHD, the typically-developing children did not adjust crossing time to time-to-arrival of the bike, but perhaps such adjustments were not necessary. Still, we must keep in mind that the sample sizes were small. In order to draw more general conclusions, greater samples are needed.

Concerning safety of decisions, our preliminary findings suggest that children with LHD seem able to make safe decisions for low-speed traffic approaching from one direction, and moreover, they tune crossing time to time-to-arrival of an oncoming object. Therefore, these children seem to have the basic perceptual-motor capacity to visually time road crossing safely. However, it remains to be seen whether this correct performance is maintained for high-speed traffic approaching from two lanes (Connelly et al., 1998; Demetre et al., 1992). On the other hand, the children with RHD made significantly more unsafe decisions than typically-developing children and children with LHD. Because the children with RHD already experienced problems on this relatively simple task, their fundamental capacity to perceive crossability of a road might be impaired. Accordingly, when crossing a real two-lane road they might experience even greater difficulties.

A possible distinction between children with LHD and RHD seems in line with recent findings on lateralisation of spatial perception in patient- and non-patient studies.
Chapter 5

Galati, Lobel, Vallar, et al., (2000) found that the right hemisphere is extensively involved in coding the position of objects relative to the observer. Postma, Sterken, De Vries, & De Haan (2000) called this egocentric processing of visual information and demonstrated that this is a right-hemispheric function. Khaw, Tidemann, & Stern (1994) has been the only study to suggest that children with damage to the right hemisphere due to Cerebral Palsy have a deficit in spatial perception. In the present study, children needed to perceive time-to-arrival of an oncoming bike. Presumably, they used egocentric information about properties of the bike in relation to their own abilities. If the information on which judgements are based is mainly processed through the right hemisphere, then, this might explain worse performance in deciding whether or not to cross by children with RHD. In addition, Kosslyn (1991), reviewing experimental studies on lateralisation, posited that spatial information that is processed through the right hemisphere is also used to guide movements. This might explain why the children with RHD, besides making unsafe decisions, also did not tune their crossing time to the bike’s time-to-arrival. Children with LHD, on the other hand, adjusted their crossing time to the bike’s arrival time.

The advantage of locomotion, as suggested by Oudejans et al., (1996b), in accepting smaller time gaps for a locomoting condition than for a standing condition was not evident. Only a difference with regard to the rejection margins of wasted gaps was found. Although the amount of wasted gaps was similar in standing and locomoting conditions, children wasted larger gaps relative to their kerb delay and crossing time in the standing condition than in the locomoting condition. This perhaps supports the idea that when locomoting, children are able to more accurately perceive time gaps where they can still cross the road than when standing still. This may be exploited when training these children.

This study suggests that when examining children with CP, researchers should discriminate between different types of CP, especially when spatial-temporal tasks are assessed. Secondly, caretakers and therapists should, besides training motor abilities and modifying instruments, pay attention to perception for action in children with disabilities. If they are trained on a perceptual-motor task, the best way seems to practice this in a natural perception-action related way (Van der Meer & Van der Weel, 1999). Training then should involve perceiving spatial and temporal properties of the environment in relation to their own capacities to prevent them from ending up in unsafe situations.
Chapter 6

Planning and control in a manual collision-avoidance task by children with hemiparesis
Abstract

We examined whether deficits in planning and control during a manual collision avoidance task in children with hemiparesis are associated with damage to the left or right hemisphere (LHD and RHD). Children pushed a doll across a scale-size road between two approaching toy cars. Movement onset and velocity served as indicators of planning and control. In Experiment 1, children with hemiparesis collided more frequently, and controlled velocity less appropriately compared to typically-developing children. Children with LHD initiated their movement later than children with RHD. Experiment 2 compared the preferred and non-preferred hand of children with LHD and RHD. Children with RHD crossed less with their non-preferred hand, while children with LHD initiated later than children with RHD. Moreover, the groups showed differences in velocity control. It is argued that planning deficits may be related to LHD. The hypothesised association between control deficits and RHD, however, was not confirmed.

Introduction

Individuals with spastic hemiparesis demonstrate deviant movement patterns compared to typically-developing individuals. By and large, these deviant movement patterns are investigated using tasks in which participants had to reach and grasp for stationary objects. There are, however, only a few studies that examined interceptive actions in individuals with hemiparesis. A distinctive feature of interceptive actions, such as hitting and catching, is that the temporal characteristics of the movement are enforced by the object to be intercepted. These studies reported differences in movement initiation and overall success as compared to typically-developing individuals, while adjustments to target perturbations were found to be surprisingly accurate (Van der Weel, Van der Meer, & Lee, 1996; Van Thiel, Meulenbroek, Smeets, & Hulstijn, 2002). The avoidance of objects is similarly constrained, yet, the goals are clearly different than for interceptive actions. The present study explores the capabilities of individuals with hemiparesis dealing with moving objects that must be avoided.

Collision avoidance requires three key components, namely 1) accurate perception to decide which action would be appropriate; the subsequent action requires 2) precise preparation and initiation of the movement, and 3) continuous spatial-temporal adjustments to changes in position and direction of the object to be avoided. The first component involves perceptual-cognitive processes, whereas the latter two involve movement planning and control processes. Essentially, successful collision avoidance necessitates that the perception and action components are appropriately tuned to each other. Collision avoidance is pertinent in pedestrian road crossing. After having found a safe place to walk across the road (e.g. Ampofo-Boateng & Thomson, 1991), the pedestrian must decide whether it is safe to cross between two oncoming vehicles or whether it is more prudent to await another gap (Lee, Young, & McLaughlin, 1984). Once the pedestrian decides to cross, he/she must precisely time the onset of walking. To avoid colliding with the foregoing vehicle, onset must not be too early. At the same time, onset must not be too late, because then the pedestrian cannot reach the far kerb before the successive vehicle crosses his/her path. Finally, when the pedestrian has started walking, the spatial-temporal characteristics of locomotion must continuously be geared to the motion of the vehicles (Te Velde, Van der Kamp, & Savelbergh, 2003b). Numerous studies have sought to understand how individuals succeed (or fail) to safely cross a traffic-filled road. In particular, vulnerable road-users such as primary-school children have received much attention (e.g. Connelly, Cognaglen, Parsonson, & Isler, 1998; Demetre, Lee, Pitcairn, et al., 1992; Lee et al., 1984; Plumert, Kearney, & Cremer, 2004; Simpson, Johnson, & Richardson,
Experimentation, however, has been complicated by obvious safety limitations. This commonly resulted in research designs that did not incorporate all three components of collision avoidance. Recently, we have developed a manual collision-avoidance task that retains the key perception and action components (Te Velde, Van der Kamp, & Savelsbergh, 2007). The task comprised a scale-size road-crossing situation, in which adults and children pushed a doll across the street between two approaching toy vehicles. The temporal gap between the two vehicles was manipulated. The younger children crossed less, but collided more often than the older children and adults. This indicates that perceptual decision making and the subsequent action were less appropriately tuned in the younger children. Evaluation of the action showed that all groups initiated the movement at the very moment the first toy vehicle traversed the future path of the doll. After movement onset, participants had to regulate the doll’s velocity to the time that remained until the second vehicle traversed the doll’s path, which was varied during the experiment. In order to describe the children’s velocity control, the Required Velocity model for interceptive actions (RV-model; Peper, Bootsma, Mestre, & Bakker, 1994) was modified. The modified RV-model expresses the future position of, in this case, the hand-held doll at the moment that the second vehicle would cross the doll’s path. The doll’s anticipated future position is based upon the doll’s and vehicle’s current positions and velocities. Accordingly, the model describes for every instant the doll being on a collision or a non-collision course with the second vehicle. This provides a continuous measure of whether the doll has attained the velocity that is required to reach the far kerb without colliding. We observed that younger children attained the required velocity closer to the collision area. In addition, the younger children’s velocity control left relatively small (safety-)margins to clear the collision area, particularly for small inter-vehicle gaps. Hence, the modified RV-model indicated that the young children were less proficient on the collision avoidance task because they geared velocity less appropriately to the motion of the object to be avoided.

The previous discussion draws both on a distinction between visual processes for perception and action (Milner & Goodale, 1995) and on the distinction between visual processes for planning and control. In a recent formulation of the latter dichotomy (Glover, 2002, 2004; Glover & Dixon, 2001), planning encompasses the selection of an action and its initial kinematic parameterisation. According to Glover (2004) this includes the timing of movement onset and initial movement characteristics. In the collision avoidance task at hand, the planning system would facilitate the perceptual decision making of when to start the crossing movement, and perhaps initial
Planning and control of children with hemiparesis

parameterisation of velocity. Control, instead encompasses the online adjustment or correction of the spatial-temporal parameters of the movement. In the present collision avoidance task this would entail the control of the future position through adjustment of movement velocity after movement onset.

The planning and control distinction has recently fuelled discussion on specific disturbances in planning and control in individuals with damage to either the left or the right hemisphere (LHD or RHD; Haaland, Prestopnik, Knight, & Lee, 2004; Rushworth, Nixon, Wade, Renowden, & Passingham, 1998; Steenbergen, Meulenbroek, & Rosenbaum, 2004). Steenbergen and colleagues have suggested that the deviant movement patterns in individuals with hemiparetic cerebral palsy may relate to different constraints imposed during movement planning (e.g. Mutsaarts, Steenbergen, & Bekkering, 2005; Mutsaarts, Steenbergen, & Meulenbroek, 2004; Steenbergen, Hulstijn, & Dortmans, 2000a). For instance, when individuals with hemiparetic cerebral palsy have to grasp a bar and subsequently rotate it, they often use a grip orientation that is incompatible with the rotation requirements of the task. In contrast to typically-developing individuals, individuals with hemiparesis only take the initial orientation of the grip into account. They do no not anticipate or plan the final hand orientation. In a recent study, Steenbergen et al. (2004) made an important qualification to this claim. It was observed that planning was more adversely affected in individuals with LHD than in individuals with RHD. A complementary finding was reported by Te Velde, Savelsbergh, Barela, & Van der Kamp (2003a). Children with cerebral palsy were asked to walk across a lab-based road in front of a slowly approaching bike. Children with RHD made more risky decisions to cross the road than children with LHD. Moreover, they did not appear to increase their walking speed to compensate for the unsafe decisions. These findings might suggest that control is more adversely affected in individuals with RHD than in individuals with LHD (see also Haaland et al., 2004).

The purpose of the present study is to provide further evidence for differential planning and control deficits in individuals with LHD and RHD, respectively. Therefore, in Experiment 1 typically-developing children and children with LHD and RHD were compared on the manual collision avoidance task (cf. Te Velde et al., 2007). If the conjecture is correct that planning is more adversely affected in children with LHD, then this would result in more deviant movement onset patterns in these children. Furthermore, if control is more adversely affected in children with RHD, then this would result in less appropriate movement control after the onset of the movement in these children. In addition, it was examined whether the perceptual judgements to cross
between two moving objects were appropriately tuned to the action processes. In this respect, it is important to note that deficits in planning (e.g. relatively late movement onset) may be easier to compensate for than deficits in control (e.g. relatively late attainment of the required velocity), which might make children with RHD more vulnerable to collisions.

