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Understanding and stimulating the development of perceptual-motor skills in child bicyclists

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“The journey of life is like a man riding a bicycle. We know he got on the bicycle and started to move. We know that at some point he will stop and get off. We know that if he stops moving and does not get off he will fall off.”

William Golding

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Summary

Learning to ride a bicycle is an essential milestone in a child's development. It can be considered a time-consuming process in which intrinsic factors such as motor bicycle skills as well as perceptual-motor bicycle skills must be obtained. Since children are physically and mentally not mature yet, they are limited in their capabilities to sufficiently cope with traffic, resulting in increased accident proneness and a higher share in accident statistics. Till now, however, few studies evaluated the intrinsic bicycle skills that influence the behaviour of child bicyclists which essential to provide child bicyclists with effective intervention programs. The main aim of the current dissertation is therefore twofold. On the one hand, the ability to perform bicycling skills depends on the child's capability to control for several motor components such as steering, balancing, pedalling or braking. This capability is related to the motor competence of the child. On the other hand, participation in traffic requires the bicyclist to perceive, interpret and anticipate the task-relevant visual information, based on which a decision is made, resulting in a sufficient motor output. Consequently, visual behaviour by means of eye tracking technology is measured in child bicyclists.

In the first chapter of the current project, the influence of motor competence as underlying construct for the development of bicycling skills was addressed. It was demonstrated accordingly, that gross motor competence was found related to children's motor bicycling skills. Furthermore, also Body Mass Index was found inversely related to bicycling skills in children. Since the ability to ride a bicycle also strongly depends on the mental and physical development of the child, a second paper aimed to examine age-related improvements on the bicycle skill test. It was found that bicycling skills are strongly related to age with 11-12 year old children outperforming 7-8 year old children and 9-10 year old children for both "before/after bicycling skills" and "transitional bicycling skills", as well as "during bicycling skills". Next to age, age at onset of bicycling also contributed to bicycling skills suggesting the younger a child learns to bicycle the better his performance.

In a second series of experiments, perceptual-motor skills of child bicyclists by means of visual behaviour have been evaluated when bicycling in real-life and when presented with a hazard anticipation test. Since it has been demonstrated that poor road conditions result in an apparent shift of visual attention from distant environmental regions to more proximate road properties in adults, it was investigated to what extent these findings are applicable for child bicyclists (aged 6 to 12 years). The results demonstrated that children spent more time looking to task irrelevant regions instead of the road than adults. Surprisingly, both adults and children made a comparable shift towards more proximate regions on the road when cycling on a low quality bicycle. When presented with a PC-based hazard anticipation test, children demonstrated delayed onset of the first fixations and reaction times to the covert hazards compared to adults. These inefficient visual search patterns in child bicyclists indicated difficulties with identifying potential hazards and strengthened the belief that children operate from a more idiosyncratic perspective rather than an integrated holistic perspective. Hazard anticipation does therefore not only depend on maturity-related factors but also on experience. Consequently, a tailored hazard anticipation training to extend child bicyclists' experience was developed. The intervention attempted to teach child bicyclists where to look, to predict and to anticipate hazardous situations. After the training child bicyclists were found to detect more hazards and anticipate hazards sooner compared to the control group who did not receive the training intervention. Trained child bicyclists are therefore suggested to have developed a better understanding of potential dangerous situations which speeded up their reaction times. However, the results also showed that child bicyclists did not improve their knowledge of where to look when the hazard was not yet salient.

Additionally, as this project aimed to develop an 'offline' educational package, validation of visual search is essential to ensure that visual behaviour in the lab reflects visual behaviour in real-life. Visual search in 13 adult bicyclists when bicycling a high and low quality bicycle path was therefore compared with visual search while watching a film clip of the same road. Gaze behaviour tended to be increasingly comparable with increasing task demand. Visual search in real-life was relatively similar to visual search behaviour in the lab when cycling the low quality bicycling path. However, when task demands were rather low e.g. when cycling on the high quality bicycling path, participants tended to display a different visual strategy.

In general, the current thesis provides insights into how motor, perceptual-motor and hazard anticipation skills in child bicyclists develop. Based on the results it can be suggested that children with better motor competence, will perform better bicycle skills and that bicycle skills improve with age. Children with lower levels of motor competence and/or higher body mass index are more likely to experience difficulties with bicycling skills. Child bicyclists were also demonstrated to show poor hazard anticipation skills compared to adults. An innovative hazard anticipation training, however, effectively improved children's hazard anticipation skills. The practical implications of this dissertation for education, policy makers and parents are discussed.

Samenvatting

Leren fietsen is een cruciale mijlpaal in de ontwikkeling van kinderen. Het kan beschouwd worden als een langdurig proces waarin de intrinsieke factoren zoals de motorische en perceptueel-motorische fietsvaardigheden verworven moeten worden. Aangezien kinderen fysiek en mentaal nog volop in ontwikkeling zijn, zijn ze gelimiteerd in wat ze al kunnen in het verkeer. Dit geeft aanleiding tot een verhoogd risico op ongevallen en een hoger aandeel in de ongevallen statistieken. Desondanks werd er tot nu toe slechts weinig onderzoek verricht naar de intrinsieke fietsvaardigheden die het gedrag van fietsende kinderen bepalen, welk onderzoek essentieel is voor het ontwikkelen van effectieve training programma's. De onderzoeksvraag van deze dissertatie is daarom tweezijdig. Enerzijds zijn de fietsvaardigheden in kinderen afhankelijk van hoe goed het de verschillende motorische componenten zoals sturen, evenwicht behouden, trappen of remmen beheerst. Men kan dus veronderstellen dat controle over deze fietsvaardigheden sterk gerelateerd is aan de motorische competentie en ontwikkeling van het kind. Daarnaast vereist deelname aan het verkeer ook dat de jonge fietser in staat is om de taak-gerelateerde informatie waar te nemen, te interpreteren en te anticiperen door een correcte beslissing te maken die zal resulteren in een correcte motorische reactie. Daarom zal het visueel gedrag van jonge fietsers onderzocht en beschreven worden met behulp van 'eye tracking'.

In het eerste deel van dit project werd aangetoond dat groot motorische competentie gerelateerd was aan de fundamentele fietsvaardigheden van kinderen wat impliceert dat motorische competentie beschouwd kan worden als de bouwsteen voor meer complexe taken. Bovendien werd aangetoond dat Body Mass Index negatief gerelateerd is aan de fietsvaardigheden van kinderen. Aangezien de mogelijkheid om te fietsen ook sterk afhankelijk is van de mentale en fysieke ontwikkeling van het kind, onderzocht een tweede studie de leeftijd gerelateerde verbeteringen op de fietsvaardigheidstest. Deze studie toonde aan dat 11-12 jaar oude fietsers beter presteerden dan 7-8 jarige fietsers en 9-10 jarige fietsers voor zowel de "voor/na fietsvaardigheden", de "transitie-fietsvaardigheden", als de "fietsvaardigheden tijdens het fietsen". Naast leeftijd droeg ook de leeftijd op welke de kinderen leerden fietsen bij tot de ontwikkeling van algemene fietsvaardigheden. Dit betekent dat hoe jonger een kind leert fietsen, hoe beter zijn prestatie zal zijn.

In een tweede serie van experimenten werden de perceptueel-motorische vaardigheden van de jonge fietsertjes onderzocht aan de hand van visueel gedrag tijdens het fietsen in "real-life", of tijdens het bekijken van een gevaarherkenningstest. Aangezien er werd aangetoond dat een fietspad van slechte kwaliteit - waar losliggende tegels, putdeksels, boomwortels en andere obstakels - de volwassen fietser dwongen om voornamelijk de weg vlak voor zich te monitoren, werd onderzocht in welke mate deze bevindingen ook van toepassing zijn bij jonge fietsertjes (leeftijd: 6 tot 12 jaar). De resultaten toonden aan dat kinderen meer tijd besteden aan het kijken naar taak-irrelevante zaken dan naar de weg. Onverwacht maakten kinderen een even grote visuele shift als volwassenen naar dichterbij gelegen zones op de weg wanneer ze moesten fietsen op een fietspad van slechte kwaliteit.

Wanneer de kinderen een risicoanticipatie-test op de computer moesten uitvoeren, werd aangetoond dat ze later keken naar en reageerden op verborgen gevaren in vergelijking met volwassenen. Deze inefficiënte visuele zoekpatronen bij jonge fietsertjes tonen aan dat ze moeilijkheden hebben met het identificeren van potentiele gevaren en versterkt de gedachte dat ze opereren vanuit een meer idiosyncratisch perspectief, eerder

dan vanuit een holistisch perspectief. Risicoanticipatie is daarom niet enkel afhankelijk van leeftijd gerelateerde factoren, maar ook van ervaring. Om gevaarherkenning, kennis en aandacht in jonge fietsertjes te stimuleren werd een interventie ontwikkeld om hen te leren kijken naar de relevante elementen in het verkeer die het mogelijk maken om op potentieel gevaarlijke verkeerssituaties te anticiperen. De interventie trachtte kinderen attent te maken op waar ze moesten kijken om gevaarlijke situaties te voorspellen en hierop te anticiperen. Na de interventie merkten de fietsertjes meer gevaren op en reageerden ze sneller op deze gevaren dan de fietsertjes die de training niet volgden. Dit doet vermoeden dat getrainde fietsertjes een beter begrip hebben van de mogelijke gevaren waardoor ze sneller kunnen reageren. Desondanks toonden de resultaten ook aan dat ze nog steeds niet goed wisten waar ze moesten kijken als het gevaar nog niet zichtbaar was.

Omdat dit project zich tot doel stelde om een ‘offline’ educatief pakket te ontwikkelen, is de validatie van visueel gedrag in het laboratorium essentieel om ons ervan te verzekeren dat dit overeenkomt met visueel gedrag in het echte leven. Daarom werd het visueel gedrag van 13 volwassen, wanneer ze een op fietspad van goede en op een van slechte kwaliteit moesten fietsen, vergeleken met hun visueel gedrag wanneer ze een videoclip van dezelfde route te zien kregen in het laboratorium. Visueel gedrag werd relatief vergelijkbaar wanneer de taakvereisten toenamen (fietspad van slechte kwaliteit). Wanneer de taakvereisten echter laag waren, bijvoorbeeld wanneer er gefietst werd op het fietspad van goede kwaliteit, dan neigden de proefpersonen verschillende visuele strategieën te hanteren, zowel in het echte leven als in het laboratorium.

Deze thesis verschaft inzicht in hoe motorische en perceptueel-motorische vaardigheden en gevaarherkenning in jonge fietsertjes ontwikkelen. Gebaseerd op de resultaten van dit onderzoek kan worden gesuggereerd dat kinderen met betere motorische competentie betere controle zullen hebben over hun fietsvaardigheden. Kinderen met minder goede motorische competentie en/of een hogere Body Mass Index zullen daarentegen meer moeilijkheden ondervinden. Daarnaast werd ook aangetoond dat jonge fietsertjes minder goed zijn in het herkennen van potentieel gevaarlijke situaties. Een innovatieve risicoanticipatie training maakte het echter mogelijk om deze vaardigheden effectief te verbeteren. De praktische implicaties van deze dissertatie met betrekking tot educatie, beleidsvoering en de ouders worden verder toegelicht.

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Part one: general introduction

1. An introduction to bicycling

1.1. The history of bicycling

The development of the bicycle started with the German Baron Karl von Drais who invented the ‘Laufmaschine’ (‘running machine’ or draisine) in 1817 as alternative to the horse since crop failure in 1816 led to starvation and horses were eaten instead. Almost entirely constructed out of wood, this two-wheeled, steerable and human-propelled machine was patented in 1818 under the name of velocipede. But many European cities started to prohibit the use of the velocipede due to increasing numbers of accidents. In 1819, a new and improved version of the velocipede was developed and became wildly popular in the London society. Between the 1820s and the 1850s the draisine laid at the heart of the developments in human powered tricycles and quadracycles, until 1863, when a French metal worker[1] added pedals and cranks to the front-wheel. Because of the iron-banded wheels and the rigid frame, this machine was nicknamed the “bone-shaker” in England. The bicycle renaissance effectively started during the late 1860s with the production of iron casted frames. Later on in the 1860s, also solid rubber tires and ball bearings significantly improved comfort for the rider.

Later in the 1870s, Eugène Meyer created the high-bicycle with a smaller rear wheel while the Englishman James Starley added a mounting step and tangent spokes. The latter is considered the father of the British bicycling industry and named his famous bicycle the “Ariel”. This new bicycle was later renamed “penny-farthing” in which the penny referred to the front wheel and the farthing, smaller in value and size, to the rear wheel. Despite the improvements to comfort and design, bicycling was quite unsafe due to the high speeds and saddle height. If a rider for example hit a cobblestone, he could be thrown over the front wheel. Broken wrists when attempting to break the fall were very common those days (also known as “taking a header” or “coming a cropper”). Soon bicycles landed across the channel in France and across the Atlantic. One of the most important changes in bicycle history is the development of the safety bicycle, accessible for men and woman of all ages. John Kemp Starley enhanced the safety bicycle by adding a chain drive to the rear wheel, equally sized wheels and a steerable front wheel. Also comfort was improved with the reinvention of the pneumatic bicycle tire by John Dunlop in 1888. This resulted in the design of the commonly known diamond formed frame (Figure 1). With better speed, safety, comfort and steering, bicycles became wildly popular among men and woman and conquered huge parts of Europe and North America as the “freedom machine”. Other improvements such as step-through frames instead of a diamond frame made bicycles more woman-friendly since they often experienced difficulties with their dresses and garments when riding a common safety bicycle. This ladies bicycle (roadster) remained popular in the Netherlands where it is also referred to as a “grandma’s bike” or “oma fiets”. While in the United States the car became more popular and the popularity of the bicycle declined around 1910, bicycles in Great-Britain and the rest of Europe remained popular for transport, racing and commuting. In the 20th century the development of the derailleur, gearing and changes in tires and frames contributed to the bicycle as we know it today (Herlihy, 2006).

[1] Whether it was Ernest Michaux or Pierre Lallemant is still a matter of debate.

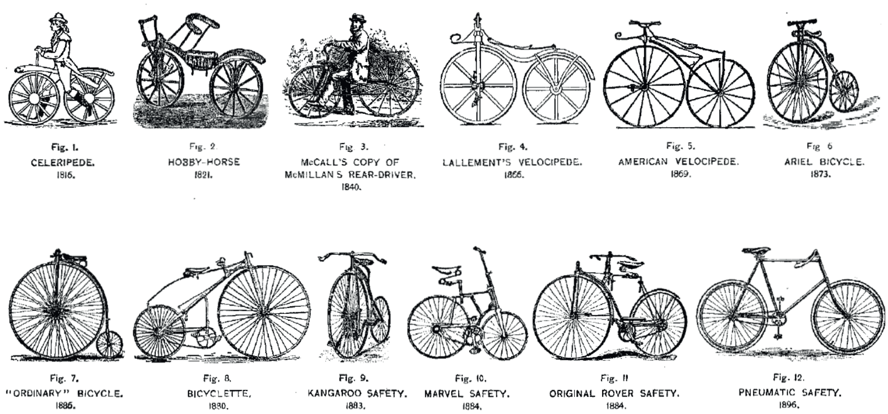

Figure 1. Evolution of the bicycle (derived from Schwab & Kooijman, 2011).

1.2. Bicycle trends

Bicycling is a virtually free and enjoyable way of transportation and is cause to many positive health- and environmental related effects (see 1.3). Nevertheless there are large differences in the amount of bicycle use across the globe. In Australia, the United States, Canada, Ireland and the United Kingdom, only 1-2% of the trips is made by bicycle while bicycling levels in Europe - the Netherlands (26%), Denmark (18%) and Germany, Sweden, Finland and Belgium (10%) - are much higher. Even when accounting for trip distance (shorter in the Netherlands, Germany, Denmark), bicycle share is far less in America, Australia and the United Kingdom. Trips in Northern Europe are primarily made for utilitarian purposes, e.g. travel to work or school (Pucher and Buehler 2012). It is noted that in the Netherlands the majority (almost 40%) of all the trips are made by children younger than 18 years old, followed by young adults (25%; 18-25 years old). Also in other European countries such as Denmark (32%; 10-19 years old) or Germany (14%; 0-17 years old) a relative similar trend is observed. In the case of Flanders, 25% of all trips are made by bicycle, with work-related trips accounting for 12.5%. Bicycling even accounts up to 27.5% of all trips made to school and is therefore the most favourite transportation method in children. Children often prefer bicycling over walking as it offers a fast and easy way to cover greater distances in less time and provides them with a sense of independence (Macarthur et al., 1998; Trapp et al., 2011). As children grow older also the distance they cover increases given that secondary schools are often located further away from home. Indeed, while 6-12-year-old children bicycle up to 3.6km each day, 13-17-year-old children already cover 8.4km and 18-24-year-old adults bicycle up to 18.2km each day (Jansens, Declercq, and Wets 2012; DEKRA 2011).

1.3. Benefits of bicycling

A global increase in the share of bicycle usage may be subject to a variety of positive environmental benefits. Not only could the transition from car to bicycle solve traffic congestions, it also might improve air quality in already overcrowded cities since motorized vehicles are a major source of greenhouse gas emissions, fine particles, volatile organic compounds and nitrogen dioxide (Oja et al., 2011; Pucher and Buehler, 2012;

WHO, 2005). As bicycling offers a zero-emission alternative to driving it has an enormous potential in fighting climate change and overall air pollution levels (de Hartog et al. 2010). For example reducing traffic intensity by 12.5% in just one street in the Netherlands already resulted in a significant decrease in NO_2-emission and fine particles (Tonne et al. 2008). It was suggested that reducing the traffic intensity therefore could result in significantly lower mortality rates. Furthermore, a shift from car to bicycle would also reduce noise pollution which might contribute to neighbourhood likelihood and liveability (Pucher and Buehler 2012).

A modal shift from car to bicycle would not only improve neighbourhood liveability and likelihood, it could also contribute to a variety of personal health related factors. According to the WHO (2007), adults (18-65 years of age) are required to engage in physical activity of moderate intensity for at least 30min/day, while children should engage in vigorous physical activity at least 1hr/day. With respect to Europe, 62.4% of the adults are considered inactive or sedentary while physical inactivity around the globe accounts up to 22% of the cardiovascular disease prevalence and is associated with diabetes, obesity, and increased risk regarding cancer, osteoporosis, and depression. This finding highlights a major problem in our western society (de Hartog et al 2010; Bauman 2004; Warburton et al. 2006). Bicycling by means of active transportation or as leisure time activity might therefore have a great potential to overcome physical inactivity (Oja et al. 2010). Indeed, bicycling provides multiple health benefits since it taxes the metabolic and cardiorespiratory system of the whole body at a range of intensities. Bicycling is inexpensive and accessible and thus appealing for groups with low levels of participation in sport or active leisure time activities (Pucher and Buehler 2012). Respecting the physical health benefits of utilitarian bicycling[2], numerous studies report improved muscular fitness, favourable body composition, improved bone health, cardiovascular and metabolic biomarkers and overall higher levels of physical activity in children. In adults, decreased risk for type-2 diabetes, high blood pressure, heart disease, stroke, and cancer is reported. Among middle-aged and elderly adults, commuter bicycling results in an inverse relationship with CVD/CHD mortality, cancer mortality and morbidity (Shephard 2008; Andersen and Cooper 2010; Oja et al. 2010). For example, Pucher and Buehler (2012) reported a 16% increase in VO_2max and 15% increase in HDL-cholesterol in commuter bicyclists after an intervention, suggesting a positive dose-response relationship between the health outcomes and the amount of bicycling. Furthermore, Matthews et al. (2007) reported a 20% risk reduction with less than one hour daily bicycling at moderate intensity and a 30% risk reduction with 100min of daily bicycling. Next to the physical health benefits, utilitarian bicycling also provides psychosocial benefits including social and mental health benefits, and reduces health inequalities between population groups. For example, Mead et al (2009) reported improvements after exercise in people suffering from depression. As bicycling is an outdoor activity, carried out in nature or a natural environment it might enhance relaxation, stress reduction, social interaction, and emotional well-being. In line, Gatersleben and Uzell (2007) reported that bicyclists were more likely to find that their trip to work was pleasant compared to car drivers. Also the social interactions and the social contact associated with bicycling are highly valued by commuters (Whitaker 2005; Pucher and Buehler 2012).

[2] Pucher and Buehler (2012) report three types of bicycling to improve health status: indoor bicycling in a gym or at home, (2) bicycling in the weekends for recreation and (3) utilitarian bicycling to get to places, for example, bicycling to work or school.

1.4. Bicycle accidents

Unfortunately bicyclists are highly vulnerable road users resulting in a fatality risk three times higher compared to car drivers for each kilometre travelled (Van Hout and Cuyvers 2007). Therefore there is a stringent need to understand the magnitude and the causes underlying bicycle accidents. Where accidents happen, when they occur and how they are caused largely depend on the country, season, time of the day and population density which makes comparison across countries or age ranges quite difficult. Although bicycle fatalities[3] seriously decreased in Europe (-34%) between 2004 and 2013, they still represent 7.8% of all the road fatalities (European Commission, 2015; DEKRA 2011) with the highest number of road fatalities occurring in the Netherlands (24%) and Denmark (17%) while in Spain (4%), France (4%) and Greece (2%) bicycle fatalities represent only a small share of the road fatalities. However, these results might provide a biased interpretation since the results do not account for the amount of bicycle trips or distance travelled. When corrected for distance travelled (per 100 million km bicycled), the Netherlands and Denmark have the lowest fatality and injury rate in bicyclists (Pucher and Buehler 2012). For Belgium, bicycle fatalities accounted up to 10% of all the road fatalities in 2013 (European Commission 2015). However it should be taken into account that only 15-30% of the bicycle accidents are officially reported (Vandenbulcke et al. 2009). Alas, some age groups are overrepresented in bicycle accidents. In children, 33% of all child fatalities occur when bicycling in traffic, representing one of the primary causes for early child death[4] (DaCota, 2013). When taking a closer look at Flanders, children between 4-19 years old (21%) and the elderly (65+; 27%) form a substantial part in accident statistics which might be attributed to their higher levels of bicycle share (see Figure 2; Carpentier and Nuyttens, 2013; Kari Schrøder Hansen et al., 2005; Maring and van Schagen, 1990; Ormel et al., 2009).

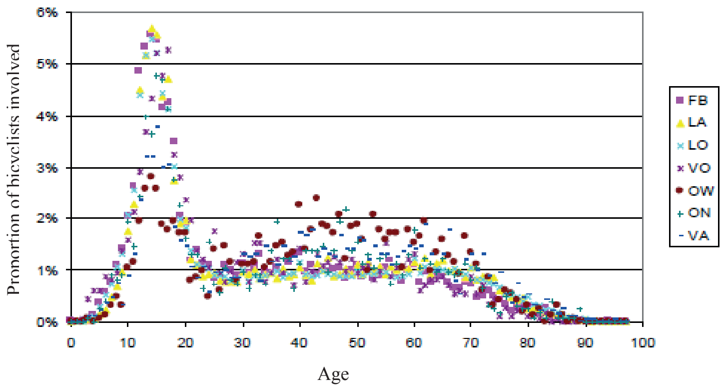

Figure 2. Bicycle accidents according to age with other road user(s) involved. FB=frontal collision, LA= collision from behind, LO=collision from the side, VO=collision with pedestrian, OW=collision with an obstacle on the road, ON=collision with an obstacle on the side of the road, VA=falling of the bicycle (Van Hout and Cuyvers, 2007).

[3] Road fatalities refer to road users who died immediately or within 30 days after the accident (European Commission 2015).
[4] Children in the age range of 0-14 years old (European Road Safety Observatory 2015b).

Most of the bicycle accidents in children take place in the morning when bicycling to school or in the afternoon when children return from school, going to their sport club or engage in other leisure time activities and occur within the urban area (Figure 3; Van Hout and Cuyvers 2007; Carpentier and Nuyttens 2013). Schepers and Wolt (2012) reported that the majority of the bicycle accidents are single-bicycle accidents in which no other road users are involved and are frequently not included in the official reports (Juhra et al. 2012). The causes for these single-bicycle accidents are often environmental related factors such as poor road quality (see chapter 3), collision with an obstacle or human behaviour related factors such as performing stunts and losing control over the bicycle. In contrast, according to Van Hout and Cuyvers (2007), the majority of the reported crashes in 6-12-year-old Flemish children is caused by collision with another traffic participant from the side (64.7%), followed by being hit from behind (15.4%) or frontal collision (12.9%). The most common violations of other road users are not providing priority (71.0%) and incorrect road-use (9.8%) while the most committed violations by the bicyclists are also not providing priority (43.7%), incorrect road-use (25.7%) and loss of control (16.1%). Other common causes for bicycle accidents in children are falling of the bicycle, bicycling up or down sidewalks, losing balance, braking to violently, skitting or not looking properly (Heesch et al., 2011; Maring and van Schagen, 1990). Spence et al. (1993) reported that 70% of the crashes in children are caused by the children themselves.

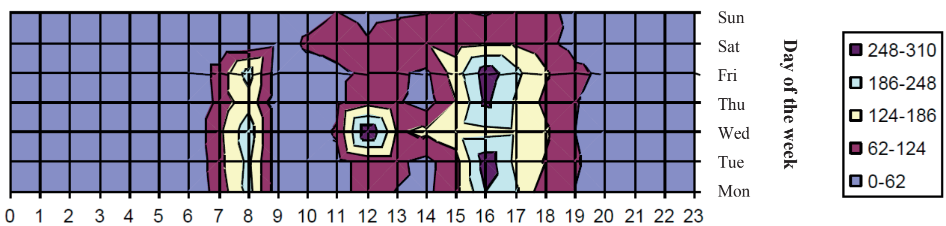

Figure 3. Bicycle accidents in children according to day and hour of the day (Van Hout and Cuyvers, 2007)**.**

It therefore seems that intrinsic factors such as a lack of traffic related knowledge, immature psychomotor skills and attention deficits strongly contribute to inappropriate road behaviour (Briem et al., 2004; Hansen et al., 2005; Nixon et al., 1987). Nevertheless, collisions with motorized vehicles are more likely to result in severe injuries or dead due to the high speed and mass of the vehicle creating high impact on the bicyclist (Acton et al 1995; Elvik 2010).

1.5. Safe bicycling

Despite the huge potential of bicycling and the numerous health and environmental related benefits which were shown to outweigh the associated risks of bicycling (Cooper et al., 2005; de Hartog et al., 2010; Matthews et al., 2007), vulnerable groups are quenched from regularly bicycling due to fear for an accident (Pucher and Buehler, 2012). Since bicyclists are vulnerable road users in traffic, this perception creates a climate of fear around bicycling. Therefore, researchers have put major effort in describing the effects of interventions regarding the extrinsic factors (e.g. road design, traffic calming measures, etc.) associated with perceived risk and bicycle accidents. Research concerning the adaptation of bicycle infrastructure and road design reported that bicycle tracks separated from major streets increase safety. Also other infrastructural adaptations to improve safety such as evenness of the road, traffic calming, colored lanes, car-free zones, or the introduction of home zones usually improve (perceived) risk and might increase bicycle share (Gårder et al., 1998; Parkin et al., 2008; Pucher et al., 2010; Pucher and Buehler, 2012; Vansteenkiste et al., 2013). Next to infrastructural changes, reducing motorized traffic density and increasing the number of bicyclists within an area is also shown to reduce the fear for accidents (Jacobsen, 2003), suggesting that the real and perceived risk for severe injuries is not intrinsic, but imposed on the bicyclist (Jacobsen et al., 2009). Since the potential for injury is associated with the kinetic energy involved of the moving object, the driver endangers the bicyclist and not the other way around (Elvik, 2010). Therefore traffic education of young bicyclists alone is not sufficient. As it might decrease accident statistics to a certain amount, it could also create an incorrect perspective regarding the responsibilities of drivers and driver education to further decrease accident statistics.

Furthermore, a number of campaigns aimed to improve safety by promoting the use of helmets. Although wearing a helmet reduces the risk of head injury (de Jong, 2012; Rivara et al., 1998; Webman et al., 2013), recent research suggest that obligatory helmet use might actually decrease health, since promoting the usage of helmets might increase the perception that bicycling is a risky activity which in turn would reduce bicycling activity and the associated health benefits (Jacobsen et al., 2009). The use of helmets might also impose a false perception of safety resulting in riskier behaviour of the bicyclist, known as risk compensation (Elvik, 2011). Drivers are reported to behave differently (more dangerously) among bicyclists when they wear protective clothing such as driving closer to the bicyclist (Walker, 2007). Furthermore, recent developments in car technology demonstrated that self-driving cars are able to detect bicyclists in order create a buffer between the car and the bicyclist, are able to recognize common riding behaviours of bicyclists and can predict a bicyclist's course. The sensors in the car can even detect hand signals of the bicyclist and integrate this information into the intended course of the car (Google, 2016).

1.6. Summary

The popularity of the bicycle in Europe is on the rise with increasing levels of utilitarian and recreational bicycle use as a result. Bicycling for transportation or as leisure time activity is appealing and affordable across diverse population groups. Especially with the introduction of affordable electric bikes[5] on the market, increasing numbers of people consider a shift from car to bicycle since electric bikes significantly decrease commuter times and increase action radius. This transition from car to bicycle should be encouraged as bicycling offers a variety of environmental benefits to fight global warming and pollution and provides opportunities to improve physical and mental health trough incorporating physical activity into daily life. Bicycling for transportation is considered to contribute to a substantial amount of the daily physical activity requirements in adults and children. Unfortunately, children and the elderly are highly overrepresented in bicycle accident statistics. Child bicyclists have therefore been suggested to lack the capabilities to deal with the complexity of traffic. However, despite a vast amount of research focused on the extrinsic factors such as road design, infrastructure or helmet use to improve real and perceived bicycle safety, research concerning the intrinsic factors of bicycling such as the development of motor and perceptual-motor skills in child bicyclists is rather scarce. Proper development of bicycle skills, the ability to perceive and comprehend complex traffic situations and come to a correct decision are essential for safe traffic participation. There is a stringent need to create a better understand the development of bicycle skills and perceptual-motor behaviour in children to provide them with means to enhance their abilities to cope with the complexity of dynamic traffic situations. Especially since habits learned while young tend to persist throughout life. Throughout the next chapters, the current dissertation will provide a better understanding regarding the development of motor and perceptual-motor skills in child bicyclists. Furthermore, theoretical models (e.g. situation awareness) for traffic behaviour, the contribution of visual attention and training programs for enhancing children's traffic skills are discussed.

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[5] Electric bikes might enhance opportunities regarding bicycle share amongst the elderly or work-related transport in adults. Electric bikes generate assisted pedalling, offering possibilities to older people who otherwise would not ride a bicycle. On the other hand, it also imposes higher risk in traffic as electric bikes weigh a lot more and reach higher speeds, this increases kinetic energy and therefore injury severity when engaged in an accident. Furthermore, recent accident statistics have reported an increase in accident risk in bicyclists above 60 years (Fietsberaad, 2013; Silverans and Goldenbeld, 2015), possibly because they are not used to high speed bicycling. Therefore, research regarding electric bikes and safety should consider the place of the electric bike in traffic, regulations and training interventions.

2. Motor bicycling skills

Riding a bicycle can be considered a keystone in a child's development. Understanding the underlying constructs of bicycling skills are therefore of major interest. Bicycling safely can be regarded as the joint function of both motor and perceptual-motor abilities (Briem et al., 2004; Ducheyne et al., 2013b). The motor component includes abilities such as steering, pedalling, balancing or braking as where the perceptual-motor component (see chapter 3) relates to perception, attention, concentration, planning and decision making (Briem et al., 2004; Corden et al., 2005; Fietsersbond Vzw, 2006) which are all essential for safe traffic participation. This part discusses the concept of motor skills and motor development in relation to the development of bicycling skills.

2.1. Motor competence and motor development

Motor competence[6] refers to the combination of flexibility, stability, strength, endurance, speed and coordination and is often classified according to function (object control skills and locomotor skills) or to the muscle groups involved (gross motor skills and fine motor skills) (D'Hondt et al., 2012, 2009; Vedul-Kjelsas and Stensdotter, 2013). Gross motor skills describe movements involving whole body movements such as running, galloping or jumping while fine motor skills include manipulation of small objects such as writing which require precision and dexterity (Burton and Miller, 1998; Gallahue and Ozmun, 2005; Magill, 2007). In other words, motor competence describes the degree of the movement quality, control and coordination of skilled performance in a wide variety of motor tasks (Burton and Miller, 1998) and is considered a general construct underlying the performance of goal-directed movement skills (Magill, 2007). Given that bicycling in children does not require extraordinary strength, flexibility or endurance, coordination and stability are the primary components of interest in this thesis. Motor competence is also considered a keystone to fundamental motor skills (FMS). Fundamental motor skills[7] consist of locomotor, object-control and stability skills and precede more context-specific and complex skills such a riding a bicycle (Vandorpe et al., 2012b). Object control skills include gross and fine movements which involve the controlling of objects such as kicking or catching a ball, while locomotor skills refer to movement skills such as walking or skipping. FMS are related to age and might be improved by training and physical activity. In contrast with FMS, motor competence is a relatively stable trait[8] from the age of six, which implies that children with superior motor competence will continue to outperform their counterparts with lower motor competence when growing older (Ahnert, 2005; Magill, 2007;

[6] The terms motor coordination, motor skills, motor competence, fundamental motor skills are often used inconsistently resulting in a variety of definitions and interpretations. Since coordination is the primary component of interest in the development of bicycling skills, motor competence will be considered synonym for motor coordination in this thesis.

[7] In early childhood, fundamental motor skills including running, jumping, hopping, catching… generally develop through interaction of environmental and biological constraints. By the age of seven, these fundamental motor skills can be refined and combined to context-specific skills e.g. in gymnastics or bicycling (Burton and Miller, 1998; Gallahue and Ozmun, 2005; Payne and Isaacs, 1995; Vandorpe, 2011).

[8] Stability refers to the relative rank within a group. Motor competence is therefore only minimally impacted by growth and development. According to Gabbard (2008), the brain reaches its full size by the age of six. Before that age, plasticity is high, suggesting that this might be a developmental critical period.

Vandorpe, 2011). Or children experiencing lower levels of motor competence probably lack FMS and will be less proficient at them.

In their model, Stodden et al. (2008) described the relationship between motor competence and physical activity in children and the interrelations to physical fitness, body weight and perceived motor competence[9] (Figure 4) (Robinson et al., 2015). In the positive spiral of engagement, children with higher levels of motor competence will demonstrate higher levels of perceived motor competence and will be more likely to participate in physical activities. This will result in a healthier weight status and continued motor skill development. In the negative spiral of disengagement on the other hand, children with low(er)levels of motor competence have lower levels of perceived motor competence and will therefore engage less in physical activities. This will results in an unhealthier health status and reduced development of motor skills. It should be noted, however, that not all of the relationships in this theoretical model have been tested extensively (partially grey, and white arrows) and are based on assumptions rather than scietific evidence. Future longitudinal studies should therefore further explore these relationships.

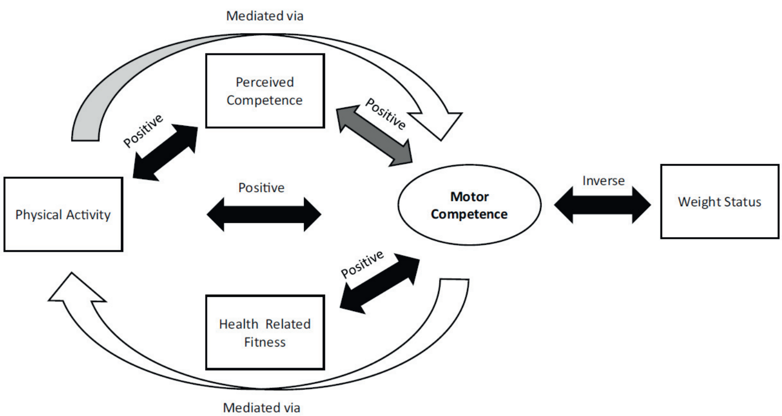

Figure 4. Motor competence in relation to its health-related variables. The black arrows indicate extensively tested and consistent relationships. The dark grey arrow refer to a moderately tested variable relationship. The partial grey arrow indicates a partially tested relationship and the white arrow indicates a limited tested relationship. This figure is retrieved form Robinson et al., 2015.

Motor competence is also based on a subject's ability to perceive sensory information, e.g. vision, to produce an effective motor response, e.g. catching a ball. This dynamic interplay to interpret sensory information and converting it into a skilful action is referred to as **perceptual-motor skill** and consists of four phases (see 3. Perceptual-motor skills). In the first phase, sensory or afferent information is captured by the sensory receptors (e.g. on the retina or Golgi) followed by the transmission of these nerve impulses to the brain via afferent neural pathways in the second phase. In the third phase, the information is processed, interpreted and a decision is made

[9] Research reported that the level of motor competence in childhood contributes to health and well-being later in life (Barnett et al., 2009; Graf et al., 2004; Wrotniak et al., 2006).

which is sent to the muscles to produce the motor outcome in the last phase (Gabbard, 2008; Gallahue and Ozmun, 2005).

Motor development refers to the continuous, age-related, change of motor behaviour through life which is driven through the interaction of the individual constraints, the environment and the task (Gallahue and Ozmun, 2005; Haywood and Getchell, 2009). It also refers to the development of sufficient gross and fine motor skills for task or goal-oriented activities (e.g. riding a bicycle) (Gallahue and Ozmun, 2005). Different models for motor development have been described in the literature. In his hierarchical model of motor development Seefeldt (1980), describes four sequential phases. The first phase consists of involuntary reflexes in infants. The second phase is characterized by the development of FMS during early childhood, including object control and locomotor skills. Before children can make the transition to the third phase, they have to break through a proficiency barrier which requires an adequate level of competency in FMS. The third phase consists of transitional motor skills (e.g. bicycling) and ultimately sport specific skills in the fourth phase. The third and the fourth phase occur from middle childhood to adulthood.

Clark and Metcalfe (2002), however, used a mountain metaphor (Figure 5) for describing motor skill development. In this ecological model, motor development is continuously influenced by changes in the individual constraints, environment and the task. Consisting of six phases, the first phase describes the reflexive phase in infants followed by the preadapted phase in which toddlers start to develop skill such as grasping or rolling. In the third phase, a repertoire of FMS is built during childhood (around the age of seven). Similar to the model of Seefeldt (1980), these building blocks are considered keystones for the development of more context-specific skills in the fourth phase. Ultimately, an individual might achieve high levels of skilfulness in the last phase, which are characterised by peaks in the mountain.

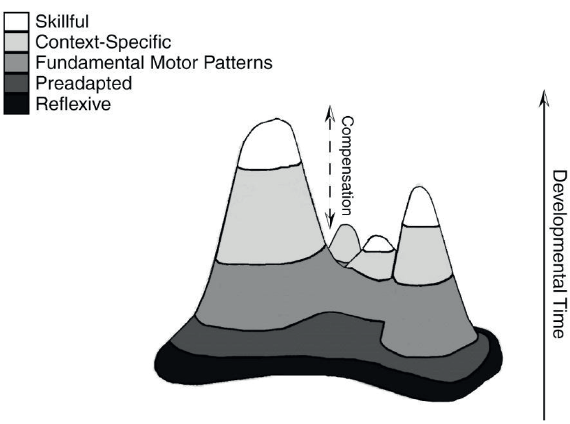

Figure 5. The mountain of motor development (reprinted from Clark and Metcalfe, 2002).

In the triangulated hourglass model (Figure 6), the development of skills is presented by the sand falling into the hourglass. While the contribution of biological factors is fixed, the contribution of environmental factors is not. Going through four phases (hourglass), Gallahue and Ozmun (2005), proposed that the rate at which individuals obtain motor competence is influenced by individual, environmental and task constraining factors (inverted triangle). The first phase is characterized by involuntary reflexes in infants which can be divided into primitive reflexes (e.g. palmar grasping) and postural reflexes (e.g. parachute reflex). These reflexes are considered as building blocks for voluntary movements. In the second phase or the rudimentary movement phase, infants start to develop voluntary movements such as reaching and grasping (object control), or crawling and walking (locomotion). Following this phase, young children start to explore and experiment with their bodies and start to develop FMS in the fundamental movement phase. This phase consists of three sub-phases; initial stage (±2-3 years), the emerging elementary phase (±3-5 years) and the proficient phase (±5-7 years). Improvements during these phases are caused by enhanced coordination, biomechanical efficiency and control over FMS. Ultimately, FMS are refined and children start to develop complex skills in a variety of sports and games. Around the start of young adulthood, the hourglass flips over and the sand pours out.

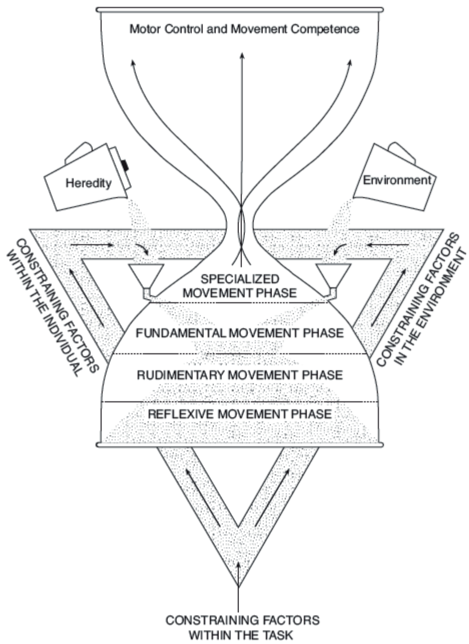

Figure 6. Triangulated hourglass model (reprinted from Gallahue and Ozmun, 2005).

2.2. Definition of motor bicycling skills

According to Van Houcke et al. (2009), bicycle skills can be defined as the ability to control the bicycle in such a way that the bicycle becomes a part of the body which enables the bicyclist to perform all the required tasks (Briem et al., 2004). The motor bicycling handling skills are therefore considered to be primarily nested within the motor component. Alternatively, bicycling safely in traffic also requires more complex traffic related skills such as signalling left before turning, looking over the shoulder while bicycling and therefore cannot strictly be separated from motor bicycling skills (Ducheyne et al., 2013b).

To measure a child’s bicycling handling skills, Ducheyne et al. (2013b), in cooperation with an expert panel (Fietsersbond Vzw, 2006; Stichting Vlaamse Schoolsport, 2008, 2005), described thirteen motor bicycling skills which should be mastered for safe and skilful bicycling in traffic. These thirteen components were: 1) walking with the bicycle, 2) mounting the bicycle and starting to bicycle, 3) looking left and right while bicycling in a straight line, 4) bicycling in a straight line over a small obstacle, 5) bicycling in a circle, 6) bicycling one handed in a circle, 7) bicycling a slalom in and out of markers, 8) looking over the left shoulder while bicycling in a straight line, 9) bicycling over obstacles, 10) bicycling on a sloping surface, 11) signalling left and right while bicycling in a straight line, 12) braking to come to a controlled stop and 13) dismounting the bicycle. These skills could be categorized into 'during-bicycling skills'[10], 'before/after-bicycling skills' and 'transitional-bicycling skills'. Whether a child learns to master these necessary skills to safely handle his or her bicycle in traffic depends on a variety of intrinsic factors. At first, it might be assumed that bicycling skills depend on the age-related physical and mental abilities of the child (Arnberg et al., 1978; Briem et al., 2004; Corden et al., 2005; Leblanc and Huybers, 2004; Maring and van Schagen, 1990). Accordingly, Hansen et al. (2005) reported that at the age of five, children have immature psychomotor skills to properly handle their bicycle in traffic while Briem et al. (2004) reported fairly rudimental bicycling skills in children of the second grade. In contrast, at the age of nine, children are reported to improve their bicycling handling skills on a variety of test items (Ducheyne et al., 2013b).

Next to age-related development, also experience might affect bicycling skills at a given age. Since more experienced bicyclists are assumed to have better control over their bicycles, in line with the power law of practice, they are less likely to have a bicycle accident (Schepers 2012; Wierda and Brookhuis 1991). Moreover, when bicycling at normal speed, Kooijman et al. (2009) reported that stabilizing actions are controlled by steering while at lower speeds, when turning or braking, steering radius increases with the addition of large lateral knee motions to maintain balance. This strengthens the belief that also motor competence is involved in the acquisition of bicycling skill proficiency.