EXPERIMENT 1

Methods
Participants
Eleven children with left-hemiparesis (i.e. primarily damage to the right hemisphere, RHD; mean age = 11.4 ± 3.1 years, mean estimated cognitive age according to school level = 9.8 ± 2.8 years), 11 children with right-hemiparesis (i.e. primarily damage to the left hemisphere, LHD; mean age = 11.2 ± 2.8 years, mean estimated cognitive age according to school level = 9.4 ± 2.2 years), and 22 typically-developing control children (mean age = 9.6 ± 2.5 years) volunteered to participate. The children with hemiparesis all had mild to moderate spastic hemiparesis and were able to complete the task according to the instructions. Precautions were taken that cognitive ability did not influence movement performance. To match the estimated cognitive age, the children were selected on the basis of school level. A line-bisection task (e.g. Ishii, Furukawa, & Tsukagoshi, 1989), which was repeated 9 times, showed that none of the hemiparetic children had a noticeable neglect. The Motor-Free Visual Perception Test, third edition (MVPT-3, Colarusso & Hammill, 2003) did not indicate differences in spatial perception between the children with LHD or RHD. However, the magnitude of the left visual hemi-field was significantly smaller in children with RHD compared to children with LHD. The individual characteristics of the children are summarised in Table 6.1. Written informed consent was obtained from children’s parents prior to the experiment. This experiment was approved by the ethical committee of the Vrije Universiteit Medical Centre and in accordance with the Declaration of Helsinki.

Tasks and Apparatus
A scale-size road on which children manually pushed a doll between two consecutively approaching toy cars was used (see Fig. 4.1, Chapter 4). Children were sitting in front of a table on which the scale-size road was painted. The road was 6 m long and 0.25 m wide with painted kerbs (0.05m wide) on both sides. The doll (Playmobil ®) was
Table 6.1. Individual characteristics of each participant: Name (four-letter code); lesion (LHD or RHD); age; c.age (corrected age according to school-level); gender (M: male, F: female); negl. (neglect: indication in cm of the middle of a 20 cm line, measured from the left – average of nine measures); left field (size of the left visual field, measured in horizontal degrees from the midline); right field (size of the right visual field, measured in horizontal degrees from the midline); mvpt-3 (standard scores on the mvpt-3); sev. (severity: mi: mild; mo: moderate, according to a questionnaire filled out at home by the parents) of children with hemiparesis; age and gender of control children.

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<th>c.age</th>
<th>M/F</th>
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*‡* children who participated in both Exp. 1 and Exp. 2; *†* child who only participated in Exp. 2.
attached to a rod that extended underneath the table through a slot in the table. By grasping and moving the rod underneath the table the children moved the doll as if the doll walked across the road. The doll’s movement path will be denoted as the doll’s track. Two small vehicles (length 0.15 m, width 0.065 m) were placed on two supports that were moved by two mechanically driven conveyer belts (length 3 m each, width 0.05 m). These were sequentially positioned under the tabletop. A slot in the table exactly in the middle of the road, through which the supports slid while standing on the running conveyer belts, made it look as if the two vehicles were driving along the road. The vehicles’ movement path will be denoted as the vehicles’ track. Approximately 0.02 m was left clear between the two conveyer belts to make space for the rod on which the doll was attached to cross the vehicles’ track.

A potentiometer connected to the rod collected position data of the doll. Two Opto Switches (comprising an infrared source and an integrated photo detector) were positioned underneath the kerbs along the road at 1.75 meter before and after the intersection with the doll’s track. Passage of the supports on which the vehicles were positioned through these Opto Switches interrupted the light beams. The Opto Switches thus provided the moments the vehicles were at 1.75m before and after the intersection point. These measures together with the known velocity of the vehicles were used to calculate the moment the vehicles crossed the intersection point. Data of the potentiometer and both Opto Switches were synchronised and collected at a sampling rate of 500 Hz (Labview, National Instruments). A video camera was placed in front of the children to record their behaviour.

Procedure and Design
Prior to the experiment, the children were allowed to push the doll across the road without the approaching vehicles at comfortable movement speed and at maximum movement speed in order to become familiar with the doll’s ‘movement abilities’. Then they received instructions for the experiment. The task was to move the doll across the road from the near kerb between the two approaching toy vehicles to the far kerb without colliding with either vehicle. If crossing between the two vehicles was considered impossible, children were instructed to move the doll across the road after the second vehicle had passed. If a collision occurred, children were politely reminded not to collide, and to pretend that they were crossing the road themselves.

Each child performed 36 trials with a total duration of approximately half an hour. For the children with hemiparesis the vehicles approached from their ipsilesional side, and for the control children the vehicles approached alternately from the left and
from the right. Three constant velocities of the vehicles (0.50, 0.75, and 1.00 m/s) and three inter-vehicle distances (0.15, 0.30, and 0.45 m) were presented, resulting in nine different conditions (seven different inter-vehicle time gaps), each of which was repeated four times. Conditions were randomly ordered within four blocks for children with hemiparesis and within two blocks for the typically-developing children. For the typically-developing children each condition was repeated in two successive trials.

**Dependent variables and data analyses**

*Perception: crossings and collisions*

The percentage of crossings (the number of trials in which the children tried to push the doll between the vehicles divided by the total number of trials, multiplied by 100) and the percentage of collisions (the number of collisions divided by the number of crossings, multiplied by 100) were determined for each child in each condition. To compare the children with hemiparesis to the typically-developing children, the intra-individual means of the percentage of crossings were submitted to a 2 (group: children with hemiparesis vs. typically-developing children) x 3 (vehicle velocity: 0.50 vs. 0.75 vs. 1.00 m/s) x 3 (inter-vehicle distance: 0.15 vs. 0.30 vs. 0.45 m) ANOVA with repeated measures on the last two factors. Further, intra-individual means of the percentage of collisions were submitted to a 2 (group: children with hemiparesis vs. typically-developing children) x 2 (vehicle: first vs. second) x 3 (vehicle velocity: 0.50 vs. 0.75 vs. 1.00 m/s) x 3 (inter-vehicle distance: 0.15 vs. 0.30 vs. 0.45 m) ANOVA with repeated measures on the last three factors. Similar ANOVA’s with repeated measures on the percentages of crossings and collisions were performed to compare children with LHD and RHD. In the case that the sphericity assumption was violated (i.e. for \( \varepsilon < 1.0 \)), Greenhouse-Geisser adjustments of the p-values were reported. Post hoc comparisons were performed using Tukey HSD test (\( p < 0.05 \)).

*Movement initiation*

Children initiate their movements in relation to the first vehicle (Te Velde et al., 2007). Movement initiation, therefore, was defined in terms of the time and distance between the leading vehicle and the doll’s track. It was determined only for trials in which children tried to move the doll between the vehicles. Time-to-intersect (TTI) is the time (s) between the moment of the doll’s movement initiation and the moment at which the rear of the first vehicle reaches the doll’s track. Distance-to-intersect (DTI) is the distance (m) between the rear of the first vehicle and the doll’s track when the doll’s movement is initiated. Because children did not cross on all occasions, particularly not
for the short inter-vehicle time gaps, factor-ANOVA on individual means for the different conditions was deemed inappropriate. Therefore, TTI and DTI were compared between children with and without hemiparesis and between children with LHD and RHD for each inter-vehicle time gap separately (0.20, 0.30, 0.40, and 0.60 s) by performing non-parametric Mann-Whitney U-tests. Not all the children crossed at each inter-vehicle time gap. Hence, rather than submitting the individual means, we used the data from all crossing attempts. Children who cross frequently are somewhat overrepresented compared to individuals who cross less.

**Velocity control**

The modified version of the RV-model (Te Velde et al., 2007) was used to gain insight into the control of movement velocity after initiation. Because it has previously been established that velocity control is related to the second vehicle (Te Velde et al., 2007), the present analyses did not consider that by moving very fast the doll might collide with the leading vehicle. To avoid a collision with the second vehicle, a minimum velocity is required until the doll clears the collision area (Fig. 4.2, Chapter 4; the boundaries of the collision area are determined by dimensions of the vehicle (width 0.065 m) and the doll (width 0.035 m)). To establish when the doll moves at the required velocity (i.e. is on non-collision course), the predicted position of the doll at the moment that the second vehicle would cross the doll’s track was determined. This predicted position was calculated by taking the doll’s current distance from the intersection point with the vehicles’ track and the distance the doll would travel until the second vehicle reached the intersection. This is captured in the following formula,

\[
x_p(t) = x_{doll}(t) - (v_{doll}(t) \times t_{vehicle}(t)).
\]

In Equation (6.1) \(x_p(t)\) is the predicted distance between the doll and the vehicles’ track at the moment the second vehicle would cross the doll’s track given the doll’s current position and velocity; \(x_{doll}(t)\) is the current distance between the doll and the vehicles’ track (negative until the intersection is reached, and then positive); \(v_{doll}(t)\) is the current velocity of the doll; \(t_{vehicle}(t)\) is the current time until the second vehicle intersects the doll’s path (positive until the intersection point is reached, and then negative). Given the dimensions of the collision area (as determined by the dimensions of the doll and the vehicles; Fig. 4.2, Chapter 4), the doll is on a non-collision course when the predicted position of the doll falls outside the collision area, that is, when \(x_p(t) > 0.05\). If, however, \(x_p(t) < 0.05\), then the minimum required velocity
is not met and, hence, the doll is on a collision course. The doll’s velocity, \( v_{\text{doll}}(t) \), should be controlled in such a way that, while pushing the doll across the road, the resulting \( x_p(t) \) falls outside the collision area at the moment the vehicle would cross the doll’s track. To avoid collisions, the required velocity should be attained at the latest when the doll enters the collision area (i.e. \( x_{\text{doll}}(t) = -0.05 \) m). Examples of a safe and an unsafe crossing between the two vehicles are given in Figure 4.5 and 4.6 (Chapter 4).

As indices of velocity control, we first determined where the minimum required velocity was attained by establishing the doll’s distance from the intersection at which the predicted position of the doll would fall outside the collision area the moment the vehicle would reach the doll’s track (i.e. \( x_{rv} \)). Secondly, we determined a safety margin by establishing the predicted position at the moment the second vehicle would reach the intersection for the moment the doll reached the intersection (i.e. \( x_p \)). For each inter-vehicle time gap separately (0.20, 0.30, 0.40, and 0.60 s) \( x_{rv} \) and \( x_p \) were compared between children with and without hemiparesis and between children with LHD and RHD by performing Mann-Whitney U-tests, including the data from all crossing attempts.

**Results**

**Perception: crossings and collisions**

The percentage of crossings was significantly higher for the typically-developing children (68.3 %) than for the children with hemiparesis (52.1 %; \( F(1, 42) = 5.49, p < 0.05, \eta_p^2 = 0.12 \)). Significant effects of velocity (\( F(2, 84) = 77.06, p < 0.01, \eta_p^2 = 0.65 \)), distance (\( F(2, 84) = 160.48, p < 0.01, \eta_p^2 = 0.79 \)), and velocity by distance (\( F(4, 168) = 2.81, p < 0.05, \eta_p^2 = 0.06 \)) on the percentage of crossings showed that both groups crossed more often when the vehicles approached relatively slow and the inter-vehicle gap was relatively large. None of the comparisons between children with LHD and RHD were significant.