2.3. Motor bicycling skills training

Since bicycle accidents in children are found to be related to the ability to perform bicycling skills, a variety of training interventions like 'Master on your bike', or the 'New Jersey Bike School Program' aimed to improve children's motor bicycling skills (Lachapelle et al., 2013; Stichting Vlaamse Schoolsport, 2005). In general, these interventions aimed to extend children's bicycling skills, confidence, knowledge of traffic signs or the road code, and are often performed within a traffic-free environment (i.e. closed car park, school playground, closed road-block). In this first 'traffic-free' stage, children learn to master their bicycle and improve their basic bicycling handling skills such as mounting and dismounting the bicycle or braking to come to a controlled stop. Once these motor bicycling skills are mastered, children progress to the complexity of traffic situations in which they learn how to position themselves on the road, how to negotiate curves and intersections, how to interact

[10] 'During-bicycling skills' consist of bicycling in a straight line over a small obstacle, bicycling in a circle, bicycling one handed in a circle, bicycling a slalom in and out of markers, looking over the left shoulder while bicycling in a straight line, bicycling over obstacles, bicycling over a sloping surface, signaling left and right while bicycling in a straight line. Furthermore, 'Before/after-bicycling skills' refer to walking with the bicycle, mounting the bicycle and starting to bicycle and dismounting the bicycle. At last 'Transitional-bicycling skills' comprise of braking to come to a controlled stop and looking left and right while bicycling in a straight line (Ducheyne et al., 2013b).

with other road-users and to interpret traffic signs properly (Ducheyne, 2013; Van Houcke et al., 2009). It should be noted that training on the road in real traffic comes with an increased risk for accidents or ethical considerations, requires an extensive cooperation with volunteers (often parents) and is therefore often not carried out by schools.

Savill et al. (1996) evaluated bicycling skills in 12- to 13-year-old children, two years after they attended a bicycle training aiming to improve children's motor and cognitive bicycling skills. Various manoeuvers such as starting off, stopping, taking left and right turns, and overtaking a parked car were evaluated. Although trained children performed better for bicycling skills and knowledge in general, trained children still displayed poor pedalling skills, often failed to signal before stopping or before turning left, and failed to check the shoulder before turning right. In 1998 Macarthur et al. examined the effect of a bicycling skills training program – 'the Kids CAN-BIKE festival' - in 141 children of the fourth grade (nine years old). The intervention contained six training stations, two of which were equipment stations and four were bicycling skills stations (straight line riding, checking the shoulder, signalling, and stopping and starting). Each station took around 15 minutes to complete. The authors concluded that this brief skills training program was not effective to enhance children's safe bicycling behaviour compared to a control population. Though the quality of the intervention might be questionable as children practiced each skill only once for 15 minutes. Another more recent training intervention in 9-10-year-old children performed by Ducheyne et al. consisted of three sessions (one session/week) and provided the children with practical exercises to improve their motor bicycling skills which must be mastered for safe traffic participation (described in chapter 2.2.; Ducheyne et al., 2013a, 2013b). In this training the first session aimed to enhance children's walking with the bicycle, mounting the bicycle, braking and dismounting the bicycle while in the second session one handed and two-handed steering skills were trained. In the last session, more complex skills such as signalling and looking over the shoulder were practiced. After training, children progressed for almost all skills suggesting that this intervention was effective to improve children's motor bicycling skills.

2.4. Summary

In conclusion, learning to ride a bicycle requires the integration of motor skills (see next chapter) which develop from childhood to adolescence. These motor bicycling skills such as pedalling, balancing and steering and progresses to more complex skills such as signalling or looking over the shoulder are supposed to be acquired before the child is ready to participate in traffic. Given that children are overrepresented in accident statistics, a variety of training courses aimed to improve children's motor bicycling skills. Unfortunately those training programs often varied in age range, focused on a variety of abilities, and lack thoroughness in reporting sub-skills contributing to the different bicycling skills. This hampers comparison between the effectiveness of training programs, our current understanding regarding the development of bicycling skills in children and the development of useful interventions. As a large share of the bicycle accidents in children is caused by poor turn manoeuvres or poor skills, motor bicycling skills are of special interest in this dissertation. Based on the literature, it can be suspected that motor competence, age and experience will have bearing onto bicycling skills.

3. Perceptual-motor skills

As pointed out in the previous chapter, bicycling does not only rely on the acquisition of motor bicycle handling skills. When crossing an intersection or when passing a bus stop, a huge amount of information comes at us the same time. How this information is perceived, which information is retained for processing, together with previous experiences will determine how one copes with the complexity of the situation. Bicycling might therefore also be considered a perceptual-motor skill (coupling between perception and action) requiring the perception and interpretation of sensory information which will result in a motor output (Gabbard, 2008). The amount of this information to be processed at the same time is however limited due to the available cognitive resources. Therefore, efficiently attributing attention to relevant objects or events and ignoring other irrelevant objects is referred to as selective attention and particularly important for traffic participation. Although both visual and auditory perception are imperative for safe traffic participation, especially for bicycling, this thesis will primarily focus on the visual component of attention. Vision is intricately linked with action and is essential for the guidance of locomotion. It also provides the individual with information regarding the body relative to the environment, the layout of the environment, identification and characteristics of objects and self-motion information (Gibson, 1958; Marigold, 2008). Accordingly, the next chapters will briefly discuss the hardware of the visual system, the neural pathways involved and visual search behaviour in a variety of tasks such as locomotor tasks e.g. walking, driving and bicycling. Regarding the development of vision in children, the reader is referred to part 5.5.1Visual, auditory and cognitive development of children.

3.1. Attention

In simple tasks such as making thee or preparing a sandwich, the processes of priming the visual system towards the features that need visual control and performing the required action all happen within a second. Norman and Shallice (1986) suggested that the attentional system aims to channel information from the gaze, visual and motor system in order to perform the action. Attention is therefore suggested to be closely related to the preparation of eye movements. Indeed, covert shifts of attention - a shift in visual awareness without an accompanying eye movement – are often followed by a shift in overt attention which refers to the shift in attention accompanied by an eye movement (Posner, 1980)[11]. Additionally, the allocation of attention can also both be driven endogenous or exogenous. Endogenous control - f.e. when searching for a knife to make a sandwich - is often referred to as ‘top-down’ control and therefore voluntary and goal-directed. On the other hand, exogenous control is controlled by external stimuli such as flashing lights, and can therefore be considered as ‘bottom-up’ control (see 3.3.4.) which directs the observer towards salient events or objects (Posner, 1980). Although Wolfe (1994) suggested that attention is mainly determined by the combination of endogenous and exogenous factors, recent research in “real-world” environments suggested that attention is predominantly driven by a top-down process (see chapter 3.4.3; Hayhoe et al., 2003; Land and Lee, 1994; Triesch et al., 2003).

[11] It has been suggested that covert attention guides overt attention to objects/features of interest. First covert attention is oriented towards a target of potential interest in the periphery, followed by a saccade to orient overt attention. However, overt attention does not necessarily have to follow covert attention (Land and Tatler, 2009).

Fundamental to the allocation of attention are information processing in working memory (see 3.2 Working memory and cognitive load), top-down sensitivity control, competitive selection and the filtering of salient stimuli (Knudsen, 2007). Attention selects the information that might gain access to the working memory. Information form the world is perceived and processed by the saliency filters (bottom-up). This visual information activates neural representation or schemata, which refer to subconscious context dependent knowledge or 'immediately knowing what is going to happen'. Also long term memories, internal state of the person, other sensory information (e.g. vision, audition, or somatic sensation) and possible motor actions that can be undertaken influence which neural representations are activated. Sensitivity control too determines which schemata are activated and regulates the strength of the signals competing for access to competitive selection in which process the activated neural representations are compared. The dominant schemata are selected and gain access to the working memory. For example, when a dominant schema represents a routine hazard, gaze control will be driven bottom-up. This implies that gaze control is not always necessary in the case of a routine hazard, since competitive selection feeds directly into sensitivity control. When on the other hand, the dominant schema needs to be processed in the working memory, an eye movement in the direction of the hazardous event might be the result (Figure 7).

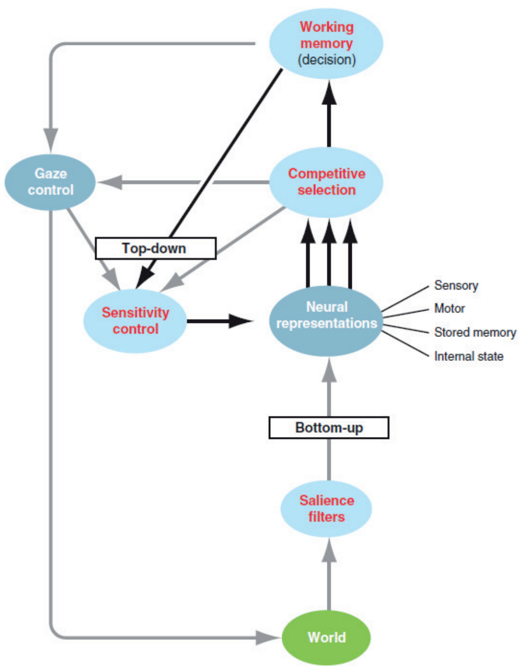

Figure 7. The functional model of attention from Knudsen (2007). Highlighted in red, the processes that contribute to attention. In green, information about the world. Voluntary attention is indicated by the dark arrows (top-down). Bottom-up attention is indicated by the grey arrows.

3.2. Working memory and cognitive load

The concept of working memory is referred to as an executive function involved in the processing and manipulation of information and is different from short-term memory that involves the recollection of recent information (Land and Tatler, 2009). It is considered a powerful process that holds a limited amount of sensory information in the short-term memory. Unless this new information in short-term memory is refreshed within twenty seconds, all information will be lost. Long-term memory, on the other hand, holds schemata of varying automation and complexity which alters the characteristics of working memory. The organization of stored knowledge in schemata reduces working memory load since schemata can be dealt with as one element. In addition, schemata become more automated when they are repeatedly employed and make working memory available for other tasks. The cognitive load theory focusses on the ease at which new information is processed by the working memory for constructing long-term schemata (Van Merriënboer and Sweller, 2005). In other words, the cognitive load theory relates to the learning of new and complex new tasks in which an abundance of information needs to be processed simultaneously before learning can start. Working memory is affected by the intrinsic nature of the tasks (intrinsic cognitive load), the resources to deal with intrinsic cognitive load (germane load) and by the way these tasks are presented (extraneous cognitive load). Intrinsic cognitive load is caused by the complexity of the materials or the complexity of the schemata to be acquired and dependent on the number of elements that need to be processed at the same time. Extraneous cognitive load refers to the load imposed by poor instructional procedures that hamper the acquisition of schemata (Paas et al., 2010). Intrinsic and extraneous cognitive load are additive which implies that when intrinsic load is high (e.g. a high number of elements need to be processed), it is essential to reduce extraneous load (e.g. easy instructional design) to reduce cognitive load. For example, cognitive load in a young bicyclist is (too) high when the bicyclist has to attribute attention to other bicyclists on the bicycle path in the opposite direction when avoiding obstacles and monitoring traffic at an intersection.

It is thought that working memory consist of four component processes (Land and Tatler, 2009). First, the capacity to focus attention refers to the mechanism by which the schema system instructs the gaze control, motor and visual system. Secondly, the ability to switch attention is the function of the schema control system and contains a ‘to-do’ list for different tasks. It is not always easy to distinguish switching attention from dividing attention but in general, task performance often deteriorates when a second task is added and divided attention is required. It has been suggested that performance on the first task declines due to a bottle-neck effect, parallel processing or limited attentional resources being divided over two tasks. Next to the ability to divide attention, also the ability to switch attention effectively between tasks is of particular importance (Dunbar et al., 2001). Altmann and Kamide demonstrated in 2007 that when participants had to switch from a simple task - such as judging if a number is odd or even - to another task - if the number is higher than ten or not - performance on the trial at the moment of task-switch is worse. This ‘cost’ is referred to as ‘switch cost’. On the other hand, pianists regularly check the positioning of the fingers on the keyboard for a few hundred milliseconds when reading the music, which attentional switch usually has no disrupting effect on the performance (Furneaux and Land, 1999). Also in more complex tasks, e.g. urban driving, the driver must alternate attention between the road, pedestrians, bicyclists, etc. In this case, switching of attention often occurs overt – there is an eye movement. Working memory is therefore an essential component for recollecting information regarding the direction of moving vehicles or the location of traffic lights and traffic signs (Best et al., 2009).

3.3. Vision

3.3.1. Focal and peripheral vision

Since the fovea provides us with high acuity and detailed visual information, most studies presume that focal vision is the primary source of visual attention. Incorrectly, as it turns out. Aside from focal vision, which is responsible for detecting the physical characteristics and conscious identification of objects within an environment, ambient or peripheral vision is concerned with the detection of the spatial characteristics of the surroundings. Peripheral vision – the largest part of the visual field - provides us with information regarding motion and location of objects in the environment, how our movements relate to these objects, and is therefore assumed to aid (fine) motor actions unconsciously (Schmidt and Wrisberg, 2004). In walking for example, it is demonstrated that walking velocity, stepping over or avoiding obstacles and braking behaviour is adapted to the flow in the peripheral visual field (Bardy et al., 1973; Bardy and Laurent, 1989; Laurent et al., 1988; Marigold, 2008). Furthermore, Summala et al. (1996) noted the importance of peripheral vision since they suggested that car drivers are able to detect movement at the far periphery which enables them to detect bicyclists through their peripheral vision. Milner and Goodale (2008) suggested that central or focal vision and peripheral vision are acquired via two parallel streams; the ventral and dorsal stream. The ventral stream is concerned with perception and the identification of objects while the dorsal stream is mainly related to visually guided actions at such objects (Goodale and Milner, 1992). Central vision is therefore suggested to be associated with the ventral stream, while peripheral vision is mainly related to the dorsal stream[12]. Despite these two parallel pathways, focal and peripheral vision remain rather interrelated than two separate visual systems. For example, sudden movements in the environment are captured by peripheral vision (also see 3.3.4 Eye movement strategies: bottom-up and top-down control) followed by a focal shift towards the event for conscious and detailed examination (Gugerty, 2011)[13]. This process is also referred to as attentional capture.

3.3.2. The eye and eye movements

For guidance and successful completion of human behaviour, humans engage in the uptake of visual information which is acquired by the eyes. Prior to discussing the stereotype eye movement strategies in a variety of tasks, the different types of eye movements are briefly reviewed. High acuity visual information is restricted to an astonishingly small region on the retina which is referred to as the fovea centralis, with an angular diameter between 0.3° to 2°. Resolution of the visual information projected on the retina, decreases rapidly away from the fovea to 1/10 of normal acuity at an eccentricity of 20° resulting in blur (Horsley et al., 2014; Land and Tatler, 2009; Land, 2006). High visual acuity at the fovea is enabled due to the high density of photoreceptors – a special type of neurons – which can connect up to 10.000 other neurons. These neurons, or cones and rods are embedded in the outer layer of the retina and sensitive for incoming light. The cones -

[12] For further reading see Goodale and Milner, (1992) and Milner and Goodale (2008; 1998).
[13] Interestingly, Gugerty (2011) noted that when task-load is increased in means of an auditory side task, the abrupt onset of visual cue's in the periphery no longer capture attention. Moreover, this highlights the danger of cellphone use while driving.

roughly 133 per degree visual angle[14] in the fovea and drops sharply from the 5° visual angle border - provide trichromatic photopic[15] (day) vision, while the rods provide monochromatic scotopic (night) vision (Duchowski, 2007). Constant relocation of the eyes is therefore essential in order to provide detailed visual information of the world around us (see Figure 8).

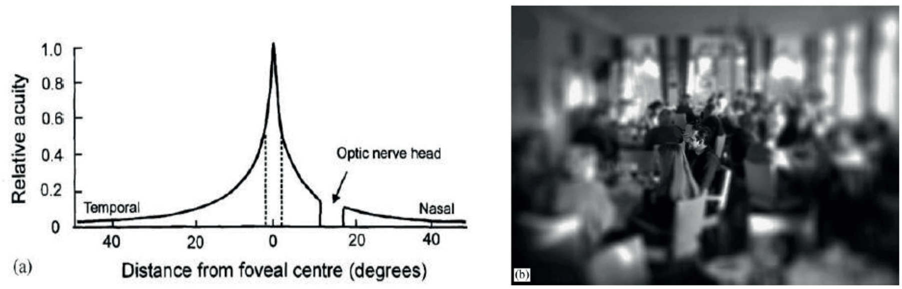

Figure 8. Left: visual acuity decreases as the light falls further from the fovea. The area around zero, between the dashed lines represents foveal vision. Visual information from outside this region represents peripheral vision. **Right**: reflection of increasing blur when moving further from the fovea. Retrieved from Land (2006).

Grace to the eye muscles[16], supporting and moving the eyes in their orbits, the eyes are relocated roughly three times per second to ensure that the object of interest is centred on the fovea (Horsley et al., 2014; Land and Tatler, 2009). These relocations of the eyes are referred to as saccades and describe both the voluntary and reflexive conjugate[17] rapid movements of the eye. Normally we are unaware of these saccades as they have to occur very fast, ranging in duration from 10ms to 100ms or 700°/s, and active suppression or blur causes almost blindness during these extremely fast eye movements (Duchowski, 2007; Land, 2006). Gaze shifts of about 10° are usually made by saccades alone, but larger gaze shifts are often aided by head – and sometimes trunk – movements (Land, 2004). The very small saccades who act as a corrective mechanism to prevent the fovea from drifting away and re-foveate the point of interest, are referred to as microsaccades (Martinez-Conde et al., 2006). Between two saccades, gaze must kept still on the object of interest to ensure the intake of visual information. These relative stable periods between saccades are defined as fixations and take at least 20ms since the process of photoreception e.g. the time for light to reach the cones, is relatively slow (Duchowski, 2007; Friedburg et al., 2004; Horsley et al., 2014; Land and Tatler, 2009).

Aside from the 'saccade and fixate' strategy (Land, 1999), smooth pursuit[18] movements aid to stabilize the image on the retina and occur when tracking a small moving object up to velocities of 15° s^{-1}. When velocities exceed 15° s^{-1}, smooth pursuit is assisted by saccades and above 100° s^{-1}, pursuit becomes entirely

[14] One degree of visual angle corresponds to 300µm of the human retina.
[15] Vision under well-lit conditions.
[16] The eyeball is supported by six muscles, four rectus muscles (lateral, medial, superior and inferior) to rotate the eyeball around the vertical and horizontal planes and two oblique muscles (superior and inferior) to rotate the eyes around the visual axis (Land and Tatler, 2009).
[17] Simultaneous.
[18] Land and Tatler (2009) attribute anticipatory powers to the smooth pursuit system. Interestingly, it is found that the eyes are able to continue to track an object at constant speed when it briefly disappeared.

saccadic. A ‘catch-up saccade’ corrects for the latency of the eyes (100 to 150 ms) when a stationary object starts to move (Land and Tatler, 2009; Salman et al., 2006).

At last, the eye movements adjusting the angle between the eyes in function of the distance to the object are called vergence eye movements (depth perception). In contrast to saccades, fixations and smooth pursuit, vergence eye movements are disconjugate movements meaning that relative to the head, the eyes moves in the opposite direction. Vergence movements can be classified as convergent, e.g. aligning both eyes to an object closer to the observer, or divergent, e.g. an object further away from the observer (Duchowski, 2007).

3.3.3. Stabilizing mechanisms

When navigating through the world, when driving in traffic, or when bicycling in the countryside, our body and head rotates at high velocities which obstructs stabilization of the image on the retina. For fixations to be maintained, ocular stabilization reflexes are required in order to support stabilizing the visual image on the retina during head movements. The vestibulo-ocular reflex (VOR) counter-rotates the eyes to the head movement to maintain fixation on the object of interest (Land, 2004). The VOR measures the velocities of head rotation in the semicircular canals, which signal is transferred via the vestibular and oculomotor nuclei to the muscles of the eyes. The latency of this reflex is 15ms (150ms in the optokinetic reflex, see below) and the gain is close to one, suggesting that rotating the eyes in the opposite direction to the head movements almost completely counteracts them. However, when rotation of the head is maintained, saccade-like movements are made in the opposite direction which is referred to as nystagmus (Kowler, 2007; Land, 2006; Land and Tatler, 2009).

At slower velocities the optokinetic reflex (OKR) assists the VOR, and operates by measuring the velocity of the image on the retina resulting in an eye movement in the same direction as the image motion on the retina. In contrast to smooth pursuit, which was used to track small moving objects, the OKR is evoked when large parts of the image move together. Moreover, while the VOR is not a feedback system since eye-movements have no effect on the semi-circular canals, the OKR sure is a feedback system in which the eyes counter rotate to the image on the retina. Like the VOR, continued rotation of the environment, up to 20° of visual angle, evokes optokinetic nystagmus, in which a saccade brings the eyes to a central position[19] straight ahead (Lappe et al., 1998; Niemann et al., 1999). Additionally, Kelders et al. (2003) describe a third stabilization reflex, the cervico-ocular reflex (COR), which is elicited by rotation of the neck. The COR is evoked by proprioception of the muscles and facet joints of the cervical spine.

A good example to illustrate the functioning of both the VOR an OKR reflexes is to hold a hand upright in front of your eyes. When slowly moving the hand back and forth (1 Hz), this evokes the OKR. When speeding up a little bit, it becomes hard to keep counting the fingers. To evoke the VOR, keep the hand still and move the head fast (5 Hz) left and right. Even at faster head movements, the fingers remain unblurred (Land and Tatler, 2009).

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[19] Under natural conditions, residual image motion is between 0.5 to 5° s^{-1} (Collewijn et al., 1981).

3.3.4. Eye movement strategies: bottom-up and top-down control

What drives our eyes around in the world? Previously, it is been described that the eyes relocate several times a second which often occurs spontaneously and unconsciously, suggesting that eye movements are driven by the properties or saliency of the image on the retina. These saliency-driven reflexive eye movements are referred to as ‘bottom-up’ driven eye movements. For example in a free viewing (task-free), the eyes are attracted towards remarkable features in the environment, ignoring influences from higher-cognitive processes. ‘Top-down’ driven eye movements or task-driven eye movements however, occur when an individual is presented with a task, e.g. “finding Wally in a book”, the eyes are mainly guided by the goal of the task, rather than the image properties. Although both bottom-up and top-down factors contribute to gaze control in natural behaviour, researchers seem to agree that ‘bottom-up’ processes are of limited relevance during goal-oriented actions such as road-crossing or making a sandwich (Land, 2006; Land and Tatler, 2009; Tatler et al., 2011). It has been suggested that visual search patterns during active tasks are influenced by short-term memory, are almost exclusively directed towards the task-relevant information and are often temporarily linked to the on-going actions (Hayhoe and Ballard, 2005; Henderson, 2003; Land, 2004, 1999). However, during free scene exploration, visual behaviour is under the control of bottom-up control in the first instances, followed by top-down control for further and more detailed inspection (Helo et al., 2014).

3.4. Neural substrates of gaze, action and attention

Even the simple task of making a sandwich consists of a variety of temporally well-coordinated and visually guided acts. In this section, the role of the brain from perception – the control of eye movements to selection of what visual information is used - to action is briefly discussed.

3.4.1. The visual system

Visual input is sent form the eyes via the *optic nerves* and the *optic chiasm*[20] to the *lateral geniculate nuclei* of the *thalamus* and ultimately to the *occipital lobes* at the rear end of the *cerebral cortex* where processing begins. The optic nerve also supplies the *superior colliculus*. Almost all visual input to the cortex flows through the *primary visual cortex*, followed by other regions in the *occipital* and *temporal lobes* where the different characteristics (colour, motion, etc.) of the visual information are independently analysed. From the occipital lobe, visual information proceeds forward via the *ventral* and *dorsal streams* (Milner and Goodale, 2008; also see 3.1.3). The ventral stream, concerned with the identification of objects, is directed towards the temporal lobe whereas the dorsal stream, concerned with the location and motion of objects, is directed towards the *parietal lobe*. The parietal lobe also controls the coordination of activities such as reaching or grasping and therefore has both sensory and motor functions.

The control of eye movements, or where to gaze is directed, is mediated by the *frontal eye fields* (FEF) and the *supplementary eye fields* (SEF). The FEF is located in the *arcuate sulcus*, and receives input from the parietal cortex – especially the *lateral intraparietal area* (LIP) – *the middle temporal visual areas* (MT), the

[20] The optic chiasm near the base of the brain is the place where the nerve fibers meet and cross over to the other side or continue on the same side of the brain (Magill, 2007).

middle superior temporal visual areas (MST) and the *prefrontal cortex*. The SEF is located in the dorsal bank of the *cingulate sulcus*, and drives the saccadic eye movements. Latencies of the eye movements from the SEF are longer compared to the FEF since the FEF feed directly to the oculomotor-related nuclei in the brain stem and to the superior colliculus (SC). The latter also acts as an organizing centre for orienting saccades and head movements. Moreover, the SC on its turn is connected back up to the FEF and LIP.

3.4.2. The motor system

Complex routines such as preparing a sandwich or riding a bicycle consist of multiple sequences of actions or objects that require actions to be performed on. It is assumed that the scripts for these actions originate in the *dorso-lateral prefrontal cortex* and involve both the eye movement system and the motor system. The eye movement system (previously described) is concerned with the location and features of objects in the nearby environment, forwarding this information to the motor system, and providing visual feedback regarding the action sequences. In turn, the motor system formulates and executes the individual muscle movements for each action sequence based on the visual, haptic and proprioceptive information (Land and Tatler, 2009).

Regarding the motor output, the sensory regions at the rear end of the cortex are separated from the motor regions of the frontal lobe through the *central sulcus*. Anterior to the central sulcus lies the *primary motor cortex* and posterior the *somato-sensory cortex* who receive input from the *cortico-spinal trac*t, *motor neurons* and indirectly via *nuclei in the brain stem* where direct connections control the fine movements of the distal segments. The primary motor cortex has a mapping of the body musculature while the somato-sensory cortex has a topographic array of the bodies' surface and muscles.

The primary motor cortex receives input regarding the muscular action patterns for immediate goals from the *premotor cortex anterior*. On its turn, the premotor cortex receives information from the parietal lobes which implies that the parietal lobes, responsible for visual control of arm and hand movements, also have a motor output via the premotor cortex. The premotor cortex is supplied in turn from the *prefrontal regions* and is therefore considered to be mainly concerned with the execution of longer-term plans rather than details of action coordination. Furthermore, generation of an action requires the cooperation of the prefrontal, premotor and parietal regions of the brain. It is suggested that motor prototypes (f.e. for grasping actions) originate in area F5 of the premotor cortex, and are sent to the anterior intraparietal area (AIP) which also receives information from the dorso-lateral prefrontal cortex (DLPF) regarding what action has to be performed. The AIP itself possesses information about the objects' meaning, has 3D representations of the particular objects and can therefore be considered to provide 'affordances'. When certain actions in a sequence have to be performed is determined by area F6 that feeds into the premotor neurons of F5 (Figure 9; Rizzolatti et al., 2001).

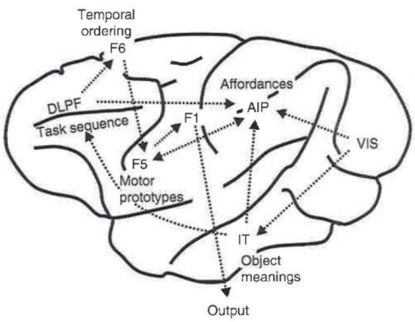

Figure 9. Overview of the interactions involved in action selection and performance. AIP: anterior intraparietal area, DLPF: dorso-lateral prefrontal cortex, F1: primary motor cortex, F5 and F6: ventral and dorsal premotor areas, IT: inferotemporal lobe, VIS: occipital visual areas. Retrieved from Land and Tatler (2011).

3.4.3. Attention

In top-down attention, the schema control system selects which part of the scene should be looked at, it is responsible for setting the goals of action and is associated with the dorsal prefrontal cortex. Top-down driven attention is therefore related to top-down eye movements. When a target is within the field of view of the gaze system, the identification process is required to determine whether the fixated target is the appropriate one. The frontal eye fields initiate gaze movements to highlight the regions of the retinotopic mappings in the visual regions of the cortex to examine if the appropriate features are present[21] (Armstrong et al., 2006; Ekstrom et al., 2008). When the object of interest is fixated, the nature of attention changes. The visual system engages in monitoring limb movements and managing the action. The link between the motor and visual system is suggested to be located in the posterior parietal cortex and for grasping in the AIP. The AIP in turn is reciprocally connected to the premotor area F5 which is concerned with the generation of specific movement patterns. The decision regarding the action to be performed is suggested to be taken in the prefrontal cortex, see Figure 10.

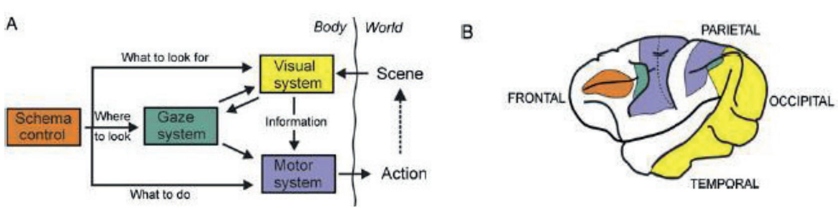

Figure 10. (A) The relations between the schema control, gaze, visual and motor systems when performing a visually guided task and (B) the associated brain regions (in the macaque cortex). Retrieved from Land (2009).

[21] The location of where the decision - whether the fixated object is correct or not - is made, is not yet clear (Land and Tatler, 2009).

4. Visual control for locomotion

Given that eye movements are associated with attention (Posner, 1980) and provide the motor system with sensory input (Land and Tatler, 2009), the modelling of eye movements gained a lot of interest in the past decades (Murray et al., 2007) as each task requires its own visual scanning pattern. Accordingly, numerous studies examined visual behaviour in sports (Button and Croft, 2009; Savelsbergh et al., 2002; Williams et al., 2002), natural behaviour and heading (Hayhoe and Ballard, 2005; Pelz and Rothkopf, 2007; Warren and Hannon, 1990; Wilkie et al., 2010), driving (Konstantopoulos et al., 2012; Mourant and Rockwell, 1970), etc. As vision is particularly important for locomotion and bicycling can be considered one form of locomotion, the current section will review the role of visual information in pedestrians, drivers and bicyclists.

4.1.1. Eye tracking methods

Before reviewing studies of driving, walking or bicycling, in which eye trackers were used, some basic knowledge of how eye-trackers work might be of interest. In general, there are two types of eye trackers. The first measures the position of the eye in relation to the head while the second measures the orientation of the eye in space. There are also four categories of eye movement measurement methodologies. These methodologies involve the use of (1) Electro-OculoGraphy (EOG), (2) scleral contact lens/search coil, (3) Photo-OculoGraphy (POG) and (4) video-based combined pupil and corneal reflection. Today, the most applied technique, which is also used in this dissertation, is based on corneal reflection (Duchowki, 2007). Only the latter technique is therefore discussed here in brief.

Corneal reflection based eye trackers work by shining infra-red light onto the eye to create a high contrast image of the eye. This results in a bright part, the pupils' reflection, and a corneal reflection also known as the Purkinje reflection. Once the eye tracker has been calibrated, gaze direction can be calculated from the relationship between the infra-red corneal reflections and the pupil reflection.

Since there is growing interest in studying visual behaviour in a variety of settings, constructors recently generated a range of 'affordable' portable and remote eye trackers with improving accuracy and speed to study visual behaviour under more naturalistic/ecological conditions. Nevertheless, these eye trackers remain inferior to the larger eye trackers which often require to fixate the participants head ('t Hart et al., 2009; Duchowski, 2007; Egan, 2012; Land and Tatler, 2009). The portable eye trackers typically make use of two camera's, one for the surroundings and the other one records the eye image. Both these cameras are attached to the head which enables the head to move freely around. The remote eye trackers on the other hand, are computer-based. Here, the eye tracker is often mounted underneath the computer screen and does only allow for minor head movements. In Figure 11, the principal specifications for the two portable head mounted eye trackers and the remote eye tracker which have been used in this dissertation are provided.

HED	ETG	RED
Principle		
Non-invasive video based eye tracker with pupil corneal reflection	Non-invasive video based glasses-type eye tracker with pupil corneal reflection	Non-invasive, image based eye tracking with pupil corneal reflection
Gaze position accuracy		
1°	0.5°	0.4°
Sampling rate		
50Hz monocular	60Hz binocular	120Hz binocular
Scene camera		
720×576p @ 25fps	1280×960p @ 25fps 960×720p @ 30fps	/
Field of view		
± 33° horizontally and vertically	60°horizontal, 46° vertical	40°horizontal, 60°vertical (±20/40°)
Head movements		
Free	Free	40cm × 20cm at 70cm distance
Outdoors		
Not in broad daylight	Yes	No
Parallax compensation		
No	Yes	No
Eyewear compatibility		
Works with contact lenses and most spectacles	Works with contact lenses and most spectacles	Works with most glasses and lenses

Figure 11. Specifications for the Head mounted Eye tacking Device (left), the Eye Tracking Glasses (middle) and the Remote Eye tracking Device (right) of SMI. All three are used in this dissertation to document eye tracking behaviour

4.1.2. Visual control of heading: optic flow

Grace to a highly efficient system for the uptake and processing of visual information humans are able to successfully navigate through the world, even with continuous changing body positions and course changes. Indeed, when moving through an environment, e.g. when walking or riding, a visual flow field is induced on the retina. The properties of this flow field depend on the direction of gaze and the direction of travel and are important for spatial orientation and visual navigation. This is known as 'optic flow' (Angelaki and Hess, 2005; Lappe and Hoffmann, 2000). According to Gibson, *"lineair translation through a stationary environment generates a radial pattern of optical flow at the eye, in which the focus of outflow specifies the observer's direction of self-motion or heading"* (Gibson in Warren and Hannon, 1990). For example, when driving straight ahead, heading can be derived from the focus of expansion (FoE), by keeping the target as close to the FoE as possible. In more natural behaviour, we constantly redirect our gaze when walking or driving, which displaces the FoE from the direction of heading. To maintain fixation, reflexive compensatory eye movements are generated which induce changes in the retinal image. This change in the retinal image, induced by eye movements is referred to as retinal flow (Angelaki and Hess, 2005; Wilkie and Wann, 2003) and is presented in Figure 12 (left). Not only flow but also egocentric visual direction can make a contribution to judge one's direction of heading. In egocentric control, judgement of direction is based on the visual angle to the target. E.g. when steering towards a target, a constant visual angle would result in overshooting the target, while reducing the visual angle would result in interception. When fixation the target and rotating the body this would result in a curvilinear path as displayed in Figure 12 (right) (Rushton et al., 1998; Wilkie and Wann, 2005). Researchers agree that a combination of both optic flow and egocentric control contribute to judgement of heading (Lappe et al., 1999; Warren et al., 2001; Wilkie and Wann, 2005).

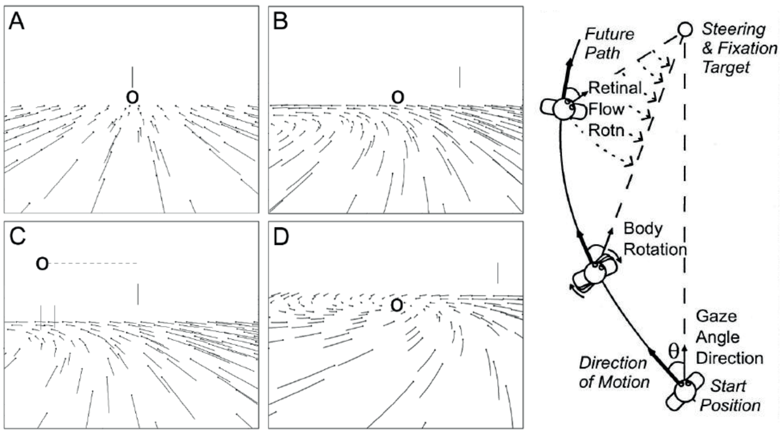

Figure 12. The figure on the left, represents retinal flow patterns when travelling along a linear trajectory (A), when sweeping gaze to the left (B), travelling a curved trajectory (C), and travelling among a linear trajectory and fixating a ground feature. The figure on the right displays the egocentric control theory (Wilkie and Wann 2003; Wilkie and Wann 2005).

4.1.3. Visual control of walking

Walking from one location to the next requires vision to help us navigate safely through the world. The most important requisite that must be controlled is the placement of the foot (Lappe and Hoffmann, 2000). In the absence of obstacles, people primarily direct their gaze close to the direction of heading or the information which is needed for future movements (Turano et al., 2001). On tarmac or smooth paving gaze tends to be fixed a few metres in front of the walker. From the generated optic flow information regarding self-motion can then be extracted (Patla and Vickers, 2003). In other words, fixations seem to 'travel' along by the observer or drift forward and are therefore called travel fixations[22] (Land and Tatler, 2009; Vickers, 2007). However, when negotiating uneven and more complex terrain, e.g. when traversing a living room littered with toys or strolling along a poorly maintained curb, people tend to adopt different gaze behaviour. When subjects had to step over a

[22] The role of travel fixations is not uncontested as it requires the OptoKinetic Reflex to be surpressed.

series of obstacles, they were found to fixate on the task-relevant areas or the areas for potential foot placement. These fixations occur two steps ahead or 0.8 to 1s in time and can be referred to as look ahead fixations (Marigold and Patla, 2007; Patla and Vickers, 2003). Patla and Vickers (1997) demonstrated that walkers did not fixate the obstacle anymore when stepping over it, suggesting that visuomotor planning occurred two steps before in a feed-forward manner. But adjustments in foot placement to a new location can be made up to the end of the stance period of the preceding step or 0.5s ahead (Hollands and Marple-Horvat, 1996) suggesting that also on line control aids sufficient locomotion.

4.1.4. Visual control of driving

Driving is a varied and complex skill which involves paying attention to other road users, vehicle control, dealing with the road itself etc., requiring a range of eye movement strategies to be employed. A fair amount of research in the field of eye tracking therefore focussed on how vision is deployed and what visual information is used when driving on a straight road, a winding road, in urban areas or driving on highways. Donges (1978) organized the steering task into a two-level model of driver steering behaviour which became one of the most influential models for visual control in driving. In brief, the guidance level, also referred to as feed-forward signals, operates in an anticipatory open-loop control mode and describes the desired future path of travel, while the stabilization level or feedback signals, works in a closed-loop control mode and compensate for deviations from the intended course (angle between heading and path curvature) and intended position (lateral deviation). Although Donges demonstrated that both signal levels are used in steering, he did not describe how this visual information could be obtained. According to Land and Tatler (2009) the feedforward and feedback signals from Donges can be identified as the far point (tangent point, FoE, or vanishing point) and the near point (lane edge marker). The far point provides visual information regarding the desired route or curvature of the road while the near point provides information about the positioning on the road. Furthermore, simulator studies have demonstrated that feedforward information from the distant regions alone resulted in very poor position-in-lane control while curvature matching was poor when only the nearest region was visible. Drivers therefore tended to fixate on the far region providing information of heading while the near regions are monitored by peripheral vision (Figure 13; Land and Horwood, 1995; Mourant and Rockwell, 1970).

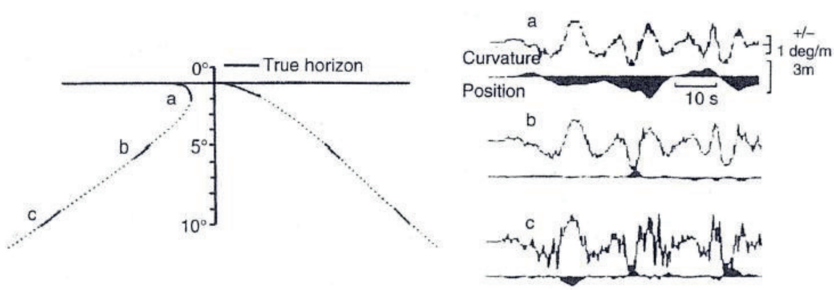

Figure 13. A simulated driving performance where only one vertical segment of the winding road was visible (a,b or c). The a represents the far point for curve matching, b the middle point aids curve matching to a lesser extent and c represents the nearest point which aids position-in-lane maintenance**.** On the right, the position of the car relative to the curvature of the road is presented. Black regions indicate discrepancies between the car track and the road (Land and Horwood 1995).

In the more challenging case of steering around bends, the distant region should provide visual information for estimating road curvature and course planning. However, which part of the road should be attended to, is still subject of debate. Land and Lee explored this problem in 1994 by examining the visual behaviour of three drivers, when driving along a curved road in Edinburgh with no other traffic. They demonstrated that drivers spent most of their time fixating the ‘tangent point’ of the bend (almost 80%), or the moving point on the inside of each bend in which the drivers line of sight is tangential to the road edge (see Figure 14A). This point moves around the bend in the same angular position (in case of constant curvature) relative to the car. The angular position of the tangent point predicts the curvature of the upcoming road. Since the TP is a near stationary point in the flow field, the eyes can rest on the TP while following this point via the OKR. Furthermore, analysis of the gaze angle and the steering wheel angle indicated a close relation between direction of gaze and steering in which gaze direction precedes steering adjustments by 0.8 s. This time-lag is very similar to the delays in walking and represents a planned delay. More recent and extensive research confirmed the use of the tangent point theory (Authié and Mestre, 2012; Chattington et al., 2007; Kandil et al., 2009; Mars, 2008). However, Wilkie et al. (2010) argued that the tangent point theory only works within continuous bends. E.g. when turning onto a parking lot or open space, this model would completely fail. Moreover, Land and Lee (1994) did not provided participants with instructions regarding the road position to maintain. Fixations near the TP might therefore also been explained by looking toward the inside road edge to ‘cut the corner’ or ‘look where you are going’ (see Figure 14B), in line with the active-gaze model of steering control (Robertshaw and Wilkie, 2008; Wilkie et al., 2008; Wilkie and Wann, 2003) and based on the point attractor model (Fajen and Warren, 2003). In this model drivers’ gaze is directed to the points which they would like to pass 1-2s ahead. Rather than relying onto one perceptual variable – the TP – this model is based upon a combination of perceptual variables such as retinal flow and gaze angle to estimate road curvature and generate a sufficient steering response. The driving task entangles even more when the driver needs to negotiate a curve when passing by a bicyclist whose position needs to be checked repeatedly. The driver therefore alternates gaze between the tangent point and the bicyclist, implying that the eye-steering coupling has to be turned-off, and the visual-motor system has to switch between the tasks. When fixating the bicyclist, visual feedback regarding the road curvature is put on hold for 0.8s to 1.5s and stored in a buffer which concurs with the delays in curve negotiation and walking. These off-road glances should not take longer than 1s for performance to deteriorate (Hildreth et al., 2000; Land, 2006).

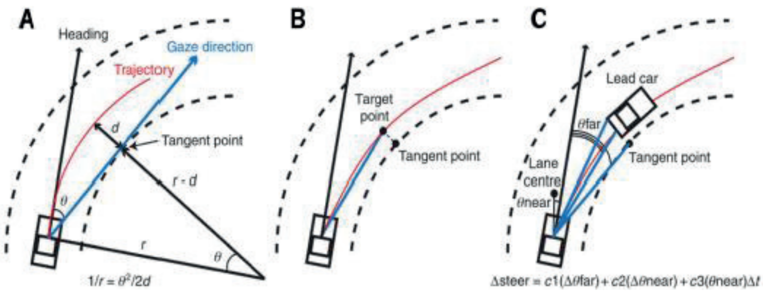

Figure 14. (A) Illustration of a driver using the tangent point from Land and Lee (1994) or (B) when using the 'look where you are going strategy' and (C) the two-point model according to Salvucci and Gray (2004a) retrieved from Vansteenkiste et al., 2014a, adapted from Mars, 2008.