The percentage of collisions was higher for children with hemiparesis (6.6 %) than for their typically-developing peers (2.7 %; \( F(1, 42) = 6.67, p < 0.05, \eta_p^2 = 0.14 \)). A significant effect of vehicle (\( F(1, 42) = 15.03, p < 0.01, \eta_p^2 = 0.26 \)) showed that in both groups the children collided more often with the second vehicle than with the first. This was particularly true for the small inter-vehicle distance, as was indicated by a significant distance effect (\( F(2, 84) = 10.36, p < 0.01, \eta_p^2 = 0.20 \)) and a significant vehicle by distance interaction (\( F(2, 84) = 5.20, p < 0.05, \eta_p^2 = 0.11 \)).
The only significant difference between children with LHD and RHD on the percentage of collisions was shown by the interaction between group and velocity ($F(2, 40) = 4.56, p < 0.05, \eta^2_p = 0.19$). Post hoc comparisons indicated that children with LHD collided more often for the intermediate vehicle velocity ($v = 0.75$), whereas children with RHD collided more often for the fast vehicle velocity ($v = 1.00$).

**Movement initiation**

Table 6.2 displays the means and standard deviations of TTI and DTI for the seven inter-vehicle time gaps. The comparison of children with and without hemiparesis did not reveal significant differences. The data suggest that for the short inter-vehicle time gaps the children with RHD initiated earlier than the children with LHD. Only for the inter-vehicle time gap of 0.30 s the comparisons of TTI and DTI were significant ($Z = 2.50, p < 0.05$ and $Z = 2.05, p < 0.05$, respectively).

<p>| Table 6.2. Means (and standard deviations) of the temporal and spatial indices of movement initiation, TTI and DTI, for the seven inter-vehicle time gaps for control children, children with hemiparesis, children with LHD, and children with RHD. Smaller values indicate that children initiated when the first vehicle was already closer (i.e., later). |
|---|---|---|---|---|---|---|---|---|</p>
<table>
<thead>
<tr>
<th>TTI</th>
<th>Gap</th>
<th>Control</th>
<th>Hemi</th>
<th>LHD</th>
<th>RHD</th>
<th>DTI</th>
<th>Control</th>
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</table>

* significant: $p < 0.05$
Velocity control

The criteria set for the modified RV-model (i.e. $xrv < -0.05$ and $xp_i > 0.05$) were met in 93% of the 951 trials in which the typically-developing children and the children with hemiparesis safely crossed in-between the vehicles. For the 85 unsafe trials, all criteria were met only once. The modified RV-model can therefore be considered a valid descriptor of the continuous changes in movement velocity for the task under investigation.

Figure 6.1a depicts $xrv$ as a function of the inter-vehicle time gap. It can be seen that for decreasing inter-vehicle time gaps the position where children attained the required velocity became closer to the collision area. In fact, for the smallest inter-vehicle time gap the children were on a collision course (i.e. they reached the required velocity when they were already in the collision area). Likewise, Figure 6.1b shows that with decreasing inter-vehicle time gaps, the predicted position $xp_i$ shifted into the direction of the collision area, indicating that the safety margin decreased, and was too small for the smallest inter-vehicle time gap. The higher percentage of collisions for the conditions with small inter-vehicle time gaps, thus, may be associated with less appropriate velocity control.

Figure 6.1 also suggests that children with hemiparesis attained the required velocity closer to the collision area and that $xp_i$ was smaller compared to control children. Only for the inter-vehicle time gap of 0.40 s the difference for $xp_i$ was significant. That is, for the inter-vehicle time gap of 0.40 s, the predicted position $xp_i$ was significantly closer to the collision area for the children with hemiparesis than for control children ($Z = 2.71$, $p < 0.05$). The difference for $xrv$ just failed to reach significance ($p = 0.065$). Figure 6.1 might also be interpreted as showing that children with RHD attained the required velocity closer to the collision area and that $xp_i$ was smaller compared to children with LHD, but these differences were not significant ($p = 0.059$ and $p = 0.063$ for the inter-vehicle time gap of 0.30 s).

Discussion

Experiment 1 compared manual collision avoidance of typically-developing children and children with LHD and RHD. Children with hemiparesis crossed less frequently than their typically-developing peers. This may indicate that children with hemiparesis were somewhat more cautious in deciding to cross. However, although the children with hemiparesis crossed less frequently, they collided more often with the toy cars than their typically-developing peers. Thus, the perceptual judgements of the children...
Figure 6.1. Means and standard deviations of the two indices of velocity control, $x_{rv}$ (a) and $x_p$ (b), as a function of the inter-vehicle time gap for control children, children with hemiparesis, children with LHD, and children with RHD. $x_{rv} > -0.05$ and $x_p < 0.05$ suggest insufficient velocity control.
with hemiparesis were relatively unsafe, which may be interpreted as perception being less appropriately attuned to the action capabilities. Te Velde et al. (2003a) reported that it were mainly the children with RHD who made unsafe decisions to cross in front of an approaching bike. The present study, however, did not discern such differences between children with LHD and RHD.

Children with hemiparesis did not differ from typically-developing children with respect to movement onset, suggesting that the planning component of action was not adversely affected when considering the hemiparetic children as a group. In addition, the children with hemiparesis controlled velocity less safely than their typically-developing peers, although only for the inter-vehicle time gap of 0.40 s. It remains difficult, therefore, to unequivocally attribute the higher percentage of collisions in children with hemiparesis to deficits in the planning or control of action.

The comparisons between the children with LHD and RHD, however, provided some evidence that children with LHD may exhibit deficits in planning as movement initiation was relatively late for the time gap of 0.30 s. This suggests that the planning of action might have been affected in children with LHD relative to the children with RHD (Haaland et al., 2004; Rushworth et al., 1998; Steenbergen et al., 2004). However, the proposition that children with RHD would show a higher incidence of deficits in control (Te Velde et al., 2003a; Haaland et al., 2004) was not statistically supported, even though Figure 6.1 might suggest that velocity control was relatively unsafe in children with RHD.

The children performed the task with their preferred side. Although the preferred hand is also affected to some extent (e.g. Van Thiel, Meulenbroek, Hulstijn, & Steenbergen, 2000), primarily focusing on this hand ignores the deficits in action capabilities of the non-preferred hand. To obtain a more lucid picture of planning and control deficits in relation to the primary side of the lesion, Experiment 2 compared the performance on the manual collision avoidance task between the preferred (i.e. ipsilesional) and non-preferred (i.e. contralesional) hand in children with LHD and RHD. Hypotheses are similar to Experiment 1, with the distinction that the effects are expected to be most pronounced for the non-preferred hand. Thus, it is expected that planning (e.g. movement onset) is adversely affected in children with LHD and that control after movement onset (e.g. velocity control) is less appropriate in children with RHD. In contrast to Experiment 1, in which the toy cars only approached from the ipsilesional side, in Experiment 2 the toy cars also approached from the contralesional side. This manipulation was included because even a minor reduction of the visual field might become apparent in movement behaviour (e.g. Barton, Behrmann, & Black,
1998; Netelenbos & Van Rooij, 2003; Schatz, Craft, Koby, & Debaun, 2004; Tant, Kuks, Kooijman, Cornelissen, & Brouwer, 2002), although the tests on hemianopia and hemineglect suggested that most children could perceive objects in both visual hemifields rather well.

EXPERIMENT 2

Method

Participants

Seven children with left-hemiparesis (RHD; mean age = 13.7 ± 1.8 years, mean estimated cognitive age according to school level = 12.1 ± 1.9 years) and five children with right-hemiparesis (LHD; mean age = 12.2 ± 2.0 years, mean estimated cognitive age according to school level = 11.0 ± 1.9 years), indicated with an asterisks (*) in the first column of Table 6.1, agreed to participate a second time. These children were chosen as they had demonstrated a longer concentration span during Experiment 1. Child ‘KACO’ only participated in Experiment 2. Both groups contained one child of whom the visual field was bilaterally reduced and one child of whom the contralateral visual field was reduced; the other children did not demonstrate clear hemianopia. According to the line-bisection task, none of the children had noticeable neglect.

Tasks and Apparatus

The same task and apparatus as in Experiment 1 was used.

Procedure and Design

During this experiment, each child performed 80 trials with a total duration of approximately 75 minutes. Half of the children moved the doll with the preferred hand during the first 40 trials, whereas the other half of the children first used their non-preferred hand. Vehicles approached alternately from the children’s ipsilesional and contralesional side. Half of the children started with the vehicles approaching from the ipsilesional side, the other half started with the vehicles approaching from the contralesional side. Five different velocity-distance combinations were presented, namely \( v=0.50 \text{ m/s, } d=0.30 \text{ m}; \ v=0.75 \text{ m/s, } d=0.15 \text{ m}; \ v=0.75 \text{ m/s, } d=0.30 \text{ m}; \ v=0.75 \text{ m/s, } d=0.45 \text{ m}; \) and \( v=1.00 \text{ m/s, } d=0.30 \text{ m}. \) Each combination was repeated four times within each of the four ‘hand-approach side’ conditions. The velocity-distance combinations were randomly ordered within 16 blocks.
Dependent variables and data analyses

**Perception: crossings and collisions**
The percentages of crossings and collisions were determined (see Experiment 1). Intra-individual means of the percentage of crossings were submitted to a 2 (group: LHD vs. RHD) x 2 (hand: non-preferred vs. preferred) x 2 (vehicle approach side: contralesional vs. ipsilesional) x 5 (velocity-distance combination) ANOVA with repeated measures on the last three factors, and the intra-individual means of the percentage of collisions to a 2 (group) x 2 (vehicle) x 2 (hand) x 2 (vehicle approach side) x 5 (velocity-distance combination) ANOVA with repeated measures on the last four factors. In the case that the sphericity assumption was violated (i.e. for $\epsilon$ smaller than 1.0), Greenhouse-Geisser adjustments of the p-values were reported. Post hoc comparisons were performed using Tukey HSD test ($p < 0.05$).

**Movement initiation**
The moments of movement initiation (TTI and DTI) were determined for each child for both hands, and both vehicle approach sides. Comparisons for TTI and DTI were made between children with LHD and RHD, the preferred and non-preferred hands, and between the ipsi- and contralesional vehicle approach side for each inter-vehicle time gap separately (0.20, 0.30, 0.40, and 0.60 s) by using Kruskal-Wallis tests, including the data from all crossing attempts. Post hoc comparisons between groups (within hand and vehicle approach side) and between hand and vehicle approach side (within group) were performed using Mann-Whitney U-tests.

**Velocity control**
The two indices for movement velocity control (i.e. $xrv$ and $xp_i$) were determined for each child, for both hands, and both vehicle approach sides. For each inter-vehicle time gap separately (0.20, 0.30, 0.40, and 0.60 s) $xrv$ and $xp_i$ comparisons were made between children with LHD and RHD, the preferred and non-preferred hand, and between the ipsi- and contralesional vehicle approach side by using Kruskal-Wallis tests, including the data from all crossing attempts. Post hoc comparisons between groups (within hand and vehicle approach side) and between hand and vehicle approach side (within group) were performed using Mann-Whitney U-tests.
Results

Perception: crossings and collisions
Significant effects of hand (F(1, 10) = 6.99, p < 0.05, ηp² = 0.41) and hand by group (F(1, 10) = 11.96, p < 0.01, ηp² = 0.56) indicated that the children with RHD crossed significantly less when they used their non-preferred hand (60%) than when they used their preferred hand (75%). This difference was not found for the children with LHD (79% and 77% respectively). The vehicle approach side did not affect the percentage of crossings, but the children did cross more in trials with relatively larger inter-vehicle time gaps (F(4, 40) = 21.10, p < 0.01, ηp² = 0.68).

The analyses did not reveal any significant main effects of group, hand or vehicle approach side for the percentage of collisions. However, the significant velocity-distance combination effect (F(4, 40) = 4.42, p < 0.05, ηp² = 0.31) and the hand by velocity-distance combination interaction (F(4,40) = 4.94, p < 0.05, ηp² = 0.33) showed that when using their preferred hand, the children collided mainly for the v=0.75 m/s, d=0.15 m combination (i.e. the smallest inter-vehicle time gap), while collisions were distributed more equally across different velocity-distance combinations when using their non-preferred hand.