4.1.5. Visual control of bicycling

The role of visual behaviour in walking and driving is fairly well documented. Although bicycling is a widespread form of locomotion too, research regarding visual control of bicycle steering is rather scarce. Vansteekiste et al. (2013, 2014a, 2015) studied the role of visual information in three isolated tasks; when steering a straight line, negotiating a curve, and steering a slalom. Vansteenkiste et al. (2013) discovered that when adult bicyclists were required to bicycle along three 15m long lanes of 10, 25 and 40cm wide at three self-selected speeds (slow, preferred, fast), participants mainly watched the path (41% of time) and the goal region (40%) suggesting that both near regions (travel path) and far regions (goal) are attended for sufficient steering. Gaze was found to shift earlier and more to the distant region when bicycling speeds were higher or lane width was wider which might be attributed to the speed-steering workload trade-off (Godley et al., 2004). These findings inspired the authors to present a new gaze constraints model which assumes that reaching a goal requires both (1) close gaze behaviour for direct control and stability and (2) distant gaze behaviour for anticipation and is influenced by task complexity, automation and attentional demand (Salvucci and Gray, 2004). The near region in this model will mainly be attended to peripherally, however, when the need for direct control increases, e.g. when lane width decreases, gaze will shift more to the close region, similarly to gaze behaviour when walking over obstacles (Marigold and Patla, 2007). Eight-year-old children performing a similar bicycle task were found to make the same gaze shifts as adults suggesting that they adopt a comparable visual-motor strategy notwithstanding that they bicycled slower compared to adults (Vansteenkiste et al., 2015).

Next to bicycling on a straight road, also the role of visual control in curve negotiation was of interest since it is still of debate which parts of the road are used for sufficient steering. When bicycling at low speeds, participants mainly gazed at the centre of the road which suggested that they preferred the 'look where you are going' strategy. When bicycling at higher speeds, however, bicyclists seemed to switch their gaze to the inner edge of the road according to the curvature matching strategy (Vansteenkiste et al., 2014a; Wilkie et al., 2010). A more complex form of curve negotiation is considered performing a slalom. Vansteenkiste (2015) described gaze behaviour in children and adults when performing a slalom task at three different speeds. Adults were found to focus more on the points between the cones suggesting that they anticipated future steering manoeuvres and planned their way through the slalom in advance. Children, on the other hand, displayed a simpler visual strategy. They fixated the cone in front until it was only 1.2s ahead of them, before switching gaze to the next cone. When bicycling speed increased, adults switched their gaze earlier to the next cone, while children switched their gaze more or less at the same time as in the slower condition. The authors therefore proposed that the more simple perceptual-motor strategy in children changed to a more flexible and holistic approach to guide steering in more experienced adult bicyclists.

4.2. Summary

Attentional control and eye movements are closely related and are driven by bottom-up and top-down processes. Orienting attention through the allocation of fixations and saccades towards the sources of relevant information in the environment allow the observer to perceive this information and generate a corresponding action. During these actions various ocular reflexes stabilize the image on the retina in order to maintain fixation which enables the visual system to take in the visual information. This information is sent via the optic nerve through the optic chiasm to the visual cortex where processing begins. Based on previous experience and mental models, a corresponding action is chosen and executed by the motor system. When walking, direction of heading can be perceived from the flow field while 'look-ahead fixations' aid the walker to navigate safely past obstacles. If one is traveling at higher speeds, e.g. driving along a straight road, direction of heading is controlled by fixating the far-point while control of lane keeping is acquired peripherally from the near-point. In the more complex task of driving a curved road, the driver is found to rely on the tangent point or on the "look-where-you-are-going strategy" to match steering and looking behaviour (Land, 2009, 2006; Land and Tatler, 2009).

Recent research regarding visual search behaviour in bicycling demonstrated that reaching a goal requires close gaze for stabilisation and lane keeping while distant gaze is used for anticipation. Depending on the task demands, the bicyclists will switch gaze mainly to the close or far region. When task demands increased, for example when negotiating curves or bicycling a slalom, children displayed a more simple visual motor strategy compared to adults which might have important implications for bicycling in the complexity of a traffic environment (Vansteenkiste, 2015). Given that children are more accident prone, have poorer visual search strategies in the lab compared to adults and gaze behaviour of child bicyclists in traffic has not yet been described in the literature, the current research project will aim to fill this gap in the literature and provide a better understanding regarding visual search behaviour of child bicyclists when bicycling in real-life or when presented with video clips of traffic situations.

5. Traffic participation and attention

The previous section described the role of visual information for isolated tasks in locomotion, walking, driving and bicycling. However, bicycling in traffic is more complex and more demanding than bicycling a straight line or bicycling a curve. A bicyclist must keep an eye on other road users, read road signs, make sure he is going in the right direction, and monitor traffic for potential hazards which requires a constant multitasking between subtasks. In the past decades many models regarding the processes that take place when a driver engages in traffic are described. How some of the existing models are relevant in traffic participation and hazard perception are discussed in the following part. It should be noted that although these models have not yet been tested for bicyclists, they might provide a more detailed understanding of how also bicyclists might navigate through traffic and make decisions to deal with dangerous events. Next, the role of visual behaviour in learner drivers and child pedestrians for the perception of hazardous situations is reviewed.

5.1. Models of traffic behaviour

5.1.1. <u>Situation awareness</u>

One of the frequently cited models in human factors such as aviation, driving or traffic participation is situation awareness. This model describes how individuals maintain awareness of 'what's going on' (Gugerty, 2011; Salmon et al., 2012). It should be noted, though, that there is still much debate on measures, theories and validity of situation awareness. In brief, situation awareness (SA) is a multidimensional concept that describes how a person develops and maintains awareness when navigating through traffic and consists of three levels: (1) perception, (2) comprehension and (3) projection (Endsley, 1995; Gugerty, 2011; Salmon and Stanton, 2013; Stanton et al., 2001; Stelling-Konczak et al., 2016). According to Endsley (1995) in the first level or the perception level (e.g. visual and auditory perception), the status, dynamics and attributes of the elements in the environment are perceived without interpretation. In driving, a driver needs to know where the other traffic participants, road signs and road markers (for lane keeping) are located. In the second level then, the comprehension level, the information acquired in the first level is combined into a holistic presentation of the environment. The driver creates an understanding of the objects and events in the current task. E.g. the driver is now aware which road rules apply based on the traffic signs or which other road users might find themselves on collision course. The last and highest level of SA or the projection level, describes the ability to predict the future status and dynamics of the elements in the environment, based on knowledge and comprehension of the situation which enables the driver to anticipate future events. SA therefore involves more than merely perceiving information of the events in the surroundings but also includes understanding the meaning of this information in order to create internal projections regarding how the situation might develop in the future to facilitate decision making (Figure 15; Endsley, 1995). The processes of interpretation (SA2) and projection (SA3) of this information in the near future take place in the working memory. Given that novice drivers have few experience and cannot rely on long-term memory schemata these processes are not yet automated. Furthermore, as vehicle handling in novices often requires conscious effort, cognitive load will be high, resulting in poorer situation awareness (Paas et al., 2010).

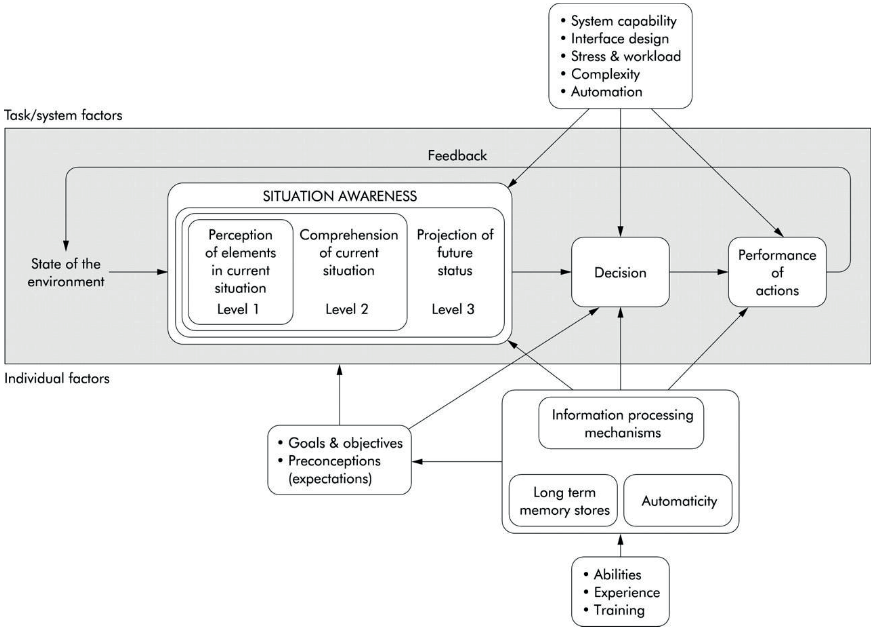

Figure 15. The model of Situation awareness of Endsley (1995).

Gugerty (2011) provided a different approach to situation awareness in which the three cognitive processes involved in maintaining SA are conceptually different from Endsley (1995) and place increasing demands on the cognitive resources. In the first level, automatic and unconscious, pre-attentive processes occur and place no demands on the cognitive resources while in the second level recognition-primed decision processes only demand little cognitive resources. This decision process may be conscious for brief periods. In the third level, controlled conscious processes require high cognitive demands. It is suggested that these automated processes primarily rely on ambient vision or auditory cues while the controlled processes mainly rely on focal vision. It is important though, to consider ambient and focal vision as interrelated rather than separate systems. For example, a car looming in the periphery of the drivers visual field might cause a saccade towards this car leading to comprehension and conscious awareness without awaiting the drivers normal scan path. This phenomenon is also referred to as 'attention capture' and is affected by cognitive load. Even experienced drivers make use of all of the three processing levels. E.g. optic flow in the periphery is used for lane keeping and control of speed and heading, which is often an automated process. On the other hand, routine actions such as changing lanes or stop in front of a red light may involve some conscious processing. At last, navigating through unfamiliar territory or avoiding hazards will require more cognitive resources (Gugerty, 2011). Situation awareness therefore appears to offer a useable framework for explaining the underlying mechanisms in collision involvement (Salmon et al., 2014). Indeed, poor situation awareness has been associated with a higher likelihood to be crash involved (Salmon and Stanton, 2013) and is very likely to be related to experience (Underwood et al., 2012).

5.1.2. SEEV-model

As described in the previous model, shifting focal attention to relevant events in a continuously changing environment for hazard avoidance, navigation or in vehicle tasks (IVT) are considered critical subskills in SA (Gugerty, 2011). How attention is allocated in real-time driving tasks, in which both routinely lane keeping and hazard detection require attention, has been described in the SEEV model presented in Figure 16 (Horrey et al., 2006). In other words, the SEEV computational model attempts to predict how subjects decide where to focus next. This decision is driven by two bottom-up factors – Salience and Effort and two top-down factors – Expectancy and Value. The Salience parameter refers to the conspicuity of an event or object such as sudden movements or high contrasting objects which attract attention (Itti and Koch, 2000). The second bottom-up parameter, Effort, may inhibit visual scanning and refers to the 'effort' to shift focal attention from one location to the next and is affected by the visual angle. E.g. a bicyclist in the blind spot of the driver – and thus a larger visual angle - would require larger eye and head movements from the driver and will therefore be focussed less frequently. The first top-down parameter, Expectancy, describes the tendency to focus on the particular areas where the relevant information is expected to be found. Areas where events occur more frequently (higher bandwidth) are therefore sampled more often. At last, Value accounts for the fact that subjects tend to seek for the most relevant information. For example, when changing lanes, the rear view mirror is highly task-relevant. According to the SEEV-model, the probability that some areas will be looked at and other not, depends on the influence of these four components. However, it should be noted that some tasks are also controlled by ambient vision, e.g. lane keeping (Gugerty, 2011; Horrey et al., 2006; Summala et al., 1998).

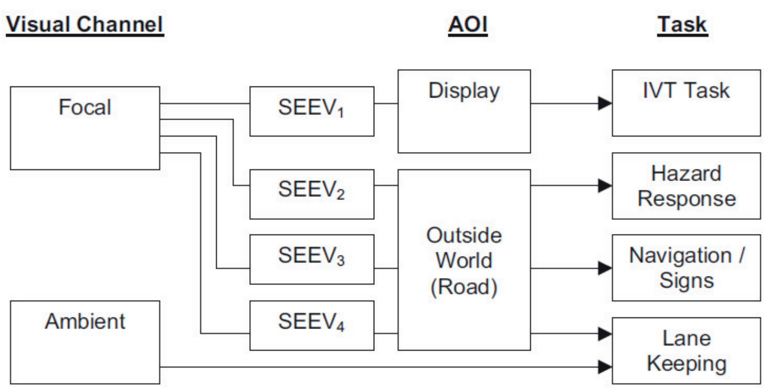

Figure 16. The SEEV model (Saliency, Effort, Expectancy, Value) for the tasks (1-4) as presented by Gugerty 2011. IVT refers to in vehicle technology.

5.1.3. The task difficulty homeostasis model

In the last model displayed in Figure 17, Fuller (2005) approaches driving behaviour differently in which driving behaviour is determined by the dynamic balance between the demands of the driving task and the capability of the driver[23]. Therefore this model is based on the subjective feeling of 'maintaining control' over the driving task rather than subjective risk estimates. When the capability of the driver exceeds the demand of the task, the task is considered as easy, whereas when the driving task equals the capability of the driver, the task is considered very difficult and increases workload. If task demand exceeds the driver's capability, the task is too difficult which might lead to loss of control over the vehicle. The difference between a driver's capability and task demand can be considered inversely proportional to the task demand. Accordingly, a task will be considered very easy when the driver's capabilities far exceed the task demands, while a simple task also might become very difficult when the demands exceed the driver's available capabilities. With capability as a more or less stable characteristic, task demand increases with any event that increases task demand. Any additional task to the driving task will increase task demand and therefore task difficulty, for example, the use of a cellular phone[24] while driving.

The (perceived) drivers' capabilities are defined by his biological characteristics existing of the driver's motor skills, physiological competence and the accumulation of procedural and declarative knowledge. The motor skills refer to the basic vehicle control skills and handling skills. Physiological competence comprises information processing, visual acuity and reaction speed whereas education, training and experience result in higher levels of knowledge. Procedural knowledge refers to perform and exercise various skills (e.g. riding a bicycle) while declarative knowledge refers to memory for facts or concepts (Meir et al., 2014). Repetitive practice has been suggested to cause declarative knowledge being proceduralized. Factors such as stress, sleepiness, mood state or attentional capture influence the driver's capability, often in a negative way. However, not only perceived capability determines task difficulty, also the amount of effort the driver is prepared to attribute to the task or the goals of the task (work related or recreational) effect the risk threshold the driver is willing to accept and varies between individuals (Fuller, 2007). The driving task demands on the other hand are determined by a variety of environmental features (road markings, road signs, visibility, road surface, other road users with the potential to occupy the intended path of the driver), operational features of the vehicle (control characteristics, information displays) over which the driver has no direct control. Added to this, the driver does have immediate control over the trajectory and speed. Since driving is a self-paced task, speed is clearly a major motivational factor and under the control of the driver. The faster a driver chooses to drive, the less time he has to search for the available information, to process this information and ultimately respond to it. Fuller (2007) suggested that drivers determine an acceptable range of task difficulty within the margins of the capabilities of the driver which is referred to as homeostasis. The closer the task demand is to capability, the less reserve a driver will have to counter a sudden increase in task demand. For example, in situations where the driver is stressed to reach his goal on time, the driver is often forced to drive faster which results in lowered safety margin e.g. when a child steps out from behind a car. Therefore the ability to estimate one's own capabilities in relation to task demand is particularly important to avoid potential collisions (Gregersen and Bjurulf, 1996).

[23] The task-difficulty homeostasis model is based on the task-capability model of Fuller (2005) and presumes that the driver drives in such way that he is able to maintain task difficulty within a certain range.
[24] Cellphone use while driving increases the risk of collision by 500% (Violanti and Marshall, 1996).

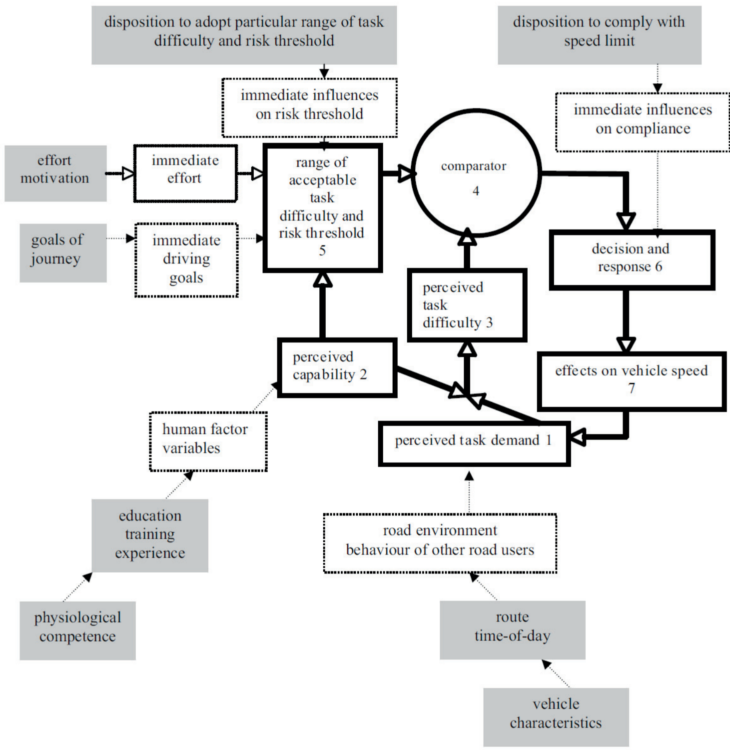

Figure 17. The task difficulty homeostasis model of Fuller 2007.

5.2. Visual search in learner drivers

Since young/learner drivers are overrepresented in accident statistics (Clarke et al., 2005) research has been concerned with the role of the cognitive aspects in driving by means of perception and attention (Lee, 2008). Numerous studies therefore recorded drivers' eye movements on real roads (Crundall and Underwood, 1998; Falkmer et al., 2005; Mourant and Rockwell, 1972, 1970) or when presented with video clips (Konstantopoulos et al., 2010; Pradhan et al., 2003) to investigate general visual attention deployment in young/learner and more experienced drivers. One of the first studies to measure visual search strategies in learner and experienced drivers on a real-road is performed by Mourant and Rockwell (1972, 1970). In 1972, they instructed six novice drivers to drive along a 4.3 mile freeway route and a 2.1 mile neighbourhood route while their eye movements were being recorded and compared to the visual behaviour of four experienced drivers. They reported that novice drivers concentrated their fixations closer in front and more to the right of the vehicle, fixated a smaller area, looked less in their mirrors and made pursuit eye movements. This indicates that the learner drivers are more concerned with their position to the curb and lane keeping rather than active exploration to detect the relevant information on their future path. The finding that learner drivers tended to fixate closer in front of the car is not supported by more recent studies of Crundall & Underwood (1998) and Falkmer & Gregersen (2005). Though the former studies did report that inexperienced drivers were found to fixate more on in-vehicle objects and show a less adapted visual search strategy to the traffic situation by means of a smaller fixation distribution along the horizontal axis whereas experienced drivers on the other hand adapt a more flexible visual search strategy, adapted to the type of the road and traffic density (Crundall and Underwood, 1998; Falkmer et al., 2005).

Due to ethical considerations and problems with internal validity some researchers studied the general visual behaviour in learner drivers in laboratories using driving simulators (Figure 18; Konstantopoulos et al., 2010; Pradhan et al., 2003) or video clips taken from the drivers' perspective (see 5.3. Hazard anticipation; Borowsky et al., 2010; Chapman and Underwood, 1998; Underwood et al., 2002a, 2002b). Driving simulators or video clips have the advantage over on-road studies that they offer the ability to present drivers with potential dangerous traffic situations without the driver being at risk for getting injured. Furthermore, also anticipatory eye glances to predefined situations including foreshadowed hazardous situations can be examined. In the simulator study of Pradhan et al. (2003) for example, it has been demonstrated that learner drivers often failed to show anticipatory eye movements to areas where a potential dangerous event could occur compared to more experienced drivers. It is argued that these poor scanning strategies in learner drivers do not result from poor skills to recognize the relevant sources of information, but are rather caused by a lack of vehicle control skills (Vlakveld, 2011). Difficulties with steering or shifting gear might results in higher mental workload[25] due to which (full) attentional capacity is unavailable for scanning the road sufficiently (see task-difficulty homeostasis model and cognitive load). Therefore, a great number of studies reported differences in eye movements and reaction times between learner and experienced drivers using video clips from the drivers perspective. This has also been referred to as hazard anticipation (Borowsky et al., 2010; Crundall et al., 2003).

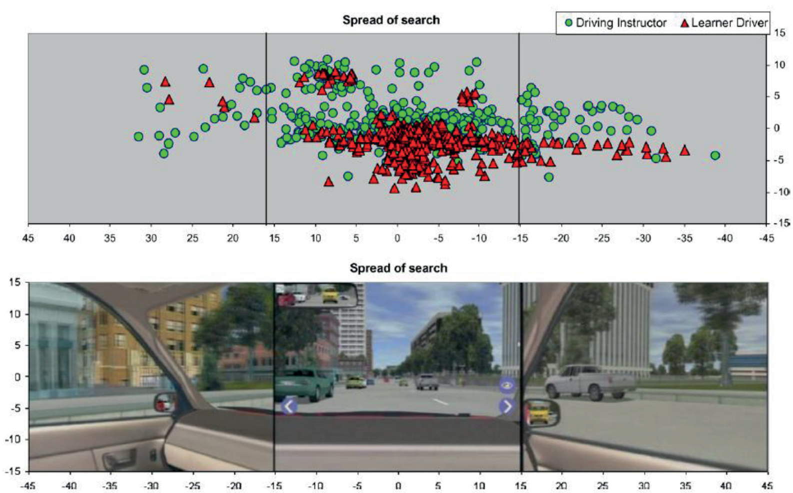

Figure 18. Visual search behaviour in novice (red triangles) and experts (green dots).

[25] Mental workload refers to the proportion of mental capacity required for performance of the task. Mental workload is therefore determined through the interaction between the task demands and the capabilities of the driver. When the task demands are high (e.g. shifting gear) and the capabilities of the driver are low (learner driver) mental workload will be high and few attention can be attributed to other aspects of the task (e.g. scanning the road ahead) (Fuller, 2005).

5.3. Hazard anticipation

A hazard is an event, a factor in the road environment, or a combination of both, which might result in an increased possibility of an accident (Vlakveld, 2011). In driving, poor hazard perception skills are considered one of the main causes for crash involvement in young/learner drivers (McKnight and McKnight, 2003; Pelz and Krupat, 1974). Hazard anticipation, also referred to as hazard perception[26], can be defined as:

"*The detection and recognition of road and traffic situations that could increase the possibilities of a crash, including the prediction of how these situations can develop into acute threats"* (Vlakveld, 2011 p77).

In other words, hazard anticipation is the ability to read the road and detect the dangerous situations unfolding on the road ahead which enables early anticipation (Wetton et al., 2010, 2011). Vlakveld (2014) distinguished two types of hazards. Overt latent hazards refer to other visible road users in front of the driver who might start to act dangerously. Covert latent hazards, on the other hand, refer to places from where a road user, who is not yet visible through obstructed view, might appear. E.g. a driver detects a football on the side of the road next to a playground. The driver's view is obstructed by cars parked on the side of the road. Although this situation is not hazardous at that instant, it might become very dangerous situation when a child suddenly crosses the street to collect his ball.

Traditionally, hazard anticipation is tested by presenting the participants with video clips from the driver's perspective. In each clip the driver is presented with one or more dangerous traffic situations while their eye movements and reaction times to the hazardous event are examined. While some hazard perception studies are performed in simulators (Liu et al., 2009; Underwood et al., 2011) others present the participant with video clips or (Borowsky et al., 2010) only measure reaction times to the hazard without eye movements (Scialfa et al., 2011; Wetton et al., 2011, 2010).

When novice drivers and experienced drivers were presented with a hazard perception test, it is found that novices scanned the roadway more narrowly along the horizontal axis, have longer fixation durations on imminent hazards (Chapman and Underwood, 1998; Underwood et al., 2002a), are less likely to fixate the critical areas (Pradhan et al., 2005) which suggests that learner drivers have difficulties to detect the foreshadowing elements that predict the hazardous event and therefore react more slowly and fail to anticipate the developing hazards (Chapman and Underwood, 1998; Crundall et al., 2013; Scialfa et al., 2011). Not only do learner drivers fail to detect the relevant cues, and as a result react more slowly to these dangerous events, they also interpret the situations differently compared to more experienced drivers (Scialfa et al., 2012, 2011; Wallis and Horswill, 2007). Indeed, the lower performance on hazard perception tests in novice drivers has been attributed to difficulties with and slower processing of the visual relevant information. Learner drivers were inaccurate in predicting where experienced drivers would look, suggesting that novices have an impoverished

[26] Vlakveld (2011) argued that hazard anticipation is a more accurate definition than hazard perception since it is not only perceiving and recognizing the hazard but also contains the actions which allow a driver to avert the crash.

internal representation of the hazards' context-dependent nature, and incomplete mental models or schema regarding the dangers that might occur on the road ahead (Chapman and Underwood, 1998; Huestegge et al., 2010; Underwood et al., 2002a). This is not surprising, since hazard anticipation is a cognitive and visual demanding skill (Scialfa et al., 2011), it seems that a lack of experience limits learner drivers to attribute their attentiveness towards the potential hazards (Meir et al., 2013). In more experienced drivers, a dominant schema is selected and unfolds in interaction with internal stimuli – emotion and motivation – and external stimuli – perceiving the environment – enabling the experienced driver to look for the relevant visual cues and anticipate forthcoming events. Experienced drivers mainly perform hazard anticipation at the procedural stage without conscious awareness.

Furthermore, Borowsky and colleagues (2010) found that novice drivers rarely fixate on merging roads when driving suggesting they only attended to potential hazards when physically present and thus salient. Novices tended to assess hazards based on one single characteristic. Situations are then perceived as equally dangerous when they share this one characteristic. Experienced drivers on the other hand, perceive the traffic situations more holistically, based on multiple characteristics (Borowsky et al., 2009). Since hazard anticipation tests have been shown to be successful at discriminating between novice and experience drivers, and poor hazard perception is associated with higher risk for accident involvement, some countries implemented a hazard perception test in the theory exam for learner drivers (Wetton et al., 2011).

5.4. Hazard anticipation training

Since experience was found to be associated with hazard anticipation skills, it can be assumed that training programs may attribute to improvements in the development of hazard perception skills and situation awareness. Therefore some leading intervention studies are discussed in brief. In 1997, Mckenna and Crick demonstrated that a training program consisting of one-to-one tutoring in which the instructor paused the video clips when the hazard started to develop and required the participant to predict possible outcomes of the situation was effective to decrease response latencies on the post-test. Also the video-based road commentary training of Isler et al. (2009) improved young drivers hazard detection rate to the level of experienced drivers. However, it is argued that (self-produced) commentary training might only decrease response latencies in learner drivers due to increased sensitivity to unexpected events rather than improved mental models.

The intervention of Chapman et al. (2002) therefore used an eye tracker to evaluate whether trainees showed improved visual search behaviour or not. The intervention required the participants to watch video clips and consisted of 5 phases: (1) producing commentary and pressing a response button as soon as the hazard was identified, (2) producing commentary while the video played at 50% of speed and areas of interest were highlighted and watching the same video's with expert commentary, (3) predicting what could happen in video's that were paused when the hazard occurred and listening to an expert commentary, (4) similar to the 2nd phase but with the video's at normal speed, (5) similar to the first phase but with new video's. Directly after the intervention, novice drivers displayed a more extended visual search behaviour along the horizontal axis, and shorter fixation durations when presented with video clips of dangerous traffic situations compared to the control group. Even when no hazards were present, trained drivers demonstrated extended search strategies and decreased fixation durations significantly, suggesting more conscious and improved visual search strategies. The researchers also suggested that the trained learner drivers were able to transfer their skills to on-road behaviour.

Subsequently, at the University of Massachussets, Pradhan et al. (2009) developed a PC-based Risk Awareness and Perception Training-3 intervention (RAPT-3) based on the RAPT-2 (Pollatsek et al., 2006a) and RAPT (Pradhan et al., 2005). First, the participant received a top-down overview of a scenario, accompanied with feedback regarding the risky aspects of the scenario. A driving scenario consisted of 5 to 12 snapshots from the perspective of the driver. Then, the learner drivers were again presented with snapshots of the scenario and had to indicate the dangerous sites by clicking on the risky locations. If the participant was able to locate the hazards on the snapshots, he was taken to the next scenario. Otherwise, the previous scenario, accompanied with feedback, was repeated. After the intervention, trained drivers more likely gazed to areas that contained information regarding a potential hazardous situation (64%) compared to untrained drivers (37%), for both near- and far-transfer scenarios. Near-transfer scenarios refer to situations quite similar to the video clips of the training while far-transfer scenarios included similar concepts as in the training, but were filmed in a completely different setting or with different traffic participants. Furthermore, the trained novice drivers anticipated 28.7% more hazards after the training. Trained drivers recognised 46% of the risks in the far-transfer scenarios and 72.7% of the near-transfer scenarios. In line, Meir et al. (2014) developed the Act and Anticipate Hazard Perception Training (AAHPT) which aimed to compare three intervention modes: an instructional, an active and a hybrid mode. In the instructional mode, participants were presented with theoretical material regarding driving scenarios while in the active mode participants observed video footage from real driving situations and were required to press a button each time a hazard was detected. In the hybrid mode a combination of the instructional and the active mode was composed. Both the active and hybrid mode – containing an active-practical component - resulted in significant improvements in young novice drivers' hazard anticipation. Novice drivers displayed a wider spread of fixations and responded to more hazards after an active training in contrast to a theoretical training suggesting that theoretical knowledge alone is not sufficient to improve hazard anticipation experience.

5.5. Visual behaviour in child bicyclists

Also children can be considered novices when it comes to walking or bicycling in traffic. As suggested by Meir et al. (2013) learner drivers' impairments regarding hazard anticipation, and the development from learner to experienced driver might show high resemblance with children's abilities to perceive hazardous situations. However, since children learn to bicycle (or start to participate in traffic, whether or not under adult supervision) between the ages of five to nine, this implies that children's motor, perceptual and cognitive skills are not developed sufficiently yet suggesting not only experience but also immature perceptual-motor abilities might influence their behaviour in traffic. The perceptual, perceptual-motor and perceptual-cognitive development of young children will therefore be briefly discussed after which the abilities of child-pedestrians' road crossing abilities and young bicyclists gap acceptance is discussed.

5.5.1. Visual, auditory and cognitive development of children

From the perspective of maturation or development, children are fundamentally different from young adults. In Table 1 an overview regarding the perceptual, perceptual-cognitive and perceptual-motor development in children is provided. With respect to the oculomotor system and perception, it is known that the ability to fixate a target is acquired in the first six months of life (Aring et al., 2007) but more complex aspects of fixations, such as fixation steadiness, continues to improve through adulthood (Luna et al., 2009). It is suggested that the development of cognitive control such as the ability to inhibit fixations to distracting peripheral stimuli appears to improve with age which results in increased fixation durations on a target while the amount of intrusive saccades decrease (Helo et al., 2014). Regarding saccade control, saccades in children are less precise and shorter compared to adults. While saccade latency has been found to decrease until the age of 15 (Bucci et al., 2012; Irving et al., 2006) saccade velocity increases until the age of 14 (Helo et al., 2014). Furthermore, cognitive control over saccades reaches adult-like performance around the age of 12 (Irving et al., 2009). Distinct from the saccade system, the smooth pursuit system (voluntarily foveating a moving stimulus), continues to develop into adolescence (Langaas et al., 1998; Robert et al., 2014) according to the maturation of the central nervous system (Luna et al., 2009).

Although the auditory component is not of primary interest in this dissertation, perception of auditory information is also essential for safe traffic participation as it provides us with information regarding the environment in which we move (Stelling-Konczak et al., 2016). Infants of six months already have a sensation of auditory stimuli comparable to that of adults (Haywood and Getchell, 2009). Auditory perception, however, consists of localization of sounds, recognizing different sounds (e.g. pitch, loudness or speech sound), patterns (e.g. time, intensity, and frequency) and auditory figure and ground (e.g. ignoring irrelevant sounds), and is suggested to develop through childhood (Barton et al., 2013; Boothroyd, 1997; Pfeffer and Barnecutt, 1996). In other words, auditory perception refers to the interpretation of sensory stimuli, generated by sound (Boothroyd, 1997). Determining the direction and distance of sound depends on the on the presence of the ears located on either side of the head. A sound coming towards the listener from an angle, arrives at a different arrival time (interaural time difference, ITD) and intensity (interaural intensity difference, IID) at each ear (Baldwin, 2012) which enables the listener to determine distance and whether the sound is coming from the rear or front. Haywood and Getchell (2009) reported that infants rapidly improve in determining both the distance and direction of sounds. Furthermore, children significantly improved their auditory discrimination skills by the age of eight to ten years, but refinements tend to continue until 13 years of age. Also, auditory pattern perception in children progresses rapidly. As infants of two to three months already react to temporal pattern changes, pre-school children further improve their abilities to perceive patterns in longer and increasingly complex contexts. At last, the ability to separate auditory figure sounds (e.g. relevant sounds) from ground sounds (e.g. background noise) is already present in infants and improves during childhood. Together, auditory perception continues to improve through childhood, especially the finer discriminations.

Regarding the perceptual-cognitive aspects of development, or the ability to acquire the relevant environmental information (e.g. visually, auditory) for integration with existing knowledge of the current situation (Mann et al., 2007), mental abilities such as processing speed (refers to the efficiency to process visual information), response suppression or inhibitory control (the ability to filter out distractors), and working memory (the capacity to maintain and manipulate information) all of which are used for effective goal-directed behaviour, continue to develop through childhood (Haywood and Getchell, 2009; Luna et al., 2004). Although each component has its distinct role, these processes often interact in order to support cognitive control of behaviour. Developmental improvements in processing speed support changes in working memory and help the transition from concrete to more abstract reasoning. Response inhibition and working memory, on the other hand modulate each other such as the efficiency of working memory is influenced by its sensitivity to interruptive signals. From the perspective of limited mental capacity in working memory (see 3.2 Working memory and cognitive load) Bjorklund and Harnishfeger (1990) reported that in young children processing space is mainly attributed to operational functioning. This implies that there is less available space for storage, resulting in poorer performance. When children gain experience, executive functions and strategies become more efficient and decrease operational space. In other words, increased familiarity with the to-be processed information decreases the amount of mental resources to be activated. For example, as inhibitory control improves with age, less irrelevant information is processed which increases functional capacity. Also improvements in short term memory span result in better execution and coordination of cognitive processes. Luna et al. (2004) argued that developmental progression of these cognitive systems is influenced by environmental factors and biological timetables, e.g. brain maturation. Processes such as synaptic pruning (the selective elimination of unnecessary neural connections) and increased myelination (insulation of established axonal connections) allow for faster and more precise information processing for top-down driven behaviour. Accordingly, that eye movements in children are guided by bottom-up processes such as local image features (e.g. luminance contrast, color) while top-down strategies take over when growing older (Açik et al., 2010; Helo et al., 2014). Açik et al. (2010) demonstrated that young children tend to focus more local details in a free scene viewing task and have difficulties to identify the global characteristics when there are distractors. It was concluded that bottom-up influences lose strength with age when top-down processes, such as reliance on expectations, take over. The question whether children performed poor due to an immature visual system remains to be addressed.

Also, the ability to generate memory guided saccades (related to working memory) towards a remembered target is already present early in life, the accuracy of the response driven by working memory improves with age due to recruitment of more additional brain regions in adults. Whereas children rely more on the basal ganglia and insula to generate memory driven saccades, adults recruited additional regions such as the temporal regions (Luna et al., 2009; Scherf et al., 2006). Moreover, Trick and Enns (1998) reported that the ability to selectively direct attention and switch attention to another item develops differently over the lifespan.

Table 1. Visual, perceptual-cognitive and perceptual-motor development in children.

Vision	Mature (years)	Reference
Ability to fixate	6 months	(Luna et al., 2009)
Fixation control and stability	15	(Luna et al., 2009)
Saccade system	15	(Helo et al., 2014)
Pursuit system (slow tracking 6°/sec)	7	(Langaas et al., 1998)
Pursuit system (fast tracking 12°/sec)	Into adulthood	(Langaas et al., 1998)
Static visual acuity	10-11	(Gallahue and Ozmun, 2005)
Dynamic visual acuity	11-12	(Gallahue and Ozmun, 2005)
Figure-ground perception	8-12	(Gallahue and Ozmun, 2005)
Depth perception	12	(Gallahue and Ozmun, 2005)
Perceptual-cognitive		
Selective attention	12	(Barton, 2006)
Switching of attention	12	(Barton, 2006)
Processing speed	15	(Hale, 1990)
Response inhibition	Into adulthood	(Tamm et al., 2002)
Ventral pathway	6-7	(Helo et al., 2014)
Dorsal pathway	10-11	(Helo et al., 2014)
Working memory	15	(Luna et al., 2009)
Filtering and priming	Through life	(Enns and Cameron, 1987)
Perceptual-motor		
Obstacle avoidance	11	(Pryde et al., 1997)
Visual motor coordination	10-12	(Gallahue and Ozmun, 2005)
Obstacle avoidance	11	(Pryde et al. 1997)

5.5.2. Child pedestrians

Since young pedestrians (5 to 9 years of age) are highly represented in severe and fatal traffic accidents (Whitebread and Neilson, 2000) a vast amount of research focussed on age-related road-crossing skills and gap-acceptance in young pedestrians. Safely crossing a street requires a pedestrian to (1) evaluate whether a place is safe to cross, (2) identify the presence of traffic, (3) 'judge' if a gap is safe to cross and (4) then cross the road consistently and adapted to the situation (te Velde et al., 2003). Road-crossing in child pedestrians can therefore also be described as the ability to read the road and predict future events to anticipate potential dangerous situations, which can be associated with hazard anticipation and situation awareness of Endsley (1995).

Altogether, whether studies evaluated road-crossing-behaviour with table top models (Ampofo-Boateng and Thomson, 1991), on-road (te Velde et al., 2003; Zeedyk et al., 2002) or with video clips (Meir et al., 2013; Meyer et al., 2014; Pitcairn and Edlmann, 2000; Thomson et al., 2005, 1996), all of them confirm that children lack sufficient perceptual-motor pedestrian skills to safely interact with a dynamic traffic environment (Ampofo-Boateng and Thomson, 1991; Meir et al., 2013; Pryde et al., 1997; Thomson et al., 1996; Whitebread and Neilson, 2000). Zeedyk et al. (2002) reported that only 7% of the 5- and 6-year-old children looked for oncoming traffic and more than half of the children failed to stop before stepping from the kerb onto the road. Young children waited longer at the curb and chose more unsafe gaps, were less adept to maintain attention, were less attuned to traffic-relevant features and had difficulties with integrating this information into a holistic appreciation of the situation (Meir et al., 2013; Pitcairn and Edlmann, 2000; Thomson et al., 2005, 1996). Children therefore seem to lack the experience to recognize potential hazards which allows them to attend these hazards before they come salient. It is suggested that children start to recognise dangerous sites and are able to identify a safe place with clear view from the age of nine (Ampofo-Boateng and Thomson, 1991). Although looking behaviour and the ability to visually judge crossing time increased with age, 12-year-olds still did not perform equally well compared to adults. Improving looking behaviour is likely to have the most impact on road crossing skills and road safety (te Velde et al., 2003; Thelen and Smith, 1994). In addition, child pedestrians have been found to have difficulties with perception and using of auditory stimuli in traffic settings too (Pfeffer and Barnecutt, 1996). When children of six, seven, eight and nine years old performed an auditory test in which they were presented with auditory stimuli they performed poorer compared to adult pedestrians. The sound stimuli consisted of recordings from a car passing at five, 12 and 25 mph from both left and right. Younger children detected the approaching vehicle significantly later, encountered difficulties to determine the direction of the approaching vehicle and were less accurate in deciding when the vehicle would have arrived at their location. When at greater speeds, the vehicle was easier to detect, but accuracy of position determination decreased (Barton et al., 2013). Overall, as auditory stimuli are often the first to be attended to (e.g. sound of an approaching car, a bicyclists ringing his/her bell), the development of proper auditory perception is essential too.

Training programmes therefore aimed to aid children in selecting safe crossing sites. Using table top models (Ampofo-Boateng and Thomson, 1991) or real road environments (Thomson et al., 1992), children were more likely to select safer sites before crossing the road after training. In an attempt to accelerate the development of road crossing skills, Thomson et al. (2005) demonstrated that children who were trained with a computer-simulated environment showed safer crossing behaviour – quicker crossing, better aligned crossing, missed fewer opportunities – and improved conceptual understanding. More recently, Meir et al. (2015) evaluated the effect of a 40-minute simulator hazard perception training[27] among 7- to 9-year-old child pedestrians in which participants were presented with three pairs of traffic scenes where each pair represented the same environment but from a different perspective. After the intervention, trained children displayed improved awareness and sensitivity to potential hazardous situations suggesting that brief interventions to improve children's hazard perception might be effective to improve road crossings skills and experience. Nevertheless, the extent of transfer from improved knowledge due to training in simulated environments to safer real-life road crossing behaviour remains questionable (Egan, 2012; te Velde et al., 2003; Zeedyk et al., 2002). Table 2 provides a summary regarding the psychological processes in children which have to be acquired for the traffic task.

[27] The Child-pedestrians Anticipate and Act Hazard Perception Test

Table 2. Essential psychological processes which have to be acquired for the traffic task after Foot et al. (1999)

Activity	**Psychological process**	**Age**
Detecting traffic	Scanning the surroundings, understanding of traffic movement, selecting relevant from irrelevant stimuli (visually and auditory).	50% of the 4-14 year olds have insufficient command
Recognising safe and dangerous locations	Identifying potential sources of danger, avoiding distractibility	Insufficient up to 9
Visual timing, dividing attention and concentration	Time-to-contact estimates, estimating distance and speed of other road users, estimating acceleration and decelerations of other road users	Improves with age
Judging information in its context	Dividing attention between various causes of danger, integrating information from separate visual fields, processing the information and control impulses	Very poor under the age of 7
Coordinating perception and action	Judging whether gaps are acceptable to cross, taking into account one's own travel speed.	No information available
Sense of responsibility	Realizing the consequences of errors	Up to 14 years old

5.5.3. Child bicyclists

Not only young pedestrians, but also child bicyclists are a (even more) vulnerable group of traffic participants. Based on their motor, perceptual-motor and cognitive abilities, children should be able to control their bicycle around the age of nine or ten with an increase in independent mobility as result (Ducheyne et al., 2013b; Whitebread and Neilson, 2000; Wierda and Brookhuis, 1991). Arnberg et al. (1978) observed bicycling skills in six- to 13-year-old children. Their results suggested rapid increases in various bicycling skills between 6 to 8 years of age after which the rate of improvement decreased. However, a vast amount of research demonstrated that this age group is also at higher risk to be involved in bicycle accidents caused by human errors (Corden et al., 2005; Lammar, 2005; Plumert and Kearney, 2014; Schoeters et al., 2014). The following age group is therefore of particular interest in this dissertation.