Movement initiation
Because the primary analysis showed no effects for vehicle approach side, a re-analysis was conducted in which vehicle approach side was removed as a factor. Table 6.3 displays the means and standard deviations of TTI and DTI for the four inter-vehicle time gaps. It suggests that children with LHD initiated later than children with RHD. The comparisons of TTI and DTI for the preferred hand for the inter-vehicle time gaps of 0.30 and 0.60 s were significant (p’s < 0.05). The comparisons between the non-preferred hand failed to reach significance (for the inter-vehicle time gap of 0.30 s, p = 0.055).

Velocity control
Because the primary analysis showed no effects for vehicle approach side, a re-analysis was conducted in which vehicle approach side was removed as a factor. Figure 6.2 depicts xrν and xρi as a function of the inter-vehicle time gaps. Generally, for the shorter inter-vehicle time gaps, xrν was larger and xρi smaller, indicating that the required velocity was attained closer to the collision area and relatively small (safety-) margins were left to clear the collision area. The higher percentage of collisions occurred for the
Table 6.3. Means (and standard deviations) of the temporal and spatial indices of movement initiation, TTI and DTI, for the four inter-vehicle time gaps for children with LHD and RHD using the preferred (pref) and non-preferred (n-pref) hand. Smaller values indicate that children initiated when the first vehicle was already closer (i.e. later).

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<th>LHD n-pref</th>
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</table>

* significant: p < 0.05

conditions with short inter-vehicle time gaps, and thus, may be related to less appropriate velocity control.

Figure 6.2 suggests that velocity control of children with LHD differed from that of children with RHD, particularly for the short inter-vehicle time gaps. For the preferred hand, however, no differences between children with LHD and RHD were found, which is consistent with Experiment 1. By contrast, for the non-preferred hand the children with LHD reached the required velocity earlier (i.e. larger x_{rv}) than children with RHD. This was significant for the inter-vehicle time gap of 0.20 and 0.30 s (Kruskal-Wallis tests and subsequent Mann-Whitney U-tests p’s < 0.05), but not for the inter-vehicle time gap of 0.40 s (p = 0.054). Moreover, for the non-preferred hand, the predicted position x_p was significantly larger for children with LHD than for children with RHD, which was significant for inter-vehicle time gaps of 0.20, 0.30, and 0.40 s (all p’s < 0.05).

Figure 6.2 also suggests differences between the hands within groups. The Kruskal-Wallis and subsequent Mann-Whitney U-tests revealed that the children with LHD reached the required velocity earlier on the road when they used their non-preferred hand (i.e. their non-preferred hand displays relatively cautious control) for inter-vehicle time gaps of 0.20 and 0.30 s (both p’s < 0.05). Moreover, for the children with LHD the predicted position of the doll was aimed further from the collision area for inter-vehicle time gaps of 0.20, 0.30 and 0.40 when they used their non-preferred hand (i.e. x_p was larger; all p’s < 0.05). Differences between the hands of children with RHD were not significant.
Figure 6.2. Means and standard deviations of the two indices of velocity control, $x_{rv}$ (a) and $x_{pi}$ (b), as a function of the inter-vehicle time gap for children with LHD and RHD using the preferred (pref) and non-preferred (non-pref) hand. $x_{rv} < -0.05$ and $x_{pi} < 0.05$ suggest insufficient velocity control.
Discussion

Children with RHD crossed less frequently with their non-preferred than with their preferred hand. By contrast, children with LHD crossed as much with their preferred as with their non-preferred hand. Finally, when using their non-preferred hand, the children with RHD crossed less than the children with LHD. Thus, only children with RHD seemed to take the impoverished action capabilities of their non-preferred hand into account when deciding to cross the road. The percentage of collisions, however, was comparable for both groups and for both the preferred and non-preferred hand. Hence, the perceptual decisions to cross the road appeared safely attuned to the action capabilities in both groups.

Children with LHD seemed to initiate their movement relatively late compared to children with RHD, particularly for their preferred hand. Interestingly, the comparisons of the non-preferred hand did not reveal significant differences. This provides at least partial support for the hypothesis that planning of action is adversely affected in individuals with LHD (Steenbergen et al., 2004).

The results on the control of the movement after onset proved more ambiguous. Like in Experiment 1, the findings confirmed the increased risk for a collision with decreasing inter-vehicle time gap. The comparison between children with LHD and RHD did not yield differences for the preferred hand. When the children used their non-preferred hand, however, the children with RHD attained the required velocity closer to the collision area for the small inter-vehicle time gaps. In addition, the safety margin at the moment the doll crossed the vehicle’s track was smaller for children with RHD in particular for the non-preferred hand. These findings might suggest that control of movement after onset is adversely affected in children with RHD compared to children with LHD (Te Velde et al., 2003a), but only for the non-preferred left hand.

Yet, the results can also be interpreted otherwise. Paradoxically, the children with LHD reached the required velocity for a safe crossing earlier with their non-preferred than with their preferred hand. That is, they behaved more safely with their non-preferred hand. It might be that the children tried to compensate for late initiation (Table 6.3). In that case, the differences between children with LHD and RHD may not be a reflection of control deficits in children with RHD, but may suggest that children with LHD overcompensated after initial planning errors. Neither alternative can be ruled out on the basis of the present study.
General discussion

Planning in children with LHD
The collision-avoidance behaviour indicated planning deficits in children with LHD, but not in children with RHD. This corroborates the findings in recent studies by Haaland et al. (2004), Mutsaarts et al. (2005), Rushworth et al. (1998), and Steenbergen et al. (2004). Moreover, this supports the findings for left hemispheric dominance in action planning in typically-developing individuals as well (Johnson-Frey, Newman-Norlund, & Grafton, 2004; Schluter, Krams, Rushworth, & Passingham, 2001). Planning, however, has a very broad meaning both theoretically and empirically. Glover (2004), for instance, refers to planning as including the selection of an appropriate target, the selection of an appropriate movement, and beyond these also the initial kinematic parameterisation of the movement (cf. Goodale & Milner, 2004). Empirical work has used the selection of the appropriate action (e.g. Rushworth et al., 1998) or the selection of the appropriate posture or movement (e.g. Steenbergen et al., 2004; Mutsaarts et al., 2004) to assess planning, while other studies (Haaland et al., 2004; Mutsaarts et al., 2005; Schluter et al., 2001) have used reaction time as an indicator of planning. Almost every single study maintains its own characterisation of planning, the present study being no exception. That is not to say, however, that similarities are absent. Both the observed increases in reaction time, and the late movement onset found in the present study suggest that children with LHD take longer before starting an action, suggesting an impairment in the initial parameterisation of the movement. In addition, the decision whether or not to act is connected to response selection and to a lesser degree to the selection of the appropriate movement or posture. The observation, therefore, that children with LHD did not take their impoverished action capabilities into account when deciding whether or not to cross with their non-preferred hand is consistent with previously reported impairments in selecting an appropriate action or movement posture. These observations may be interpreted to support the contention that LHD is associated with a general planning deficit. It should be mentioned that the number of participants in the present study is low. In addition, because we performed separate test for each inter-vehicle time gap there is an increased chance of Type-I errors. Taken together, the findings must be interpreted with some care.

Control in children with RHD
We did not find unambiguous support that children with RHD are more susceptible to movement control deficits. Although velocity control after movement onset of children
with RHD can be interpreted as less appropriate than in their peers with LHD, alternative interpretations in terms of overcompensation in children with LHD cannot be excluded. The latter interpretation may find some support in the work of Haaland et al. (2004). They argued that LHD may be associated with a deficit in selecting the optimal velocity for a given context. Our LHD children might have planned a high initial velocity to compensate for a somewhat late movement onset, although this was not evident for their non-preferred hand. In Haaland’s interpretation RHD is associated with deficits in end-point spatial accuracy. Our RHD group did not confirm such an interpretation. However, Haaland’s reasoning is in part based on the claim that control only involves spatial parameters of the movement (see Glover, 2004). This idea originates from studies that chiefly examined reaching to and grasping stationary objects. Evidence from interceptive actions that include temporal constraints, however, shows that not only spatial, but also temporal parameters (e.g. timing, speed) can be adjusted online to satisfy the task constraints during the control phase of an interceptive action (Brenner & Smeets, & deLussanet, 1998; Caljouw, Van der Kamp, & Savelsbergh, 2006; Schenk, Mair, & Zihl, 2004). Nonetheless, even with such an extended definition of control, the present study cannot substantiate the conjecture that RHD would be associated with deficits in movement control.
Chapter 7

Epilogue
Introduction

Child pedestrians are one of the most vulnerable groups among traffic participants. In the United Kingdom, 5- to 11-year-old and 12- to 15-year-old child pedestrians are twice to six times more at risk to become injured or die in traffic than members of any other age group (Scottish Office, 1999). More than one-third of pedestrian accidents in the UK involve children under the age of 16 (UK Department for Transport, Scottish Executive & National Assembly for Wales, 2005). In the Netherlands, the casualty rate among children has shown a considerable decline over the last ten years. And although the current traffic casualty rates of children in general are relatively low (Ministerie van Verkeer en Waterstaat, 2006), the risk for a fatal accident is still much higher for the child pedestrian as compared to the child cyclist or car passenger (www.swov.nl).

Crossing a road involves many components: for example, selecting a safe site and route, looking behaviour, judging to cross, timing movement initiation, and walking behaviour. Each of these components may contribute to the increased accident proneness of the child pedestrian. An important goal for research is therefore to identify the components that limit child pedestrians’ safe crossing at different ages. A considerable amount of research has focused on children’s ability to find a safe place to cross the road by, for instance, using table-top models of various traffic situations (e.g. Ampofo-Boateng & Thomson, 1991; Thomson, Ampofo-Boateng, Lee, et al., 1998). In the same vein, children were taught traffic rules and/or rules of thumb for finding a safe site. Experimentally, such interventions result in a better knowledge base for selecting a safe site (at least in the short term), but the suggested relation between children’s knowledge of traffic rules and accident rate has not remained undisputed (e.g. Duperrex, Roberts, & Bunn, 2002b).

The present thesis focused on the components of road crossing that have been relatively neglected by researchers: the perceptions and action after the pedestrian has found a safe place to cross the road. In other words, the present thesis considered road crossing as a collision avoidance task, and hence its scope is limited to children’s ability to perceptual judge whether it is safe to cross a road and their ability to subsequently tune their actions to the motion of the objects to-be-avoided (e.g. timing movement onset and/or adjust movement velocity). An important question in the thesis is therefore whether children’s accident proneness is associated with limitations in one or more of these perceptual-motor components of road crossing. It is a basic premise (and finding) of the thesis that even a tentative answer to this question calls for the investigation of children in action. Our understanding of children’s collision-avoidance behaviour
cannot be complete without having children navigate in an environment with moving objects.

Following this line of reasoning, an increase in child pedestrians’ safety in traffic not only requires improving their knowledge of the rules of traffic, but also practicing the perceptual-motor components of road crossing. The typical intervention programme, however, does not involve children actually learning to move to avoid moving objects. The objective of the thesis, however, was not to design intervention or training programmes, but rather to put forward and provide empirically support for some of the preconditions for such a programme to be successful. To this end, this final chapter will provide a brief summary of the most relevant findings of the work reported in this thesis. It discusses both the effects of age (in typically developing children) and hemiparetic CP on collision-avoidance behaviour, and delineates how the different perceptual-motor components may be associated with child pedestrians’ vulnerability in traffic situations. Based on this evaluation, suggestions for road-crossing training programmes and interventions are offered.