Similar to driving and crossing the road, the development of motor (see chapter 2) and perceptual-motor skills (time-to-contact, gap acceptance, attention, planning and decision-making) play a key role in safe and skilful bicycling behaviour (Briem et al., 2004). In contrast, bicycling occurs at lower/higher speeds compared to driving/walking and requires complex perceptual-motor skills such as simultaneously coordinating control over the bicycle in relation to other moving objects in the environment (cars) (Plumert et al., 2007). For example, when children had to bicycle on a traffic playschool ground with reduced-scale roads, bicycle lanes, pedestrian lanes and changing traffic signals, young children missed more signals (changing traffic light) often resulting in overshooting the stopping line (Briem et al., 2004) suggesting that children had difficulties with synchronizing perceptual information and their motor movements (Chihak et al., 2010; Plumert et al., 2007). The University of Iowa were the first to address age-related differences in gap-acceptance when bicycling in six traffic filled intersections. Children of 10 and 12 year old and adults rode an instrumented bicycle through a virtual environment while braking, pedalling torque, and steering behaviour were measured (see Figure 19). Compared to adults, children's road crossing behaviour and gap choices were less attuned resulting from difficulties with judging time-to contact, coming to the decision whether or not to cross and coordinating their own movement in relation to that of the approaching cars (Plumert, 2003; Plumert et al., 2007, 2004). This mismatch in judging how long it would take for the approaching car to arrive might be attributed to the fact that children use distance rather than a combination of speed and distance to estimate time to contact (Connelly et al., 1998; Plumert, 2003). The perceptual-motor system can therefore be considered to undergo changes until adulthood, especially in terms of moving the self in relation to (fast) moving objects (Plumert et al., 2011). However, when 10-year-old participants rode their bicycle through 12 traffic filled intersections, it was found that children had more time to spare at the last intersection and were willing to accept smaller gaps compared to the first intersection suggesting that experience leads to considerable improvements in perceptual-motor functioning and decision making (Adolphe et al., 1997; Plumert et al., 2011). Therefore not only age related factors but also experience, and practice might cause improvements in decision making and road crossing behaviour. Sine anticipation and decision-making are associated with experience, interventions to promote child bicyclists' hazard anticipation are of interest. In addition, given that bicyclists often share the road with car drivers, auditory perception for gathering information regarding approaching traffic when vision is obstructed or when traffic is outside the field of view (e.g. covert hazards) is even more important for bicyclists compared to pedestrians or car drivers (Stelling-Konczak et al., 2016). For example, as bicyclists often engage in manoeuvers in between faster-moving traffic, with cars coming from different directions, localisation of traffic, localisation accuracy, distinguishing approaching cars from receding ones by auditory perception is essential. Other factors contributing to higher accident proneness in children are overestimation of their own capabilities, motivational factors, attitudes to risk and task load (see task-difficulty homeostasis model). For example, boys are more likely to make speed-related mistakes or showing off. Furthermore, as children grow older, their fear for accidents decreases when they gain more confidence which might contribute to riskier behaviour (Briem et al., 2004).

Figure 19. Photo from the bicycle simulator at the University of Iowa, used to measure gap-acceptance in child bicyclists. Retrieved from Plumert et al. (2011).

5.6. Summary

The recordings of learner drivers visual search strategies in real-life, simulators or video clips, demonstrated that they have difficulties with attending to the essential visual information. When they were presented with video clips of potential dangerous situations, novice drivers are more likely to miss the foreshadowing elements that might predict the development of a potential hazard. As a result, they fail to anticipate the hazard in time to avoid a collision. This suggests that novices lack a decent understanding of potential dangerous situations. Similar to novice drivers, also child pedestrians have difficulties with perceiving visual information of dangerous situations, and integrating this information into a holistic appreciation of the situation. This suggests that hazard perception is not utterly dependent on maturation but on experience too. Nevertheless, hazard perception in children, especially in child bicyclists, remains scarcely reported in contrast to the extensive amount of research regarding hazard perception in car drivers. Therefore the current dissertation focusses on developing a hazard perception test for child bicyclists in order to create a better understanding of hazard perception skills in child bicyclists. Furthermore, since hazard anticipation interventions in novice drivers are found to be effective in improving hazard perception skills, and child-pedestrians road crossing behaviour can be improved by training, it can be assumed that young bicyclists might benefit from a hazard anticipation intervention as well. Accordingly, the current thesis aims to develop a hazard perception intervention for child bicyclists.

6. General overview and outline

6.1. General overview

The popularity of the bicycle as mode of transportation is rising rapidly. With increasing shares of recreational and work- or school-related bicycle use, this transition from car to bicycle offers a variety of environmental and health related benefits. Unfortunately, more bicycles on the roads also implies a rising number of accidents with children and the elderly being over-represented in crash statistics. This is partly caused by their higher bicycle usage, but also due to their higher accident proneness. Despite the fact that research already focused on the extrinsic factors such as road design, infrastructure or helmet use, it is surprising that research concerning the intrinsic factors contributing to the accident-proneness in bicycling children is rather scarce. Bicycle crashes can be divided into single bicycle accidents and accidents with another traffic participant. Since single bicycle accidents in children are mainly caused by poor turn manoeuvres, the development of motor competence as underlying construct for the development of bicycling skills is of interest in the current dissertation. On the other hand, for the bicycle crashes involving another traffic participant, the development of cognitive factors such as situation awareness and decision-making skills are still poorly understood. Consequently, there is a stringent need to understand the development of bicycle skills and perceptual-motor behaviour in children in order to provide them with means to enhance their abilities to cope with the complexity of dynamic traffic situations. A variety of training courses therefore focused on children's motor bicycle skills and aimed to improve skills such as pedalling, balancing and steering or more complex skills such as signalling or looking over the shoulder. Unfortunately, the majority of these training programs measured different bicycling skills in children of a wide age range which seriously limits our current understanding regarding the development of bicycling skills in children.

Not only motor bicycling skills, but also perceiving the complexity of traffic situations, comprehending the acquired information and then making the correct decision are essential in safe traffic participation. This skill has also been referred to as hazard anticipation and closely related to situation awareness. In car driving, this topic gained much attention over the years. Learner drivers have been demonstrated to have difficulties with attending to the essential visual information and are more likely to miss the foreshadowing elements predicting the development of a potential hazard. Hazard anticipation tests for learner drivers have therefore been incorporated in the drivers theory exam. Given that child bicyclists are vulnerable and have a substantial higher accident-proneness, it is rather remarkable that research focussing on hazard perception and decision making in child bicyclists is lacking. Furthermore, it might be questioned whether visual search strategies and hazard anticipation in drivers are directly transferable to visual search behaviour of learner child bicyclists since bicycling and driving are intrinsic different tasks.

Bicyclists travel at higher speeds compared to pedestrians and require steering to change direction, rather than making point turns. On the other hand, bicyclists often find themselves amidst faster moving car drivers which induces certain differences in the uptake of visual information and steering behaviour. Whereas cars are stable from themselves, bicycles are single track vehicles requiring the bicyclist to sustain a certain speed in order to maintain balance. This might have its implications on steering behaviour as steering and balancing becomes more difficult the slower the bicyclist goes. Bicycling is therefore more subject to behaviour of other road users, road conditions and weather conditions (Schwab, 2012; Vansteenkiste et al., 2014b). Furthermore, bicyclists have an almost unrestricted view on the environment, while a car driver's field of view is limited due to vehicle properties. Also differences in speed induce changes in the visual flow field and processing-speed of the acquired information. Finally, child bicyclists are far less experienced than adult car drivers and do not yet possess fully matured perceptual-motor abilities. These task- and developmental characteristics probably affect child bicyclist's abilities to perceive and interpret traffic-related events, which limits comparison between learner drivers and child bicyclists. On the other hand, next to the differences, also some substantial similarities between learner drivers and child pedestrians have been reported in the literature. Child pedestrians for example, have difficulties with integrating the perceived visual information from different parts of the environment into one holistic perception of the situation. Furthermore, child pedestrians are less adept to identify the potential dangerous situations when crossing the road. They only attend to the hazard when salient and physically visible in the environment suggesting an impoverished understanding regarding the nature of hazardous situations which has been associated with experience rather than immaturity. According to the theory of situation awareness (Endsley, 1995), it can be suggested that young bicyclists display poorer situation awareness compared to adults which hampers them to attend to the relevant visual information (perception; SA1), decide whether or not a situation might contain risk (comprehension; SA2) and to make predictions regarding the future developments of the situation (projection; SA3). In contrast, adult bicyclists will perceive, comprehend and anticipate these hazardous situations more automated grace to more elaborated schemata resulting from extensive experience and knowledge in a wide variety of traffic situations. Although it can be suggested that child bicyclists lack the regarding where to look and therefore often fail to anticipate the forthcoming event, scientific evidence remains absent. Given that situation awareness has been closely linked to hazard anticipation, a hazard anticipation test for bicyclists could provide a more detailed understanding in the development of perceptual traffic skills. Especially since habits learned when young tend to persist throughout life. Furthermore, since hazard anticipation interventions in novice drivers and child pedestrians are found to effectively improve hazard anticipation, it can be assumed that young bicyclists might benefit from a brief and tailored hazard anticipation intervention as well. In turn, this might lead to primary prevention measures by means of adapted traffic education for children. Therefore a brief hazard perception training is developed.

6.2. Outline

- **<u>Chapter one: the development of motor competence as keystone for bicycling skills.</u>**

In chapter one of the present dissertation, gross motor competence of the child in relation to his or her performance in bicycling skills is objectively assessed in order to gain insight in the development of bicycling skills in nine year old children. Given that this relation has, to the best of our knowledge, not been addressed yet in the literature and the ability of children to perform bicycling skills was found to play an important role in bicycle-related injuries, the focus on assessing and optimizing gross motor competence may be an important step towards safer bicycling behaviour in children. Therefore, paper one of the current project assesses gross motor competence of nine year-old children with the KörperKoordinationsTest für Kinder (KTK) (Kiphard and Schilling, 2007) in relation to children's motor bicycling skills as measured with the bicycle skills test of Ducheyne et al. (2013b). The KTK is a non-sport specific, easy to administer and has been found highly reliable and valid (Cools et al., 2009; Iivonen et al., 2015). Furthermore, updated reference values for Flemish 6-12-year-old children have been provided (Vandorpe et al., 2011).

Given that the literature lacks consistency regarding the evaluation of bicycling skills and the ability to control the various motor components of bicycling strongly depends on the mental and physical development of the child, paper two aims to evaluate differences in bicycling skills of seven- to 12 year-old children. This is essential for constructing tailored training programs accustomed to age. In addition, the association of experience and expertise with regard to bicycling skills are examined.

- **<u>Chapter two: gaze behaviour in a laboratory context and real-life</u>**

Although research in the lab offers the advantage of internal validity, reliability and ethical considerations, ecological validity is often questionable. Paper three in chapter two of this project therefore aims to address to what extent unrestrained gaze behaviour in real-life and gaze behaviour in the lab are similar. Visual search in 13 adult bicyclists, when bicycling a real bicycle path and while watching a film clip of the same road is compared.

- **<u>Chapter three: visual behaviour of young bicyclists in real-life</u>**

Since a recent study by Vansteenkiste et al. (2014) described how low quality bicycle paths cause an apparent shift of visual attention from distant environmental regions to more proximate road properties in adults, paper four in chapter three of the current dissertation investigates to what extent these findings are applicable for child bicyclists (aged 6 to 12 years). This experiment made use of a novel eye tracking device, the 'Eye Tracking Glasses' (SMI, Teltow GER), which could perform eye tracking even in full sunlight.

- **<u>Chapter four: hazard perception and hazard anticipation training for young bicyclists</u>**

Child pedestrians and novice drivers have been reported to suffer poor hazard anticipation skills, which can be improved by training. Given that research regarding hazard anticipation in bicyclists is scarce, chapter four of this dissertation aims to examine whether these findings apply for child bicyclists too. In paper five, simultaneous registration of eye movements and decision-making with a PC-based hazard perception test impose new standards for hazard anticipation testing in child bicyclists. An exploratory hazard anticipation test for bicyclists is developed and tested, using video clips of real traffic situations that were filmed from the perspective of a bicyclist. Accordingly, the exploratory hazard anticipation test examined gaze behaviour, environmental awareness and hazard anticipation of child and adult bicyclists. In paper six, the previous exploratory study is repeated with an adapted hazard anticipation test for young bicyclists. While participants watched video clips filmed from the perspective of a bicyclist, both visual behaviour and reaction times to the overt and covert latent hazards were recorded, in order to examine hazard detection and anticipation.

As hazard anticipation does not only depend on maturity-related factors but also on experience, paper 7 focusses on the development of a training program to help child bicyclists learn to detect, predict and anticipate hazardous situations. This hybrid intervention – based on a combination of expert commentary when watching the clips and learning to predict how situations might develop - required children to indicate when a hazard was present in different video clips (presented on a projection screen), which requires the perception of the relevant cues (SA1), and comprehension of this information (SA2). Next, children created a prediction of how the situation could develop (SA3).

6.3. Specific research aims and hypotheses

The original research has the following specific research aims:

1. Using a cross-correlational study, the association between motor competence, BMI and motor bicycling skills among 9 year old child bicyclists as measured with the bicycle skills test of Ducheyne et al. (2013b) will be evaluated (Chapter 1). It is hypothesized that motor competence will have influence on bicycling skills and that BMI will negatively affect bicycling skills in children.

2. To objectively examine the development of motor bicycling skills in 6 to 12 year old children using a cross-sectional study design (Chapter 1). It is hypothesized that bicycling skills will improve with age. Furthermore, it is hypothesized that experience, by means of age at onset of bicycling, will have influence on bicycling skills score.

3. To determine whether visual behaviour when bicycling in real-life, reflects visual search behaviour when bicycling the same trajectory on a mounted bicycle in front of a projection screen in the lab (Chapter 2). It is expected that visual behaviour will become increasingly comparable between the lab and real-life with increasing task-demands by means of quality of the bicycle path (increased comparability on the low quality bicycle path).

4. To evaluate whether visual search behaviour of child bicyclists is affected more by the quality of the bicycle path compared to adult bicyclists using a cross-sectional design (Chapter 3). It is hypothesized that participants will spent more time looking at the road on the low quality bicycle path compared to the high quality bicycle path and that children's visual behaviour will be affected more by the quality of the bicycle path compared to adults.

5. To develop a hazard anticipation test in order to gain insight into visual behaviour and decision-making skills of 9 year old child bicyclists (Chapter 4). Using a cross-sectional design, adult and child bicyclist are compared. It is expected that children will demonstrate poorer hazard anticipation skills by higher response latencies for the potential hazards. In addition, we expect that child bicyclists will notice the hazards later, which will be reflected in higher latencies of the first fixation on the potential hazards.

6. To evaluate the effects of a hazard anticipation training intervention on situation awareness, decision-making and hazard anticipation skills in 9 year old child bicyclists (Chapter 4). Using a cluster-randomized control repeated measures design, the intervention group is hypothesized to improve hazard anticipation compared to the control group by means of response rate, response latency and first fixation latency.

Part two: original research

Chapter 1: The development of motor competence as a keystone for bicycling skills

Paper 1: Associations between cycling skill, general motor competence and body mass index in 9-year-old children

ABSTRACT

Learning to ride a bicycle is an important milestone in a child's life. Unfortunately young traffic casualties remain overrepresented in traffic reports, with single-bicycle crashes as principal cause in children. This correlational, cross-sectional study[28] focuses on the association between cycling skills and two intrinsic characteristics: general motor competence and body mass index (BMI). Therefore, general motor competence, BMI and practical cycling competence were measured in 9-year-old children (n=40). Significant correlations were found between cycling skills and general motor competence ($r = 0.434$, $p \leq 0.01$), and between cycling skills and BMI ($r = -0.400$, $p \leq 0.05$). A multiple regression analysis revealed that children's general motor quotient and BMI together predicted 19% of cycling skill score. These findings indicate that general motor competence and bicycle skills are not independent of each other stressing the importance of young children's characteristics when actively participating in traffic. In addition, BMI might be negatively associated with the development of cycling skills in children.

[28] This part is based on **Zeuwts L**, Ducheyne F, Vansteenkiste P, Cardon G, Lenoir M (2015). Associations between cycling skill, general motor competence and body mass index in 9-year-old children. E*rgonomics* , 58(1), 160-171 DOI: 10.1080/00140139.2014.961971

1. Introduction

In Flanders, bicycling is a common way to commute to school. A longitudinal study showed that initially 46% of the 10-year-old children cycled to school, while at the age of 16, 78% of the respondents indicated that they cycle to school (Cardon et al., 2012). In the UK, Australia and the USA, however, a decline in the number of children cycling to school emerged. Although cycling to school is not a common practice in these countries, over 90% of American children own a bicycle and often prefer cycling rather than walking as a fast and easy way to cover greater distances (Macarthur et al., 1998; Shephard, 2008; Trapp et al., 2011). Therefore, bicycling still has a huge potential considering the associated health and environmental related benefits (Chillón et al., 2012; Davison et al., 2008). Nevertheless, when promoting cycling in children, road-safety and appropriate road-skills are essential. Juhra et al. (2012) reported that with the increased usage of bicycles, the number of bicycle crashes increased. In concordance, bicycle crashes in Flanders represented 18% of all traffic crashes in 2011, which equals an increase of 12% with respect to 2007 (Carpentier and Nuyttens, 2013). It was estimated that 62% of all bicycle victims requiring hospitalisation were involved in a single-bicycle crash. In addition, children (5-11 years) and older bicyclists (>65 are at higher risk for each kilometre travelled by bicycle, to get involved in a single-bicycle crash and being treated at an emergency department (Ormel et al, 2009; Schepers, 2012; Schepers and Wolt, 2012).

Consequently, understanding the influence of extrinsic factors (e.g. bicycle paths, distance, parental support, gender) as well as intrinsic factors (e.g. bicycle skill, age) related to single-bicycle crashes is important (Rivara et al., 1998). Despite previous research concerning traffic conditions and road design (Møller and Hels, 2008; van Schagen and Brookhuis, 1994), helmet use in children (Corden et al., 2005; Spence et al., 1993), and attitudes and behaviour, such as signalling and the use of lights when dark (Colwell and Culverwell, 2002; McLaughlin and Glang, 2010), the intrinsic factors in cycling remain scarcely reported. Adequately manoeuvring a bicycle is an acquired and complicated skill which requires the integration of (1) cognitive aspects, e.g. attention, decision-making and concentration; (2) (gross) motor skills e.g. steering, balancing, braking and pedalling and (3) sensory skills, all of which develop from childhood to adolescence (Briem et al., 2004; Leblanc and Huybers, 2004). Since the majority of the single-bicycle crashes in children (0-12 years) can be attributed to poor turn manoeuvres (55%), cycling skills and experience are of interest in this study (Briem et al., 2004; Ormel et al., 2009; Ducheyne et al., 2013a; Ducheyne et al., 2013b). Kooijman et al. (2009) observed human control over a bicycle at low, moderate and higher speeds. When cycling at normal speeds, most stabilising actions are controlled by steering. However, pedalling at lower speeds, for example when turning or braking, results in larger steering actions and additional large lateral knee motions. This strengthens the belief that motor skills might underlie cycling skills.

Motor competence refers to the combination of flexibility, strength, endurance, speed and coordination (D'Hondt et al., 2012, 2009; Vedul-Kjelsas and Stensdotter, 2013). Since cycling at young age does not require extraordinary flexibility, strength and endurance, coordination is the primary component of interest here. Therefore, from here on, the term motor coordination is used synonymously for motor competence. In addition, it is a general construct closely related to physical activity, perceived motor competence, physical fitness, and is considered the underlying keystone in fundamental motor skill (FMS) development. FMS consists of locomotor skills (running, galloping, leaping, etc.), object control skills (manipulating, catching, etc.), stability skills (dynamic balance or turning), and precedes more complex and context-specific skills, for example riding a bicycle (Stodden et al., 2008; Vandorpe et al., 2012a). In contrast to FMS, which are not age-specific and might be improved by physical activities, motor coordination is a relatively stable trait from the age of six on. Stability refers to the maintenance of ranking in a group over time which implies that children with superior motor coordination will continue to outperform their counterparts with lower motor coordination (Ahnert, 2005; Vandorpe, 2011b; Vandorpe et al., 2012a). For example, in gymnastics, motor coordination was successfully used to/capable of distinguishing sub-elite from elite gymnasts (Vandorpe et al., 2012b). As perceived motor competence, which is an important correlate of actual motor competence, was associated with cycling skills, the question rises to what extent actual motor competence can predict cycling proficiency in children? It might be expected that children who score higher on a general motor test battery will have better outcomes on a practical cycling skills test. Since Ducheyne et al. (2013a) only tested parental perceived motor competence, the influence of actual measured gross motor competence on children's cycling skills is still unknown.

According to the model of Stodden et al. (2008), motor competence and physical activity are tightly coupled to weight status. Unfortunately, up to one third of the European primary school children and between 30% and 80% of European adults struggle with overweight (Branca et al., 2007). It is well documented that gross motor competence in overweight children is impaired, and deteriorates with age compared to normal-weight peers. Difficulties with physical tests involving propulsion or lifting of the body, such as various locomotor skills, caused by increased overall mass were reported (Casajus et al., 2007; D'Hondt et al., 2012; D'Hondt et al., 2009; D'Hondt et al., 2011). From this mechanical point of view, negative effects of childhood overweight and obesity were mainly described for weight bearing tasks (e.g. walking, running, jumping, etc.). D'Hondt et al. (2008) reported overweight and obese participants to perform worse when performing a fine motor peg board task while seated also. Moreover, Gentier et al. (2013a) showed that overweight was associated with longer reaction times, suggesting that the perceptual-motor system was not developing optimally in these children. Likely, children with overweight engage in less physical activity which results in less stimulation of the nervous system and specific brain regions involved. Subsequently, these neuromuscular dysfunctions might cause difficulties with motor skill development (Gentier et al., 2013a, 2013b; Gill & Hung, 2014). Given that children do not bear their own weight while cycling, excess mass in itself is not supposed to largely affect bicycle skills. In contrast, the suboptimal perceptual-motor functioning in children with an increased BMI might well do so.

In the present cross-sectional study, we focus on two intrinsic factors: motor competence and body mass index (BMI), since cycling skills, BMI and motor competence have not yet been investigated together. It is expected that gross motor competence will be positively associated with cycling skills and will have predictive value for it, and that a negative relationship between BMI and cycling skills will emerge. Since bicycling is a specific skill, a relation between general motor competence, BMI and cycling skills might add value to the promotion of fundamental skill interventions and daily physical activity.

2. Methods

2.1. Participants

All 9-year-old children (n = 40) from a randomly selected elementary school in Flanders, Belgium, were invited to participate in the study, which was conducted in the spring of 2013. Participating children were asked to bring their own bicycle to school to complete the off-road practical cycling test. Permission for this study was received from the local Ethics Committee of the Ghent University Hospital and informed parental consent was obtained for all participants. Parents were also asked to complete a questionnaire concerning their children's cycling experience (see 2.2.4.).

2.2. Procedure

Tests were performed during school hours in the school's playground. First children's height and weight were measured. Subsequently, gross motor competence was examined using the Körperkoordinations Test für Kinder (KTK; see Section 2.2.2). At last, children went outdoors to perform a practical cycling test consisting of 13 subtests (see 2.2.3). During all tests, children wore light sports clothing. For the KTK test, no shoes were allowed. For examination of the bicycle skills children wore their normal shoes. A group of master students in Movement and Sport Sciences was trained to examine anthropometry, KTK and cycling skills. One group of experimenters examined KTK and anthropometry, while a second group of trained experimenters evaluated the cycling skills. This procedure minimised the potential effects of common-method bias.

2.2.1. Anthropometry

Standing height and weight were measured using Seca 213 and Seca 813 (Germany) respectively. Height and weight were used to calculate BMI (kg/m^2) for each participant. All anthropometric and gross motor competence tests were performed on bare feet.

2.2.2. Gross motor competence

Children's level of gross motor competence was assessed using the KTK (Kiphard and Schilling, 2007) which is a frequently used standardised German test battery suitable for children between 5 and 15 years of age and considered a highly reliable and valid instrument (test-retest reliability coefficient of 0.97) (Vandorpe et al., 2011; Smits-Engelsman and Henderson, 1998). This field test consists of four subtests which enables the evaluation of a child's gross motor coordination and dynamic balance skills (Vandorpe et al., 2011; Vandorpe 2011). In addition, testing takes only 15 minutes per child. The competence level of the child is expressed as a motor quotient (MQ). The four subtests are as follows (figure 1):

(1) Walking backwards (WB) over balance beams of 6 – 4.5 – 3 cm wide and 5 cm high. Three trials per balance beam were performed resulting in nine trials. A total of 24 steps for each balance beam (8 per trial) were counted which makes a maximum score of 72 steps.

(2) Moving sideways (MS) in 20 s by stepping from one plate (25 cm × 25 cm × 5.7 cm) to the next, transferring the first plate to the other side, stepping on it, and so on. Two trials were performed with a short break in between the two trials. The number of relocations were counted and summed for the two trials.

(3) Hopping for height (HH) on one leg over an increasing pile of foam pillows (60 cm × 20 cm × 5 cm). Participants had to jump on the same leg two times before and after the pile. Three, two or one point(s) were/was given for each successful performance after first, second or third attempt, respectively. A score of 39 points could be gathered for each leg resulting in a maximum score of 78 points.

(4) Jumping sideways (JS) over a wooden slat (60 cm × 4 cm ×2 cm) as many times as possible in 15 s. Two trials were performed and scores were summed.

For each item a raw score and a scaled score were calculated based on the manual of Kiphard & Schilling (2007). These scores were summed and transferred into a gender- and age-specific MQ which are based on the performance of 1228 normally developing German children in 1974. This MQ enables comparison between children of different ages and gender with limited interference of physical fitness. Normally developing children score typically between 86 and 115. Values below or above correspond to poor or high motor coordination levels.

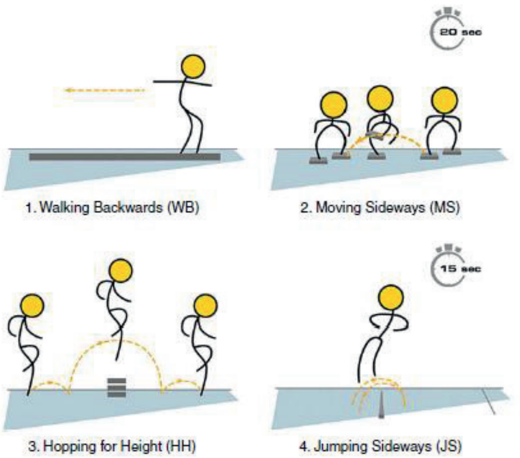

Figure 1. The KTK

2.2.3. Practical cycling test

The practical cycling test of Ducheyne et al. (2013a) was used. In summary, 13 basic cycling skills (figure 2) that children should manage to cycle safely in right-hand traffic were tested. The tests were carried out on an asphalt surface in the playground of the school to guarantee safety, and experimental control. Children were instructed how to perform the tests, but were not allowed to practice. Three researchers were trained on the scoring procedure of all test stations during four hours. For each test a 10-point scale was used to assess the general performance of the skill. The speed and fluency of the performance as well as the ability to keep balance and to perform the test without interruptions were taken into account when scoring the general performance. When the test was performed fluently and without mistakes, 10 points were awarded. When no mistakes were made, but performance was not fluent, 8 points were given. For each mistake made, two points were deducted. Furthermore, for 11 test items, the researchers additionally indicated whether the child was able to fulfil some specific points of interest. For each specific point of interest that was fulfilled, one point was added to the general performance score. This sum score (sum of the general performance score and the points of interest) was then converted to a score on ten (= cycling skill score). The sum of the different cycling skill scores, converted to a score of 10, was used as children's total cycling skills score. Interrater reliability of the cycling test scores was good with ICC's ranging from 0.75 to 0.98 (Ducheyne et al., 2013a).

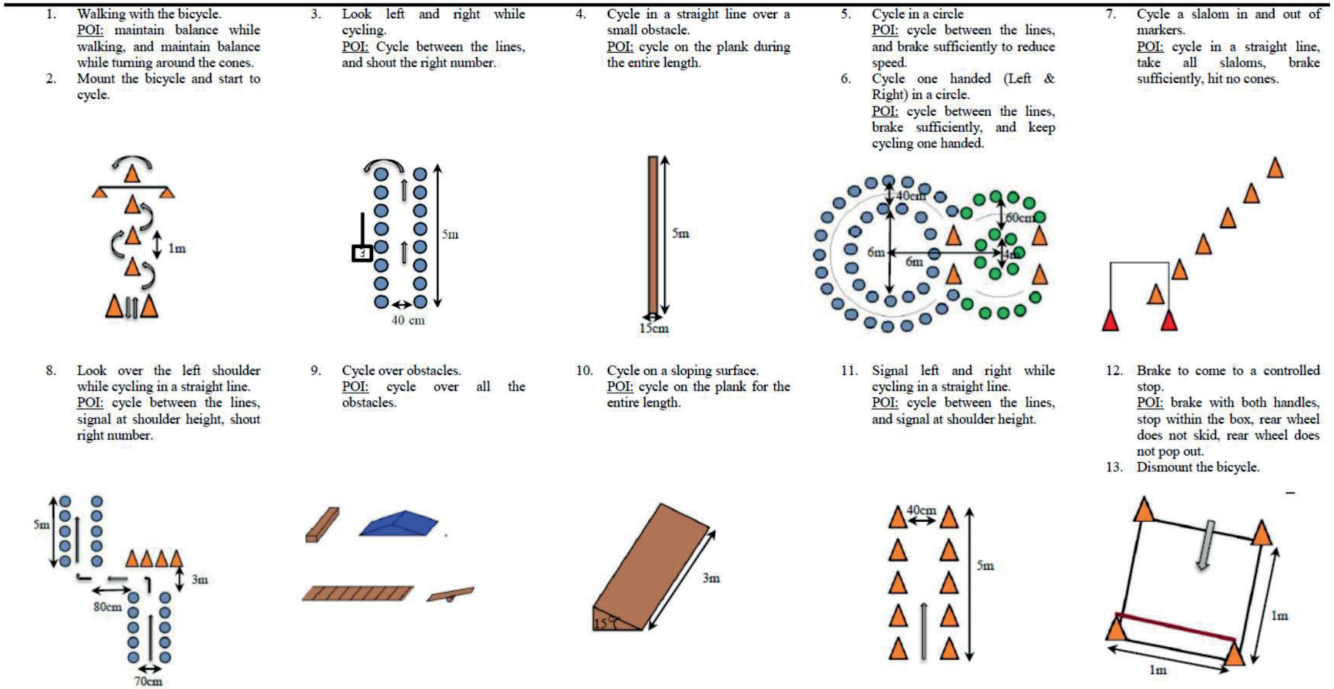

Figure 2. The cycling skills test and the points of interest (POI; see Ducheyne et al 2013a for a detailed description).

2.2.4. Parental questionnaire

Parents were asked to complete a questionnaire concerning cycling behaviour and cycling experience. Cycling experience was calculated by subtracting age at debut of cycling from actual age. To estimate cycling behaviour, a matrix was used differentiating between seasons (autumn, winter and spring), transportation method (walking, cycling, car, bus) to and from school, and minutes children cycled outside school hours. Parents indicated how many days/week each method was used by their child, as well as distance from school, and trip duration. In addition, an estimation of the amount of time children spent on their bike (min/week) could be made.

2.3. Data analysis

Filemaker Pro 11 was used for the input of the raw scores of KTK and cycling ability tests. MQ-scores and scores for the cycling test were calculated for all participants. SPSS 20.0 for windows was used for statistical analysis. Descriptive statistics were calculated for height, weight, BMI, cycling experience and minutes cycling per week. Differences for gender were analysed with independent samples t-testing. Total cycling skill score, cycling experience, MQ and BMI were entered into a bivariate correlation to examine the underlying associations. Factors significantly correlating with total cycling score were then entered into a backward stepwise multiple regression analysis to examine their predictive value.

3. Results

3.1. Descriptive results

3.1.1. Sample characteristics

Table 1 presents sample characteristics for height, weight and BMI. Nine-year-old boys (47,5%) and girls were equally represented. Following the standard definitions of Cole et al. (2000), in boys, 14 participants were categorised as healthy weight, 4 as overweight and 1 as obese. In girls, 17 children were healthy weight while 4 were overweight. There were no differences between boys and girls for height, weight or BMI.

Table 1. Means and standard deviation for height (cm), weight (kg) and BMI (kg/m²) in nine-year-old children.

	Girls	Boys
N	21	19
Height	136,67 ± 5,06	138,26 ± 7,41
Weight	31,66 ± 5,42	33,81 ± 7,07
BMI	16,88 ± 2,12	17,58 ± 2,72
% normal weight	81.0%	73.7%
% overweight	19.0%	21.1%
% obese	5.3%	0%

Note. Tests of the skewness in BMI did not reveal any significant departures from normality in girls (Skewness = 0.752, SE = 0.501) or boys (Skewness = 0.302, SE = 0.524). Participants were classified for weight status according to Cole et al. (2000). There were no differences between boys and girls for height, weight, and BMI.

3.1.2. Cycling skills and cycling experience

Five children did not indicate their age at debut of cycling. In general boys (n=17) started cycling at 4.73 ± 1.13 years of age while girls (n=18) started cycling at 5.19 ± 1.09 years of age however, this difference was not significant. Although only 13 children cycled to school, and only 15 children used their bicycle for transportation in general, boys (n=19) used their bicycle more often than girls (n=21) (31,89 ± 40.15 min/week vs. 9.45 ± 15.26 min/week; t = 2.381, $p = 0.032$). Mean results for the cycling skills in 9-year-old boys and girls are presented in table 2. No significant differences were found between boys and girls for total cycling score or any of the bicycle subtests. Compared with the reference values, provided by Ducheyne et al. (2013a), 9-year-old boys and girls scored worse on five subtests, walking with the bicycle, looking left and right while cycling in a straight line, cycling one handed in a circle, cycling in a circle, cycling a slalom in and out of markers, and on the total cycling score. Participants scored higher on braking to come to a controlled stop.

Table 2. Descriptive statistics (mean, SD, min and max) for cycling scores in nine-year-old children. Reference values by Ducheyne et al. (2013a).

	Testscores	Range			Reference values
	Mean ± SD	Min	Max	% scoring 5/10 or less	Mean ± SD
1. Walk with the bicycle***	7.29 ± 1.45	3,33	10,00	7.5	8.11 ± 1.79***
2. Mount the bicycle and start to cycle	8.55 ± 1.62	1,00	10,00	2.5	8.27 ± 1.84
3. Look left and right while cycling in a straight line***	6.92 ± 1.76	2,08	9,58	22.5	8.33 ± 1.63***
4. Cycle in a straight line over a small obstacle	6.84 ± 2.19	1,82	10,00	15.0	6.52 ± 3.50
5. Cycle one handed in a circle***	4.27 ± 2.08	0,42	8,33	67.5	6.37 ± 2.30***
6. Cycle in a circle	7.07 ± 1.70	2,73	9,09	15.0	8.28 ± 1.96
7. Cycle a slalom in and out of markers***	7.45 ± 2.16	0,71	9,29	17.5	8.90 ± 1.69***
8. Look over the left shoulder while cycling in a straight line	6.35 ± 2.26	0,77	9,23	27.5	7.05 ± 2.98
9. Cycle over obstacles	9.29 ± 0.85	7,00	10,00	0.0	9.21 ± 1.44
10. Cycle on a sloping surface	6.47 ± 2.04	1,82	10,00	17.5	6.76 ± 2.69
11. Signal left and right while cycling in a straight line	5.56 ± 2.09	1,25	9,17	37.5	5.79 ± 2.83
12. Brake to come to a controlled stop***	7.89 ± 1.09	5,71	9,29	0.0	7.29 ± 2.02***
13. Dismount the bicycle	8.92 ± 1.21	7,00	10,00	0.0	9.04 ± 1.48
Total Cycling score (…/10)**	7.14 ± 0.96	4,45	8,73	2.5	7.58 ± 1.34**

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.00$

3.1.3. Gross motor competence

Descriptives for the KTK are presented in table 3. No gender differences in raw test scores for jumping over pillows (HH), MS and MQ were found. Girls performed significantly better in WB and JS than 9-year-old boys. Compared to the reference values described in Vandorpe et al. (2011a), girls performed better for WB, JS and MS. However, boys scored higher for MS than the reference values.

Table 3. Descriptive statistics (mean, SD, min and max) for KTK according to gender and reference values for 9-year-old Flemish boys and girls. Reference scores by Vandorpe et al. (2011).

	Boys (n=19)				Girls (n=21)			
	mean	**min**	**max**	**Reference**	**mean**	**min**	**max**	**Reference**
1.WB	35.95 ± 11.12***	8.00	58.00	41.04 ± 12.87	49.33 ± 8.86	32.00	72.00	43.81 ± 13.73***
2.HH	51.05 ± 17.46	14.00	77.00	58.18 ± 11.69	53.05 ± 13.71	17.00	76.00	52.92 ± 12.61
3.JS	59.21 ± 7.26*	41.00	70.00	57.95 ± 10.45	65.14 ± 7.43	48.00	77.00	57.17 ± 11.04***
4.MS	44.53 ± 5.16	37.00	54.00	40.07 ± 6.61***	46.24 ± 4.86	37.00	53.00	40.03 ± 6.23***
MQ	98.00 ± 12.51	74.00	118.00	98.22 ± 13.08	103.14 ±12.02	72.00	123.00	92.34 ± 14.91

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.00$

3.2. Correlations for Motor Quotient, BMI and cycling skills

In table 4, correlations for the cycling tests, with the KTK subtests and BMI are presented. A significant positive correlation was found between total cycling score and MQ. In addition, subtests of the bicycle test were correlated with subtests of the KTK and BMI. Scores for looking left and right while cycling in a straight line correlated positively with scores for WB, MS and MQ. and negatively with BMI. Positive correlations for cycling in a circle were found for HH, MS and MQ, while a negative correlation with BMI was found. Cycling a slalom relates positively to HH, MQ and negatively to BMI. Looking over the left shoulder while cycling in a straight line only relates negatively to BMI while signalling left and right was positively related to HH and MQ. Braking to come to a controlled stop is only positively related only to HH. For total cycling score, only HH and MS were found to correlate positively. BMI correlated negatively with MQ in 9-year-old children as well as with cycling skills. All subtests of the MQ were negatively correlated with BMI. Cycling over obstacles was the only cycling skill which significantly correlated with cycling experience. Minutes cycling per week only correlated with walking with the bicycle. Appendix 1 (Table A1) covers a complete overview of all correlations.

Table 4. Correlations for the bicycling subtests, with the KTK subtests and BMI.

Cycling skills	1. Total Cycling score	2.1. Cycling experience	2.2. Minutes cycled per week	3. MQ	3.1. WB	3.2. HH	3.3. JS	3.4. MS	4. BMI
1. Walk with the bicycle	**0.331***	0.192	**-0.322***	0.212	0.105	0.183	0.167	0.304	-0.064
2. Mount the bicycle and start to cycle	0.164	0.028	0.004	-0.045	-0.045	0.014	-0.008	-0.049	-0.179
3. Look left and right while cycling in a straight line	**0.731****	0.026	-0.207	**0.415****	**0.390***	0.293	0.273	**0.340***	**-0.387***
4. Cycle in a straight line over a small obstacle	**0.526****	-0.042	0.169	0.088	-0.242	0.232	0.044	0.092	0.000
5. Cycle one handed in a circle	**0.822****	0.111	-0.029	0.301	0.070	0.299	0.166	0.307	-0.270
6. Cycle in a circle	**0.615****	-0.003	-0.131	**0.339***	0.198	**0.412****	0.119	**0.335***	**-0.526****
7. Cycle a slalom in and out of markers	**0.678****	-0.041	-0.094	**0.515****	0.249	**0.553****	0.198	0.298	**-0.408****
8. Look over the left shoulder while cycling in a straight line	**0.708****	0.048	0.104	0.255	0.197	0.215	0.149	0.271	**-0.342***
9. Cycle over obstacles	**0.479****	**0.397***	0.136	0.109	-0.043	0.142	0.169	0.140	-0.080
10. Cycle on a sloping surface	**0.714****	0.215	0.128	0.299	0.025	0.268	0.299	0.307	-0.089
11. Signal left and right while cycling in a straight line	**0.827****	0.118	0.040	**0.325***	0.083	**0.436****	0.109	0.278	-0.221
12. Brake to come to a controlled stop	0.039	0.280	0.298	0.078	-0.049	**0.323***	-0.020	0.008	-0.194
13. Dismount the bicycle	-0.122	0.220	-0.146	-0.081	-0.080	-0.040	0.049	-0.079	0.089
Total Cycling score	-	0.175	-0.008	**0.434****	0.140	**0.497****	0.251	**0.390***	**-0.400***

*$p < 0.05$, ** $p < 0.01$

3.3. Multiple regression analysis

A backwards stepwise multiple regression analysis to examine the influence of MQ and BMI together on bicycle skills scores produced an adjusted R square of 0.196. MQ tended to have the highest influence on bicycle skills (β = 0.316, t = 1.940, $p = 0.060$). BMI however was not found to be a significant predictor (Table 5).

Table 5. Backwards stepwise multiple regression analysis for cycling skills, MQ, and BMI.

		β	-95% to 95% CI	*t*	*p*-Level	*r*	r^2
Cycling skills							
	MQ	0.316	-0.001 – 0.050	1.940	0.060	0.487	0.237
	BMI	-0.251	-0.231 – 0.032	-1.539	0.132		

Note: Adjusted r^2 = 0.196, F = 5.753 (2, 37), p = 0.007

4. Discussion

4.1. Cycling skills and gross motor competence

The main aim of this study was to examine to what extent gross motor competence as measured with the KTK related to fundamental cycling skills. Motor competence was shown to underlie FMS (e.g. walking, running or jumping) which are essential prerequisites for more complex skills (i.e., cycling). For example, in gymnastics, children with higher levels of motor coordination were shown to outperform children with lower motor coordination, suggesting some sort of spillover effect of motor competence in general to more task-specific competencies (Ahnert, 2005; Vandorpe, 2011b). In concordance, motor competence was found to explain 19.6% of variance in cycling skills suggesting that motor-competent children are more likely to perform better on the cycling skill test. As motor coordination becomes a stable construct around the age of six, this emphasises the importance of motor development in young children (<6 years) (Holm et al., 2009; Stodden et al., 2008; Vandorpe et al., 2011a).

Cycling skills in general were positively associated with HH and MS. Hopping on one leg required the children to jump over an increasing pile of pillows which demanded appropriate strength in both legs, flexibility, balance and precise coordination between trunk and legs (Holm et al., 2009; Tveter and Holm, 2010). In order to maintain balance and create propulsion, cycling too required strength in both legs, flexibility and coordination between upper and lower body. Moreover, the requirement of strength and flexibility in both cycling and KTK subtests might have partially explained the positive correlations between cycling skills and HH or MQ in general. For example, when signalling left and/or right, the cyclist had to maintain heading, with only one hand left for steering. Therefore, adequate coupling between arm and leg movements, as well as coordination of the trunk was essential for balancing. In addition, due to increased task-difficulty, cycling speed was decreased, which resulted in additional steering and lateral leg movements which in turn complicated proper balancing (Kooijman and Schwab, 2013). Although balancing is one of the key components to ride a bicycle, no delineated relation between dynamic balance and bicycling was found (Briem et al., 2004). Surprisingly, only looking left and right while cycling in a straight line was related to WB (used to estimate dynamic balance). Although more extreme movements such as turning the head, required control over more degrees of freedom, varying task demands between walking and cycling caused postural differences, which might explain the lack of relationship.

Moreover, when cycling at higher speeds, bicycles become increasingly self-stable due to the somewhat strange mass distribution which might explain the lack of relation in the skills where speed was easier to maintain (Kooijman et al., 2009). Accordingly, mounting, dismounting and coming to a controlled stop, where cycling speed was lowest, should therefore require the most skill. However, these skills were not related to cycling skill score or MQ, which might give an incorrect representation. The other cycling tasks were quite difficult compared with cycling on the street, no additional workload was added for the three low speed tasks, whereas (dis)mounting on the street might be more challenging due to uneven road surface, baggage or clothing.

As MS was found to be related to total bicycling score, it mainly contributed to cycling in a circle and looking left and right. The latter might be explained by additional trunk rotation, which aids checking over the shoulder. Although jumping on one leg was related with total bicycling scores, JS was not. Lack of association between cycling subtests and MQ can be attributed to mainly low or (e.g. cycling one handed in a circle) high mean test scores (e.g. cycle over obstacles) and small score ranges, questioning the sensitivity of some test items. Although Schepers (2012) reported an inverse relationship between the amount of bicycle usage (km/week) and the risk of single-bicycle-crashes, this study was unable to find a (significant) relation between cycling skills and cycling experience or minutes cycling per week. Therefore, children with longer cycling experience did not perform better while children with better motor competence did. As cycling skills did not improve with experience, this seems to be contradictory to the effect of experience or training found by Schepers (2012) and Ducheyne et al. (2013a). However, given the small sample size, only 13 children cycled to school and 15 children used their bicycle for transportation which might explain low correlations for cycling experience and cycling skills. Children were likely living at walking distance of their school, or were brought by car.

In conclusion, an overall relation between cycling skills and motor competence supports the suggestion of the underlying construct of motor competence in movement skill development. Therefore, the moment children actively start participating in traffic should be matched to their individual characteristics. Alternatively, lowering saddle height to ensure children with lower motor competence can touch the ground with both feet and easy manageable brake levers are possible modifications to the bicycle which simplify bicycle handling. Given that motor competence is a relatively stable trait from the age of six, physical activity in infants and pre-schoolers should be promoted, since FMS also have bearing on other tasks and participation in sport activities later in life (Stodden et al., 2008; Riethmuller, et al., 2009; Reilly, 2010; Lopes et al., 2012; Vandorpe et al., 2012b). Because children engage more and more in sedentary leisure time activities (e.g. TV-viewing, computer games or playing with tablets), participating in free and unstructured (outdoor) play for at least 60 min/day, active leisure time activities, structured physical activity for at least 60 min/day involving large-muscle activities, can help to get children used to an active and healthy lifestyle (Goodway et al., 2014). In addition, a physically stimulating and challenging play environment for children in childcare settings might help pre-schoolers developing FMS.

4.2. Influence of BMI on bicycle skills

The negative association found between gross motor competence and BMI conforms to previous research which described decreased gross motor competence due to overweight (D'Hondt et al., 2011; D'Hondt et al., 2012; Gentier et al., 2013b; Graf et al., 2004). However, the negative relation found between BMI and cycling skills underlined a more profound deficit in the construct of motor coordination. According to the mechanical hypothesis, maintaining position on the bicycle might be more difficult for cyclists with overweight. In addition, complex bicycle movements and additional body movements caused alterations in equilibrium, therefore making it harder to control steering, especially in heavier children (e.g. cycling a slalom in and out of markers or when signalling left and right). Despite riding a bicycle can be considered a task which mainly requires gross motor coordination, body mass is being carried all the time. Therefore, the mechanical consequences caused by increased body mass cannot explain this inverse association between BMI and cycling skills alone. Recently, Gentier et al. (2013b) evaluated fine and gross motor control in healthy-weight and obese children. When obese participants performed worse on fine motor skills as well, it was suggested that difficulties in perceptual-motor competence hinder proper movement execution. Since cycling skills decreased with increasing BMI, our results supported the evidence in favour of deficits in the integration and processing of sensory information due to overweight. The importance of perceptual-motor competence in cycling was pointed out by Plumert et al. (2011). When crossing gaps in a virtual environment children had less time to spare and spent more time on the curb indicating problems with coupling visual information to motor output. Although this improved with practice due to better control over the bicycle and the ability to anticipate what is going on. Since both perceptual-motor competence and cycling skills are negatively associated with BMI, children suffering from overweight might require special attention.

In conclusion, children with higher BMI performed worse for MQ and cycling skills. Therefore, increased body mass appears to negatively affect a variety of tasks (D'Hondt et al., 2012; Lopes et al., 2012). Because of the increasing popularity of sedentary activities (computer, TV, tablets, etc.) children hardly reach the appropriate amount of daily physical activity which results in an higher incidence of childhood overweight. Especially children with lower motor competence are at higher risk to become overweight (Stodden et al., 2008). Since, BMI and motor competence are interrelated and affect participation in sports, physical activity and physical well-being later in life, parents, schools and caregivers should be aware of the importance of a healthy lifestyle and physical activity. Therefore, motor skill development should be key in interventions aiming to reduce long term overweight. Appropriate time for active play and challenging environments may be beneficial (Lopes et al., 2012).

4.3. Limitations and future research

Although cycling experience was included in this study, future research might consider measuring motor coordination in children before they learn how to ride a bicycle. In line with the current results, children with better motor coordination might acquire cycling skills at greater pace than those with poor motor control. As only one age group was studied with a limited number of participants, and few were classified overweight or obese, our findings might have limited generalisability. As motor competence has bearing on skills such as cycling, the influence of motor competence on other complex tasks might be of interest.

5. Conclusion

To our knowledge this was the first study investigating cycling skills in relation to motor competence and BMI in children. Our results demonstrated a spillover effect of general motor competence to more complex skills, emphasising the importance of proper motor development in young children. Given the relative stability of motor competence from the age of six, interventions aiming to improve motor skills should focus on infants and pre-school children to prevent early motor delay. Also heavier children and/or children with lower motor competence should be given special attention since cycling skills were also associated with BMI. The consequences of a global increasing sedentary lifestyle on childhood motor development are far-reaching, not only with respect to health, but also in the context of mastering specific skills (for example cycling) that are essential for a normal development.

Acknowledgements

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Table A1. Correlations for cycling skills, KTK, BMI, cycling experience, and minutes cycling per week.

	Cycling experience	Minutes cycled per week	BMI	Total cycling score	1. Walk the bicycle	2. Mount the bicycle and start to cycle	3. Look left and right while cycling	4. Cycle in over a small obstacle	5. Cycle one handed in a circle	6. Cycle in a circle	7. Cycle a slalom in and out of markers	8. Look over the left shoulder	9. Cycle over obstacles	10. Cycle on a sloping surface	11. Signal left and right	12. Brake to come to a controlled stop	13. Dismount the bicycle	2. MQ	2.1. Balancing Backwards	2.2. Hopping for Height	2.3. Jumping Sideways	2.4. Moving Sideways
0.1 Cycling experience	1																					
0.2. Minutes cycled per week	,173	1																				
0.3. BMI	,012	,240	1																			
1. Total cycling score	,175	-,008	-,400*	1																		
1.1. Walk the bicycle	,192	-,322*	-,064	,331*	1																	
1.2. Mount the bicycle and start to cycle	,028	,004	-,179	,164	-,279	1																
1.3. Look left and right while cycling in a straight line	,026	-,207	-,387*	,731**	,325*	,074	1															
1.4. Cycle in a straight line over a small obstacle	-,042	,169	,000	,526**	-,072	,069	,162	1														
1.5. Cycle one handed in a circle	,111	-,029	-,270	,822**	,425**	-,024	,592**	,411**	1													
1.6. Cycle in a circle	-,003	-,131	-,526**	,615**	,360*	-,035	,425**	,203	,494**	1												
1.7. Cycle a slalom in and out of markers	-,041	-,094	-,408**	,678**	,147	-,080	,472**	,363*	,444**	,424**	1											
1.8. Look over the left shoulder while cycling in a straight line	,048	,104	-,342*	,708**	,088	,175	,616**	,104	,555**	,336*	,411**	1										
1.9. Cycle over obstacles	,397*	,136	-,080	,479**	,102	,041	,327*	,289	,286	,220	,231	,274	1									
1.10. Cycle on a sloping surface	,215	,128	-,089	,714**	,265	-,019	,411**	,353*	,528**	,312	,498**	,484**	,460**	1								
1.11. Signal left and right while cycling in a straight line	,118	,040	-,221	,827**	,166	,004	,623**	,406**	,697**	,452**	,505**	,636**	,337*	,560**	1							
1.12. Brake to come to a controlled stop	,280	,298	-,194	,039	-,209	,062	-,092	,049	-,011	-,104	,124	,084	-,031	-,114	,028	1						
1.13. Dismount the bicycle	,220	-,146	,089	-,122	-,034	,311	-,222	,005	-,129	-,030	-,314*	-,334*	,009	-,166	-,173	-,334*	1					
2. MQ	,106	-,263	-,472**	,434**	,212	-,045	,415**	,088	,301	,339*	,515**	,255	,109	,299	,325*	,078	-,081	1				
2.1. Balancing Backwards	,053	-,387*	-,368*	,140	,105	-,045	,390*	-,242	,070	,198	,249	,197	-,043	,025	,083	-,049	-,080	,664**	1			
2.2. Hopping for Height	,315	-,093	-,390*	,497**	,183	,014	,293	,232	,299	,412**	,553**	,215	,142	,268	,436**	,323*	-,040	,717**	,293	1		
2.3. Jumping Sideways	,061	-,252	-,345*	,251	,167	-,008	,273	,044	,166	,119	,198	,149	,169	,299	,109	-,020	,049	,739**	,486**	,355*	1	
2.4. Moving Sideways	-,036	-,231	-,288	,390*	,304	-,049	,340*	,092	,307	,335*	,298	,271	,140	,307	,278	,008	-,079	,717**	,452**	,265	,581**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Paper 2: Development of cycling skills in 7- to 12-year-old children

ABSTRACT

OBJECTIVE: Cycling[29] is a complex skill consisting of motor skills such as pedalling, braking and steering. As the ability to perform cycling skills is based on the age-related development of the child, experience and age related reference values are of interest in light of customized testing and training. **METHODS:** 138 children from the 2nd (7-8 year), 4th (9-10 year) and 6th (11-12 year) grade performed a practical bicycle test consisting of thirteen test items with specific points of interest. Moreover, age at onset of cycling, cycling to and from school, independent mobility and minutes cycling per week were estimated using a parental questionnaire. **RESULTS:** It is found that cycling skills are strongly related to age with 11-12-year-old children outperforming 7-8-year-old children for 11 test items and 9-10-year-old children for 8 test items. **CONCLUSIONS:** Next to age, age at onset of cycling also contributed to cycling skills. Therefore our results suggest cycling skills to be associated with physical and mental development. Subsequently age related reference values are provided to customize testing and training.

[29] This part is based on **Zeuwts L**, Vansteenkiste P, Cardon G, Lenoir M (2016). Development of cycling skills in 7 to 12-year-old children. *Traffic Injury Prevention*. Epub ahead of print, DOI 10.1080/15389588.2016.1143553

1. Introduction

In Belgium and other European countries cycling to work or school is gaining popularity. During childhood, bicycles often represent the road to freedom as they offer the opportunity to cover greater distances at faster speed in contrast to walking (Shephard 2008). Therefore, learning to ride a bicycle is a keystone in a child's development apart from a variety of positive health and environmental benefits (Oja et al. 2011; de Hartog et al. 2010; Cooper et al. 2006). However, when promoting cycling, road-safety and appropriate bicycle skills deserve attention since an increase in bicycle usage (DEKRA 2011) leads to an increase in the number of bicycle crashes (Juhra et al. 2012). Especially children (9 to 12 year old) and older cyclists (>65 year old) are at risk (Hansen et al. 2005; Lammar 2005; Maring and van Schagen 1990; Ormel et al. 2009; Rivara et al. 1997; Schepers and Wolt 2012). As the majority of the bicycle accidents in children (55%) are caused by poor turn manoeuvres (Ormel et al. 2009) or falling off the bicycle (Lammar 2005), development of proper cycling skills amongst children is of major interest. Other factors that contribute to crashes are losing control over the bicycle, playing with the bicycle, not looking properly and doing tricks (Simpson and Mineiro 1992). Until recently, many studies focussed on extrinsic safety measures such as traffic condition and road design (Møller and Hels 2008; van Schagen and Brookhuis 1994) or secondary prevention measures including the usage of helmets (de Jong 2012; Karkhaneh et al. 2013). In contrast, intrinsic safety measures such as the development of cycling related motor and cognitive skills in children are less well described.

Cycling in traffic is a complex skill and related to levels of (1) motor, (2) cognitive and (3) sensory information processing skills which develop from childhood to adolescence (Briem et al. 2004; Zeuwts et al. 2015; Ducheyne 2013c). In this study we focus on the motor component which contains basic skills as pedalling, braking and steering (Van Houcke et al. 2009). However, next to these three types of manipulations of the bicycle, controlling a bicycle also implies the mastery of more complex skills like mounting and dismounting, obstacle negotiation, speed adjustments after a visual check over the shoulder etc. (Savill et al. 1996; Stichting Vlaamse Schoolsport 2005). These skills are supposed to be acquired before the child is ready to independently participate in traffic by bicycle. Therefore, mastering the skill of cycling can be considered as the foundation for safe traffic behaviour (Ducheyne 2013a; Van Houcke et al. 2009).

The age-related development of a child is considered as a predictive factor for the performance of cycling skills (Arnberg et al. 1978). Our current understanding of the development of cycling skills is however obscured by the variety of subskills underlying skilful cycling. These subskills do not necessarily develop at the same time. For example, the isolated act of braking is fairly easy to learn and is mastered at a young age, but it becomes more difficult in combination with keeping balance on the bicycle. In addition, in the current literature on bicycle skills, different test instruments are used. Even more important is that most studies have focused on a rather narrow age range, which does not allow to document cycling skills in an age-related perspective. Hansen et al. (2005) reported immature psychomotor skills and difficulties with managing moving objects in five year old children to be the cause of accidents. At the age of five, children learn to balance and pedal their bicycle in order to maintain heading and round corners without falling off. During practice, more complex skills are mastered in a closed setting or under adult supervision and become increasingly important around the age of nine when children are allowed to cycle independently for short distances (Stichting Vlaamse Schoolsport 2005; Ducheyne et al. 2013a). For example, Van Schagen & Brookhuis (1994) measured more complex skills such as signalling and slowing down for manoeuvring at intersections in 8- to 9-year-old children, while Ducheyne et al. (2013a) evaluated skills such as looking over the left shoulder, looking left and right, cycling in a straight line and cycling over obstacles in 9- to 10-year-old children. The observation of the low scores for one handed cycling skills such as signalling might be explained by the complexity of maintaining balance and the coordination of additional body movements. Savill et al. (1996) evaluated, skills like starting off, stopping, taking left turns and right turns, and overtaking a parked car in 12- to 13-year-old children. Although trained children performed better for cycling skills and knowledge in general, 69% of the trained and 85% of the untrained children displayed bad pedalling skills, 54% to 87% failed to signal before stopping, 27% failed to signal before turning left and 36% failed to check the shoulder before turning right. Although several bicycle tests and training courses aimed to improve children's bicycle skills, those training programs varied in age range, focused on a variety of abilities, and lack thoroughness in reporting subskills contributing to the different bicycle skills which hampers comparison between the programs (Savill et al. 1996; Ducheyne et al. 2013; Lachapelle et al. 2013; Hansen et al. 2005). In several of these studies it is noted that ceiling effects emerge in some test items, while on other skills the improvement is limited (Savill et al. 1996; Ducheyne et al. 2013).

Next to age-related development, experience might also affect cycling skills at a given age since more experienced cyclists have better control of their bicycles, they are less likely to have single-bicycle accidents (Schepers 2012; Wierda and Brookhuis 1991). This is however not tantamount to promoting cycling training at a very young age. Hansen et al. (2005) observed that even though children are more experienced when they start to cycle at 4 or 5 years compared to 7-year-old children, the former appear to have a higher risk of getting injured.

So far, most of the existing studies regarding bicycle skills focus on relatively small age groups and use different test instruments (van Schagen & Brookhuis 1994; Ducheyne et al. 2013a; Briem et al. 2004). As the ability to control the various motor components of cycling strongly depends on the mental and physical development of the child, this study aims to provide age-related reference values for Flemish children, essential for constructing training programs accustomed to age. Consequently, the association of experience and expertise with regard to cycling skills will be examined.

2. Methods

2.1. Participants and Procedure

All children (Table 3.) from the second, fourth and sixth grade of a randomly selected elementary school in Flanders were invited to participate in this study. Parents of the participating children received a questionnaire concerning their children's cycling experience and transportation habits during the week and weekends. In addition, permission for this study was received from the local Ethics Committee of the Ghent University Hospital and informed parental consent was obtained for all participants. Children were asked to bring their own bicycle for the off-road practical cycling test. 62.0% Of the children brought a citybike, 32.8% a mountain bike, 0.7% a race bike and 4.4% a motocross bike. Tests were performed on the school's playground during the school hours. First, children were called away from class in groups of five. They were asked to get their bicycle from the cycle shed, put on their bicycle helmets and received a short briefing regarding the different bicycle subtests. Then each child completed the first subtest before the group moved on to the next subtest. Children were allowed to quit the bicycle test at any time without any clarification.

Table 3. Age, experience, length, weight and BMI for the participants.

	Boys	Girls
2nd grade	30	22
Age (years)	7.85±0.38	7.69±0.30
Experience (years)	3.66±0.86	3.46.±1.01
Length (m)	1.34±0.24	1.25±0.6
Weight (kg)	26.48±3.69	23.32±2.92
BMI	16.93±8.29	14.82±1.49
4th grade	26	18
Age	9.65±0.49	9.74±0.21
Experience	6.00±0.95	5.81±0.78
Length	1.41±0.07	1.39±0.07
Weight	31.67±4.28	30.75±4.96
BMI	15.86±1.59	15.95±2.66
6th grade	28	14
Age	11.81±0.41	11.98±0.55
Experience	7.67±1.28	7.39±1.03
Length	1.52±0.08	1.55±0.07
Weight	38.55±7.63	42.54±8.62
BMI	16.40±2.35	19.15±5.98

2.2. Questionnaire

Prior to the bicycle test, parents were asked to complete a questionnaire concerning their child's age at onset of cycling and cycling behaviour based on the questionnaire of Ducheyne et al. (2012). To document cycling behaviour to and from school, a matrix was constructed which differentiated between the seasons (autumn, winter, spring), and transportation method (walking, cycling, by car, by public transport) to and from school. Parents indicated how many days/week their child used each transportation mode. In addition, distance to school, time spent cycling to school, number of bicycle trips made (and time) other than cycling to school during the week and weekend were questioned. Based on the duration (minutes) of the trips to and from school, the duration of the bicycle trips in the week and the duration of the bicycle trips made in the weekend, the number of cycling minutes per week was estimated. Finally, independent mobility was examined by the question "how far is your child allowed to cycle from home on his/her own?" (1= not allowed, 2= 0m to 250m, 3= 250m to 500m, 4= 500m to 1km, 5= 1km to 3km and 6= 3km to 5km, 7= more than 5km). This questionnaire was found to be reliable and valid (Ducheyne et al. 2012).

2.3. Practical Bicycle Test

For this study the practical cycling test of Ducheyne et al. (2013) was used. In total, 13 basic cycling skills which children should be able to manage to cycle in right-handed traffic were tested. Each of these cycling skills is attributed to one of three factors; "during cycling skills", "before and after cycling skills" and "transitional cycling skills". "During cycling skills" include eight skills in which the actual cycling movement is ongoing (e.g. cycle in a circle, cycle a slalom,…). The factor "before and after cycling skills" is concerned with three skills that take place before and after the actual cycling movement (e.g. walking with the bicycle, mounting the bicycle and start to cycle and dismounting the bicycle). Finally "transitional cycling skills" consist of two remaining cycling skills which is situated in between "during cycling skills" and "before and after cycling skills" (braking to come to a controlled stop and looking left and right while cycling). The tests were performed on the asphalt surface of the school's playground to guarantee children's safety. Children received instructions on how to perform the various test items but were not allowed to practice before the actual test. Fluency and speed of the performance in general, maintaining balance and the ability to cycle without interruptions for each subtest was assessed using a 10-point scale. For each mistake, two points were deducted. In addition, for eleven test items children had to fulfil some specific point of interest. For each point of interest fulfilled, one point was added to the performance score. The score for each subtest was then converted to a score on 10 points. Based on the score for each subtest, total cycling skill score was calculated and converted to a score on 10 points. Interrater reliability for the cycling skill test was good with intraclass correlation ranging from 0.75 to 0.98 (see figure A1 in the appendix for more information; Ducheyne et al. 2013; Zeuwts et al. 2015).

2.4. Data Analysis

Filemaker Pro 11, Inc/US was used to collect the raw scores from the bicycle test and the questionnaires. Cycling experience, cycling behaviour and cycling scores were calculated in Excel and exported to SPSS 20.0 for windows, IBM/New York, for further statistical analysis. To compare the cycling scores of our population to those of Ducheyne et al. (2013) we corrected for age using the formula obtained from the multiple regression analysis (figure 2) since the average age of the sample of Ducheyne et al. (2013) was slightly younger. A One-Sample T Test was used to compare the scores between the 4^{th} graders in our study and the 4^{th} graders of Ducheyne et al. (2013). Analysis of transportation to and from school, minutes cycling per week, bicycle scores, and three cycling factors was performed using an ANOVA with grade as factor. Backward stepwise multiple regression analyses were used to examine the relationships for cycling skills, age, experience, minutes cycling per week and cycling to and from school. To analyse independent mobility and the points of interest for each of the bicycle skills, a Chi Square analysis was used. Post-hoc analyses were performed using standardized residuals. Statistical significance was set at $p < 0.05$ for all analyses.

3. Results

3.1. Cycling Behaviour in Children

Descriptive statistics regarding the participating children are provided in table 3. Independent mobility in children, presented in table A1, clearly describes a shift from 7-8-year-old children to 11-12-year-old children. It is found that children of 7-8 years old are almost never allowed to cycle on their own, while children between 9-10 years old are scattered over the continuum. Finally, 11-12-year-old children are allowed to cycle up to 5km from home alone (Chi^2= 63.293; df=12; p<0.001). Total cycling time increased with age (figure A2 ; F=4.589; p=0.012), although post hoc analysis indicated that only the difference between the 11-12-year-old and the 7-8-year-old children reached significance (p = 0.014). No other significant difference was found in spite of the apparent trend that is visualised in figure A2. Transportation methods to and from school in children are presented in figure 1. Children of 7-8 years old are mainly brought by car (57.31%) followed by bicycle (30.98%), walking (9.75%) and at last public transport (1.96%). Also children of 9 to 10 year old are predominantly dropped off at school by car (58.10%), again followed by bicycle (29.52%), and walking (12.38%). However, this pattern shifts amongst 11-12-year-old children who indicated to cycle to school (62.56%), before being dropped off (32.74%) or walking to school (4.70%). For cycling to and from school (F=9.443; p<0.001) and coming by car (F=4.839; p<0.01) differences between age groups were significant. Children of 11-12 year old cycle more to school than 7-8 year old (p=0.001) and 9-10-year-old (p=0.014) children. Children from 9-10 years old (borderline significance p=0.059) and from 7-8 years old (p=0.024) are brought by car more than children from 11-12 years old.

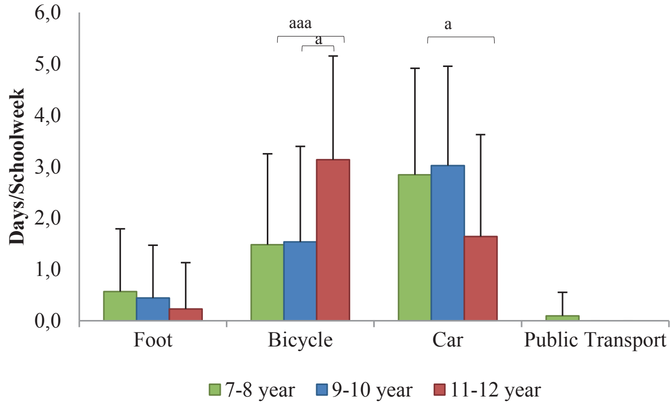

Figure 1. Transportation methods to and from school in children of the second, fourth and sixth grade. [aaa] $p < 0.001$; [aa] $p < 0.01$; [a] $p < 0.05$

3.2. Cycling Skills

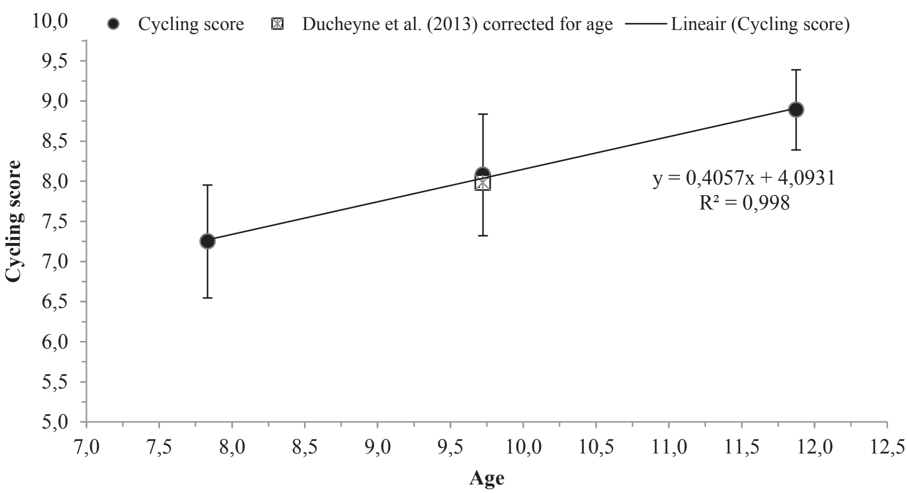

Figure 2. Mean cycling skill scores according to age and mean cycling skill score for Ducheyne et al. (2013) corrected for age.

At first, the cycling scores among 9-10-year-old children (9.72 ± 0.24 years of age) are comparable to the cycling scores of 9-year-old children of Ducheyne et al. (2013) when corrected for age based on the equation in figure 2 ($t = 0.879$; $p = 0.384$). In addition, there was no difference in bicycling skills scores depending on the type of bicycle (e.g. city bike, mountain bike, race bike and BMX). Secondly, the scores for each individual test-item and total cycling score according to their grade, are presented in table A2 (appendix). Children of 7-8 years old scored lower for the majority of the "during cycling skills" and "transitional cycling skills" than children of 9-10 years old and lower for the majority of "before/after cycling skills", "transitional cycling skills" and the "during cycling skills" than 11-12-year-old children. Children of 11-12 years old performed better than children of 9-10 years old for the majority of the "before/after cycling skills", "transitional cycling skills" and "during cycling skills". In general, 7-8-year-old children scored lower than 9-10-year-old children ($p<0.001$) and 11-12-year-old children ($p<0.001$) while 9-10 year old children scored lower than 11-12-year-old children ($p<0.001$).

Table A3 (appendix) presents scores for the points of interest in percentages, in which percentages indicate the amount of children who showed correct behaviour. Children of 11-12 years old were mainly better for the one handed cycling skills and looking over the shoulder while children of 7-8 years old mainly score lower for skills which involve signalling or looking over the shoulder.

3.3. Multiple Regression Analysis

A backward stepwise multiple regression analysis was performed to examine the association of age, age at onset of cycling, commuting by bicycle to and from school, minutes cycling per week and estimates of independent cycling regarding cycling skills. Age and age at onset of cycling were found to have a significant influence on cycling skills. Both age and age at onset of bicycling explained 68.6% of the variance in scores on the bicycling skills test, while age alone explained 61.5% of the variance. However, commuting by bicycle to and from school, minutes cycling per week and independent cycling were not found to be significant predictors in cycling skills (table 2). Moreover, cycling to school, minutes cycling and independent cycling do not significantly skew the results.

Table 2. Backward stepwise multiple regression analysis for age, age at onset of cycling, commuting by bicycle, minutes cycling per week and independent cycling.

	β	-95% to 95% CI	t	p	R	R^2	F	p
Age	0.394	0.331 to 0.456	12.552	≤0.001	0.787	0.615	157.559 (1,98)	≤0.001
Age	0.392	0.335 to 0.448	13.833	≤0.001	0.832	0.686	108.148 (1,98)	≤0.001
Age at onset	-0.279	-0.395 to -0.164	-4.796	≤0.001				
Age	0.384	0.301 to 0.468	9.113	≤0.001	0.837	0.684	43.398 (1,98)	≤0.001
Age at onset	-0.257	-0.378 to -0.135	-4.184	≤0.001				
Cycling to school	-0.016	-0.100 to 0.068	-0.379	0.706				
Minutes cycling	0.044	-0.034 to 0.122	1.125	0.264				
Independent cycling	0.000	-0.003 to 0.003	0.094	0.925				

4. Discussion

Research concerning the development of cycling skills is limited. Moreover, most studies only focus on a small age range and lack an extensive analysis of the basic elements underlying more complex cycling skills

(Ducheyne et al. 2013a; McLaughlin & Glang 2010; Macarthur et al. 1998). Nonetheless, understanding age-related development, and the factors which contribute to skilled bicycle performance is essential in the context of training. Therefore, this cross-sectional study aimed at describing age-related differences in cycling skills, ranging from basic cycling skills to more complex, traffic-related skills which require advanced coordination of the upper and lower limbs. Age-related reference values are provided which are essential to construct customized training programs. Furthermore, the association between cycling behaviour, age at onset of cycling and cycling skills is discussed.

4.1. Age Related Reference Values

The results of our study demonstrate an age-related increase in cycling skills. Moreover, the 4th graders in this study scored as good as the 4th graders in Ducheyne et al. (2013) when corrected for age, which might improve generalizability of the obtained results in light of the age-related reference values. For the "transitional skills", younger children have difficulties with looking left and right while cycling in a straight line and braking to come to a controlled stop. When checking the shoulder, it is found that 11-12-year-old children were better able to cycle between the lines and to maintain heading. In addition, for braking and coming to a controlled stop in a demarcated zone, younger children tend to misjudge their stopping range resulting in overshooting or stopping too early which might be attributed to inefficient use of both the brake levers. Accordingly, Briem et al. (2004) reported that child bicyclists of the second grade anticipated signal changes (e.g. changing traffic lights) by placing both feet on the ground to brake several meters in front of the crossing, instead of using their brakes. While this might be a successful strategy on long range stops, this often resulted in serious overshootings for shorter range stops. However, in contrast to our findings the researchers also found that found that cycling speed, the number of overshootings (e.g. stopping outside the demarcated zone) and the number of mistakes (e.g. not stopping at a red light), increased with age. Given that child bicyclists could not get hurt and often grimaced or grinned but bicycled on when they noticed the stopping signal too late suggests that motivational factors determined the performance of the child bicyclists. As child bicyclists grew older, they gained more confidence resulting in increased bicycling speeds and more overshootings, especially on short range. In addition, attitudes such as risk taking or showing-off and social desirability might have increased the number of mistakes

For the "during cycling skills"; cycling one handed in a circle, cycling in a circle, looking over the left shoulder while cycling in a straight line, cycling over obstacles, cycling over a sloping surface and signalling left and right while cycling in a straight line are found to be related to age (Ducheyne 2013c). Analysis of the points of interest clearly indicates that younger children have difficulties in coordinating a complex task which requires balancing and additional body movements while cycling. For example, maintaining heading when signalling or checking the shoulder. Consequently, if signalling and checking the shoulder are combined (test 8), or precise steering and speed adjustment is required when cycling one handed in a circle (test 5), children from the second grade score the lowest with very low minimum scores. However, not only children from the second grade show difficulties with cycling between the lines. Also children from the fourth and the sixth grade have problems to cycle between the lines which highlights the complexity of these skills.

Although the majority of the cycling skills improve with age, there are some exceptions to this rule. Indeed, scores for keeping the bicycle in balance when stepping over an obstacle and cycling between the lines are rather low and do not improve with age. With respect to balancing and lifting the bicycle over an obstacle, adjusted weight and size of the bicycle are of interest in children. Concerning difficulties with the ability to maintain heading might be attributed to the speed-steering workload trade-off (Vansteenkiste et al. 2015). Conform this trade-off, children might have difficulties to adapt their speed with respect to the steering demands of the respective task which results in steering errors and overshooting.

In line with Ducheyne (2013b), high scores (>8/10) in all age groups are found for mounting the bicycle, cycle a slalom in and out of markers, cycling over obstacles and dismounting the bicycle reflecting the relative simplicity and the low task demands of these skills. In contrast, since fourth graders score as well as sixth graders for the "before and after cycling skills", cycling in a circle and cycling a slalom in and out of markers, this might suggest some kind of ceiling effect for these skills. However, the lack of an age-effect and the relative high scores for cycling a slalom in and out of markers with their respective points of interest in the younger groups is somewhat surprising since it was shown that children displayed difficulties with the interrelations between speed, time and distance (gap selection) until the age of 10 (Pitcairn and Edlmann 2000). Pryde et al. (1997) found that children under the age of 8 made more errors in obstacle avoidance in contrast to 11 year old children which can be attributed to the development of visual acuity, depth perception and visual-motor coordination (Gallahue and Ozmun 2005). Therefore, it could have been expected that children from the second grade would make more judgemental mistakes, or cycle at an inappropriate speed resulting in missing or overshooting cones. Since obstacle avoidance (static cones) is an internally paced task, simplified visual-motor strategies adopted by the children are sufficient to navigate through a complex environment (Franchak and Adolph 2010). However, when presented with a dynamic environment, young children were shown to adopt risky traffic behaviour. Plumert et al. (2009) evaluated children's capabilities to select appropriate gaps in road crossing behaviour. They found that children between 5 to 9 year old often selected gaps that were too short in contrast to older children (12 years old) who selected much safer gaps. Gap selection in road crossing is more complex as it requires the integration of information over the moving self in relation to moving objects. When cycling a slalom, however, children must only adapt their actions relative to static objects (cones).

4.2. Cycling Experience

Since the development of cycling skills is found to be related to the development of gross motor coordination (Zeuwts et al. 2015), improvements in cycling skills might be attributed to an age-related increase in motor coordination (Vandorpe et al. 2011). In line with this rationale, age and age at onset of cycling were related much stronger with cycling skills when compared to "independent mobility", "minutes cycling per week" and "cycling to and from school". The observation that the amount of cycling did not relate with cycling skills supports Hansen et al.'s (2005) observation that age at onset of cycling is a stronger predictor of cycling skills than the amount of time spent on the bicycle. Somewhat contradictory to our findings that the younger a child learns to cycle the better his or her performance, Hansen et al. (2005) also reported that children between 4 and 5 are at higher risk to get injured in the first two years of cycling compared to 6- or 7-year-old children who learn to cycle. This can be attributed to immature psychomotor skills and a lack of knowledge to manage traffic situations. Therefore it is concluded that next to maturation, also the years of cycling experience (number of years since age at onset of cycling) add to cycling skill development which is in line with the power law of practice (Wierda and Brookhuis 1991).

4.3. Cycling Behaviour

Regarding cycling behaviour in children, time spent cycling and independent mobility increase with age but no association is found with respect to the development of cycling skills. Nevertheless, older children (11-12 years old) use their bicycle more often to cycle to and from school and spend more time cycling a week than children of 7-10 year old, which is conform the longitudinal study by Cardon et al. (2012) (n=1070). They explored children's cycling behaviour to school, starting from the age of 10 until the age of 16. It was found that 46% of the 10-year-old Flemish children indicated to cycle to school on a regular basis, which increased with age (69% of the 11-year-old children and 83% of the 12-year-old children). Subsequently, as children grow older, the number of pupils bicycling to school, and the time spent cycling increases, this contributes to the daily requirements of physical activity (Cooper et al. 2006). Notwithstanding the health benefits associated with regularly cycling to school, a substantial amount of young children is still brought to school by car (Janssens et al. 2012). However, in support of our results and those of Cardon et al. (2012), as children grow older and become more independent, an increasing amount of children prefers to cycle to school. This suggests that children's cycling behaviour in our study is comparable to cycling behaviour in Flemish children in general which might improve generalizability regarding our results.

4.4. Suggestions and Limitations

In general, as suggested by Ducheyne et al. (2013), training programs should focus on the "during cycling skills" since performance for these subskills is relatively low and children from the fourth and sixth grade also show difficulties with maintaining heading while performing additional tasks. Therefore it is suggested that that training programs for children of the second grade start with "before and after cycling skills" and "transitional cycling skills" which consist of relative uncomplicated and simple skills such as mounting and dismounting the bicycle, cycling a straight line and rounding corners, walking with the bicycle at hand and braking within a predefined zone with attention for the correct use of both brake levers. Children from the fourth grade continue by learning to signal, checking their shoulder, cycling over obstacles and cycling over sloping surfaces. Finally, more complex tasks, e.g. one handed cycling skills such as signalling at shoulder height while checking the shoulder or cycling one handed around a corner can be taught. However, teachers should bear in mind that previously learned cycling skills should receive attention year after year to ensure automation.

Since children from a randomly selected typical Flemish school were tested, our results are limited in generalizability. Indeed, since the development of cycling skills might be specific for region, country and culture, this offers opportunities for future research. Additionally, also a more effective enquiry of time spent cycling might provide a more accurate estimation of children's cycling behaviour and experience. A more detailed description of cycling behaviour in f.e. a "cycling journal", by GPS or pedometer over a prolonged period would improve the estimation of cycling experience. Moreover, in recent studies the value of a cycling route planner was suggested (Su et al. 2010). As cycling skills are found to be age-related, future research should focus on the development of cycling skills in children making the transition from elementary school to secondary school.

4.5. Conclusion

This was the first study to evaluate the development in children's cycling skills in elementary school. Our study clearly demonstrates an increase of cycling skills which is mainly attributed to age. Accordingly, our findings therefore suggest physical and mental development to be associated with cycling skills. Subsequently age related reference values are provided to customize testing and training. Next to age, age at onset of cycling is found to contribute to cycling skills suggesting that the younger a child learns to cycle, the better his or her skills will be.

Acknowledgements

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5. Appendices

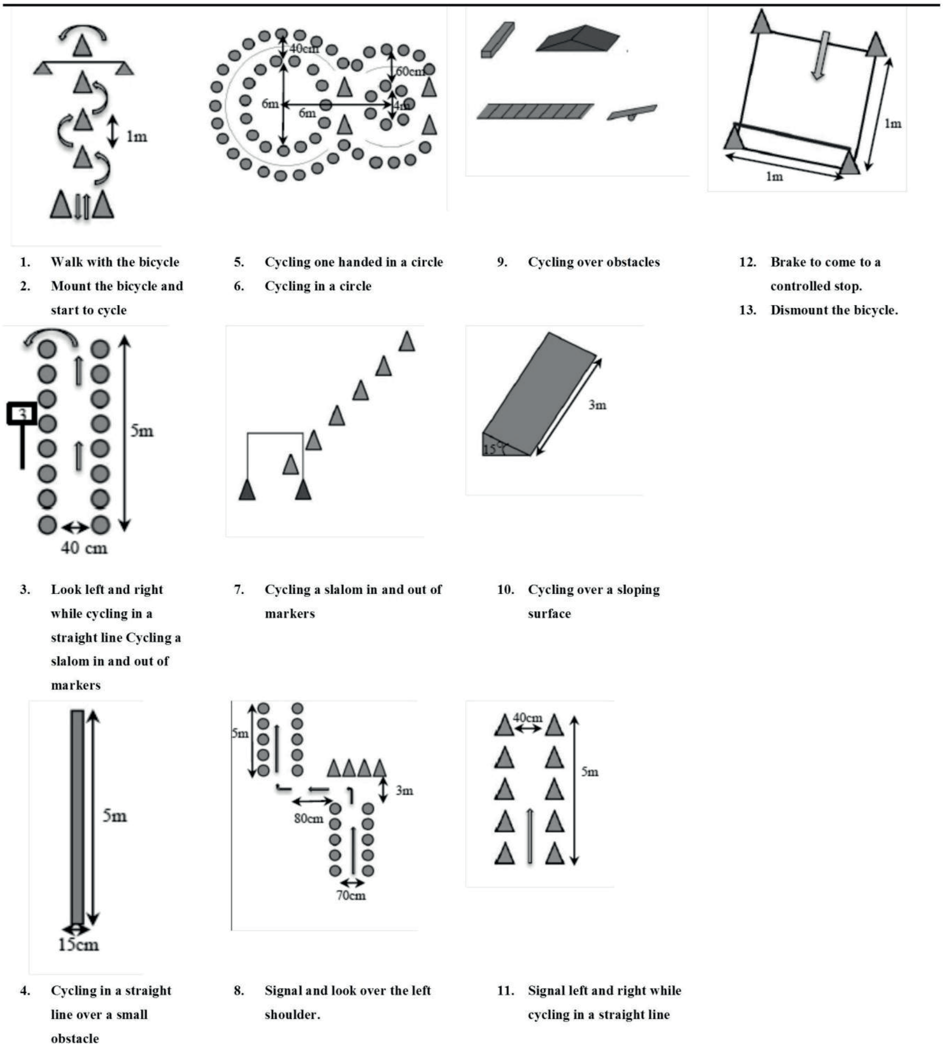

Figure A1. The cycling skills test (Ducheyne et al. 2013)

Table A1. Independent mobility of 7-12 year old children.

	7-8 years		9-10 years		11-12 years	
	%	Std. Res.	%	Std. Res.	%	Std. Res.
Not allowed	**59.10**	3.2	**20.80**	-1	**7.70**	-2.7
0m - 250m	**27.30**	1.3	**25.00**	0.7	**5.10**	-2
250m - 500m	**9.10**	-0.4	**20.80**	1.4	**7.70**	-0.7
500m - 1km	**2.30**	-1.1	**12.50**	1.1	**7.70**	0.3
1km - 3km	**0.02**	-2.3	**12.50**	-0.4	**33.30**	2.7
3km - 5km	**-**	-2.3	**8.30**	-0.5	**28.20**	2.9
>5km	**-**	-1.3	**-**	-0.9	**10.30**	2.1

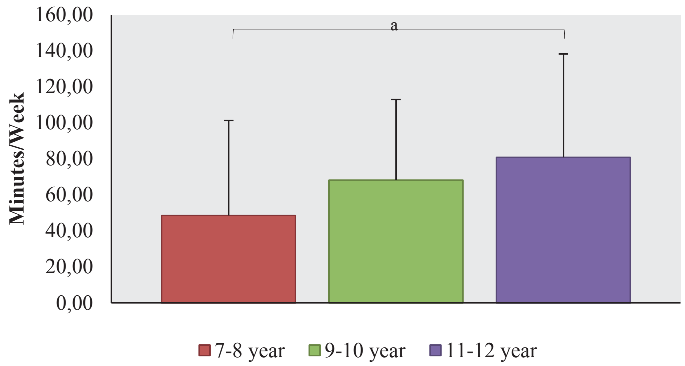

Figure A2. Mean time spent cycling by each grade.
[aaa] $p < 0.001$; [aa] $p < 0.01$; [a] $p < 0.05$

Table A2. Means, SD, Min and Max for the cycling skills according to age.