The need for action

The theoretical starting point of the present work is James J. Gibson’s (1979) ecological approach to perception and action. Gibson argued that action and perception are inseparable or mutually dependent. Gibson (1979) emphasised this by stating that “we perceive in order to move but we must also move in order to perceive” (p. 223). Therefore, to study one while neglecting the other might fail to reveal aspects of either (Turvey, 1977). This would also be true for road crossing; when attempting to study the perception of traffic gaps, the action component cannot and must not be ignored. We found that children’s and adults’ verbal judgements about whether a road affords crossing in conditions in which they were not required to cross the road were not identical to decisions in conditions where they were instructed to actually cross the road; the size of the gaps that participants judged to be crossable was smaller than the size of the gaps they actually crossed (Chapter 3; see also Chapter 2; Demetre, Lee, Pitcairn, et al., 1992). The difference between the two task conditions may be qualitative. Perception without and with subsequent action may rely on the pick-up of different types of information (Michaels, 2000; Van der Kamp & Savelbergh, 2000), and tap into two anatomically and functionally separate visual systems (Goodale & Humphrey, 1998; Milner & Goodale, 1995; see also Glover, 2004). Consequently, a perceptual judgement is not necessarily an entirely valid indicator of actual road
crossing. The substitution of the crossing action by a perceptual judgement not only fails to reveal the control of action, it may also obscure the intricacies of perception. It is therefore pertinent that the key characteristics of the coupling between perception and action are being maintained in experimental studies (as well as in intervention programmes).

Unfortunately, it is not completely clear what the key characteristics of a coupling between perception and action are in the context of road crossing. The least one can say is that the actor must move, that is, she or he must be able to establish and maintain an instantaneous relation between (visual) information and movement (Gibson, 1979; Warren, 1988). That is, the actor must be able to exploit information to make online adjustments in movement; if not, the coordination and control of the action will be reorganised (e.g. Milner & Goodale, 1995). Because safety considerations do not allow children to actually cross a road during an experimental session, most prior research required children only to make perceptual judgements without making an action (e.g. Connelly, Conaglen, Parsonson, & Isler, 1998; Hoffman, Payne, & Prescott, 1980; Pitcairn & Edlmann, 2000). This research therefore did not involve a perception-action coupling and hence should be interpreted with care. By contrast, the experiments reported in the present thesis examined collision avoidance in different road-crossing simulations. Importantly, the simulations allowed children to actually act in an environment with moving objects; participants either walked across a lane with a slowly moving bike or pushed a doll in between toy cars on a scale-size road. In both simulations, visual information to control collision-avoidance behaviour was directly available. A few earlier studies have also tried to retain the pertinent characteristics of a perception-action coupling including Lee’s pretend road studies (e.g. Demetre et al., 1992; Lee, Young, & McLaughlin, 1984) and studies using virtual reality (Plumert, Kearney, & Cremer, 2004; Simpson, Johnson, & Richardson, 2004).

While these simulations have in common that the collision-avoidance task preserved several characteristics of the perception-action coupling, there are also important differences with real-life road crossing. For instance, the design with the approaching bike on a small lane (Chapter 3 and 5) did only permit the use of low speeds, and hence the speeds were substantially lower than that of regular traffic, even when compared to low speed residential areas. These low speeds may have resulted in an underestimation of collision risk for young children (see also Connelly et al., 1998; Chapter 4). By contrast, the simulations on the scale-size road (Chapter 4 and 6) allowed a much more rigorous control and manipulation of the ‘traffic environment’. The simulation involved two vehicles with speeds and inter-vehicle distances that
together with the width of the road provided participants with similar time pressures that may be encountered on a real road without the threats of that real road. Except for a change in effector (i.e. arms instead of limbs), the disadvantage of the scale-size road simulation is that the participants have a birds-eye view on the road-crossing situation instead of being directly immersed in it. The stationary point of observation (i.e. eye) implies that egocentric information sources about the relative times the actor and vehicle cross the intersection point such as for instance the bearing angle (Fajen & Warren, 2004; Gibson, 1950; Lenoir, Musch, Thiery, & Savelsbergh, 2002) are not available. The participants therefore may have relied on other information sources than they would otherwise have exploited. A similar critique appears valid for the pretend road studies. Although these preserved more realistic traffic speeds and involved locomotion (albeit that children pretended that they were crossing in front of an approaching vehicle), the spatially different locations of the vehicle and pedestrian paths implies that normal egocentric sources of information may not have been available. Virtual reality (e.g. Plumert et al., 2004; Simpson et al., 2004) has the advantage that egocentric sources of information can be made available. However, the space to move is often small, and more importantly, some have reported that movement control strategies for interceptive actions in a virtual environment are not identical to the strategies used in a natural environment (Dessing, Peper, & Beek, 2004; Zaal & Michaels, 2003). Perhaps the virtual reality environment affects the relative contribution of the two visual systems; that is, rather than actually interacting with physical objects, participants mimic the action (i.e. they acted as if they caught a ball), thereby possibly enhancing the involvement of the ventral vision for perception system (Goodale, Jakobson, & Keillor, 1994).

In sum, it is unclear what the precise impact of the different simulations is, and also which simulation best generalises to collision avoidance in real road crossing. It is an important step for further research to evaluate the merits and shortcomings of the different simulations in relation to real road crossing. Hence, when in the next section the components associated with children’s collision proneness are discussed, we should keep in mind that although at least some important characteristics of the perception-action coupling are preserved, they remain simulations of the real thing.

**Why are young children vulnerable to collisions?**

Chapter 3 examined how children judged the affordance ‘crossability’ of a small lane on which a bicycle slowly approached. The children aged 5 to 7 years walked across the
small lane safely, they did not collide more often than the children aged 10 to 12 years or adults. Yet, they more often rejected crossable gaps, suggesting that they tended to be prudent. Complementary analyses showed that the participants’ decisions to cross were related to the size of the gap as well as to the approach velocity of the bike. In other words, the children used information about relevant movement characteristics of the object to-be-avoided to make a decision to cross. Based on this, judging whether or not to cross in itself does not seem to be a prime cause for increased collision proneness of young children, which is in line with previous research on the pretend road (Demetre et al., 1992; Lee et al., 1984; Young & Lee, 1987). Yet, this still does not offer an explanation as to why young children are more likely to collide. Hence, the timing of movement initiation and movement execution were also analysed. The findings indicated that young children took more time before they started walking (see also Lee et al., 1984; Thomson, Tolmie, Foot, et al., 2005), but did increase average walking speed in the case of smaller gap sizes, like the adults did. Longer kerb delays may result in shorter safety margins with the approaching bike, and hence an increased likelihood to collide with it, at least, when the adjustments in walking speed are insufficiently large or made too late.

The continuous changes in movement speed in relation to the objects to-be-avoided were investigated into more detail in Chapter 4. The scale-size simulation involved more realistic traffic gaps. The participants were to push a doll between two vehicles that approached one after the other. This set-up yielded new insights into the relation between age, collision rate and movement control. The more realistic time pressures resulted in fewer attempts to cross by the young children (5- to 7-years-old) than by adults; however, the young children collided more frequently. Like their older peers and adults, they initiated their movement at about the time that the rear of the first vehicle passed the intersection point. Lee et al. (1984) observed a similar movement initiation strategy in adults. Remember that in Chapter 3, in which children tried to cross in front of one slowly moving bike, the young children waited longer before starting to move. This age-related difference in movement initiation strategy in Chapter 3 and 4 may therefore be due to the presence of one versus two vehicles, respectively. Crucially, the youngest children attained the velocity that was required for safe travel later, sometimes well into the collision area, particularly when the size of the gap between the toy vehicles was small. It thus appeared that it is the poorer ability to attune movement velocity to the motion of the vehicles to-be-avoided that is associated with the increased amount of collisions among the younger children. The inappropriate regulation of movement speed after movement onset may suggest that in the younger
children online movement control processes were insufficiently attuned to the task constraints (Glover, 2004; Glover & Dixon, 2001; 2002). That is, collision avoidance requires a continuous pick-up of information that specifies the changing positions and speeds of the self (or doll) and the objects to-be-avoided. It appears that young children have difficulty in making instantaneous adjustments in movement execution (i.e. velocity) when the situation requires such. It is unclear whether this is due to the pick-up of less useful information or whether the children have difficulty to use the information for making the necessary online adjustments in movement execution. To scrutinise these issues, further research should subject children to more refined manipulations of the motion of vehicles to-be-avoided, such as for instance a change of vehicle speed or inter-vehicle distance during approach. The scaled-road simulations allow for such type of manipulations, but any other set-up (e.g. virtual reality), as long as they can accommodate real collision avoidance actions preferably with two approaching vehicles, could do the job.

All the same, the results of Chapter 4 strongly suggest that the ability to control movement velocity is one of the components that contribute to young children’s vulnerability to collisions. This could never have been revealed if the participants were only required to make verbal judgements. Finally, not only age differences in the online control processes, but also differences in planning processes for collision avoidance need further investigation. It is a matter of debate, but one hypothesis states that movement planning involves the initial parameterisation of the movement kinematics, including the timing of movement initiation (e.g. Glover, 2004; cf. Goodale & Milner, 2004). Although young children’s movement initiation strategies did not differ from adults’ (at least when crossing in-between two moving vehicles), the young children did not take their poorer ability to match movement velocity to the required velocity into account. That is, their movement onset timing or even their judgement to cross was not optimally adapted to their ability to control movement velocity.

**Implications for real road crossing and training programmes**

On the one hand, the present thesis reveals that young children in situations with low time pressures (i.e. very slowly moving vehicles) appropriately perceive the crossability of a road; they correctly decide when it is safer to cross or when it is safer to halt (Chapter 3). This suggests that at the level of the affordance (perception-action coupling) they seem sufficiently skilled, at least when traffic speed is low. On the other hand, however, young children in situations with relatively high and more realistic time
pressures (Chapter 4) collided more often and insufficiently adjusted movement velocity to the task. In other words, the continuous fine-tuning of walking speed to the spatial-temporal characteristics of the approaching vehicles may be one of the components that is associated with the young children’s vulnerability in real road crossing. It should, therefore, next to the teaching of traffic rules in general and rules of thumb for finding a safe site to cross, be a spearhead in training programmes that aim to improve young children’s road-crossing skills.

For such training programmes to be successful, it is pertinent to first choose the most appropriate practice setting. It goes without saying that a programme that aims to teach children to attune their movements to a continuously changing environment must create the opportunity for children to actually engage in collision avoidance activity. That is, children must learn to establish and maintain online couplings between (visual) information and movement variables. The choice of a practice setting is neither trivial nor simple; it should not only be attractive and motivating for young children, but at least include two slowly approaching vehicles and preferably allow for a broad range of vehicle approach speeds. Except for the scale-size simulations as used in the present thesis, or situations akin the pretend road studies where children walk adjacent or over (e.g. pedestrian bridge) real roads, new techniques such as immersive virtual reality may be especially promising and a bit more attractive. Also youth traffic gardens may be attractive for the young children, but learning experience may be a little harder to control. Evidently, it is important that teachers are aware of the possible shortcomings of these simulations; generalisation to real road crossing cannot be guaranteed with the present state of the research.