	7-8 year			9-10 year			11-12 year				
	Mean±SD	min	max	Mean±SD	min	max	Mean±SD	min	max	F	p
A. Before and after cycling skills[aa,b,ccc]	8,66±0,66	6,93	9,73	9,08±0,54	7,33	9,73	9,39±0,53	7,00	10,00	17.707	0.001
1. Walk with the bicycle[b,ccc]	7,09±1,36	4,20	9,20	7,69±1,08	5,00	9,20	8,48±1,09	5,80	10,00	15.442	0.000
2. Mount the bicycle[ccc]	9,52±0,70	7,00	10,00	9,77±0,52	8,00	10,00	9,95±0,22	9,00	10,00	7.630	0.001
3. Dismount the bicycle	9,38±0,89	7,00	10,00	9,80±0,70	6,00	10,00	9,73±1,41	1,00	10,00	2.248	0.110
B. During cycling skills[aa,bbb,ccc]	6,77±0,89	4,25	8,81	7,78±0,96	4,49	9,58	8,78±0,71	7,41	9,81	62.149	0.001
1. Cycling in straight line over a small obstacle[b,ccc]	7,73±1,37	4,50	10,00	7,99±1,54	0,90	10,00	8,88±1,33	5,50	10,00	8.024	0.001
2. Cycling one handed in a circle[aaa,bbb,ccc]	4,42±1,69	0,80	7,50	6,35±1,23	2,50	9,20	7,68±1,18	5,00	9,60	62.967	0.000
3. Cycling in a circle[a,ccc]	7,40±1,03	5,50	9,10	8,04±1,15	5,50	10,00	8,53±1,19	6,40	10,00	11.804	0.000
4. Cycling a slalom in and out of markers	8,83±0,74	6,40	10,00	8,53±1,16	5,70	10,00	8,99±0,82	6,40	10,00	2.792	0.065
5. Look over the left shoulder while cycling in a straight line[aaa,bbb,ccc]	5,45±1,68	2,30	9,20	7,27±1,56	3,10	9,20	8,70±1,28	3,80	10,00	52.542	0.000
6. Cycling over obstacles[a,b,ccc]	8,87±1,49	4,00	10,00	9,53±0,89	6,00	10,00	9,84±0,39	8,00	10,00	10.309	0.000
7. Cycling on a sloping surface[a,b,ccc]	5,75±2,21	1,80	10,00	7,04±2,54	0,00	10,00	8,48±1,78	3,60	10,00	17.486	0.000
8. Signal left and right while cycling in a straight line[aaa,bbb,ccc]	5,74±1,97	1,70	9,20	7,53±1,29	4,20	10,00	9,14±0,92	6,70	10,00	59.368	0.000
C. Transitional cycling skills[aa,bbb,ccc]	7,04±1,31	3,35	9,40	7,79±0,96	4,35	9,40	8,65±0,93	6,75	10,00	26.973	0.001
1. Look left and right while cycling in a straight line[aa,bbb,ccc]	6,80±1,57	3,30	9,20	7,57±0,85	5,80	9,20	8,67±0,82	6,70	10,00	29.031	0.000
2. Brake to come to a controlled stop[ccc]	7,28±1,70	2,10	10,00	8,01±1,55	2,90	10,00	8,63±1,21	5,70	10,00	9.143	0.000
Cycling score[aaa,bbb,ccc]	7,25±0,70	5,40	8,60	8,08±0,76	5,10	9,40	8,89±0,50	7,80	9,80	69.492	0.000

[a](p≤0.05), [aa](p≤0.01), [aaa](p≤0.001) significant different for 7-8-year and 9-10-year-old children
[b](p≤0.05), [bb](p≤0.01), [bbb](p≤0.001) significant different for 9-10-year and 11-12-year-old children
[c](p≤0.05), [cc](p≤0.01), [ccc](p≤0.001) significant different for 7-8-year and 11-12-year-old children

Table A3. Scores in percentage for children showing correct behavior (standardized residual) and Chi Square for each point of interest for 7-8-year-old, 9-10-year-old and 11-12-year-old children.

Subskill	Points of interest	7-8 year	9-10 year	11-12 year	Chi-Square	df	p
1. Walk with the bicycle	1.1. Bicycle in balance while stepping over the obstacle	51,9 (-0.9)	61,4 (-0.1)	75,6 (1.1)	5,474	2	0,065
	1.2. Bicycle in balance while turning the bicycle	63,5 (-1.2)	86,4 (0.6)	90,2 (0.8)	12,058	2	0,002
3. Look left and right while cycling a straight line	3.1. Looking left: calling the right number	80,8 (-0.9)	100,0 (0.5)	100,0 (0.5)	17,633	2	0,000
	3.2. Looking left: cycling between the lines	50,0 (-0.3)	36,4 (-1.5)	73,2 (1.8)	11,751	2	0,003
	3.3. Looking right: calling the right number	78,8 (-0.9)	97,7 (0.5)	100,0 (0.6)	16,248	2	0,000
	3.4. Looking right: cycling between the lines	44,2 (-0.8)	47,7 (-0.4)	68,3 (1.4)	5,929	2	0,052
4. Cycle in straight line over a small obstacle	4.1. Cycling over the plank during the entire time	40,4 (-0.9)	47,7 (-0.1)	61,0 (1.1)	3,926	2	0,140
5. Cycle one handed in a circle	5.1. Left hand: without correcting with the other hand	19,2 (-3.2)	54,5 (0.4)	85,4 (3.2)	40,563	2	0,000
	5.2. Left hand: cycling between the lines	11,5 (-1.7)	29,5 (1.0)	29,3 (0.9)	5,888	2	0,053
	5.3. Right hand: without correcting with the other hand	23,1 (-2.9)	61,4 (0.8)	80,5 (2.5)	32,32	2	0,000
	5.4. Right hand: cycling between the lines	11,5 (-2.1)	22,7 (-0.5)	48,8 (2.8)	16,835	2	0,000
6. Cycle in a circle	6.1. Cycling between the lines	40,4 (-0.7)	54,4 (0.8)	46,3 (0.0)	1,923	2	0,382
7. Cycle a slalom in and out of markers	7.1. Without hitting any of the cones	94,2 (0.2)	90,9 (-0.1)	90,2 (-0.1)	0,592	2	0,744
	7.2. Take all the slaloms	94,2 (0.3)	81,8 (-0.6)	95,1 (0.3)	5,724	2	0,057
	7.3. Cycling between the lines	100,0 (0.1)	97,7 (-0.1)	97,6 (-0.1)	1,246	2	0,536
	7.4. Cycling through the gate	98,1 (0.0)	100,0 (0.1)	97,6 (-0.1)	1,003	2	0,606
8. Look over the left shoulder while cycling in a straight line	8.1. Signalling at shoulderheight	48,1 (-2.0)	77,3 (0.5)	95,1 (1.8)	25,965	2	0,000
	8.2. Shouting the right number	51,9 (-2.1)	90,9 (1.0)	97,6 (1.4)	34,135	2	0,000
	8.3. Cycling between the lines	25,0 (-2.5)	56,8 (0.7)	73,2 (2.1)	22,617	2	0,000
10. Cycle on a sloping surface	10.1. Cycle on the plank for the entire length	25,0 (-1.7)	40,9 (0.1)	58,5 (1.9)	10,746	2	0,005
11. Signal left and right while cycling in a straight line	11.1. Signalling left: cycling between the lines	50,0 (-1.7)	72,7 (0.2)	92,7 (1.7)	20,134	2	0,000
	11.2. Signalling left: signalling at shoulder height	42,3 (-2.4)	79,5 (0.7)	97,6 (2.0)	36,252	2	0,000
	11.3. Signalling right: cycling between the lines	50,0 (-1.0)	52,3 (-0.7)	82,9 (1.8)	12,283	2	0,002
	11.3. Signalling right: signalling at shoulderheight	46,2 (-2.4)	84,1 (0.7)	100,0 (1.9)	38,111	2	0,000
12. Brake to come to a controlled stop	12.1. Using both brakes	23,1 (-2.3)	52,3 (0.8)	61,0 (1.7)	15,269	2	0,000
	12.2. Stopping within the box	61,5 (-0.9)	70,5 (-0.1)	87,8 (1.2)	7,997	2	0,018
	12.3. Rear wheel does not skid	82,7 (0.0)	90,9 (0.6)	75,6 (-0.5)	3,572	2	0,168
	12.4. Rear wheel does not jump up.	88,5 (-0.3)	95,5 (0.2)	92,7 (0.0)	1,618	2	0,445

Chapter 2: Gaze behaviour in a laboratory context and in real-life

Paper 3: Is gaze behaviour in a laboratory context similar to that in real-life: A study in bicyclists

ABSTRACT

Numerous laboratory-based studies recorded eye movements in participants with varying expertise when watching video projections in the lab. Although research in the lab offers the advantage of internal validity, reliability and ethical considerations, ecological validity is often questionable. Therefore the current study[30] compared visual search in 13 adult cyclists, when cycling a real bicycle path of high and low quality and while watching a film clip of the same road. Dwell time towards five Areas of Interest (AOIs) was analysed. Dwell time (%) in the lab and real-life was comparable only for the low quality bicycle path. Both in real-life and the lab, gaze was predominantly driven towards the road. Since gaze behaviour in the lab and real-life tended to be comparable with increasing task-complexity (road quality), it was concluded that under certain task constraints laboratory experiments making use of video clips might provide valuable information regarding gaze behaviour in real-life.

[30] This part is based on **Zeuwts L[1]**, Vansteenkiste P[1], Cardon G, Lenoir M (2016). Is gaze behaviour in a laboratory context similar to that in real-life: A study in bicyclists *Transportation Research Part F. (In Press).* [1] Indicates shared first authorship.

1. Introduction

During most of our activities in daily life we use proactive eye movements for the pickup of visual information to be further processed and integrated in our actions in a wide variety of tasks (Foulsham et al., 2011). In sports and traffic education settings, exploring the visual scanning strategies in groups of varying expertise is of particular interest, since perception and processing of visual information have significant influence on performance (Memmert et al., 2009; Wulf, 2007). Although visual search in the real world is part of a well-coordinated system between body, head, and eyes when performing actions (Pelz et al., 2001) and substantially different from the laboratory, a large body of research measured eye movements in conditions not involving a significant motor response from the participants. Individuals have been presented with photographs (Henderson, 2003; Huestegge et al., 2010) or videos (Wetton et al., 2011) while visual search patterns have been measured. The main advantages of presenting participants with video clips while tracking their eye movements are experimental control, repeatability and safety (Chapman et al., 2002; Vickers, 2007; Williams et al., 2002). The main drawback of such designs is that the ecological validity is jeopardized. The evaluation of an individual's expertise in an artificial context that is different from the context in which this particular expertise has been built might be questionable indeed. The disruption of our natural perception-action cycle might lead to differences in the amount and nature of the information collected, and/or in the way this information is further processed. It is grace to this continuous linkage between information and action that we build our expertise in a wide variety of tasks.

Several studies have indeed indicated some inconsistencies between artificial and real-life eye tracking. Dicks, Button, & Davids (2010) compared gaze behaviours of football goalkeepers presented with video simulations (1) where the participants had to produce a verbal response or (2) a movement with a joystick. During three other conditions participants faced penalties in real time (3) where they were required to produce a verbal response, (4) a simplified body movement and (5) an actual interceptive movement response. During the actual interceptive task, when goalkeepers were presented with actual penalties, they fixated earlier and for a longer duration on the ball in contrast to the other simulated conditions. These results showed that in perceptual-motor behaviour, gaze functions differently depending on the task constraints, which might be attributed to the differentiation between ventral and dorsal stream (Milner and Goodale, 2005; Montagne et al., 2008; van der Kamp et al., 2001). The ventral stream is primarily concerned with perception and transforms visual input into internal representations. The dorsal stream on the other hand is involved with the rapid link between perception and movement control (Milner and Goodale, 2008).

Similar to the study of Dicks, Button & Davids (2010), Foulsham et al. (2011) reported significant differences in gaze behaviour while walking in real-life and watching the video of their own walk. Participants spent more time watching the path and fixated other pedestrians sooner when immersed in a real world which reflects the need of the participants to plan their footsteps. As gaze is highly task and temporal dependent, visual behaviour measured with video simulation tasks in laboratories may give an incorrect understanding of which visual information is used by skilled performers. In addition, laboratory based experiments often present video clips or images on a computer screen which results in a smaller visual angle than in the real world, easier detectable peripheral cues and the absence of vestibular cues and dimensionality which might result in a central bias (Foulsham et al., 2011; Kemeny and Panerai, 2003).

In conclusion, the value of eye tracking studies is defined by the trade-off between ecological validity (real-life) and internal validity (labo) (Duchowski, 2007). In skilled actions, such as in driving or sports, the relevant information for the task is often fixated just-in-time, highly task specific and in relation to a sequence of motor actions (Ballard and Hayhoe, 2010; Foulsham et al., 2011; Hayhoe et al., 2003; Land and Tatler, 2009). Therefore eye tracking in real-life with head mounted eye trackers, which allow full freedom of movement, can be considered the golden standard (Williams et al., 2005). In contrast, because it is almost impossible to control for all variables in 'real-life' experiments, presenting participants with film clips is in favour of experimental validity.

Since validation of screen-based studies is of particular interest, the current study describes visual search recorded with a head mounted eye tracker while cycling a real road and while watching a film clip of the same road on a projection screen when cycling on stationary bicycle. As this study is part of a strategy towards implementation of an educational package, and these 'off-line' training programs are used both in traffic education and sports training, validation of visual behaviour is essential to ensure that visual behaviour in lab conditions reflects visual behaviour in real life. To improve generalizability of the results, and guarantee a certain range of environmental conditions two types of bicycle path (low quality and high quality) were chosen. Given that the low quality bicycle path requires the bicyclist to continuously monitor the bicycle path for safe navigation, we hypothesize that gaze behaviour on the real road and in the lab will be more comparable.

2. Methods

2.1. Participants

A convenience sample of 13 adults (26.16±3.47 years of age; 8 females) participated in this study after signing the informed consent. Adults were recruited from Ghent University staff. Participants received a cinema ticket in return for their participation in the experiment. Informed consents were obtained from all participants. Parents read and signed an informed consent to approve for their children to participate in the test. In addition, permission for this study was received from the local Ethics Committee of the Ghent University Hospital.

2.2. Apparatus

Gaze behaviour during the real-life cycling task was recorded using the IviewX Eye Tracking Glasses 2.0 (SMI; Teltow GER) which had a gaze tracking accuracy of 0.5° over all distances (automatic parallax compensation), a gaze tracking range angle of 80° horizontally and 60° vertically, and a sampling rate of 50Hz binocular (figure 1). Eye movements were recorded by two small cameras in the eye tracking glasses while the scene camera recorded the surroundings at 30 fps, a resolution of 1024x720p, and a scene camera field of view of 60° horizontally and 46° vertically. The ETG was connected to a customized Samsung Galaxy S4 Smart recorder which was put in a small pouch and carried by the participant around his/her hip.

For the lab task, a Head mounted Eye tracking Device (HED; SMI; Teltow GER) was used. Video clips, consisting of the movie clips of the participants' own trials recorded with the ETG, were presented on a 2x1,50m projection screen which resulted in a visual angle of 53° horizontally and 41° vertically, while eye movements were recorded at 50Hz with a spacial accuracy of 1° (figure 2). Eye movements were saved using the IviewX software.

Table 1.Comparison of the ETG and HED.

	Real life	Laboratory
Eye tracking system	ETG	HED
Accuracy	0.5	1
Sampling rate	50	50
Stimulus	Real life environment	Scene camera images of real life exp.
Recording device	Smart recorder (samsung S4) carried along in small bag	Laptop which was stationed next to participant
Fixation detection algorithm		

Figure 1. Participant with the ETG.

Figure 2. Participant with the HED.

2.3. Procedure

On arrival participants were asked to sign an informed consent. After a brief explanation of the testing procedure, participants were randomly assigned to one of the two road types – low quality (LQ) or high quality (HQ) - to start with. For the real life cycling task, the saddle of the city bicycle (female model) was adjusted to the participant's height. Then, participants were asked to put on the ETG and a bicycle helmet. A five point calibration prior to the start of the test was performed indoors. Moreover, calibration was checked at the beginning of the test track, in the middle and at the end of each bicycle path. Following calibration, the Samsung Galaxy S4 Smart recorder was stowed away in the pouch on the hip belt and participants were asked to follow the test leader for a short familiarization trail. Participants were accompanied by two experimenters to the start of the two selected bicycle tracks. Here the participants were instructed to cycle the test track, consisting of a high quality bicycle path and a low quality bicycle path (±700m) at a self-selected pace. At this point, both experimenters cycled behind the participant to ensure unrestricted gaze behaviour. The two bicycle tracks in this experiment were cornered by a river on one side and trees on the other side of the track. The high quality bicycle path was 2m wide and had a smooth brick surface. In contrast, the low quality cycling track was only 1m30 in width and consisted of large tiles with crooked surface and holes in between (see figure 3).

For the lab-task, eleven months later, participants were called to the laboratory again to watch the movie clip of their own bicycle trip. Participants were asked to take place on a mounted city bicycle (female model), ± 2m in front of the projection screen, and were instructed to imagine that they were riding a bicycle in the real world. They were presented with their own video clips of the low quality bicycle path and the high quality bicycle path, which were recorded for each participant independently during the previous part of the experiment. They were unaware that the presented clips were coming from their own trial. Participants were required to cycle at a self-defined pace that felt natural. The order of cycling the high quality bicycle path and low quality bicycle path for the real cycle task and the simulation task were also randomized.

Figure 3. Screenshot of the LQ (left) and HQ (right) bicycle path with the four AOI's superimposed. A fifth AOI 'Pedestrians and cyclists' was not visible all the time.

2.4. Data analysis and Statistics

On both tracks, a trajectory of ±550m, was selected for further analysis. Beginning and ending of this trajectory was marked, based on landmarks. Scene video images and eye tracking recordings were combined to 'a gaze overlay video' in the BeGaze 3.2 analysis software of SMI (Teltow, GER). For the ETG and HED data, the analysis algorithm 'SMI fixation detection algorithm' was used. Making use of Semantic Gaze mapping, fixations were manually assigned to one of the five Areas of interest (AOI's): Road, Side, Focus of Expansion (FoE), Surroundings, and Pedestrians and Cyclists (see figure 3). Semantic gaze mapping was found to be a valid and reliable alternative for fixation-by-fixation analysis under conditions similar to the current study (Vansteenkiste et al., 2013). Eye movements which were not detected as fixations, saccades between the AOIs, and data loss were calculated as the difference between the sum of the dwell time percentages and 100%. This is referred to as 'no data'. Only when data loss did not exceed 50%[31] (Vansteenkiste et al., 2014a, 2013), participants were included for further analysis. Table 2 represents the number of participants with a sufficient dwell time % (>50%) for condition (LAB vs REAL) and road type (HQ vs LQ) to be included for further analysis. Dwell time for an AOI refers to the total amount of time a participant spends fixating the AOI. To

[31] Eye trackers do not provide information regarding the reasons for data loss. Additionally, there is no consensus with respect to the minimum tracking ratio for reliable results. Therefore, Vansteenkiste (2015) analysed dwell time with different inclusion criteria ranging from including only participants with less than 25% of data loss until including all participants. It was concluded that the inclusion criterion of 50% 'No Data' resulted in a good compromise between the number of participants included and missing data.

measure the variability in horizontal and vertical gaze distribution for both conditions (REAL and LAB) and road types (HQ and LQ) the raw data files were exported from BeGaze. Subsequently, the standard deviations for the X- and Y-coordinates of each fixation were calculated.

Table 2. Number of participants (pp) included for Pearson Correlation based on mean tracking ratio (TR) and standard deviation.

Road Type/Condition		LAB	REAL
Low Quality	Number of pp	12	11
	TR (%)	86,18	76,60
High Quality	Number of pp	13	12
	TR (%)	82,23	62,45

2.5. Statistics

For statistical analysis, SPSS 20.0 was used. Similarity between the two conditions (REAL and LAB) for dwell time % to each AOI (5 AOIs + No Data) for all trials in the two conditions (LQ and HQ) was calculated using a Pearson's Correlation Coefficient. Significance level was set at $p \leq 0.05$. A Repeated Measures ANOVA with two within-subjects factors (road type and condition) was used to analyse the differences for dwell time % for each AOI (Focus of Expansion (FoE), Surroundings, Pedestrian & Cyclists, Road, Side and No Data). The Huynh-Feldt correction was applied and significance level was set at $p \leq 0.05$.

3. Results

3.1. Comparison of gaze behaviour

Overall, a significant Pearson correlation coefficient of 0.507 ($p \leq 0.001$) for dwell time % between the LAB and REAL condition was found. When dwell time (%) was compared between LAB and REAL for each road condition (LQ and HQ) separately, a significant Pearson correlation coefficient was found for the low quality bicycle path ($r = 0.663$; $p \leq 0.001$) but not for the high quality bicycle path ($r = -0.030$; $p = 0.821$).

Mean dwell time percentages for AOI per condition and road type are presented in table 3. The repeated measures ANOVA resulted in significant interaction effects (road type x condition) for the AOIs Pedestrian and cyclists, Surroundings and Road (borderline significance). This indicates that the differences in dwell time between LQ and HQ bicycle path are more pronounced in real life than in the lab. There was no significant interaction for FoE, Side and No Data.

In the LAB-condition, participants showed higher dwell time percentages for the Focus of Expansion, Pedestrians and Cyclists and Side. However for the AOIs Surroundings, Road participants showed higher dwell times in the REAL-condition. In addition, the amount of data loss was higher in the REAL-condition and on the high quality bicycle path (figure 4).

For road type, participants showed higher dwell time percentages for the AOIs Focus of Expansion, Surroundings, Pedestrians and Cyclists on the high quality bicycle path. When cycling on the low quality bicycle path, the AOI road was fixated more compared to when cycling on the high quality cycling path. For the AOI Side, participants spent an equal amount of time fixating this AOI on the high and low quality bicycle path.

Table 3. Mean and standard deviations for dwell time % towards each AOI.

	LAB	REAL	LAB_LQ	LAB_HQ	REAL_LQ	REAL_HQ	Road Type * Condition			Road Type			Condition		
							F-Value	*p*	d	*F-Value*	*p*	d	*F-Value*	*p*	d
FoE	24,45±4.43	5.40±1.51	21,28±20,30	27,63±13,58	1,83±2,27	8,89±8,56	0,022	0,884	0.066	15,782	0,003	1.777	4,032	0,072	0.898
SURROUNDINGS	6.89±2.44	13.26±3.61	4,67±5,22	9,11±11,50	2,90±3,25	23,63±19,25	9,426	0,012	1.373	15,63	0,003	1.768	3,595	0,087	0.848
PEDESTRIAN & CYCLIST	10.94±1.79	4.09±1.26	1,73±1,86	20,14±12,37	0,42±0,51	7,75±8,14	14,515	0,003	1.704	19,486	0,001	1,974	26,427	<0,001	2.299
ROAD	29.49±4.75	48.01±3.92	45,50±25,72	13,47±9,96	71,92±16,51	24,11±18,43	4,373	0,063	0.935	46,049	<0,001	3.035	13,506	0,004	1.644
SIDE	12.24±1.91	3.17±0.86	12,93±8,70	11,56±6,70	4,14±4,14	2,22±2,35	0,052	0,824	0.102	0,976	0,347	0,552	17,937	0,002	1.894
NO DATA	15.99±2.47	26.10±2.62	13,89±8,27	18,08±14,39	18,80±10,85	33,40±9,08	2,284	0,162	0.676	16,434	0,002	1.813	9,725	0,011	1.395

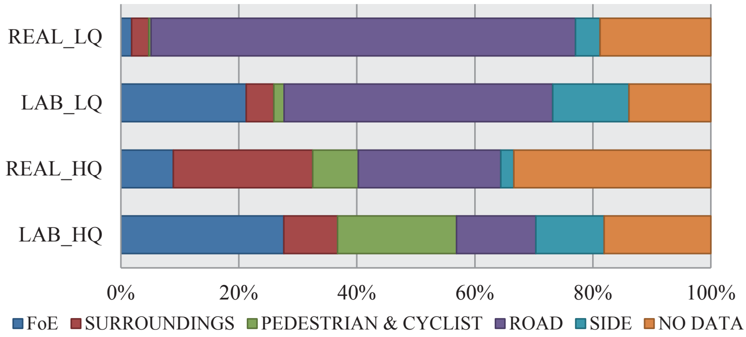

Figure 4. Dwell time % towards each AOI

3.2. Horizontal and vertical gaze distribution

For horizontal and vertical gaze distribution there was no interaction effect for condition and road type (table 4). Participants showed a more extended gaze distribution in the horizontal plane on the low quality bicycle path while there was no difference for gaze distribution in the vertical plane between the two road types. In the real-life cycling condition, participants showed a more extended visual search along the vertical axis while there was no difference in visual search along the horizontal axis.

Table 4. Horizontal and vertical gaze distribution

	LAB	REAL	SD_LAB_HQ	SD_LAB_LQ	SD_REAL_HQ	SD_REAL_LQ	Road Type * Condition			Road Type			Condition		
							F-Value	*p*	d	*F-Value*	*p*	d	*F-Value*	*p*	d
X-coordinates	92,56±44,48	101,86±32,85	97.92 ± 41.85	87.19 ± 48.38	118.28 ± 26.77	85.43 ± 30.93	1,67	0,225	0.578	5,489	0,041	1.048	0,67	0,432	0.366
Y-coordinates	81,87±34,08	112,37±33,79	82.53 ± 32.35	81.20 ± 37.30	112.38 ± 29.25	112.35 ± 39.28	0,008	0,929	0.04	0,018	0,896	0.06	17,239	0,002	1.857

4. Discussion

This study aimed to document the trade-off between ecological validity and internal validity of gaze behaviour in real life and the laboratory. Since studies regarding visual behaviour often make use of pictures or movies in restricted laboratory settings, generalisation towards visual behaviour in the real world remains questionable as the evaluation of expertise is often context dependent. Therefore the current investigation aimed to address to what extent unrestrained gaze behaviour in real-life and gaze behaviour in the lab are similar. Visual search during cycling a real road and cycling a stationary bicycle in the lab under different environmental conditions is analysed.

Regarding the (dis)similarities between gaze behaviour in the lab and real-life, the nature of the task complexity and task demands are of interest (Dunbar et al., 2001; Egan, 2012; Jovancevic et al., 2006) since fixation behaviour in real-life is suggested to be dominated by task-relevant objects (Hayhoe et al., 2003; Land and Tatler, 2009). Indeed, when task demand is higher (i.e. when cycling the low quality bicycle path) visual search in real-life and in the lab shows more similarities than when task demand is lower (high quality bicycle path). When cycling the LQ bicycle path, safe travel requires continuous monitoring of the bicycle path for direct control (Vansteenkiste et al., 2014b, 2013). Therefore gaze is predominantly driven to the road, both in real-life (71,92%) as in the laboratory (45,50%). Foulsham et al. (2011) compared gaze behaviour of fourteen adults when walking in real-life and watching a video clip of their own walk in the laboratory. Accordingly, they found that gaze behaviour in real life was more directed to the road. Also for walking, ’t Hart et al. (2009), suggested a more pronounced bias of gaze allocation towards the travel path compared to the laboratory conditions which might be attributed to the increased task demands of navigating through a complex environment. However, when cycling the LQ bicycle path in the lab, task demands decrease since there is no need for direct control of the bicycle. This resulted in decreased dwell times towards the road as monitoring the road is not a prerequisite of safe travel in the lab condition.

Although gaze in real-life was directed significantly more towards the road compared to gaze in the lab (figure 4), since the road was fixated most in both conditions it might be suggested that both in the laboratory and in real-life gaze is strongly controlled by top-down processes (Hayhoe et al., 2003; Jovancevic et al., 2006; Land, 2009). Top-down cognitive processes guide gaze behaviour when and where it is needed (Tatler, 2009). Previous research suggested that attention is primarily driven top-down in “real world active tasks” (Hayhoe et al., 2003). Nevertheless, Land (2009) concluded that gaze in both passive visual tasks and visually guided actions is dominated by top-down instructions which might support the findings of our study.

Moreover it can be assumed that cycling in real-life is more demanding than cycling in the laboratory since actual steering and navigating in the lab were eliminated. As a result, participants in the lab condition could allocate their visual attention more towards more distant or attracting regions of the visual field (Vansteenkiste et al., 2013) f.e. the focus of expansion which is essential for proper navigation, pedestrians and other cyclists (Risko et al., 2012). However, figure 4 presents a shift in gaze behaviour according to the task requirements (LQ vs HQ). When engaging in the laboratory condition, participants were told to behave as they normally would when cycling in the real world. Therefore it appeared that the participants were aware of the task demands resulting in a top-down influence of task requirements on gaze behaviour (’t Hart et al., 2009; Foulsham et al., 2011). This implicates that gaze behaviour in the lab - under certain task constraints - might predict gaze behaviour in real-life to some extent.

Nevertheless, an individual's expertise in a wide variety of tasks is also context dependent e.g. the context in which this particular expertise has been built ('t Hart et al., 2009). This might lead to differences in the amount and nature of the collected information, the processing of this information, and the linkage between information and action. The disruption between perception and action in simplified laboratory-based studies is suggested to influence visual perception due to separated visual pathways for perception (ventral stream) and action (dorsal stream) (Milner and Goodale, 2008, 2005). Accordingly, Bootsma (1989) argued that the disruption between perception and action, might result in disproportionately increased use of ventral stream processing. Dicks et al. (2010), repeating the study of Savelsbergh et al. (2005), compared the influence of active and passive interceptive tasks in a real and simulated environment on goal keepers visual behaviour. In contrast to the simplified laboratory conditions where the hip or kicking leg of the penalty taker was fixated, it was found that during the actual interceptive task in a real environment, the goalkeepers predominantly attended to the ball. The authors concluded that a video simulation task requiring a button press or the manipulation of a joystick may be insufficient for evaluating an athlete's visual search behaviour in his sports environment.

Therefore the participants of our study cycled a stationary bicycle to ascertain that the perception-action coupling was closer to the natural situation. Nonetheless, visual search in the lab showed certain substantial differences compared to gaze behaviour in real life e.g. (1) the road was fixated more when actually cycling compared to the video simulation where participants fixated more towards (2) the focus of expansion (Table 2). However, the smaller screen size in the laboratory resulted in smaller AOIs and smaller field of view compared to the real world which in turn might cause a misinterpretation of the reported gaze behaviour. E.g when dwell time percentages from the video simulation towards the road and the side of the road are combined, the amount of time spent fixating the travel path between the two conditions becomes increasingly similar.

Given that head mounted eye tracking devices often provide a measure of the eye tracking precision under ideal conditions and eye tacking accuracy is often measured at one fixed distance, this might have resulted in a parallax effect (Holmqvist et al., 2011). Parallax errors result from the scene camera and eye camera not being on the same line and increases when an object is closer or further from the distance which was used for the calibration. To counter calibration issues a calibration grid with concentric circles at different distances could improve calibration and provide a measure of eye tracking accuracy. However, according to the manufacturer the ETG used in this paper should compensate for the parallax effect.

Furthermore, the centrality bias – a strong tendency to fixate the centre of the screen – is suggested to account up to 56% of eye movements when viewing static images due to a framing effect of the monitor (Egan, 2012). Tatler et al. (2011) reported this central bias to be weaker when participants are presented with continuous video clips. Conform to Egan (2012) and Tatler et al. (2011), participants appeared to fixate the focus of expansion substantially more often in the video simulation task compared to cycling in real-life. However, this tendency to fixate the centre of the screen is not entirely supported by means of horizontal gaze distribution since there was no significant main effect for condition. Notwithstanding that horizontal gaze distribution only appears to differ between road types and not condition, vertical gaze distribution in the video simulation task was considerably more dense compared to the real-life cycling task. Likely, less extensive scanning in the vertical plane might be attributed to the reduced visual angle due to the smaller screen side in the lab-condition.

According to the study of ’t Hart et al. (2009), the video clips which were used in this study were obtained from the head-centered camera of the eye tracker (sample rate: 30Hz). This implies that observers visual scanning in the lab condition is limited since observers’ gaze allocation is restricted and directed to the places in the environment the wearer of the camera looked. Future research might therefore try to make use of a virtual reality environment. Additionally, presenting participants – when cycling on a stationary bicycle in the lab - with video clips of the travel path in front as well as the left and right side of travelled path might ascertain more realistic visual scanning behaviour. With respect to contrast sensitivity, also the resolution of the projections should be considered.

Moreover, according to the study of Dicks et al. (2010), our study attempted to sustain the natural link between perception and action. As the participants of our study were instructed to cycle at a self-defined cadence on a stationary bicycle, the disruption of the perception-action coupling was reduced. Nevertheless, it was not possible to synchronize the video clips with the bicycle ergometer. Therefore this study is limited since only a qualitative observation of participants cycling behaviour with respect to cycling speed and steering behaviour in the lab condition was made. To increase ecological validity in laboratory studies, future studies might want to make use of virtual reality which offers the possibility of synchronizing the bicycle ergometer and video stimuli, measure head movements and use a wider field of view. Also the integration of vestibular information, f.e. the increased sensation of vibrations when cycling over a LQ bicycle path, might favor ecological validity. Furthermore, including skilled and beginner bicyclists might have influence on visual behaviour as well, given that control over the bicycle in beginner bicyclists in not yet automated which might increase task-demands.

5. Conclusion

As this study is part of a strategy towards implementation of an educational package, the validation of visual behaviour in simulated or laboratory environments and real-world environments is of interest. Although laboratory studies offer the advantage of internal validity and ethical considerations, ecological validity is often questioned. Therefore gaze behaviour when cycling a low quality and high quality road in real life and in the lab was analysed. It is found that gaze behaviour between the two conditions is somewhat different. However, with increasing task complexity, these differences in gaze behaviour tend to disappear. This implies that under certain task constraints, lab experiments making use of video clips might provide valuable information regarding gaze behaviour in real-life, especially in more demanding tasks.

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Chapter 3: Visual behaviour of young cyclists in real-life

Paper 4: The implications of low quality bicycle paths on the gaze behaviour of learner cyclists

ABSTRACT

In a recent study, Vansteenkiste et al. (2014) described how low quality bicycle paths cause an apparent shift of visual attention from distant environmental regions to more proximate road properties. Surprisingly, this shift of visual attention was not accompanied by an adaptation in cycling speed. The current experiment[32] investigated to what extent these findings are applicable for young learner bicyclists (aged 6 to 12 years). Since young learner bicyclists do not yet have mature visual and motor skills, it was expected that the implications of a poor road surface would be larger for them than for experienced adult bicyclists. In general, children looked less to the road and more to task irrelevant regions, but the magnitude of the shift of visual attention when cycling on a low quality bicycle track was similar to that of adults. Although children cycled slower than adults, they did not cycle slower on the low quality track compared to the high quality track. Overall, our results suggest that children displayed a different visual-motor strategy than adults, characterized by lower movement times and a different visual behaviour, and that they responded in a similar way to environmental constraints compared to adults.

[32] This part is based on Vansteenkiste P[1], **Zeuwts L[1]**, Cardon G, Lenoir M (2016). The implications of low quality bicycle paths on gaze behavior of cyclists: a field test. *Transportation Research Part F. (Submitted).* [1] Indicates shared first authorship.

1. Introduction

Recently, many studies have emphasized the benefits of a modal shift from car driving to bicycling as a healthy, sustainable and cheap way for short-distance displacements (Rabl & de Nezelle, 2012; de Hartog et al., 2010). An increasing number of bicycle users leads to reduced health problems related to a lack of physical activity, reduces road congestion, and has been associated with an improved emotional well-being (Hamer & Chida, 2008; Oja et al., 2011; Pucher and Buehler, 2012). Therefore, many countries have recognized the potential benefits of promoting cycling as a mode of transportation. Unfortunately, with increasing numbers of bicyclists, also the number of bicycle accidents increase (Juhra et al., 2012). Even though the individual risk of accidents decreases with increasing numbers of bicyclists (Jacobsen, 2003), and the benefits of cycling far outweigh the risks (de Hartog et al., 2010), the actual and perceived risks of cycling in busy traffic is still a major drawback for many people (Horton, 2007). Although all bicyclists can be considered vulnerable road users, accident analyses show that especially children (<15 years of age) and older people (>65 years of age) are at risk (Carpentier and Nuyttens, 2013; DEKRA, 2011).

Since human locomotion is primarily guided and controlled by visual information (Patla, 1997; Shinar et al., 1977; Wilkie et al., 2010), identifying the differences in gaze behaviour between 'high risk groups' and less accident prone bicyclists could improve our understanding regarding the causes for their overrepresentation in accident statistics. Unfortunately, the visual behaviour of bicyclists is poorly documented, and to our knowledge, the visual behaviour of young learner bicyclists cycling on real cycling tracks has not yet been described.

In a recent study, Vansteenkiste et al. (2014) showed that low quality cycling tracks affect the visual attention of adult bicyclists to a large extent. On a low quality cycling track, gaze was directed more than twice as much towards the proximate road properties as compared to on a high quality track (63% vs. 25%, respectively). This suggests that on low quality cycling tracks, cyclists have less spare time to anticipate to the upcoming trajectory compared to a high quality track, which may affect the alertness and responsiveness of bicyclists to environmental hazards. Unfortunately, this study only included experienced adult bicyclists. To investigate to what extent the visual behaviour of young learner bicyclists is different from that of adults, this experiment was repeated with 6 to 12 year old children.

Experiments in obstacle avoidance and road crossing behaviour have shown that children younger than ten years old adopt different visual-motor strategies than adults (Ampofo-Boateng and Thomson, 1991). Compared to adults, they rely less on peripheral vision (Franchak and Adolph, 2010), look more to irrelevant areas (Whitebread and Neilson, 2000), anticipate less on future actions (Berard and Vallis, 2006), and have more difficulties to synchronize their actions to other moving objects (Chihak et al., 2010; Connelly et al., 1998). To compensate for this lack of mature perceptual-motor skills, children seem to adopt more cautious locomotor strategies, characterized by lower moving speeds and larger safety margins when an obstacle has to be avoided (Pryde et al., 1997).

If these findings can be translated to cycling behaviour, children in the current experiment will probably cycle slower, spend more time watching irrelevant regions and spend less time watching the distant road. Since children adopt more cautious locomotor strategies in complex environments, it is also expected that the difference in cycling speed between adults and children will be bigger on the low quality cycling track than on the high quality cycling track.

2. Methods

2.1. Participants

A convenience sample of eighteen adults (aged 26.50 ± 3.42 years; 10 females) and sixteen children (aged 9.25 ± 1.95 years; 10 females) took part in the study. However, the data of three adults and four children did not meet the inclusion criteria (see section 2.4. Data analysis). Adults were recruited from Ghent University staff, children were recruited by spreading a request for volunteers via a school in the vicinity of the university campus. All children were accompanied by at least one of their parents and received a cinema ticket at the end of the experiment. Informed consents were obtained from all participants. Parents read and signed an informed consent to approve for their children to participate in the test. In addition, permission for this study was received from the local Ethics Committee of the Ghent University Hospital.

2.2. Apparatus

Gaze behaviour was recorded using the Eye Tracking Glasses 2.0 (ETG) of SensoMotoric Instruments (SMI; Teltow, Germany). The frame of these eye tracking glasses contains two small cameras to record eye movements of both eyes, and one scene camera to record the forward view of the participant. Using dark pupil position and corneal reflection, the system records eye movements at 30Hz and with an accuracy of 0.5°. Eye movements and scene camera images were saved on a 'Smart Recorder', which was the size of a smartphone and was put in a waist bag. In contrast to the Head mounted Eye tracking Device (HED; SMI; Teltow, Germany), used in the experiment of Vansteenkiste et al. (2014), the ETG was capable of performing eye tracking in broad daylight.

Figure 1. Child participant with eye tracker (ETG)

2.3. Protocol and cycling route

On arrival the participant (and his/her accompanying parent) was briefed about the experiment, and asked to read and sign the informed consent. For the adults, the saddle of a standard city bicycle (women's model) was adapted to the participant's height. Children were asked to bring their own bicycle. When the participant was ready, the eye-tracking glasses were put on and the three-point calibration of the eye tracking device was performed indoors. Participants were accompanied by two experimenters (one cycling in front, one cycling behind) to the start of one of the two selected bicycle tracks, where a quick calibration check was performed. After this, the participant was instructed to cycle at a self-selected pace in front of the experimenters until the next crossroad (±700m).

The two bicycle tracks selected for the current experiment were separated from the car road by trees on the one side, and neighboured by a bush and a river on the other side (see Fig. 2). One of the two tracks is a recently renewed cycling track of 2m in width and has a smooth brick surface. This track will be referred to as the high quality track (HQ). The other track is only 1m30 wide and consists of large tiles that are often crooked and are lacking at some places. This track will be referred to as the low quality track (LQ).

Participants were randomly assigned to start on the LQ or the HQ track. When the participant completed the two tracks, another calibration check was performed, and the experimenters accompanied him/her back to the university. Finally, the gaze data was saved, and the eye tracking device was removed from the participant.

2.4. Data analysis

Based on landmarks, a trajectory of ±550m (± 1min 50sec.) on both tracks was selected for further analysis. The time necessary to complete these trials (*cycling duration* in seconds) was used as a measure for cycling speed. Scene video images and eye tracking recordings were combined to a ‘gaze overlay video’ using the BeGaze 3.2 analysis software of SMI (Teltow, Germany). The two trials were then selected for further analysis, and the SMI fixation detection algorithm was applied to determine fixations (unfortunately, SMI currently does not disclose details concerning the algorithm). Using the analysis tool ‘Semantic Gaze Mapping’, all fixations were manually assigned to one of the following five Areas Of Interest (AOIs) : ‘Road’, ‘Side’, ‘Focus Of Expansion’ (FoE), ‘Surroundings’, and ‘Pedestrians & Cyclists’ (See Fig. 2). The *average fixation frequency* (# fixations per second) and *average fixation duration* were calculated per trial and per AOI, for both adults and children. The total dwell-time (i.e. “the sum of the duration of the fixations and saccades that hit the AOI”; BeGaze 3.1 manual jan. 2012, SMI) to each AOI was divided by the trial duration to calculate the *dwell time percentage* to each of the AOIs. This fixation-by-fixation analysis has been described as a valid and time-saving alternative to the classic frame-by-frame analysis (Vansteenkiste et al., 2013).

Figure 2. Screen shot of the low quality (left) and high quality (right) cycling track with AOI overlay. Note that this grid was not used to determine the fixation location, each of the fixations was assigned manually to one of these AOIs, or to a fifth AOI ‘Pedestrians & Cyclist’.

The difference between the sum of the dwell time percentages and 100% was named '*NoData*'. This measure represents eye movements that were not detected as fixations, saccades between AOIs, blinks, fixations outside of the reach of the scene camera, and data loss during the experiment. Participants were only included for further analysis when the share of NoData was less than 50%[33]. Gaze data of three adults and three children did not meet this inclusion criteria. Additionally, data of one child was lost due to computer failure. Therefore further analysis is based on the remaining 15 adults (aged 25.93 ± 2.71 years; 8 females) and 12 children (aged 9.08 ± 2.07 years; 8 females).

Finally, the eye movement distribution was analyzed by calculating the standard deviation of the x and the y coordinates of the gaze, relative to the reference frame (scene camera). A more distributed focus of attention therefore results in higher standard deviations. It should be taken into account however that this measure only applies for eye movements, not head movements.

2.5. Statistics

The effects of age and road quality on cycling speed, fixation frequency, fixation duration, dwell time %, and eye movement distribution (x and y coordinates) were analyzed using repeated measures (M)ANOVA tests with HQ and LQ as within subjects factor, and the age group as between factor. Where applicable, the AOIs were added as measures. Significant interaction effects were further investigated using independent-samples T-tests and paired-samples T-tests. The Huynh-Feldt correction was applied and significance level was set at $p \leq 0.05$.

3. Results

3.1. Cycling duration

Average completion times per road type and age group can be found in table 1. Adults cycled significantly faster than the children ($F_{1,25} = 23.355$; $p < 0.001$; $d = 1.945$), but no significant effect of road quality was found on the cycling speed ($F_{1,25} = 0.203$; $p = 0.656$; $d = 0.181$). No speed*age interaction was found either ($F_{1,25} = 0.047$; $p = 0.830$; 0.087).

Table 1. Average completion time in seconds per road type and age group. Same superscript letters indicate significant differences.

	High Quality	Low Quality	Average
Adults	102,38 ± 8,49	103,62 ± 7,89	103,00 ± 8,08[b]
Children	122,31 ± 14,97	122,74 ± 14,12	122,52 ± 14,24[b]
Average	111,23 ± 15,35	112,11 ± 14,55	

[33] Unfortunately eye-trackers do not give any information about the reasons for data loss, and there is no consensus about what the minimum tracking ratio should be for reliable results. The current results of dwell time % were analyzed with different inclusion criteria ranging from including all participants to including only participants with less than 25% NoData. Based on these analyses, the inclusion criterion of 50% NoData was selected. This seemed a good compromise between having more participants with more missing data, or having a smaller group with less missing data.
See appendix A for dwell time percentages with different inclusion criteria.

3.2. Fixation frequency and duration

An overview of average fixation frequencies and durations can be found in Table 2. In general, no difference in fixation frequency was found between adults and children ($F_{1,25}$ = 0.070; p = 0.794; d = 0.106). However, adults fixated the AOI Road more frequently ($F_{1,25}$ = 14.396; p = 0.001; d = 1.527), and less frequently the AOIs Side ($F_{1,25}$ = 17.511; p < 0.001; d = 1.684) and Surroundings ($F_{1,25}$ = 8.493; p = 0.007; d = 1.173) compared to children.

Both adults and children fixated the AOIs Road ($F_{1,25}$ = 108.182; p < 0.001; d = 4.186) and Side ($F_{1,25}$ = 9.830; p = 0.004; d = 1.262) more frequently on the low quality track, while Surroundings ($F_{1,25}$ = 44.681; p < 0.001; d = 2.690), FoE ($F_{1,25}$ = 32.906; p < 0.001; d = 2.309) and Pedestrians & cyclists ($F_{1,25}$ = 28.784; p < 0.001; d = 2.159) were more frequently fixated on the high quality track. Other differences between adults and children, and between the high and low quality track, were not significant (p > 0.05).

Adults and children did not show significant differences in overall average fixation duration ($F_{1,25}$ = 0.009; p = 0.924; d = 0.038), nor for average fixation duration per AOI (p < 0.05). However, an overall significant interaction effect was found ($F_{1,25}$ = 4.495; p = 0.044; d = 0.853). This interaction effects suggests that the fixation duration of children decreases on the low quality track compared to the high quality track, while it stays equal for adults. A similar interaction effect was also found for fixation duration towards AOIs Road ($F_{1,25}$ = 7.224; p = 0.013; d = 1.082), Side ($F_{1,24}$ = 4.850; p = 0.037; d = 0.886) and Cyclists & pedestrians ($F_{1,19}$ = 9.931; p = 0.005; d = 1.268), with children showing a decreased fixation duration in the low quality track.

Furthermore, average fixation duration was found to be significantly lower on the low quality track when looking at AOIs surroundings ($F_{1,24}$ = 9.146; p = 0.006; d = 1.217) and FoE ($F_{1,22}$ = 4.968; p = 0.036; d = 0.897). Other differences between adults and children, and between the high and low quality track, were not significant (p > 0.05).

Table 2. Averages and standard deviations of fixation frequency (number of fixations per second) and fixation duration (in milliseconds). Fixations under 'Undefined' are those that were not defined to any of the other AOIs since they fell outside of the reach of the scene video. Same superscript letters indicate significant differences. Note that independent samples T-tests and paired-samples T-tests were only carried out for significant interaction effect.

		Fixation frequency			Fixation duration		
AOI	**Group**	**High Quality**	**Low Quality**	**Average**	**High Quality**	**Low Quality**	**Average**
Road	adults	0,84 ± 0,58	2,41 ± 0,59	1,62 ± 0,98^{i}	144,29 ± 17,54^{l}	149,91 ± 15,31	147,10 ± 16,43
	children	0,43 ± 0,23	1,53 ± 0,67	0,98 ± 0,75^{i}	162,04 ± 21,58^{l,n}	142,53 ± 23,14^{n}	152,28 ± 24,05
	Average	0,66 ± 0,49^{a}	2,02 ± 0,76^{a}		152,18 ± 21,06	146,63 ± 19,15	
Side	adults	0,12 ± 0,10	0,22 ± 0,21	0,17 ± 0,17^{j}	141,06 ± 47,36	155,87 ± 31,86	148,47 ± 40,31
	children	0,34 ± 0,23	0,66 ± 0,45	0,50 ± 0,39^{j}	158,46 ± 29,14^{o}	136,68 ± 18,41^{o}	147,57 ± 26,31
	Average	0,22 ± 0,20^{b}	0,41 ± 0,40^{b}		149,09 ± 40,22	147,01 ± 27,79	
Surroundings	adults	0,84 ± 0,57	0,16 ± 0,14	0,50 ± 0,53^{k}	150,11 ± 21,69	128,84 ± 29,25	139,47 ± 27,49
	children	1,30 ± 0,56	0,43 ± 0,37	0,87 ± 0,64^{k}	160,08 ± 22,50	148,73 ± 22,98	154,40 ± 22,99
	Average	1,05 ± 0,60^{c}	0,28 ± 0,29^{c}		154,71 ± 22,21^{f}	138,02 ± 27,92^{f}	
FoE	adults	0,44 ± 0,38	0,15 ± 0,20	0,30 ± 0,33	161,92 ± 37,03	152,38 ± 31,00	157,15 ± 33,75
	children	0,38 ± 0,28	0,18 ± 0,13	0,28 ± 0,24	172,43 ± 30,50	145,77 ± 32,85	159,10 ± 33,86
	Average	0,41 ± 0,33^{d}	0,17 ± 0,17^{d}		167,18 ± 33,61^{g}	149,08 ± 31,42^{g}	
Cycl-Ped	adults	0,32 ± 0,25	0,04 ± 0,07	0,18 ± 0,23	157,29 ± 23,73	169,93 ± 46,95^{m}	163,61 ± 36,78
	children	0,33 ± 0,26	0,06 ± 0,05	0,19 ± 0,23	172,58 ± 31,37^{p}	133,71 ± 30,74^{m,p}	154,06 ± 35,69
	Average	0,32 ± 0,25^{e}	0,05 ± 0,06^{e}		165,3 ± 28,40	150,96 ± 42,52	
Undefined	adults	0,02 ± 0,03	0,00 ± 0,01	0,01 ± 0,03	149,06 ± 78,39	95,70 ± 8,33	122,65 ± 59,10
	children	0,00 ± 0,01	0,01 ± 0,01	0,01 ± 0,01	144,15 ± 62,72	121,9 ± 15,56	133,03 ± 39,46
	Average	0,01 ± 0,03	0,01 ± 0,01		147,78 ± 66,94	104,43 ± 16,53	
Overall	adults	2,57 ± 0,44	2,98 ± 0,54	2,78 ± 0,53	153,18 ± 25,61	150,01 ± 14,88	151,60 ± 20,64
	children	2,78 ± 0,56	2,87 ± 0,84	2,83 ± 0,70	161,99 ± 22,98^{q}	142,62 ± 20,51^{q}	152,31 ± 23,48
	Average	2,67 ± 0,50	2,93 ± 0,68		157,10 ± 24,42^{h}	146,73 ± 17,64^{h}	

3.3. Gaze location

An overview of the dwell time percentages per age group, road type, and AOI, is presented in Table 3 and Figure 3. No Age*Road quality interactions were found ($p < 0.05$ for all AOIs), except for NoData ($F_{1,25}$ = 5.234; p = 0.031; d = 0.921). For the adults, the share of NoData was lower on the low quality track than on the high quality track, while this did not change among children.

Adults were found to spend significantly more time watching the road ($F_{1,25}$ = 15.468; p < 0.001; d = 1.583) whereas children looked more to the side of the road ($F_{1,25}$ = 17.608; p < 0.001; d = 1.689) and the surrounding environment ($F_{1,25}$ = 5.606; p = 0.026; d = 0.953). No significant difference in dwell time % was found for the AOIs FoE ($F_{1,25}$ = 0.186; p = 0.670; d = 0.174), cyclists & pedestrians ($F_{1,25}$ = 0.034; p = 0.856; d = 0.074), and NoData ($F_{1,25}$ = 2.295; p = 0.142; d = 0.61).

On the low quality road, participants looked significantly more to the road itself ($F_{1,25}$ = 94.300; p < 0.001; d = 3.909) and the side of the road ($F_{1,25}$ = 6.863; p = 0.015; d = 1.054), and less to surroundings ($F_{1,25}$ = 47.089; p < 0.001; d = 2.762), FoE ($F_{1,25}$ = 21.257; p < 0.001; d = 1.856), and cyclists & pedestrians ($F_{1,25}$ = 25.423; p < 0.001; d = 2.029). Furthermore, the size of NoData was lower on the low quality road compared to the high quality road ($F_{1,25}$ = 6.998; p = 0.014; d = 1.065).

Table 3. Dwell time percentages per AOI, Age, and road quality. Same superscript letters indicate significant differences.

		Road		
AOI	**Group**	**High Quality**	**Low Quality**	**Average**
Road	Adults	24,31 ± 19,86	70,28 ± 16,84	**47,30 ± 29,56^{a}**
	Children	11,73 ± 6,94	43,18 ± 17,17	**27,45 ± 20,55^{a}**
	Average	**18,72 ± 16,54^{d}**	**58,24 ± 21,58^{d}**	
Side	Adults	1,97 ± 1,85	4,09 ± 4,03	**3,03 ± 3,27^{b}**
	Children	7,30 ± 5,54	14,08 ± 11,52	**10,69 ± 9,50^{b}**
	Average	**4,34 ± 4,71^{e}**	**8,53 ± 9,52^{e}**	
Surroundings	Adults	23,35 ± 18,2	3,45 ± 3,45	**13,40 ± 16,37^{c}**
	Children	34,84 ± 15,6	9,60 ± 8,24	**22,22 ± 17,75^{c}**
	Average	**28,46 ± 17,75^{f}**	**6,19 ± 6,7^{f}**	
FoE	Adults	11,44 ± 12,31	3,20 ± 4,78	**7,32 ± 10,09**
	Children	8,82 ± 6,99	3,53 ± 2,90	**6,18 ± 5,89**
	Average	**10,27 ± 10,20^{g}**	**3,35 ± 3,99^{g}**	
Cycl-Ped	Adults	7,81 ± 6,89	0,85 ± 1,40	**4,33 ± 6,03**
	Children	7,97 ± 6,92	1,19 ± 1,13	**4,58 ± 5,96**
	Average	**7,88 ± 6,77^{h}**	**1,00 ± 1,28^{h}**	
NoData	Adults	31,12 ± 9,57^{k}	18,13 ± 10,50^{j,k}	**24,62 ± 11,88**
	Children	29,35 ± 9,59	28,41 ± 10,04^{j}	**28,88 ± 9,61**
	Average	**30,33 ± 9,43^{i}**	**22,70 ± 11,36^{i}**	

AOI: Area of interest, FoE: Focus of Expansion, Cycl-Ped: Cyclists and pedestrians.

Table 4. Horizontal and vertical distribution of eye movements for both adults and children. Same superscript letters indicate significant differences.

	SD of X-coordinates			SD of Y-coordinates		
	HQ	LQ	**Average**	HQ	LQ	**Average**
Adults	120,81 ± 23,85	82,73 ± 26,90	**101,77 ± 31,61**	105,44 ± 29,23	106,55 ± 36,83	**105,99 ± 32,67**
Children	134,62 ± 32,02	102,74 ± 33,17	**118,68 ± 35,80**	121,42 ± 27,57	123,31 ± 33,57	**122,37 ± 30,05**
Average	**126,94 ± 28,09[a]**	**91,62 ± 30,95[a]**	**109,28 ± 34,28**	**112,54 ± 29,11**	**114,00 ± 35,76**	**113,27 ± 32,30**

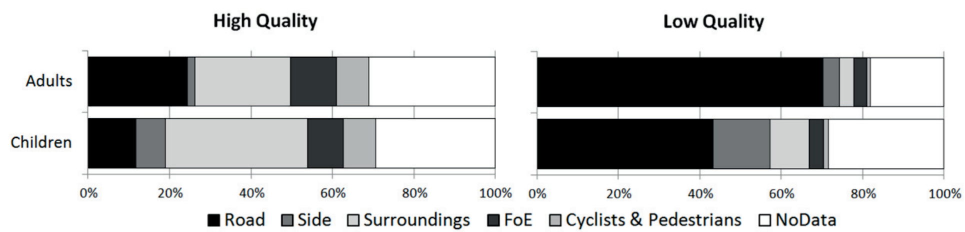

Figure 3. Dwell time percentages towards the 6 AOIs per age group and per road type.

3.4. Eye movement distribution

There was no interaction effect between road quality and group for the gaze distribution along x-axis ($F_{1,25}$ = 0.701; p = 0.411; d = 0.337) nor along the y-axis ($F_{1,25}$ = 0.006; p = 0.941; d = 0.031) (Table 4.). No differences were found either between the eye movement distribution of adults and children both on the x-axis ($F_{1,25}$ = 2.583; p = 0.121; d = 0.647) as on the y-axis ($F_{1,25}$ = 2.108; p = 0.159; d = 0.584). Along the x-axis, eye movement distribution was significantly larger on the high quality road compared to the low quality road ($F_{1,25}$ = 89.114; $p < 0.001$; d = 3.800), but not along the y-axis ($F_{1,25}$ = 0.080; p = 0.779; d = 0.114).

4. Discussion

This study aimed to examine visual behaviour in child and adult cyclists when cycling on a high and low quality bicycle path. In general, children were found to cycle slower than adults, and looked more towards the side of the road and the surroundings, whereas adults focussed more on the road itself. The quality of the cycling track did not have any effect on the cycling speed of both adults and children but it did affect their gaze behaviour. Both children and adults showed an apparent shift of attention towards the AOI 'road' when cycling on the low quality cycling track. Surprisingly, the low quality road did not have a larger effect on the gaze behaviour of children than it had on the adults. Although no differences were found in overall fixation duration of adults and children, children seemed to make shorter fixations on the low quality track than on the high quality track whereas the fixation duration of adults remained unchanged.

4.1. Cycling speed

In car driving, it has been shown that drivers adjust their speed to deal more easily with hazards and/or potential difficulties (Fuller et al., 2008), and that narrower lane widths increase steering workload and reduce speeds through a speed-steering workload trade-off (Godley et al., 2004). It therefore seems surprising that no significant reduction of cycling speed was found on the low quality bicycle track for both adults and children. However, drivers respond to variations in task difficulty both in terms of autonomic arousal and adjustments in speed (Fuller, 2005; Taylor, 1964; Vansteenkiste et al., 2014). By increasing their attentiveness to task-relevant stimuli (i.e. more attention to the road), the participants increased their capability, and could deal more easily with the higher task demand of the low quality track, as proposed in the Task-Capability Interface model (TCI model; Fuller, 2005). As a result, there was no need to adapt cycling speed within the environmental constraints imposed in this experiment.

Children cycled slower than adults, but the difference in cycling speed was not larger on the low quality track than on the high quality track. Since children do not yet possess the perceptual-motor and cycling skills of adults (Assaiante, 2011; Chihak et al., 2010; Hatzitaki et al., 2002; Plumert et al., 2011; Zeuwts et al., 2014), it was assumed that children would have lower capabilities, and therefore would be affected more by a higher task demand (cfr, TCI-model). However, children also cycled slower on the high quality track. Possibly, children adapted their cycling speed to their capabilities on both the high and the low quality road. Therefore, like the adults, children also had spare capacity that they could employ by increasing their attentiveness to task-relevant stimuli. For both the children and the adults, increasing their attentiveness to task-relevant stimuli was enough to cope with the increased task difficulty on the low quality track, and no speed adjustments were required. An alternative explanation however, is that the difference in cycling speed might be due simply to the fact that children's bicycles are smaller than adult bicycles.

4.2. Gaze

Gaze behaviour of the adults in this study was comparable to the results of Vansteenkiste et al. (2014), underlining the generalizability of our findings. Regarding the difference between adults and children, the average fixation frequency and duration of children was not different than that of adults, but children spent substantially more time looking at the side of the road and the surroundings, whereas adults spent more time looking towards the road. Nevertheless, the effect of a low quality cycling path on gaze behaviour was not larger in the child group than it was in the adult group.

It has been suggested that children make less use of their peripheral vision to guide actions than adults (Franchak and Adolph, 2010). Considering the higher percentage of dwell time towards the AOI 'side' children might have fixated the edges of the track sometimes for lane keeping, whereas adults predominantly control this task using peripheral vision (Franchak et al., 2011). The less efficient use of peripheral vision might also be a reason why children looked more to the surroundings than adults. Whereas adults are able to process some of the peripheral cues without actively looking at them, children will be more likely to fixate elements in this AOI. This implies that both children and adults might have paid as much attention to the surroundings, but that adults used more covert attention to do so (directing attention towards and AOI without making an accompanying eye movement). Alternatively, the finding that children spent more time watching the surroundings is also in line with earlier suggestions that children have difficulties to distinguish between what is relevant and irrelevant on the road, and that they often fail to give adequate priority to relevant features even when the task requires them to do so (Foot et al., 1999; Whitebread and Neilson, 2000).

A narrowing of the eye movement distribution along the x-axis on the low quality track is in line with the narrowing visual search described in hazardous car driving situation by Chapman and Underwood (1998). In contrast to their study however, the current study did not reveal shorter fixation durations of the experienced (adult) group compared to the inexperienced (children) group. The fixation duration of the children even decreased as they cycled on the low quality road. Possibly, the unpredictable structure of the low quality track was visually more complex for the children than for the adults, leading to shorter fixations (Chapman and Underwood, 1998). Nevertheless, this finding is remarkable since adults are believed to use more and shorter fixations than children when confronted with complex tasks (Whitebread and Neilson, 2000). It should also be noted that there might be other possible causes for the differences in gaze behaviour between children and adults. Firstly, since children cycled slower than adults, they might have had more time to look at the surroundings. Secondly, some of the differences in gaze behaviour might be caused by a lower point of view of children compared to adults.

4.3. Perceptual motor strategy

Overall, our results suggest that children displayed a different visual-motor strategy than adults, characterized by lower movement times and a different visual behaviour. Although the steering behaviour is in line with earlier suggestions that children adopt a more cautious strategy (Berard and Vallis, 2006), and the visual behaviour is in line with the suggestions that children are not yet able to adopt a task-appropriate visual strategy and often fail to ignore irrelevant stimuli (Day, 1975), these two findings seem to be contradictory. Apparently, the cautious strategy applies to the motor behaviour, but not so to the visual behaviour. Pryde et al. (1997) emphasized that not only separate systems such as the sensory and motor system should be sufficiently developed for efficient visual-motor behaviour, but also the coupling between them. Therefore, they used a jigsaw puzzle metaphor to describe the development of mature visual-motor strategies. It is only when all elements of the system are sufficiently developed, they can be fully integrated into an adult-like strategy for visual-motor behaviour. Regarding the current results, children might have had sufficiently developed motor skills, but no appropriate visual skills to adopt an adult like visual-motor strategy.

4.4. Limitations

An important limitation of the current study is that the children ranged from 6 to 12 year old. Several studies have suggested that important changes in the visual behaviour of children occur around the age of 7-8 years old (Ampofo-Boateng and Thomson, 1991; Pryde et al., 1997; Whitebread and Neilson, 2000). Therefore, a sample of five to seven year old children and a sample of seven to twelve year old children would have shed more light on the development of these perceptual and motor strategies. Furthermore, it could be questioned whether adults and children acted natural during the experiment. The question whether participants alter their visual behaviour or not when they are aware that their eye movements are being recorded is a recurring concern in eye tracking experiments. Finally, since adults were experienced cyclists and children were largely still learner cyclists, some of the differences reported in the current experiment might be due to experience rather than maturity. This issue could be clarified in future research by including experienced children and inexperienced adults in a similar experiment.

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5. Appendix

Table A: Effect of inclusion criteria on dwell time percentages. Column # indicates the number of participants that would be included in the analyses with the inclusion criterion

Inclusion criterion		#	High Quality Road	High Quality Side	High Quality Surr.	High Quality FoE	High Quality Cycl. & ped.	High Quality NoData	Low Quality Road	Low Quality Side	Low Quality Surr.	Low Quality FoE	Low Quality Cycl. & ped.	Low Quality NoData
No loss of data	Adults	18	26,02	2,27	21,67	9,72	6,64	33,68	66,74	4,77	3,59	2,68	0,72	21,50
	Children	16	11,71	6,04	30,59	7,56	7,31	36,79	40,88	15,72	8,36	3,04	1,06	30,93
Less than 50 %	Adults	15	26,33	1,99	23,39	11,45	7,87	28,97	71,33	4,08	3,47	3,20	0,85	17,07
	Children	13	11,57	7,18	33,97	9,19	8,92	29,17	46,63	13,59	9,48	3,51	1,28	25,50
Less than 40%	Adults	15	26,33	1,99	23,39	11,45	7,87	28,97	71,33	4,08	3,47	3,20	0,85	17,07
	Children	10	11,65	7,95	35,48	10,52	8,57	25,83	48,09	13,88	9,86	3,51	1,52	23,14
Less than 35%	Adults	11	27,42	1,87	25,86	12,70	6,73	25,42	72,93	3,68	3,40	3,53	0,88	15,58
	Children	8	13,01	8,16	31,20	11,85	10,28	25,50	48,89	13,01	11,39	4,23	1,74	20,75
Less than 30 %	Adults	7	25,29	2,08	28,31	13,23	6,38	24,73	76,38	4,49	3,28	2,55	0,51	12,80
	Children	5	12,54	8,90	28,70	15,14	10,80	23,92	54,58	9,74	13,18	4,64	1,66	16,20
Less than 25%	Adults	5	18,88	1,40	31,12	18,74	6,84	23,02	73,96	3,58	3,96	4,02	0,50	13,98
	Children	2	13,70	7,55	34,55	17,00	9,95	17,25	52,90	12,45	12,45	5,15	2,40	14,65

Chapter 4: Hazard perception and hazard perception training for young cyclists

Paper 5: A hazard-perception test for cycling children: an exploratory study

ABSTRACT

In car driving, hazard perception tests have revealed important differences in perceptual-cognitive skills between novice and experienced drivers. Although these insights have led to new educational programs for learner drivers, similar research has not yet been done for other road users such as bicyclists. In the current investigation[34], a first hazard perception test for bicyclists has been developed and tested on both adults and children of ± eight year old. The test consisted of three sections in which visual behaviour, environmental awareness, and risk perception were evaluated respectively. Although only few differences in visual behaviour and environmental awareness were found, adults were found to react earlier on hazards than children. These results suggest that children have difficulties to interpret the necessary information to react timely to hazardous traffic situations. Alternatively, the current set-up of the hazard perception test might not have been suitable to detect differences in visual behaviour between children and adults in traffic situations. Therefore the development and use of future hazard perception tests for bicyclists is discussed.

[34] This part is based on Vansteenkiste P[1], **Zeuwts L[1]**, Cardon G, Lenoir M (2016). A hazard perception test for cycling children: an exploratory study. *Transportation Research Part F*, 41, part B, 182-194. DOI: 10.1016/j.trf.2016.05.001. [1] Indicates shared first authorship.

1. Introduction

Cycling is often promoted as a cheap and healthy way of transportation. The increasing number of bicyclists (DEKRA 2011) has been associated with many positive effects for both the cyclists and the environment (de Hartog et al. 2010; Oja et al. 2011). Unfortunately, it also led to more bicycle accidents. Accident statistics show that especially children and older cyclists are at risk (Carpentier and Nuyttens, 2013; Juhra et al., 2012; Maring and van Schagen, 1990). Therefore, many studies have investigated possible safety measures. Most of these studies focussed on limiting extrinsic risk factors such as road design (Thomas & DeRobertis 2013), and secondary prevention measures such as bicycle helmet usage (de Jong 2012; Karkhaneh et al. 2013). In contrast, few studies have investigated the importance of intrinsic factors such as cycling skills and cognitive skills, and how they relate to bicycle safety.

Safe cycling can be seen as a joint function of cognitive and motor capacities (Briem et al. 2004). Learning to master cycling skills is an essential first step to independent traffic participation by bike (Ducheyne et al. 2013), but safe traffic participation also requires cognitive skills such as perception, anticipation, and decision-making (Briem et al. 2004). Since the coupling between perception and action undergoes changes until late childhood (Plumert et al. 2011; te Velde et al. 2005; Chihak et al. 2010), children are limited in what they can learn and how they can behave in traffic environments (Connelly et al. 1998). In obstacle avoidance and road crossing tasks while walking, the perceptual-cognitive abilities of children have been reported to be insufficient to use adult-like locomotor strategies (Whitebread & Neilson 2000; Franchak & Adolph 2010). Therefore, they often adopt simpler strategies when confronted with complex situations (Day 1975; Berard & Vallis 2006; Ampofo-Boateng & Thomson 1991; Pryde et al. 1997). Although the lack of mature perceptual-cognitive skills might be a contributing factor to the overrepresentation of children in accident statistics, the development of these skills in function of safe traffic participation is still poorly documented.

In car driving, learner and newly qualified car drivers have been identified as a higher risk group for traffic accidents (Pollatsek et al. 2009; Fisher et al. 2006). In contrast to cycling, the perceptual-cognitive skills of learner drivers have been thoroughly studied using hazard perception tests (Sagberg & Bjørnskau 2006; Wetton et al. 2011; Borowsky et al. 2010; Vlakveld 2011). Hazard perception is the ability to detect and interpret hazardous situations, unfolding on the road ahead, which enable early anticipation (Wetton et al. 2011). During a typical hazard perception test, video clips of real traffic situations are presented to the participants and they are asked to press a button when they perceive a hazardous situation. Alternatively, some hazard perception tests use a driving simulator instead of video clips, or pose questions about the traffic scenarios instead of asking to press a button when a hazard is perceived (Liu et al. 2009; Hosking et al. 2010).

Results of hazard perception tests showed that experienced drivers detect hazardous situations faster and show shorter reaction times to these hazards (Huestegge et al. 2010). Furthermore, inexperienced drivers are less likely to detect foreshadowing cues, recognize them and therefore often miss the chance to anticipate on developing hazards (Wetton et al. 2011; Vlakveld 2011). The ability to perceive and predict the development of hazardous situations is closely related to the concept of situation awareness (SA) which describes how individuals create understanding of what is going on around them (Endsley 1995; Salmon & Stanton 2013; Vlakveld 2011). According to Endsley (1995), three interrelated levels of situation awareness can be defined. Level one would be the perception of elements in the current situation or the ability to perceive possible hazards.

The cyclist actively searches the environment for stimuli which could intervene with his goals. Level two is the comprehension of the current situation. The cyclist relies on long-term memory knowledge to interpret the stimuli in the environment. Long term knowledge offers a more coherent and organized framework for information processing that develops from experience. The last level describes the ability to predict the future actions of the elements in the current situation. Level three is based on knowledge of the declarative memory and assessment of the elements which lead to the decision-making process and action guidance. For example, a novice cyclist might achieve the same level one SA as a more experienced cyclist, but may not be able to integrate all the essential elements to comprehend the situation to its full extent and therefore show inferior hazard perception because of less developed schemata. Since poor hazard perception skill in novice drivers was associated with elevated crash risk, a hazard perception test was incorporated in the theory exam for learner drivers in some countries (Wetton et al. 2011; Hosking et al. 2010).

Although the use of hazard perception tests has led to a better insight in the visual search behaviour of car drivers and to adapted educational programs, it is surprising that similar research has not yet been done for other road users such as cyclists. Especially since recent evidence suggests that different road users interpret the same situations different because of differences in cognitive and physical task demands (Salmon et al. 2013; Walker et al. 2011). Learner cyclists might benefit even more from a hazard perception training than learner car drivers since children have few to no experience with complex traffic situations to rely on. In addition, the perceptual-cognitive skills of children are still developing, which also might have an effect on their ability to interpret and react to traffic situations (Ampofo-Boateng & Thomson 1991; Chihak et al. 2010b; Plumert et al. 2004). A hazard perception test for cyclists could provide more insights in the development of traffic skills from learner to experienced bicyclists. In turn, these insights could lead to primary prevention measures such as adapted traffic education for children and better design of road infrastructure. In the current study, an exploratory hazard perception test for cyclists was developed in which multiple aspects of traffic related cognitive skills were investigated. Risk perception, visual attention and reaction times to the hazards were analysed and the usability of the hazard perception test was evaluated.

2. Methods

2.1. Development of the hazard perception test

Film clips for the Hazard Perception Test (HP-test) were collected by cycling in real life traffic environments, while frontal images were captured using a GoPro Hero2 (30Hz, full HD and 170° FOV). In addition, some hazardous traffic scenarios were staged and filmed on a calm street using volunteers as ‘traffic’. All video footage was analysed by the authors and based on video quality and the type of traffic situation that was filmed. Ultimately, 33 fragments of 20 to 30 seconds were selected for the hazard perception test (see Fig 1 for an example of three clips, and Appendix 1 for a description of all clips). The clips also included the corresponding sounds which had been recorded by the GoPro. Only three clips did not contain a (potential) hazard. The videos were corrected for vibrations using the video stabilising software ‘Mercalli V2’ (ProDad) and were provided with a 3-2-1 countdown before the start of the clip. Then, all clips were uploaded into the eye-tracking experiment designing software ‘Experiment center 3.4’ (SensoMotoric Instruments, Teltow, GER).

The HP-test was subdivided into three subtests of ten, nine and fourteen clips. These three subtests roughly focussed on the three levels of situation awareness: perception, comprehension and projection.

Participants were asked to attentively watch the traffic scenarios and imagine that they were cycling themselves. In the first part, participants were only asked to look at the video clips as they were cycling, corresponding with the first level of situation awareness. In the second part, the participants were asked one multiple choice question about the video fragment after each clip. This question could be traffic related (e.g. what traffic sign did you see?; followed by four possible signs & ‘i don’t know’) or non-traffic related (e.g. which animal did you see?; black cat- black dog - bird - white dog - i don’t know). The last part of the test examined the ability to anticipate hazardous situations. Participants were asked to click with the computer mouse when they detected a hazardous situation. A hazard was defined as a traffic situation that would force the cyclist to break or change direction. Each time the participants noticed a hazard, they were allowed to click the mouse button only once. Three clips did not contain a hazard, two clips contained 2 (potential) hazards. So in total there were 13 (potential) hazards to react to. The third part of this explorative hazard perception test examined participants’ ability to understand the traffic situation and predict if the traffic situation would become dangerous. After every clip, the experimenter asked the participant for what hazard they clicked and why. Additionally, participants also had to indicate on a scale from 0 to 5 how hazardous they thought the traffic situation was (with 0 being very safe and five being very dangerous).

Figure 1. Screenshots of three clips of the HP-test. 1 is from the first part of the test. Participants were only asked to watch the clips attentively. 2 is from the second part of the test. Participants were asked how many other people were on the street during the clip. 3 is from the last part of the test. Participants were asked to click when they detected a hazard, and were asked to indicate how dangerous the clip was. These video clips can also be watched using following links: 1) http://youtu.be/SdczsCGRWFk 2) http://youtu.be/hGoMAXIihlE 3) http://youtu.be/JBqzTYOyBp8

2.2. Participants

The HP-test was completed by a convenience sample of 27 adults and 21 children. All adult participants were students of Ghent University (Belgium) who use their bike on daily basis for transportation to the university campus. All adults read and signed an informed consent that was approved by the ethical committee, and completed the test at the department of Movement and Sport Sciences. The children were recruited via an elementary school nearby the university. Parents read and signed an informed consent to approve for their children to participate in the test. All children were in the third year of elementary school and were tested in an empty classroom of the school. All participants completed the HP-test, but only participants who had an eye tracking ratio (% of time that the direction of gaze could be determined) of more than 80%, and an average eye tracking accuracy of 0.6° or less, were selected for further analysis (see also Table 1). Seventeen adults (eight male) were included in the analysis. Their average ride to the university campus took 13.88 ± 8.14 minutes and 13 out of the 17 adults had a drivers licence. The eleven children (5 male) that were included in the analysis owned their own bicycle and were already able to ride a bicycle independently for on average 3.09 ± 1.30 year. Only one of the 11 children already used his/her bicycle to cycle to school. Two children reported to cycle five days a week, three of them cycled once a week, the remaining six children did not cycle weekly. All participants had normal or corrected-to-normal vision.

Table 1. Age and tracking ratio (TR) for the adults and children

	Age (y)	**min.**	**max.**	**TR (%)**
Adults (n=17)	21,65 ± 1,93	18	25	92,87 ± 3,72
Children (n=11)	8,36 ± 0,50	8	9	89,61 ± 4,46

2.3. Apparatus

The HP-test was carried out using the Remote Eye tracking Device (RED) of SensoMotoric Instruments (Teltow, GER). This system consisted of a 22 inch computer screen on which the video fragments were shown, a laptop which ran the Experiment Center 3.4 software, and an eye tracking device which was mounted underneath the computer screen (see Figure 2). Using iView X recording software, the RED recorded binocular gaze behaviour at 120Hz using non-invasive video based eye-tracking. All gaze data, the answers to the questions in part 2 of the experiment, and the reaction time on hazards in part 3 were saved on the laptop by the iView X software of SMI.

Figure 2. Experimental set up. Red dots on the eye-tracker are infra-red lights, and cannot be seen by the participant

2.4. Procedure

On arrival, participants were informed about the aims of the experiment and were asked to take place on a chair at 60 to 80 cm in front of the screen. The eye tracking hardware was adapted to the height of the participant and the eye tracker was calibrated using a 5 point calibration grid. When the first calibration did not result in an accuracy lower than 0.6°, the calibration was repeated. If no adequate accuracy was obtained after five calibrations, the test was continued with the best possible calibration. Since the RED works best when the head is within a certain range relative to the eye tracking device, the participants were asked to stay more or less in this position throughout the experiment. The experimenter received live feedback on the position of the participant relative to the eye tracking device (see Fig. 2) and could ask the participant to move forward/backward or to the side if necessary. At the end of the test a calibration check was performed. The whole experimental procedure took 30 to 40 minutes per participant.

2.5. Analysis

2.5.1. <u>Part 1: Gaze behaviour</u>

Gaze behaviour was recorded in the three parts of the current hazard perception test. Since the task was different in each part, analysis of gaze behaviour was done for each part separately. However, the analysis of gaze behaviour was similar for each of these three parts, and focussed on the general distribution of attention of the participants. The number of fixations made by children and adults was calculated for each clip, using the 'SMI Event Detection' algorithm. Six Areas Of Interest (AOIs) which need to be monitored for safe travel were identified and appointed in each clip using the dynamic AOI editor of the gaze analysis software BeGaze 3.4 (SenoMotoric Instruments, Teltow, GER). These AOIs were 'Road', 'Traffic signs', 'Traffic lights', 'Cars', 'Pedestrians', and 'Cyclists'. AOIs were chosen by the authors as appearing in most of the video clips and relevant to the cyclist for safe traffic participation. Using the BeGaze analysis tools, the number of fixations and the dwell time percentage to each of these AOIs were then calculated. Results were exported to Microsoft Excel and SPSS for further analysis. Note that not all of these AOIs were present in each clip. For each of the three parts of the experiment, an average number of fixations in each AOI, and dwell time percentage towards the AOIs was calculated for each participant.

2.5.2. Part 2: Environmental Awareness

A general percentage of correct answers over the nine clips was calculated for each participant. This percentage gives an estimation to what extent participants perceived and were aware of the elements in the environment. This measure will be referred to as 'environmental awareness' which can be compared the concept of situation awareness (Endsley 1995). The percentage of correct answers was also calculated for traffic related (4/9), and non-traffic related (5/9) clips separately (one question for each clip).

2.5.3. Part 3: Risk Perception and reaction time

Similarly, 'risk perception' was calculated for each clip, based on the judgement of how dangerous the participant rated each traffic scenario on a scale from 0 (very safe) to 5 (very dangerous). The scores given to each clip were averaged for average risk judgement. Average scores of the four low risk clips (according to the authors), and the 10 higher risk clips were also calculated separately. Low risk clips were defined as situations in which there was no possible hazard or imminent threat to the cyclist.

Finally, for each participant the results of the reaction time relative to the start of the clip were exported to Excel and analysed per clip. Responses were considered correct when participants reacted within the hazard perception time window and mentioned the correct hazard after each clip. The hazard perception time window for each hazard started with the first frame the hazard was visible and ended with the last frame before a potential crash was inevitable. An additional variable 'average reaction time' was calculated for each participant by taking the average of his/her reaction times. Since participants did not always respond to each hazard, a response rate was calculated per participant (#reactions/#hazards). Reaction time data of three adult participants were lost during the analysis.

2.5.4. Statistics

All comparisons between adults and children were done using independent samples T-tests. Difference in response rate between adults and children was calculated using chi²-tests. Significance level was set at $p \leq 0.05$. Effect size (cohen's d) was calculated in Excell.

3. Results

3.1. Part 1: Gaze behaviour

In general, gaze behaviour of adults and children was similar. Both groups spent most of the time watching the road, followed by pedestrians, cars, and traffic lights (see Fig. 3 for all gaze behaviour results). Adults were found to make significantly more fixations on cars than children ($t_{26} = 2.070$; $p = 0.049$; cohen's $d = 0.76$), and tended to have a higher dwell time % to cars ($t_{26} = 1.829$; $p = 0.079$; cohen's $d = 0.68$). However, no other significant differences in #fix and dwell time % were found between adults and children for any of the AOIs ($p > 0.05$).

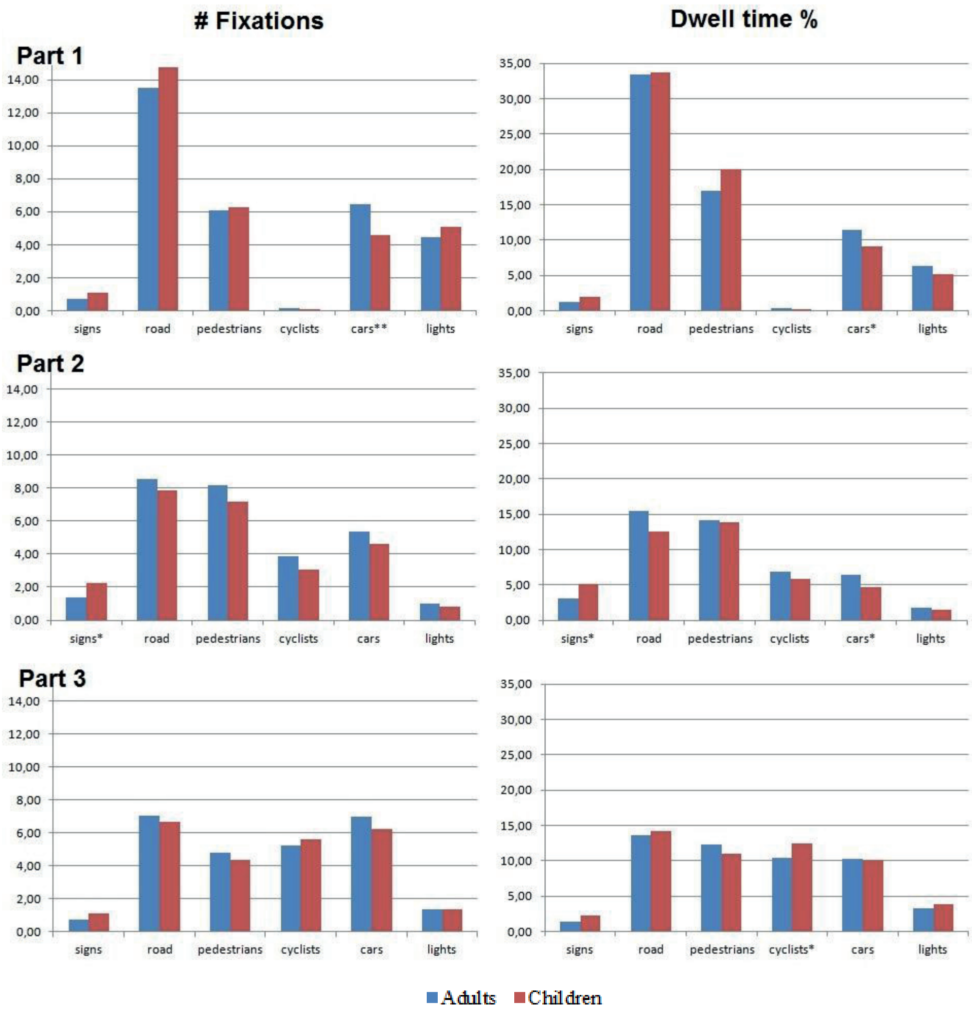

Figure 3. Number of fixations and dwell time percentage to each AOI for each per part of the test, signs' and 'lights' refer to traffic signs and traffic lights respectively. **$p < 0.05$ *$0.05 < p < 0.10$

3.2. Part 2: Environmental Awareness

In the second part of the HP-test, no significant difference in #fix or dwell time % was found between adults and children ($p > 0.050$ for all AOIs). Overall, adults answered 59 ± 14% of the questions correctly, compared to 52 ± 15% for the children, but this difference was not significant ($t_{26} = 0.805$; $p = 0.218$; cohen's d = 0.48). However, adults tended to answer the non-traffic related questions better than the children (65 ± 26% and 45 ± 24%, respectively; $t_{26} = 1.975$; $p = 0.059$; cohen's d = 0.73). The difference between adults and children was not significant when only traffic related questions (4 of the 9 clips) were taken into account (53 ± 19% and 58 ± 21%, respectively; $t_{26} = -0.693$; $p = 0.494$; cohen's d = 0.27).

3.3. Part 3: Risk Perception and reaction time

As was the case in the second part of the test, no significant differences were found in #fix or dwell time % ($p > 0.050$ for all AOIs). On a scale from 0 (very safe) to 5 (very dangerous), children tended to rate the clips as more hazardous than the adults (average score of 1.95 ± 1.31 and 1.58 ± 1.18, respectively; $t_{26} = -2.031$; $p = 0.053$; cohen's d = 0.30). This difference between children and adults was most pronounced in the four least 'hazardous' situations (1.43 ± 1.13 vs. 0.68 ± 0.72, respectively; and $t_{26} = -4.028$; $p < 0.001$; cohen's d = 0.97) than in the ten others (2.16 ± 1.32 vs. 1.95 ± 1.14, respectively; and $t_{26} = -1.084$; $p = 0.288$; cohen's d = 0.15). In general, children tended to have a lower percentage of correct reactions than adults (see Table2 for more details).

Table 2: Percentage of correct reactions for adults and children per clip. a: clips without hazard, b: clips with two hazards. When no hazard was present, not reacting was interpreted as a 'correct click'.

	% of correct 'clicks'			
Clip nr	Adults	Children	chi²	p
1	64%	64%	0,244	0,62
2[a]	79%	45%	2,932	0,09
3[b]	100%	73%	4,339	0,04
	100%	73%	4,339	0,04
4[b]	93%	73%	1,857	0,17
	79%	36%	4,573	0,03
5	50%	73%	1,326	0,25
6	43%	82%	3,896	0,05
7	93%	73%	1,857	0,17
8	21%	55%	2,932	0,09
9	79%	91%	0,698	0,40
10	57%	82%	1,724	0,19
11[a]	100%	100%	/	/
12	71%	100%	3,741	0,05
13	71%	36%	3,074	0,08
14[a]	79%	45%	2,932	0,09
Overall average	74%	69%	0,326	0,57

Adults reacted significantly earlier than the children in five of the 13 possible hazards, and tended to react earlier in two. The average moment of reaction on a possible hazard was 0.581 seconds earlier in the adult group than in the children group (see Table 3 for more details).

Table 3. Average reaction time for adults and children per clip. a: clips without hazard, b: clips with two hazards.

	Average reaction time per clip (in ms from start of clip)						
clip nr.	Adults	children	Difference (children-adults)	df	t-value	p-value	Cohen's d
1	14529 ± 495	14114 ± 2774	-416	13	,363	,731	0,24
2[a]							
3[b]	5312 ± 437	6462 ± 729	1151	20	-4,662	,000	1,47
	9463 ± 572	10008 ± 368	544	20	-2,410	,026	0,96
4[b]	6949 ± 454	8069 ± 857	1120	19	-3,938	,001	1,35
	12455 ± 233	13339 ± 638	884	13	-2,704	,066	1,64
5	10366 ± 996	11044 ± 1088	678	13	-1,251	,233	0,63
6	15675 ± 1499	16289 ± 1346	614	13	-,828	,422	0,44
7	10808 ± 111	10978 ± 676	170	19	-,707	,502	0,41
8	4442 ± 683	5294 ± 480	852	7	-2,209	,063	1,28
9	9686 ± 1064	11180 ± 512	1495	19	-4,157	,001	1,33
10	18248 ± 2385	18655 ± 1762	407	15	-,403	,692	0,20
11[a]							
12	11406 ± 304	11902 ± 288	496	19	-3,826	,001	1,29
13	12522 ± 480	12628 ± 1382	106	12	-,149	,890	0,14
14[a]							

4. Discussion

In the current exploratory hazard perception study, visual behaviour, environmental awareness, risk perception, and reaction time to hazards, of young inexperienced bicyclists and adult experienced bicyclists were investigated and framed within the three levels of situational awareness (Endsley 1995; Salmon et al. 2014). Due to the fact that only seventeen adults and eleven children were included in the current experiment, and the fact that all children came from one single elementary class, the results should only be considered as a pilot study. Nevertheless, based on the current results and regarding the existing literature in car driving, some important suggestions for future research can be made.