What practice method should be used to improve the young children’s online movement control in such a way that they cannot only safely negotiate traffic under low time-pressures constraints, but also under time pressures that they will encounter in real traffic? If we take as a starting point that young children indeed are able to adjust movement velocity in low time-pressure situations (i.e. low vehicle speeds), then one method would be to enhance that ability by gradually increasing the time pressure that children encounter. The step-by-step increments in time pressure (e.g. by increases in vehicle speed or decreases in inter-vehicle distances) may be so marginal that the amount of errors the children make during practice remain relatively low, thereby slowly adapting the ability to control movement to high time-pressure situations until the children are able to perform under realistic time pressures. In the motor learning literature, this method is known as ‘learning without errors’ or ‘errorless learning’ (e.g. Maxwell, Masters, Kerr & Weedon, 2001). The idea is that the absence of errors during
learning minimises the involvement of explicit processing to skill learning due to it being unnecessary for the learner to test hypotheses about how to improve performance. Hence, errorless learning is thought to encourage the use of implicit, unselective learning processes, which have been shown to lead to more robust perceptual-motor performance that is less likely to break down during secondary tasks performance (e.g. Masters, Law & Maxwell, 2002; Maxwell et al., 2001). Hence, using an errorless learning method to practice young children’s collision avoidance behaviour is less dependent on the teacher’s instruction, and it may have the additional benefit that after learning children’s performance is less likely to be degraded in distracting circumstances.

In contrast to the more implicit movement control processes, perceptual judgements and planning processes may benefit more from declarative or explicit methods of learning. For instance, practice may involve instructing children only to accept gaps that are (sufficiently) large or to start walking as soon as the foregoing car has cleared the intersection point. In this way, the children’s timing of movement onset may become better attuned to their ability to control velocity. Thomson et al. (2005) found that these types of training result in better conceptual understanding among the children, and an improved accuracy of perceptual judgements (without action) of whether a traffic gap is crossable. Importantly, the improvements were found to sustain for a long period after practice.

**Hemiparetic CP and collision avoidance**

The findings in Chapter 5 and 6 show that children with CP as a group are too heterogeneous to be able to identify one simple perceptual-motor disturbance that adversely affects collision avoidance behaviour in children with CP. Even a ‘straightforward’ distinction by type of CP, like hemiparesis, is not very helpful. Based on the presumption that the left and right hemisphere have different functions in perception and action (e.g. Steenbergen & Gordon, 2006), the present thesis distinguished between children with damage to the left hemisphere (LHD) and children with damage to the right hemisphere (RHD). Chapter 5 assessed whether 4- to 14-year-old children with CP were able to walk as safely as typically-developing children across a small lane on which a bike slowly approached. It was found that contrary to children with LHD, children with RHD were more likely to make unsafe decisions to cross in front of the approaching bike. Moreover, they did not increase walking velocity to compensate for these unsafe decisions. It was suggested that the observed vulnerability
to collisions for the children with RHD might be due to deficits in the pick-up of egocentric visual information that specifies the spatial-temporal properties of the environment in relation to the self, which is thought to be supported by the right hemisphere (Galati et al., 2000; Postma et al., 2000; Khaw et al., 1994; Kosslyn et al., 1991). Additionally, the children with RHD’s inability to adjust walking velocity may point to deficits in online movement processes (e.g. Glover, 2004).

Chapter 6 employed the scale-size road simulation to investigate the online control of movement velocity in terms of the velocity required to avoid collisions with the moving vehicles. Collision-avoidance behaviour of primary-school children with LHD and RHD with both the preferred and non-preferred hand were compared to collision-avoidance behaviour of typically-developing children. Remember that in the scale-size road situations the time pressures were considerably higher than in the set-up with the slowly moving bike (Chapter 5). This probably explains that in this study the children with hemiparesis as a group collided more often than the typically-developing children. The higher incidence of collisions among children with hemiparesis was not due to differences in timing onset, but seemed to be related to less appropriate control of movement velocity. The amount of collisions of children with LHD and RHD, however, was comparable. Yet, children with LHD initiated somewhat later than the children with RHD, but only when using their preferred hand. This was interpreted as a possible indicator of a planning deficit in children with LHD, corroborating earlier results by Steenbergen and colleagues (for overview see Steenbergen & Gordon, 2006). In contrast to what was expected from the outcomes of Chapter 5, no clear differences were discerned between children with LHD and RHD with regard to the control of movement velocity to the objects to-be-avoided.

In short, the findings of Chapter 5 and 6 leave us with an uncertain picture regarding the ability to avoid collisions by children with hemiparetic CP. On the one hand, for low speeds the children with RHD seemed to judge crossability unsafely and while not attuning movement velocity sufficiently to the slowly approaching bike. Under higher time pressures, on the other hand, both the children with LHD and RHD made more unsafe perceptual judgements and collided more often than typically-developing children. This higher proneness for collisions was associated with deficits in online velocity control for both groups of hemiparetic children. Because of the large inter-individual variability among children with hemiparesis, the large age range and the relative small number of participants in the experiments reported in Chapter 5 and 6, these findings are best considered as preliminary. Further research should aim to replicate the findings, investigate the individual differences in more detail, and include
more refined manipulations of the motion of vehicles to-be-avoided, such as for instance a change of vehicle speed or inter-vehicle distance during approach, to scrutinise the precise deficit(s) in velocity control. The same is true for the proposal that the children with LHD may have deficits in movement planning processes, as was indicated by a relatively late initiation of movement onset (Chapter 6).

**Implications for rehabilitation**

The present state of affairs makes any strong recommendation for rehabilitation a little premature, but some general directions can be provided. First, similar to the proposed intervention programmes for typically-developing children, children with hemiparesis should practice collision avoidance behaviour in coupled perception-action situations. From an ecological approach, physical therapy or rehabilitation emphasises the interaction between the child, the task and the environment as a basis for children’s learning (Ahl, Johansson, Granat & Carlbergh, 2005). Recent evidence indicates that children with CP may improve perceptual-motor performance if provided with sufficient practice (e.g. Gordon, Charles, & Wolf, 2006). Rather than being a passive recipient of treatment, it is important that a child with hemiparesis practices to achieve functional goals. For instance, previous work has demonstrated that children with hemiparesis show better movement control when a functional goal is available (e.g. bang-the-drum) than when they are required to make abstract movements (e.g. move-as-far-as-you-can; Van der Weel, Van der Meer, & Lee, 1991). This also implies that rehabilitation should not exclusively focus on movement execution processes, but should promote perceptual-motor activities. Specifically, children with hemiparesis often use wheelchairs, tricycles, or other aids for locomotion. It has been shown, for instance, that children with hemiparesis exploit similar perception-action couplings irrespective of whether they walk or use a wheelchair to navigate through a cluttered environment (Savelsbergh, Douwes Dekker, Vermeer, & Hopkins, 1998). Hence, the use of these types of aids create the possibility to engage in actual collision-avoidance behaviour in order to improve the pick-up and use of information to control movement. At the same time, their use would re-focus children’s attention from the deficits in movement control or execution to the achievement of a functional goal (avoiding collisions).

On the other hand, Gordon, Charles, & Wolf (2005; 2006) have recently shown that so-called constrained-induced movement therapy (CIMT) may benefit children with hemiparesis. CIMT modified for children involves extended and repetitive targeted
practice (e.g. 60h) of the impaired limb by restraining the preferred limb of a movement in a functional activity. Gordon et al. (2005), for instance, used a sling to restrain the use of the preferred or non-involved hand. Children performed activities such as the game Connect Four (i.e. ‘boter, kaas en eieren’) to target grasping and wrist orienting movements. During the extended practice, the task constraints (e.g. decreasing the opening in the box in which the disks are placed) are gradually manipulated to approach the functional goal in small steps by successive approximation (called ‘shaping’ by Gordon et al., 2005), a method which is not unlike the errorless learning that was described in a previous section (Implications for real road crossing and training programmes). The method was found to improve hand-movement efficiency and reduced environmental functional limitations, which was retained for at least six months (Gordon et al., 2006). Such a simple, but very intensive ‘improving-by-using’ programme may be adapted to improve hemiparetic children’s road-crossing skills, in particular when the focus of intervention is on the online movement control processes.
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Samenvatting
Samenvatting

Botsingen voorkomen tijdens oversteken: gedrag van kinderen met en zonder hemiplegie.

Het oversteken van een straat is één van de gewoonste zaken in ons leven. Als voetganger lijken wij er geen enkel probleem mee te hebben om onszelf door de verkeerschaos heen te manoeuvreren. Echter, uit statistieken over verkeersveiligheid blijkt dat jonge kinderen een relatief grote kans hebben om betrokken te raken bij een ongeluk wanneer zij zich als voetganger verplaatsen in het verkeer. Hun mogelijkheden om deze taak succesvol uit te voeren lijkt dus beperkt. Het is zaak om te onderzoeken wat de oorzaak is van de kwetsbaarheid van deze jonge kinderen.

De studies die in dit proefschrift staan beschreven gaan na of de mate van risico om een ongeluk te krijgen is gerelateerd aan de mate waarin voetgangers bepaalde vaardigheden beheersen die noodzakelijk zijn om veilig een straat over te steken. Hiertoe is het gedrag van volwassenen en kinderen van verschillende leeftijden, en kinderen met een fysieke beperking, namelijk hemiplegie, bestudeerd. Het doel is om een gedetailleerd beeld te krijgen over bepaalde deelaspecten van het oversteken die mogelijk een oorzaak vormen voor de kwetsbaarheid van kinderen. Er is gekozen voor de volgende drie deelaspecten, namelijk 1) de beslissing om over te steken tussen de stroom van het verkeer door; 2) de timing van de bewegingsinitiatie; en 3) de coördinatie van de spatiotemporele karakteristieken van het bewegen gerelateerd aan het aankomende verkeer.

De theoretische achtergrond van dit proefschrift wordt gevormd door de ecologische psychologie zoals beschreven door J.J. Gibson. Daarbij wordt ervan uitgegaan dat perceptie en actie onlosmakelijk en wederkerig met elkaar zijn verbonden. Een voorbeeld daarvan is dat een voetganger waarnemt of hij wel of niet een straat kan oversteken, en door het oversteken zelf neemt hij waar of hij een juiste beslissing heeft gemaakt. De term *affordance* geeft de mogelijkheden tot actie van de omgeving weer in termen van lichaams- en actiematen van het individu (zoals beenlengte en loopsnelheid). Voor oversteken houdt dit in dat een bepaalde tijd tussen een gepasseerde en een nog aankomende auto voor volwassenen wel voldoende is om de weg over te steken, maar voor kinderen, die niet zo snel lopen als volwassenen, of voor kinderen met fysieke beperkingen, onvoldoende kan zijn. Zo kunnen voor ieder individu andere actiemogelijkheden gelden in identieke verkeerssituaties. De experimentele hoofdstukken 3 en 5 onderzoeken deze koppeling bij volwassenen en kinderen van verschillende leeftijden, en kinderen met hemiparetische Cerebrale Parese (CP) tijdens een gesimuleerde overstektaak.
Naast de bestudering van de oversteektaak in termen van een koppeling tussen perceptie en actie, wordt ook de koppeling op een ander niveau, namelijk die tussen omgeving en bewegingsuitvoering, onderzocht. Een voorbeeld hiervan is het aanpassen van de loopsnelheid aan de spatiotemporale karakteristieken van het aankomend verkeer dat ontworpen moet worden. De hoofdstukken 4 en 6 onderzoeken de koppeling tussen bewegingsinitiatie en snelheid van een door de proefpersonen handmatig bewogen poppetje en de bewegingskarakteristieken van motorisch aangedreven speelgoedautootjes in een geschaalde oversteeksituatie. In deze studies worden ook volwassenen en kinderen van verschillende leeftijden, en kinderen met hemiplegie onderzocht.

Waarom hebben jonge kinderen een verhoogd risico op ongelukken?

Er is al veel onderzoek gedaan naar het risico dat jonge kinderen lopen om een ongeluk te krijgen wanneer zij als voetganger deelnemen aan het verkeer. Het risico is duidelijk gerelateerd aan de mate waarin kinderen in aanraking komen met het verkeer. Lag de leeftijd waarop kinderen het meest kwetsbaar zijn vroeger nog tussen de vijf en negen jaar, tegenwoordig is het risico groter bij iets oudere kinderen. Dat heeft mogelijk te maken met het feit dat kinderen steeds later zelfstandig over straat mogen van hun ouders. Het blijkt namelijk dat met name jonge kinderen, d.w.z. kinderen onder de negen jaar, nog over onvoldoende mogelijkheden beschikken om veilig te kunnen oversteken. In de complexe verkeerssituatie van tegenwoordig zou dat fataal kunnen zijn.

Hoofdstuk 2 geeft een uitvoerige literatuurbeschrijving over vier deelaspecten van het oversteken van een straat, namelijk a) in welke mate kinderen in staat zijn om zelfstandig een goede plek op straat te vinden om veilig over te steken; b) hoe goed zij uitkijken alvorens de straat over te steken; c) hoe kinderen bepalen of zij wel of niet tussen de verkeersstroom door kunnen oversteken; en d) hoe het loopgedrag van kinderen is als zij eenmaal hebben besloten een straat over te steken.

Uit dit literatuuroverzicht blijkt dat kinderen jonger dan negen jaar moeite hebben met het vinden van een goede plek om over te steken. Zij redeneren vaak als volgt: als ik geen auto zie, dan kan ik oversteken, ongeacht of hun gezichtsveld wordt geblokkeerd door bijvoorbeeld geparkeerde auto’s of een struik. Alvorens over te steken en tijdens het lopen op straat vergeten kinderen ook vaak om naar links en rechts te kijken om zo naderend verkeer te zien aankomen. Wanneer er specifiek wordt gevraagd of ze tussen een stroom van auto’s door kunnen oversteken blijkt juist dat
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kinderen erg voorzichtig zijn. Zij steken alleen over als de ruimte tussen twee achtereenvolgende auto’s behoorlijk groot is. De mate van voorzichtigheid neemt echter af naarmate de snelheid van het verkeer toeneemt. Het lijkt er dus op dat kinderen een ‘afstandstrategie’ hanteren terwijl een ‘tijdstrategie’, waarin ook rekening wordt gehouden met de snelheid van het verkeer, beter zou zijn. Op het gebied van het loopgedrag tijdens oversteken is nog maar weinig onderzoek gedaan en kan niet veel meer worden gezegd dan dat kinderen vaak hollend of huppelend over straat gaan.

Naast deze beschrijving van de beheersing van de vier deelaspecten van het oversteken is er in de literatuur ook beschreven of het zin heeft om kinderen hierop te trainen om zo de kans op ongelukken te verkleinen. Al vanaf de leeftijd van vijf jaar blijken kinderen te kunnen worden getraind in het aanleren van veilig overstekgedrag. Zij kunnen leren onderscheiden welke plekken veilig en onveilig zijn, maar helaas weten ze hun kennis onvoldoende toe te passen in de praktijk. Wanneer kinderen erop worden gewezen dat zij moeten kijken alvorens over te steken, dan doen zij dit. Echter, na verloop van tijd verdwijnt dit effect en kijken zij weer net zo weinig als voorheen. Voor het inschatten van de mogelijkheid om wel of niet over te steken geldt hetzelfde: op korte termijn is er kans op verbetering, maar deze verbetering houdt niet langdurig stand. Wat betreft de training van het loopgedrag is er maar weinig bekend.

Naar aanleiding van dit literatuuroverzicht rijst de vraag of wij nu weten wat de oorzaak is van het verhoogde risico van jonge kinderen om een verkeersongeluk te krijgen en of hier adequate trainingsmethodes voor zijn. Enkele punten vallen daarbij op: in een aantal gevallen werd alleen naar een totaalscore gekeken en werden niet de afzonderlijke deelaspecten beoordeeld. Ook werd er regelmatig alleen gekeken wat het kennisniveau van de kinderen was, terwijl bleek dat de transfer van kennis naar de praktijk maar matig bleek. Als laatste is het opvallend dat er van een natuurlijke koppeling tussen perceptie en actie bijna nooit sprake was. Het is daarom moeilijk te bepalen waar kinderen nu echt moeite mee hebben en wat er dus getraind moet worden. Ten aanzien van de trainingsstudies is het daarom nog maar de vraag of er wel getraind werd wat er getraind moest worden en of dit op een dusdanige manier werd gedaan dat er een verbetering te verwachten viel. Met name het feit dat er in veel gevallen geen natuurlijke koppeling tussen waarnemen en bewegen werd gehandhaafd, maakt het twijfelachtig of tijdens echt oversteken het nieuw aangeleerde gedrag kon worden toegepast.

De hoofdstukken 3 en 4 bestuderen de componenten inschatten, timing van bewegingsinitiatie en coördinatie van beweging gerelateerd aan de omgeving afzonderlijk en in een natuurlijk gekoppelde situatie. In beide studies is de
werkelijkheid nagebootst door een schaalmodel van een weg te creëren. Dit levert situaties op waarin kinderen vrij kunnen bewegen in een omgeving met bewegende voertuigen, maar die wel een volledige veiligheid voor het kind garanderen.

Hoofdstuk 3 onderzoekt hoe kinderen de *affordance* ‘oversteekbaarheid’ inschatten van een klein weggetje waarop één fiets langzaam nadert. Jonge kinderen (vijf tot en met zeven jaar) maken niet vaker een onveilige beslissing dan de oudere kinderen (10 tot en met 12 jaar) en volwassenen, zij zijn zelfs iets voorzichtiger. De analyses laten zien dat alle groepen een strategie gebruiken die is gebaseerd op zowel de afstand als de snelheid van de fiets. Wel wachten de jonge kinderen langer alvorens te starten met lopen, waardoor een wat kleinere veiligheidsmarge overblijft dan wanneer zij eerder zouden starten met lopen. Dit brengt mogelijk een vergroot risico op een ongeluk met zich mee.

Bewegingsinitiatie en aanpassingen van bewegingssnelheid aan de spatiotemporale karakteristieken van het verkeer worden in meer detail onderzocht in hoofdstuk 4. Hiertoe moeten de proefpersonen handmatig een poppetje tussen twee motorisch aangedreven speelgoedautootjes door duwen op een geschaald weggetje bovenop een tafel (zie Fig. 4.1). De tijdsdruk tijdens deze taak is groter dan in de taak van hoofdstuk 3. Jonge kinderen steken minder vaak tussen de autootjes door over dan volwassenen, maar botsen wel vaker. Alle groepen starten de beweging ongeveer als de achterkant van het eerste autootje passeert, maar de benodigde snelheid om veilig over te kunnen steken wordt later behaald door de jonge kinderen dan door de andere groepen, met name wanneer de ruimte tussen de twee autootjes klein is. De vermindering van de veroorzaakte aanpassing van de bewegingssnelheid aan de benodigde snelheid blijkt gerelateerd aan het aantal botsingen door de jonge kinderen. Dit suggereert dat de directe bewegingscontrole waarbij bewegingsuitvoering instantaan gerelateerd moet worden aan de continue veranderingen in de omgeving nog onvoldoende is ontwikkeld bij jonge kinderen. Echter, het kan niet worden uitgesloten dat jonge kinderen hun beweging niet goed plannen. Wanneer zij beslissen om over te steken lijken zij onvoldoende rekening te houden met hun verminderde capaciteit om bewegingen aan de situatie aan te passen.

Deze zaken zouden niet aan het licht zijn gekomen als niet werd onderzocht in een situatie waarin perceptie direct aan actie is gekoppeld. Dit benadrukt nogmaals de noodzaak voor zo een gekoppelde situatie in plaats van bijvoorbeeld verbale beslissingen wanneer wel of niet overgestoken zou kunnen worden.
De praktijk van het oversteken en trainingsprogramma’s

Op het niveau van de affordance (perceptie-actie koppeling) lijkt het dat kinderen voldoende kwaliteiten bezitten om veilig te kunnen oversteken, tenminste als de snelheid van het verkeer laag is. Echter, wanneer de tijdsdruk hoger wordt blijkt dat het aanpassen van eigen snelheid onvoldoende is afgestemd op de continue veranderingen in het verkeer. Dit zou dus een oorzaak kunnen zijn van het verhoogde risico dat kinderen lopen om een ongeluk te krijgen en zou dus een onderdeel van verkeerstraining moeten zijn. Om succesvol te zijn is het noodzakelijk dat trainingen plaatsvinden in een setting waarin kinderen daadwerkelijk bewegen en waarin hun bewegingen op een natuurlijke wijze zijn gekoppeld aan de te ontwijken voertuigen. Afgezien van een schaalmodel kan hierbij worden gedacht aan verkeerstuinen of een virtuele omgeving. Het vergt de nodige creativiteit om zowel een effectieve als een voor kinderen uitdagende en aantrekkelijke trainingsmethode te vinden. Daarnaast is het van belang dat een juiste trainingsmethode wordt gekozen. Het leren aanpassen van eigen bewegingssnelheid aan het naderende verkeer zal wellicht het meeste baat hebben bij een impliciete trainingsmethode, terwijl de beslissing om over te steken mogelijk beter kan worden aangeleerd door een expliciete methode. Dit zal nog moeten worden onderzocht.

Het voorkomen van botsingen bij kinderen met hemiplegie

Kinderen met hemiplegie als gevolg van Cerebrale Parese (CP) worden regelmatig geconfronteerd met hun fysieke beperkingen tijdens het lopen. Hun loopsnelheid is over het algemeen lager dan van kinderen zonder fysieke beperking en de mate van flexibiliteit in het aanpassen aan veranderende situaties lijkt daarbij verminderd. Bovendien ondervinden zij vaak perceptuele beperkingen die weer gevolgen hebben voor het bewegen. De invloed die CP of hemiplegie heeft op de veiligheid in verkeersdeelname is nog niet eerder onderzocht. Echter, omdat kinderen met een milde tot matige vorm van CP of hemiplegie vaak wel zelfstandig willen functioneren, is het zinvol om ook voor deze groep na te gaan in hoeverre zij veilig als voetganger kunnen deelnemen in het verkeer.

De studies die in de hoofdstukken 5 en 6 worden beschreven maken gebruik van dezelfde simulaties als in de hoofdstukken 3 en 4, maar onderzoeken het overstekgedrag bij kinderen met hemiplegie en vergelijken dit met het gedrag van kinderen zonder fysieke beperking. Het wordt al snel duidelijk dat een groep kinderen met CP of hemiplegie te heterogeen is voor het onderzoek om duidelijke conclusies te
trekken. Er is er daarom in beide hoofdstukken voor gekozen om de groepen onder te verdelen in kinderen met laesies aan de linker hersenhelft (LHD) en kinderen met laesies aan de rechter hersenhelft (RHD).

Hoofdstuk 5 laat geen verschillen zien in de beslissingen om over te steken en het aantal botsingen tussen kinderen met CP en kinderen zonder fysieke beperking. Echter, wanneer de resultaten individueel worden bekeken, blijkt dat kinderen met RHD vaker een onveilige beslissing maken dan kinderen met LHD en dat zij hun snelheid onvoldoende aanpassen om deze beslissing te compenseren. Er wordt gesuggereerd dat dit ofwel te maken zou kunnen hebben met problemen in de verwerking van egocentrische visuele informatie die de spatiotemporale karakteristieken van de omgeving tot henzelf specificeert, danwel met problemen in de directe controleprocessen tijdens de bewegingsuitvoering (het instantaan aanpassen van de loop snelheid).

Naast het onderscheid tussen LHD en RHD wordt in hoofdstuk 6 ook een onderscheid gemaakt tussen het bewegen met de voorkeurszijde en de niet-voorkeurszijde. In tegenstelling tot hoofdstuk 5 botsen kinderen met hemiplegie vaker dan de kinderen zonder fysieke beperking. Mogelijk heeft dit te maken met de hogere tijdsdruk van de taak in hoofdstuk 6 (schaalmodel weg met twee autootjes) dan die in hoofdstuk 5 (één langzaam naderende fiets). Kinderen met LHD starten de beweging met hun voorkeurszijde wat later dan de kinderen met RHD, wat mogelijk te maken heeft met problemen in de planning van bewegingen bij deze groep. Deze problemen zijn in de literatuur vaker beschreven bij personen met LHD. Wat opvalt is dat, in tegenstelling tot hoofdstuk 5, geen verschillen kunnen worden aangetoond in de mate van directe controle van bewegingsuitvoering.

Het is duidelijk dat de studies uit hoofdstuk 5 en 6 nog geen eenduidig beeld geven ten aanzien van de mogelijkheden van kinderen met hemiplegie (LHD en RHD) om botsingen te voorkomen en veilig een weg over te steken. De resultaten uit deze hoofdstukken zullen dus als preliminair moeten worden beschouwd en meer onderzoek, waarbij gedetailleerd naar individuele verschillen wordt gekeken, is noodzakelijk. Daarbij is het aan te bevelen om de groepsgrootte te verhogen en de heterogeniteit binnen groepen zo klein mogelijk te houden.

**Aanbevelingen voor revalidatie van kinderen met hemiplegie**

Een kant-en-klare richtlijn voor de behandeling van kinderen met CP of hemiplegie valt naar aanleiding van dit onderzoek niet te geven. Wel kan een aantal algemene principes
worden gegeven. Belangrijk is dat in de therapeutische setting een interactie tussen kind, taak en omgeving moet worden gehandhaafd om zo effectief handelen aan te leren. Interactief oefenen met een functioneel doel lijkt de beste manier om een zo optimaal mogelijk gedrag uit te lokken. Er zal niet alleen op het niveau van bewegingsuitvoering, maar ook op het niveau van perceptie-actie koppeling moeten worden geoefend. Dit kan door functioneel te oefenen waarbij gebruik wordt gemaakt van rolstoelen, driewielers of andere hulpmiddelen. Het gaat dan niet zozeer om de uitvoering van het rolstoelrijden, fietsen of anderszins verplaatsen, maar om de interactie met (bewegende voorwerpen in) de omgeving. Deze manier van oefenen leidt de aandacht af van de handelingen die niet mogelijk zijn en focust juist op het uitvoeren van functionele activiteiten.
List of publications
Publications

Articles

Book chapters

Abstracts
Dankwoord
Dankwoord

De basis voor dit proefschrift is in 2000 gelegd met een reis naar Brazilië tijdens mijn studie Bewegingswetenschappen. Eigenlijk wilde ik er even tussenuit en iets anders doen, zoals vrijwilligerswerk in een ‘arm land’ en mijn voorkeur ging uit naar Brazilië. Professor Savelsbergh (ik zal je verder Geert noemen…) van internationalisering wist mij ervan te overtuigen om daar een onderzoeksstage te gaan doen, want hij had nog wel ergens een kaartje van iemand die op een universiteit in Brazilië werkte… Na wat speurwerk hebben we een e-mail gestuurd en al snel kregen we een positieve reactie. Via de e-mail stuurden we een onderzoeksvoorstel en ik was welkom (soms kunnen dingen zo eenvoudig zijn…). Vervolgens was het tijd om beurzen te regelen en dat ging me niet slecht af. Ik kreeg van welgeteld vier stichtingen en fondsen geld (Schuurman Schimmel – van Outenen Stichting, dr. Hendrik Muller’s Vaderlandsch Fonds, Stichting Vrije Universiteits Fonds en Stichting Anna Fonds) waarmee ik uiteindelijk de hele reis heb kunnen financieren en ik was klaar om op ‘t vliegtuig te stappen! Na vier weken rondreizen met Michel en een paar uren verblijf in een ‘ziekenhuis voor de armen’ vanwege voedselvergiftiging bleef er vier en een halve maand over voor de onderzoeksstage. Prof. Dr. Barela (een totaal andere Barela dan de persoon die Geert oorspronkelijk in gedachten had) en zijn vrouw Ana hadden voor mij een studentenhuis geregeld. Dat hield in: Barela had tegen zijn student Thátia, die met 3 andere meiden op zoek was naar een huis, gezegd dat ze een huis met een extra kamer moest huren omdat ik kwam… zo werkt dat… Daar kon ik verblijven na een eerste logeerpartij bij de Barela’s thuis, waar ik overigens ook wel vijf maanden mocht logeren…. Het lab was een grote loods waarin nagenoeg alles mogelijk was! Daar heb ik de experimenten uit de hoofdstukken 3 en 5 uitgevoerd. Daarbij heb ik veel hulp gehad van Barela, Thátia, Paulo, Paula, Dani, en nog een aantal andere lab-genoten: MUITO OBRIGADO MEUS AMIGOS!!! Het lijkt me hier ook op zijn plaats om de kinderen en hun ouders te bedanken dat ze mee hebben gedaan aan het onderzoek. Een experiment duurde meestal zo’n twee uur en de temperatuur was over het algemeen tussen de 30 en 40 graden binnen, soms zelfs zo warm dat de computers het niet aankonden. De ventilatoren stonden er dan niet voor die kleine kinderen die zo goed hun best deden, maar om de computers te koelen…… Ook wil ik de staf van Centro de Reabilitação Infantil “Princesa Victória” bedanken, die voor mij hebben geregeld dat er kinderen met CP aan het onderzoek konden deelnemen. Naast ‘t harde werken (dagelijks van 8.00 tot 18.00 uur in ‘t lab en dat werd hoogstpersoonlijk door Barela gecontroleerd) heb ik heel veel lol gehad met m’n huisgenoten Thátia, Tânia, Marcia en Adriana en al hun vrienden, die ook mij direct als hun vriendin beschouwden en mij dan altijd uitnodigden voor
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Eenmaal terug in Nederland kwam Geert met z’n eerste potje geld… of ik een student assistentschap wilde doen. Dat hield in: met John van der Kamp baby’s onderzoeken (project: ‘baby dark’) naar hun reik- en grijpgedrag… Ik was er niet helemaal weg van, want ik had niet zo veel met baby’s, maar ergens leek ’t me wel een goed idee, je weet maar nooit wat voor een opstapje dat is… Dat bleek een goed opstapje, want na mijn afstuderen bleek Geert weer een potje geld te hebben, zodat ik door kon gaan met baby’s onderzoeken (ditmaal project: ‘baby-occlusie’) en ondertussen één of twee artikelen schrijven over mijn ‘Bazilië-onderzoek’. Die artikelen bleven wat rommelen, totdat John erbij werd betrokken en er rigoureus het mes in zette… au! De trend was gezet, John zou mij voortaan begeleiden waarbij de door mij aangeleverde teksten volledig rood, blauw of zwart, meestal onleesbaar becommentarieerd, terugkwamen… Dat onleesbare werd overigens steeds leesbaarder (als je het handschrift maar vaak genoeg onder ogen krijgt begin je de samenhang te ontdekken. Gelukkig werd ’t vanaf Hong Kong rood, groen, paars of blauw digitaal verbeterd…). Uiteindelijk mocht ik eerst nog een review artikel schrijven voordat de twee ‘Bazilië-artikelen’ af waren. Dankje, Geert dat je mij drie weken voor de deadline vroeg of ik dat wilde schrijven en dank John dat je er ook zo veel tijd in hebt gestoken…

Drie artikelen (en dus hoofdstukken) verder leek ’t ons een goed plan om er toch maar een heel proefschrift van te maken. Dat hield in dat Geert weer potjes geld boven tafel toverde, het zoveelste contract voor mij regelde waarbij flexibel met de flexwet omgegaan moest worden en ik nog twee experimenten ging doen. Dat zijn de experimenten uit de hoofdstukken 4 en 6 geworden. Samen met Joost bedachten we een mooie onderzoeksaufzet wat een leuk kluswerkje werd voor Siro, leuk project zo gelijk na je aanstelling bij de FBW. Het ging niet altijd even relaxed, maar het is toch helemaal goed gekomen, dankjewel!! Hans, ook bedankt voor je ondersteuning, met name toen ’t hele zaakje naar Heliomare verhuisd moest worden en weer terug… Bij deze ook Simone & Paulion bedankt voor het helpen tijdens de data verzameling. En natuurlijk alle collega’s die zichzelf of hun kinderen ter beschikking van mijn wetenschap stelden, dank jullie wel! Hierbij ook Johannes Verheijden van BOSK, die
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Per 1 januari 2005 waren Geert z’n potjes geld toch echt uitgeput en mijn betaalde leven aan de VU afgelopen… dus op gastvrijheidsbasis één dag per week doorgeploegd om die laatste twee artikelen de deur uit te krijgen en het proefschrift af te ronden… Dat viel niet altijd mee naast het harde werken in het Handen Centrum Utrecht, waar ik inmiddels al weer twee jaar werk. Maar zie hier, ik ben er toch gekomen!

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Kamergenoten uit ‘t ‘kippenhok’ Simone, Paulion, en Bianca, het kakelen was altijd heel erg gezellig, en ook Hemke en Rob met jullie heb ik toch ook een tijdje met plezier in één kamer vertoefd. Op het gebied van inhoudelijke, statistische en matlab-ondersteuning ben ik nog dank verschuldigd aan Raoul, Frank, Martine, Lieke, en Marco. En dan het reizen… de weg van en naar de VU werd ondanks regelmatige vertragingen nooit vervelend door aanwezigheid van mijn treinmatjes (ook wel snatermatjes genoemd) Marc, Karen en Ronald, ondanks de soms vroege uurtjes toch altijd gezelligheid in de trein (daar waren onze medereizigers het niet altijd mee eens…). En klokslag 12 was ‘t lunchen geblazen met mijn ‘lijgenoten’ van TC2, wat mij betreft vaak een amusante bezigheid, hoefde ik even niet te snateren of kakelen, maar kon ik rustig luisteren naar ‘discussies op hoogstaand niveau’. Mijn Engels liet het helaas nog wel eens afweten vonden de reviewers van tijdschriften, maar native speakers Ugo en Ambreen hebben mijn ‘Denglish’ teksten gelukkig nog wat opgekrikt, zodat ook de reviewers het uiteindelijk leesbaar genoeg vonden om te publiceren, bedankt. Luc Vanhercke, bedankt voor de poppetjes van het Tsjechische verkeersbord uit je fotocollectie. En verder familie, schoonfamilie, vrienden, vriendinnen, buren en
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