4.1. Gaze behaviour

There were no differences in the total number of fixations made by children and adults. In contrast to what we expected, children did not spend less time looking at traffic signs. At first, this seems counterintuitive since children are expected to be less experienced with the position and use of traffic signs, and therefore, would be less likely to notice them (Borowsky et al. 2008). However, after inquiry with the class teacher, it turned out that there was a ‘traffic education week’ the week before the tests were carried out. Due to the task demands in the second part and since it is known that traffic education has a strong short term effect (van Schagen & Brookhuis 1994), this focus on traffic signs was most likely the reason why children spent as much time looking to the traffic signs as the adults.

A difference between children and adults that is more likely to be due to the differences in traffic experience, than due to a selection bias, is that adults spent more time fixating cars in the first and the second part of the test. In car driving, experienced drivers were also found to pay more attention to potential dangers involving the behaviour of other road users than learner drivers (Underwood 2007). Since most of the adults in current study already had a driving licence, they were most likely more aware of the potential danger of other road users and their own vulnerability as a cyclist. Therefore children have difficulties to pay attention to the features which might create a hazardous situation. The fact that adult cyclists were more aware of other road users and cars might be explained by the concept of situation awareness (Endsley 1995; Salmon et al. 2014). Situation awareness is based upon schemata which are mental templates that determine how the world is perceived and how this information is used to direct the corresponding actions. Since adults have more traffic-related experience and encountered a variety of dangerous traffic situations, they created a more extended database of mental templates which in turn directs decision-making. In contrast, children have little experience regarding traffic which is reflected in less developed schemata or internal representations of specific traffic situations (Salmon et al. 2014). For example a child might have an internal representation of an intersection but it does not include cars or motorcyclists. As the child never experienced a dangerous traffic situation at the intersection, they do not actively search for elements which could predict the hazard. This lack of attention for other cars might be problematic for children since the failure to check for oncoming traffic was identified as one of the most significant causal factors for intersection crashes (LandTransport, 2005, in: Bao and Boyle (2009). On the other hand, longer dwell times do not necessarily imply that adults are more aware of the cars since a short fixation might be sufficient for proper risk assessment. In addition, as not all the cars presented in the video clips were possible hazards, longer dwell times on this AOI might therefore also implicate a less efficient visual search for other possible hazards. However, research in road crossing already showed that children have difficulties to make short anticipatory fixations and need more time to process visual information (Whitebread & Neilson, 2000). It would therefore seem unlikely that the lower dwell-time percentages to cars among children could be attributed to a more efficient visual search process.

In addition, the absence of more pronounced differences in gaze behaviour between the young and adult bicyclists might be due to the absence of the motor component of riding a bicycle. Cycling requires the participant to steer, pedal, and keep balance while monitoring the environment. In young children these cycling skills are quite rudimentary and often require conscious control (Briem et al. 2004; Ducheyne et al. 2013; Zeuwts et al. 2014). Especially when traffic situations become more demanding, this might lead to increased mental workload (Vansteenkiste et al. 2014). Consequently, excluding the motor component of the bicycle task decreased the mental workload, and might have given the children the possibility to pay more attention scanning the environment than they would have in real traffic situations, bridging the gap with visual search behaviour in adults. Compared to real traffic, scanning the environment on a computer screen is less demanding, and hazardous situations might be detected easier (Foulsham et al. 2011).

In-situ experiments, or experiments in a simulator-like environment where participants are seated on an instrumented bicycle, would benefit the ecological validity of gaze behaviour research. As a more extensive visual search is required when cues to a hazard often appear away from the centre of the screen, differences in horizontal and vertical visual search might be more pronounced between experienced and young cyclists when the experimental setting is more realistic. These realistic settings can also be used to evaluate the validity of ‘easier’ hazard perception set-ups using a single computer screen. Reliable and validated hazard perception tests for bicyclists could be used for various experimental purposes such as testing the influence of music on cycling skills, evaluating the development of cycling skills under various educational programs, etcetera.

With regard of future research, it should be carefully considered if eye-tracking will be an important added value for the experiment or not. In the current experiment, about 40% of the participants were not included in the final analysis due to eye tracking problems[35]. Although eye tracking systems are getting increasingly easy to use, experiments with eye tracking are still more time consuming for both collecting and analysing data. Especially for large scale experiments, excluding eye tracking data and focussing on reaction time could be more favourable.

Nevertheless, information about the visual behaviour of children and adults could shed light on the underlying cognitive processes of hazard perception. For example, experiments in car driving have suggested that a shorter time interval between the first fixation and the response time reflects more automated decision-making (Vlakveld 2011; Chapman et al. 2002). Future hazard perception tests focussing on visual behaviour of bicyclists should therefore consider to measure the time difference between first fixation onset and reaction time to a hazard as an estimation of the speed of decision-making. Unfortunately, in the current experiment, only the general distribution of visual attention was of interest. Therefore the AOIs were only assigned according to their physical location (i.e. cars, road, …) instead of their (potential) hazardousness. Experienced car drivers were also found to have a more extensive visual search pattern, and to adapt it more to changing environments and the presence of hazards (Underwood et al. 2002; Underwood et al. 2003; Crundall & Underwood 1998). In line with these results, alternative measures, such as horizontal and vertical search, pupil diameter, fixation sequence, etc., could be used to investigate the effects of various traffic scenarios on the visual search behaviour of young and adult bicyclists.

The question then still remains however, whether the experimental task (looking only, answering a question, reacting, …) will affect visual behaviour. In the current study, differences in visual behaviour were only found in the first part. This might indicate that this part was more suitable to detect differences in visual behaviour than the other two parts. Unfortunately, since different video fragments were used, a comparison between the three parts is difficult to make. Nevertheless the fact that the experimental set-up could possibly alter the participants visual behaviour should always be taken into account.

4.2. Environmental awareness

Adults tended to answer the non-traffic related questions better than the children. The better perception and recalling of random elements of the viewed scenario could have been supported by more mature perceptual-cognitive skills and a more efficient use of foveal vision (Franchak & Adolph 2010) although adults and children do not differ in the size of their Usefull Field Of View (Dye & Bavelier 2010; Cohen & Haith 1977). More generally however, since ‘perception of elements in the environment’ is the first level of situation awareness, the

[35] For the current study, results were very similar when all participants were included in the analysis of the environmental awareness, risk perception and reaction time. However, to improve comparability between tests, and to keep the methods coherent, we chose to use the inclusion criteria for all results instead of only for the gaze behaviour.

higher score of adults might be a sign of a better overall situation awareness (Endsley 1995; Stanton et al. 2001; Gugerty 2011). Unfortunately, the development of situational awareness in children in function of traffic safety has not yet been investigated.

Alternatively, the higher score of the adults on non-traffic related questions could have been caused by the adults changing their visual search more efficiently to the task than children did. Since participants knew a question would follow, possibly the adults adapted their visual search in function of gathering information for potential questions instead of paying attention to traffic. Children's gaze strategies on the other hand have been found to be less flexible and they tend to use a more simple gaze strategy (Berard & Vallis 2006). In the context of the current experiment, children therefore might only have focussed on the 'cycling' task, while adults adapted their visual search in function of the potential questions to be asked.

4.3. Risk perception

The finding that children judged the clips as more dangerous than the adults is in line with the idea that children adopt more cautious strategies when confronted with complex traffic tasks (Whitebread & Neilson 2000). However, this difference might also have been caused by the children being more insecure about their answer. The finding that the difference between adults and children was most pronounced for the 'safe' scenarios is in line with the idea that children were not sure if there indeed was no danger in the scenario, and therefore did not give the lowest score. Ampofo-Boateng & Thomson (1991) also argued that children have difficulties in taking another viewer's perspective and that their judgement of safety is often based on one single strategy, such as the presence of approaching cars. Experienced adults on the other hand, rather consider the traffic situation as a whole (Borowsky et al. 2009).

The current results suggest that children and adults not only slightly differ in the first level of situation awareness, but also in the second which is comprehension of the current situation (Endsley 1995). However, the hazards in the current study were mostly rather apparent. Since children tend to rely on clear cues to judge a hazard as dangerous or not (e.g. approaching cars), they might have difficulties to detect developing and covert/latent hazards (Crundall et al. 2012; Vlakveld 2011). Therefore, future tests in risk perception (or more generally situation awareness) in children, should make a distinction between different types of hazards (Vlakveld 2011).

4.4. Reaction Time

As earlier results suggested that children have difficulties in perceiving and understanding the traffic situations, it was expected that they would miss some of the hazards, as was the case in the experiment of Briem et al. (2004). Surprisingly, children only tended to have a lower percentage of correct reactions than the adults. However, as was mentioned in the previous paragraph, the hazards in the current study were quite evident. Possibly, if the hazard perception test would also include covert/latent hazards (see Vlakveld 2014), children might show a lower response rate to these hazards than adults. Adults did systematically react earlier in five of the thirteen video clips. In car driving, the delayed decision making of non-experienced drivers compared to experienced drivers has often been linked to a lack of traffic-related experience and knowledge (Underwood 2007; Scialfa et al. 2011; Crundall et al. 2013; Chapman et al. 2002; Hosking et al. 2010). Although situation awareness does not include the anticipatory actions themselves, it precedes decision-making and action guidance (Endsley 1995). The lower reaction times for children in hazardous situations might be explained by less developed schemata. Therefore children only reacted when cues became more salient. In addition, schemata are tied to scripts which support decision-making and provide sequences of actions which improve with experience. Experience tightens the connection between scripts and schemata resulting in more automated and efficient reactions (Endsley 1995; Salmon et al. 2014). However, besides a lack of experience, children do not have developed mature perceptual-cognitive skills. Therefore, the differences in reaction time might partly be due to a generally lower reaction time. Future hazard perception tests for children should therefore incorporate a simple reaction time test.

An alternative for reporting differences in reaction time is computing a hazard perception score for each video clip which can be calculated based on the reaction time within a response window (Wetton et al. 2011). This response window starts with the first frame in which the cue of the oncoming hazard is available and ends with the last frame a collision would be unavoidable. This score can be compared more easily across different scenarios. In addition, a general test score can be provided for each age group. Furthermore, since children might react on changes in the hazard perception clip without understanding what exactly is going on, it could be recommended to ask participants why the clip was perceived as dangerous, when they reacted to a potential hazard.

4.5. Conclusion

To our knowledge, this was the first study to explore the differences between experienced adult bicyclists and inexperienced young bicyclists using a hazard perception test. Although only few differences in visual behaviour and environmental awareness were found, adults were found to react earlier on hazards than children. The lower reaction times of children in the current study might be caused by a lack of sufficient perceptual and cognitive skills in all three levels of situation awareness which in turn resulted in longer reaction times for dangerous situations (Endsley 1995; Underwood et al. 2012; Borowsky & Oron-Gilad 2013). Although children looked quite similar as adults, longer reaction times for hazardous situations in the last part of the test suggest that children only reacted when dangerous events become unavoidable and therefore might miss the chance to anticipate. In addition, the slower reaction times also might suggest an immature perception-action coupling since they lack experience based knowledge (schemata) which guides decision-making (via scripts). The lack of these mature perceptual and cognitive skills could be a contributing factor to the higher accident proneness of cycling children. However, since some of these differences were also found between experienced and novice car drivers (Borowsky & Oron-Gilad 2013; Scialfa et al. 2012; Underwood et al. 2002), the question remains whether the differences between adults and children were due to a difference in traffic experience, or a difference in maturity of the perceptual-cognitive system. More insights in the development of situation awareness and perceptual-cognitive skills of young learner cyclists could lead to more effective educational programs and better designed infrastructure, and hazard perception tests for bicyclists seem to be a valuable tool to study this.

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5. Appendix

Video	Description	
Part 1: Watching		
Video	**Description**	
V1	While cycling, the cyclist passes by two runners and a street on the right side.	
V2	The cyclist passes by a cycle shed where some of the cycles leap out. An opposing car drives by.	
V3	A man is unloading his van which is parked on the street.	
V4	The cyclist has to give way for road works.	
V5	The lights turn red.	
V6	While cycling, a woman who is pushing baby buggy is passed and a car turns left just in front of the cyclist.	
V7	A van and a car are parked on the cycle suggestion path.	
V8	The cyclist is waiting for the lights to turn green.	
V9	The cyclist cycles on the bicycle path.	
V10	The cyclist crosses an intersection with tram trails.	
Part 2: Questions		
Video	**Description**	
V1	While cycling, the cyclist passes by a traffic sign and a street on the right side.	
V2	The cyclist passes by a street from the right side which has priority.	
V3	The cyclist cycles around a roundabout.	
V4	The cyclist cycles through a busy shopping street.	
V5	A van and a cyclist come from a street on the right.	
V6	The cyclist has to choose the right bicycle path from a couple of possibilities.	
V7	The cyclist passes by an orange flickering light.	
V8	The cyclist is waiting to cross a street with a refuge in the middle. The light for the cyclists on the refuge turns green while the light for camera remains red.	
V9	The cyclist passes by pasture with horses.	
V10	While cycling on the road 4 balloons appear from behind a car while a cyclist is coming from the left and a pedestrian from the right is crossing the street in front of the camera.	
Part 3: Reaction		
Video	**Description**	**Description of the hazard**
V1	(Practice clip) The cyclist passes by a bus stop on the left side while a pedestrian leaves the bus.	A women leaves the bus in front of the cyclist.
V2	The cyclist crosses an intersection	The intersection
V3	The cyclist crosses an intersection while a pedestrian and a cyclist, coming from the right, cross the intersection.	The pedestrian and the cyclist.
V4	A man far in front and, a lady close in front of the cyclist cross the street followed by a car coming from the right.	The lady close in front, and the car coming from the right.
V5	While cycling between tram trails, a car comes from the right.	Car coming from the right.
V6	While cycling a narrow country road, a van has to give way for the cyclist.	The van on a narrow street.
V7	A door suddenly slams open while cycling along some parked cars.	The door of the car.
V8	While cycling along parked cars, a car in front of the cyclist leaves its parking place.	The car leaving its parking place.
V9	A cyclist from the street on the right turns in front of the camera.	The cyclist.
V10	While cycling on the cycling path, the camera suddenly has to move to the roadway due to a roadblock on the bicycle path.	Roadblock.
V11	A woman pushing a baby buggy is walking on the pavement alongside the bicycle path.	The woman.
V12	While cycling alongside parked cars, a pedestrians steps out in front of the cyclist from behind a van.	The pedestrian.
V13	The cyclist passes an intersection while suddenly the lights turn red.	The lights.
V14	Cycling a roundabout.	The roundabout.

Paper 6: Hazard perception in young and adult cyclists

ABSTRACT

Child bicyclists are at greater risk to get involved in a traffic accident. Although hazard perception tests between inexperienced and experienced car drivers revealed significant differences in perceptual-cognitive skills, a similar test for bicyclists is not yet existent. Therefore this study[36] aimed to compare visual search patterns and reaction times of child bicyclists and adult bicyclists utilizing a hazard perception test for cyclists. Seventy-five children and forty-one adults were presented with eleven video clips filmed from the perspective of the bicyclist. The participants were required to press a response button whenever they detected a hazardous situation. Children were found to have significantly delayed reaction times and time until the first fixation on the latent covert hazards compared to adults. The inefficient visual search patterns in children may be attributed to an immature visual system. However, the finding that children fixated later on the hazards and only responded to the covert latent hazards when they became salient indicate difficulties with identifying possible hazards. Altogether, the findings of this study suggest that children's situation awareness is dependent upon experience too, and not just maturation. Therefore, implications for training young bicyclists will be discussed.

[36] This part is based on **Zeuwts L**, Vansteenkiste P, Deconinck F, Cardon G, Lenoir M (2016). Hazard perception in young and adult bicyclists. *Accident Analysis and Prevention.* Epub ahead of print, DOI: 10.1016/j.aap.2016.04.034.

1. Introduction

Bicycling is a virtually free and enjoyable way of transportation. In Flanders 13% of all trips is made by bicycle and cycling represents the most common mode to commute to school for children and young adults (Janssens, Declercq, and Wets, 2012). Besides the health benefits associated with cycling to school or work, such as improved fitness, reduced risk for colon cancer or cardiovascular mortality, cycling also has the potential to decrease traffic congestion and air quality degradation (de Hartog et al. 2010; Oja et al. 2011). Moreover, in accordance with the European guidelines, cycling is a promising way to meet international guidelines for daily activity (60min/day of moderate or vigorous physical activity for school-aged youth and 30 min/day for adults) (European Communities 2006; European Commission, 2008; Oja et al., 2011; Shephard, 2008).

Unfortunately, increased bicycle-usage has also led to more traffic casualties where especially children (9-12 years old) and older cyclists (>65 year old) are at risk (Carpentier and Nuyttens 2013; Juhra et al. 2012; Maring and van Schagen 1990; Ormel et al. 2009; Schepers and Wolt 2012). In Europe, 2017 cyclists were killed in traffic accidents, representing 7.8% of all road accident fatalities (European CARE report 2015). Moreover, 9-14-year-old children represent almost 10%, and 14-19-year-old children represent 11% of all the bicycle accidents in Flanders (Carpentier and Nuyttens 2013). Therefore, the causes underlying accident involvement in young cyclists, i.e. the influence of extrinsic factors (e.g. environmental characteristics, distance to work or school, bicycle facilities,…) and intrinsic factors (cycling skills, cognitive skills, attitudes,…) in relation to bicycle safety have been studied (Chihak et al. 2010; Ducheyne et al. 2013; Grechkin et al. 2013; Maring and van Schagen 1990; Møller and Hels 2008; Plumert et al. 2004, 2011; Trapp et al. 2011; Vansteenkiste et al. 2014; Zeuwts et al. 2014).

For instance, safe cycling requires the development of sufficient motor and cognitive abilities (Briem et al. 2004). On the motor side, learning to control and ride the bicycle on closed roads or playgrounds can be considered the essential first step, which is often mastered under adult supervision (Ducheyne et al. 2013). However, on the cognitive side, the transition from playground to traffic also requires additional anticipatory and decision-making skills to adequately anticipate or respond to other traffic. These skills are found to undergo changes until late childhood as a result of experience and development (Plumert et al. 2011; Thelen and Smith 1994). In support of this, a number of studies have shown that children appeared to have more difficulties with coordinating their actions in relation to other moving vehicles, which resulted in delayed onset of movement, larger variability in time to spare and less time to spare before contact with oncoming traffic (Chihak et al. 2010; Grechkin et al. 2013; Plumert et al. 2004, 2011). This evidence stems road crossing studies (using a bicycling simulator), where participants are presented with a number of intersections with continuous traffic. Still, safe cycling requires not only gap interception and go-no-go decisions for road crossing, but also the anticipation of hazardous situations in traffic, such as a car directly turning in front of the bicyclist or people stepping out of the bus. Anticipating dangerous situations is referred to as hazard perception, and is defined as the ability to read and detect dangerous situations unfolding on the road ahead, a process that enables early anticipation (Wetton et al. 2010; Wetton, Hill, and Horswill 2011).

Traditionally, hazard perception is studied by presenting individuals with video clips filmed from the driver's perspective. Each clip contains at least one dangerous traffic situation that requires imminent action. Herein, participants' eye movements and reaction time to the hazardous situation are of interest. Vlakveld (2014) distinguished two types of dangerous traffic situations: overt latent hazards and covert latent hazards. Overt latent hazards refer to other visible road users who might start to act dangerously, while covert latent hazards refer to places from where a possible road user might appear who is not yet visible through an obstructed view.

When novice and experienced car drivers are presented with the hazard perception test, novices are found to overlook more traffic conflicts, show less extensive scanning patterns and have more difficulties detecting the foreshadowing elements or precursors for hazardous situations. This results in slower response times to hazards compared to more experienced drivers (Huestegge et al. 2010; Wetton, Hill, and Horswill 2011). Moreover, learner drivers have been shown to make less anticipatory eye glances on covert latent hazards, which implies that novice drivers lack the ability to perceive and predict dangerous traffic situations (Borowsky, Shinar, and Oron-Gilad 2010; Underwood et al. 2002; Vlakveld 2011).

The documentation of hazard perception in children, including its development and underlying factors, is an important step towards safer traffic participation. In pedestrians, children's lack of road crossing experience limits their attentiveness and ability to anticipate possible hazards (Meir, et al. 2015a,b, 2013; Rosenbloom et al. 2015). Furthermore, Meyer, Sagberg, and Torquato (2014) presented two groups of children between 8 to 12 years, 13 to 17 years of age and an adult group with a hazard perception test for drivers to explore the relationship between age and hazard perception in children. Compared to the adult group, children demonstrated longer hazard perception latencies and lower response rates for situations containing hazardous behaviour caused by other vulnerable road users. This might be explained by a more egocentric view which suggests that children are less likely to identify with other road users (Meir et al. 2015b, 2013; Meyer et al. 2014), hence children lack the ability to predict how a situation might develop over time to anticipate the forthcoming events. However, these findings are limited since the video clips presented in this experiment were made from the perspective of a car driver, which is an experience children lack, and no clear distinction between covert and overt hazards was made.

The ability to predict and to anticipate traffic situations is closely related to the concept of situation awareness (SA) which consists of three interrelated levels (Endsley 1995). First the driver perceives a hazardous situation (perception). Then, the situation is interpreted (comprehension), and finally, the driver predicts how the situation will develop (projection). These three levels of SA are based on mental models or schemata, i.e. long-term memory structures that contain prototypical situations. Decision-making then involves pattern recognition or matching of situations with these mental models. Experience and training contributes to the formation of sophisticated and extensive mental models and will speed-up pattern matching, thus decision-making. Therefore it can be concluded that novice drivers lack an accurate internal representation of the context-dependent nature of hazardous situations. (Borowsky et al. 2010; Meir et al. 2013). As poor hazard perception skills in novice car drivers were shown to be related to elevated crash risk, in England and Australia a hazard perception test was successfully incorporated in the theory exam for learner drivers (Hosking, Liu, and Bayly 2010; Wetton, Hill, and Horswill 2011).

To conclude, the concepts reported above mostly concern studies in pedestrians and car driving while, despite an overrepresentation of young cyclists in accidents, research regarding gaze and hazard perception in cyclists is limited. Therefore the main aim of this study is to compare visual search patterns and reaction times between young cyclists and adult cyclists using a hazard perception test consisting of video clips from the perspective of a cyclist. We will document the visual search patterns of child and adult bicycle users by means of eye tracking methodology. Having access to the visual information on a potential hazard is a prerequisite that forms the basis of the first level of Endsley's (1995) situational awareness. It is expected that the lack of experience in children will result in missing more hazards and/or perceiving these hazards later than adults. In addition, reaction times to hazardous situations are expected to be longer in children for the same reason.

2. Methods

2.1. Development of the hazard perception test for cyclists

First, a collection of video clips (n = 365; mean duration ± 35 s) was created, including at least one hazardous event in each clip. All video clips were filmed from the perspective of a cyclist with a GoPro Hero2 camera (30Hz, full HD and 170° Field Of View) mounted onto a helmet and were gathered in the cities and surroundings of Antwerp and Ghent. Film clips were analysed and edited with Kinovea. Each clip contained a run up time to appearance of the hazard of at least five seconds and lasted at least five seconds after that event. In addition, each clip was stabilized to minimize vibrations due to the state of the bicycle path or head movements using 'Mercalli V2' (ProDad).

Subsequently, the experimenters rated each clip for image quality, the role of changing traffic signals, temporal proximity to other conflicts, and the existence of evasive action taken by the camera in response to the traffic conflict according to the criteria of Wetton, Hill, and Horswill (2011). Film clips that passed this first inspection by the experimenters were then rated by a panel of three traffic experts specialized in hazard perception or research in cycling. First, the experts indicated what hazard(s) were appearing in the clip and how dangerous they perceived the hazard on a five point scale (1 = not dangerous, 5 = very dangerous). Second, experts classified the events as an acute hazard, a covert latent hazard, or an overt latent hazard (Vlakveld 2011). An acute hazard reflects a situation in which a reflexive response is required on a sudden hazard, for example a child that suddenly enters the street from behind a car. Possible hazards that do not develop into an imminent threat are referred to as latent hazards. Covert latent hazards then are potential hazards where other road users are hidden from view such as a truck blocking view on a pedestrian crossing, while overt latent hazards refers to visible road users who might start to act dangerously.

Next, for each video clip the presence of the anticipatory cue was scored on a five point scale according to Wetton, Hill, and Horswill (2011) (1 = no anticipatory cue; 2 = early anticipation of a traffic conflict requires attention to obvious cues; 3 = early anticipation of a traffic conflict requires attention to slightly subtle cues; 4 = early anticipation of a traffic conflict requires attention to quite subtle cues, 5 = early anticipation of a traffic conflict requires attention to very subtle cues).

Finally, the experts had to identify the hazard instigator. Clips with no clear anticipatory cue or clips which were rejected by the expert panel were excluded for further use. Ultimately, 11 qualitative film clips were chosen for further testing (**table 1**).

Table 1. Description of the hazardous situations, the types of hazards and the time frame in which the hazard developed from first frame visible until a possible crash (Vlakveld 2011).

Clip	Type of hazard	Description	Time frame (s)
1	Overt	A car in the opposite direction of the cyclists is about to turn left but oversees the cyclist.	4.97 s
2	Overt	A man walks from the sidewalk onto the bicycle path without looking.	5.19 s
3	Overt	A car parks on the right hand side of the street. The driver opens his door without checking the rear view mirror for cyclists.	3.16 s
4	Overt	A bus is about to stop at the bus stop. When the cyclist passes the bus stop, pedestrians are stepping out of the bus not paying attention to the cyclist.	4.15 s
5	Overt	A car suddenly turns right in front of the cyclist.	5.88 s
6	Covert	A man steps on the street from behind a van.	2.33 s
7	Covert	A woman comes out of a double parked car, steps onto the bicycle path from behind another car.	2.78 s
8	Covert	A man opens the door of his parked car and steps out of the car.	4.79 s
9	Covert	View on the car coming from a street on the right hand side is blocked by vegetation.	3.24 s
10	Covert	View on the pedestrian at a pedestrian crossing is blocked by a container.	2.78 s
11	Covert	View on a cyclist who comes out of cross street on the right is blocked by houses.	2.20 s

2.2. Participants

The hazard perception tests were completed by 88 children (average age: 10.53±1.10 years) who have at least two years of bicycle experience (age at onset of bicycling: 5.03±0.99 years) and 41 adults (average age: 21.64±1.06 years). Children were tested in in the month of May at their school. Parents read and signed the informed consent which was approved by the Ghent University ethical committee. Additionally a questionnaire concerning the children's cycling behaviour and cycling experience was completed. Adults were tested in the month of June. All adults read and signed the informed consent and completed the same questionnaire.

2.3. Apparatus

The Hazard Perception test (HPtest) was performed using the Remote Eye tracking Device (RED) of SensoMotoric Instruments (SMI, Teltow, Germany). Film clips were presented on a 22 in. computer screen with an eye tracking device mounted underneath. The eye tracker projects two beams of infrared light onto the pupils, which are reflected by the eyes and captured by a camera inside the eye tracker. Based on this reflection, the software determines the location of the individual's gaze relative to the computer screen. The software SMI Experiment Center 3.4, which was run from a laptop connected to the PC screen, was used to perform the HPtest. With iView X recording software of SMI, the RED recorded eye movements and reaction times of the participant at 120 Hz, binocular (**figure 1**).

Figure 1. Experimental set-up

2.4. Procedure

On arrival, participants were given a brief explanation about the experiment. Then they were asked to take a seat at a table. A computer display was located 60-80 cm in front of the participant. The eye tracker was calibrated using a five point grid. When the calibration did not result in an accuracy lower than 1°, this procedure was repeated. After the calibration, an explanation of the HPtest was given. Participants had to imagine they were actually cycling the bicycle and were instructed to press the mouse button only once each time they detected a hazardous situation which required them to act in order to avoid a crash. A hazard was defined as each situation which required the participant to brake or stop to avoid a possible or imminent threat. Participants were unaware of the number of hazardous situations in the video clips. After each film clip participants were asked to indicate which hazard they had seen. In the middle and at the end of the HPtest a calibration check was performed.

2.5. Analysis

Before further analysis, the tracking ratio in all participants, i.e. the percentage of time that gaze could be recorded in relation to the duration of the trial, was checked. Only in thirteen children this tracking ratio was considered too low (i.e. smaller than 80%) to be included for further analysis which resulted in a sample population of 75 children and 41 adults.

2.5.1. Response rate and reaction time

For each clip and for each situation, response rates, which refers to the amount of correct 'clicks' for each hazard, were calculated for children and adults. Subsequently, reaction times were measured relative to the critical time frame in which the hazard appeared for the first time and were exported from BeGaze 3.4 (SensoMotoric Intruments, Teltow, Germany). This interval referred to the first frame the hazardous situation became visible until the last frame before a potential collision was possible and was validated by three experts.

2.5.2. Gaze behaviour

The number of fixations was calculated using the 'SMI Event Detection' algorithm. For each video clip the hazardous events were determined and then indicated as Areas Of Interest (AOIs) using the dynamic AOI editor of the gaze analysis software BeGaze 3.4 (SensoMotoric Instruments, Teltow, Germany). Using the BeGaze analysis tools the following measures were analysed: (a) The number of fixations on each AOI, i.e. the number of times that the participant fixated or re-fixated the area of interest. (b) The entry time of the first fixation (s) on the hazard was defined as the first frame in which the participant fixated on the AOI. (c) Duration of the first fixation (s) was defined as the time of the first fixation of the participant on the AOI. (d) Dwell time (s) is defined as the total amount of time spent fixating on the AOI.

2.5.3. Statistics

Differences in response rate between children and adults were measured using a chi square analysis. General differences in reaction time and gaze related variables of children and adults were analysed using a Mann Whitney U test since only 11 video clips were used. Significance level was set at $p \leq 0.05$. Additionally, differences regarding reaction time and gaze behaviour for each clip independently were analysed using an independent samples t-test. Since multiple independent samples t-tests were used, significance level for reaction time, entry time, first fixation duration, dwell time on the hazard and number of fixations on the hazard were set at $p \leq 0.01$ (Rothman 1990).

3. Results

In general children responded more often (54.9%) to the hazards than adults (47.7%; χ^2= 7.143; $p \leq 0.01$). In Table 2, results for reaction time, time until the first fixation, duration of the first fixation, dwell time, and number of fixations on the hazard are presented. Children reacted about 0.35 s slower than adults to a hazardous situation when compared to adults. Moreover, children's first fixation on the hazardous situation was about 0.30 s slower and the duration of their first fixation was about 0.10 s shorter. In line, dwell time on the hazard in children was 0.23 s shorter than in adults. However, no difference was found for the number of fixations.

Table 2. Mean reaction time, time until the first fixation, duration of the first fixation, dwell time, and number of fixations for children and adults on the hazard.

	Children	Adults	Mann-Whitney U score	Z-score	Significance
Reaction time (s)	2.28±1.13	1.93±1.12	48932.50	-5.064	0.000
First fixation (s)	1.61±1.21	1.23±1.07	189658.00	-6.139	0.000
First fixation duration (s)	0.35±0.27	0.44±0.30	199079.00	-4.864	0.000
Dwell time (s)	1.38±0.90	1.60±0.94	206783.50	-3.820	0.000
Number of fixations	4.08±2.74	4.20±2.69	230591.50	-0.595	0.552

3.1. Response rate and reaction time for each clip

For each clip, response rates for children and adults are provided in percentages to enable comparison between both groups (Table 3). Children seemed to respond more than adults in 7 of the video clips, although there was no significant difference in response rate for any of the presented video clips between children and adults, except for clip 9. Adults generally reacted faster (see Table 4). Reaction times in adults were significantly shorter than those in children for 7 out of 11 clips. For covert hazards, reaction times in adults were smaller than in children for all clips with a covert hazard, and for 1 out of 5 clips with an overt hazard.

Table 3. Response rate for each situation in percentage, chi-square and standardized residuals between brackets

Clip	Type of hazard	Children	Adults	Chi Square	p
1	Overt	79.5 (-0.4)	90.2 (0.5)	2.263	0.132
2	Overt	67.0 (0.1)	63.4 (-0.2)	0.164	0.685
3	Overt	33.0 (0.7)	19.5 (-1.1)	2.471	0.116
4	Overt	12.5 (0.2)	9.8 (-0.4)	0.205	0.651
5	Overt	51.1 (0.3)	43.9 (-0.5)	0.586	0.444
6	Covert	65.9 (0.6)	51.2 (-0.8)	2.543	0.111
7	Covert	72.7 (-0.4)	85.4 (0.6)	2.503	0.114
8	Covert	38.6 (0.9)	22.0 (-1.3)	3.504	0.061
9	Covert	37.5 (1.1)	17.1 (-1.6)	5.455	0.020
10	Covert	55.7 (-0.3)	63.4 (0.4)	0.687	0.407
11	Covert	55.7 (-0.4)	65.9 (0.6)	1.196	0.274

Table 4. Reaction time (RT) in seconds for each clip.

Clip	Type of hazard	Children RT (s)	Adults RT (s)	t	p	Cohen's d
1	Overt	3.35±0.57	3.01±0.48	2.995	0.003	0.645
2	Overt	3.50±1.17	3.46±0.77	0.134	0.893	0.180
3	Overt	1.96±0.84	1.65±0.91	0.915	0.367	0.354
4	Overt	2.55±0.98	1.94±1.09	1.039	0.318	0.589
5	Overt	3.01±1.04	2.74±1.02	0.929	0.357	0.262
6	Covert	1.19±0.32	0.91±0.48	2.955	0.004	0.686
7	Covert	1.66±0.39	1.34±0.42	3.854	0.000	0.799
8	Covert	3.45±0.80	1.99±0.98	4.649	0.000	1.632
9	Covert	1.74±0.74	0.98±0.31	4.330	0.000	1.340
10	Covert	1.60±0.63	0.99±0.42	5.071	0.000	1.154
11	Covert	1.35±0.24	1.17±0.24	3.034	0.003	0.750

3.2. Gaze behaviour

From Table 5 it appears that adults glance to the location of the hazard significantly earlier than children in 5 out of 11 clips while there was a trend in 2 out of 11 clips. Children glanced later at 4 out of 6 covert hazards and 1 out of 5 overt hazards than adults. Also significant differences were found between children and adults for the duration of the first fixation on the hazardous situation, which was longer in adults for 3 of the clips while there was a trend in 2 of the clips. In adults, first fixation on the hazard was longer in 2 (out of 6) of the covert and in 1 (out of 5) of the overt hazards (Table 6) while there was a trend for 2 covert hazards. For Dwell time on the hazard, adults fixated the hazardous situation significantly longer than children in 2 out of 11 video clips while there was a trend in5 clips. In addition, dwell time was longer in adults for 1 covert hazards and 1 overt hazards (Table 7) while there was a trend for 3 covert hazards and 2 overt hazards. There is no clear trend in the number of fixations as children only made more fixations in one of the clips (Table 8).

Table 5. Entry time on the hazardous situation in each clip.

		Children		**Adults**				
Clip	***Type of hazard***	***Mean***	***SD***	***Mean***	***SD***	***t***	***Sig.***	***Cohen's d***
1	Overt	2.54	1.12	2.09	0.99	2.140	0.034	0.423
2	Overt	2.94	1.18	2.09	1.29	3.560	0.001	0.687
3	Overt	1.59	0.89	1.15	0.88	2.521	0.013	0.490
4	Overt	1.81	1.31	1.58	1.21	0.922	0.358	0.181
5	Overt	1.57	1.02	1.68	0.98	-0.583	0.561	0.114
6	Covert	0.90	0.75	0.86	0.64	0.267	0.790	0.053
7	Covert	1.22	0.69	0.89	0.49	2.941	0.004	0.543
8	Covert	2.23	1.30	1.50	1.11	3.028	0.003	0.601
9	Covert	0.83	0.99	0.56	0.69	1.560	0.122	0.301
10	Covert	0.88	0.76	0.53	0.48	3.037	0.003	0.552
11	Covert	0.93	0.58	0.67	0.35	2.928	0.004	0.552

Table 6. First fixation duration (s) on the hazard for each clip.

		Children		**Adults**				
Clip	***Type of hazard***	***Mean***	***SD***	***Mean***	***SD***	***t***	***Sig.***	***Cohen's d***
1	Overt	0.34	0.25	0.42	0.26	-1.607	0.111	0.310
2	Overt	0.41	0.32	0.51	0.36	-1.600	0.112	0.303
3	Overt	0.26	0.16	0.39	0.24	-3.448	0.001	0.626
4	Overt	0.46	0.38	0.53	0.43	-0.878	0.382	0.167
5	Overt	0.40	0.25	0.37	0.22	0.572	0.568	0.113
6	Covert	0.38	0.27	0.44	0.28	-1.069	0.287	0.205
7	Covert	0.39	0.25	0.51	0.18	-2.818	0.006	0.523
8	Covert	0.44	0.31	0.58	0.36	-2.245	0.027	0.425
9	Covert	0.32	0.22	0.40	0.28	-1.464	0.146	0.293
10	Covert	0.29	0.23	0.49	0.27	-4.042	0.000	0.764
11	Covert	0.17	0.11	0.22	0.09	-2.094	0.038	0.415

Table 7. Dwell time (s) on the hazard for each clip.

		Children		**Adults**				
Clip	***Type of hazard***	***Mean***	***SD***	***Mean***	***SD***	***t***	***Sig.***	***Cohen's d***
1	Overt	1.56	0.83	1.96	0.95	-2.362	0.020	0.450
2	Overt	1.48	1.05	2.07	1.20	-2.750	0.007	0.524
3	Overt	1.09	0.70	1.39	0.78	-2.085	0.039	0.398
4	Overt	1.30	0.88	1.39	0.92	-0.510	0.611	0.098
5	Overt	2.47	0.83	2.59	0.79	-0.739	0.461	0.145
6	Covert	0.88	0.55	0.82	0.46	0.656	0.513	0.131
7	Covert	1.11	0.57	1.35	0.51	-2.250	0.026	0.444
8	Covert	1.96	1.05	2.38	0.95	-2.175	0.032	0.428
9	Covert	1.21	0.70	1.24	0.64	-0.245	0.807	0.051
10	Covert	1.22	0.57	1.51	0.46	-2.972	0.004	0.560
11	Covert	0.80	0.46	0.95	0.37	-1.922	0.058	0.362

Table 8. Number of fixations on the hazard for each clip.

		Children		Adults				
Clip	*Type of hazard*	*Mean*	*SD*	*Mean*	*SD*	*t*	*Sig.*	*Cohen's d*
1	Overt	4.76	2.62	5.24	2.54	-0.960	0.339	0.188
2	Overt	3.93	2.75	4.24	2.64	-0.590	0.557	0.116
3	Overt	4.52	2.95	5.58	3.38	-1.765	0.080	0.336
4	Overt	3.57	2.65	3.51	2.55	0.120	0.904	0.022
5	Overt	7.75	3.04	7.49	3.51	0.415	0.679	0.080
6	Covert	2.68	1.79	2.15	1.08	1.998	0.048	0.361
7	Covert	2.99	1.67	3.15	1.26	-0.534	0.594	0.106
8	Covert	4.49	2.39	4.68	2.07	-0.428	0.670	0.086
9	Covert	3.51	2.16	3.58	2.13	-0.174	0.862	0.035
10	Covert	3.33	1.67	3.27	1.07	0.254	0.800	0.0442
11	Covert	3.95	2.35	4.37	1.83	-1.063	0.291	0.198

4. Discussion

This study aimed to examine hazard perception in young and adult cyclists, using a computer-based hazard perception test. Both visual behaviour and reaction time to the overt and covert latent hazards were recorded, while participants watched video clips filmed from the perspective of a bicyclist. In general, children were slower to react to covert hazards compared to adults. Moreover, children fixated the hazards later and showed less extensive visual scanning than adult cyclists. Limitations such as immature perceptual and cognitive skills as well as insufficient understanding of the traffic situation have been suggested to hamper hazard perception in children. Therefore the results of this study will be discussed in the light of maturation and experience.

4.1. Findings

From the perspective of maturation, children's inefficient visual scanning behaviour may be attributed to an immature visual system. It is known that spatial and temporal accuracy of saccades and smooth pursuit capacity continues to develop well into adolescence (Langaas et al., 1998; Robert et al., 2014) as a function of maturation of the central nervous system and development of cognitive abilities such as sustained attention (Meir et al., 2013) and predictive control (Kowler 2011; Land 2006). Delayed and inaccurate saccades in combination with a limited ability to sustain attention to the relevant information may contribute to the inefficient scanning pattern, and partly explain the delay in first fixation on the hazardous situation in the current study. Furthermore, difficulties with smooth pursuit might explain the smaller dwell times in children since they are not yet capable of following moving targets efficiently and predicting future events (Hoffman et al., 1980). This is consistent with the findings of Grechkin et al. (2013) who showed that children persistently underestimate time-to-contact of gap interception with the oncoming car (in a virtual environment). Of note, depth perception and vergence ability, i.e. change fixation between a near and far target, develop until at least the age of twelve (Gallahue and Ozmun, 2005; Yang et al., 2002). Although these visual abilities are not required in a HPtask on a 2Ddisplay, they are considered to restrict children's perceptual capacities in real world (3D) situations. In sum, natural development of the visual system and cognitive function act as constraints on the uptake of relevant information, which is required to predict future events and to inform decision-making (Chihak et al., 2010). Clearly, hazard perception in child cyclists is not just dependent on the development of the visual system and cognitive abilities. Children's limited experience may also contribute to inefficient visual scanning behaviour and delayed reaction times to covert latent hazards (Underwood 2007; Underwood et al., 2002). In car driving, young novice adults, who have a mature visual system, still have difficulties in identifying possible hazards and scan areas from where potential hazards might appear less often compared to experienced drivers (Fisher et al., 2006). Also, road crossing studies in young pedestrians, both off- and on-road, demonstrated that children base their judgments exclusively on the presence of cars that are visible. These examples show that a person's situation awareness is dependent upon experience too, and not just emerges as a function of maturation. SA is defined as "the perception of the elements in the environment within a volume of time and space (level 1), the comprehension of their meaning (level 2) and the projection of their status in the near future (level 3)" (Endsley 1995; pp. 36). Endsley's SA theory entails that quick and correct decision-making involves pattern recognition or matching, which requires the formation of sophisticated internal models (schemata), containing prototypical (traffic) situations. Limited experience (or training), as for example in children, will restrict one's capacity to perceive important cues (SA level 1). The finding that, in the current study, children fixated later on 5 hazardous situations, of which the majority was covert and latent, is consistent with this notion. Although differences in reaction times and fixation times are rather small and delayed perceiving and reacting on potential hazards does not necessarily have to result in a crash, it does increase the risk. It shows that the children did not possess the capacity to perceive that other road-users who were hidden from view, e.g. by other road users or vegetation, were on collision course. Children tend to focus on the most salient factor (Meir et al., 2013), instead of elements such as obscuring obstacles or blind summits that may "contain" information on hazards (Ampofo-Boateng and Thomson, 1991; Meir et al., 2013). This also relates to the second (comprehension) and third (projection) level of SA, i.e. children lack the capacity to comprehend whether or not a cue contains risk and make projections about future events that may turn out to be hazardous. In the comprehension stage the bicyclist creates an understanding of the current situation based on memories and past experiences. Finally, the bicyclists makes a prediction of the recognized traffic situation based on his traffic related knowledge. Difficulties in assessing the features that create dangerous situations may result in inadequate visual search patterns and longer reaction times as found in this study (Ampofo-Boateng and Thomson 1991 Meir et al., 2013; Whitebread and Neilson 2000). Since adults have already encountered a variety of dangerous traffic situations, they have developed a more extensive database of mental templates (internal models or schemata, according to Endsley), which facilitates the decision-making process. It has been suggested that delayed reaction times and inadequate visual scanning behaviour in novice drivers could be attributed to limited cognitive resources due to inadequate vehicle control skills (Underwood et al., 2002, 2003). The current findings show that visual scanning and hazard perception in children are far from optimal, even when the motor component (steering, pedalling, balance etc.) is absent. Inadequate gaze behaviour can thus not be the result of limited cognitive resources due to a complex double-task (i.e. cycling). This supports the notion that children have not yet developed adequate SA, and therefore are unable to sufficiently understand or interpret might happen on the road.

4.2. Limitations and future research

Firstly, it is remarkable to find that, although the video clips in our study were found to be suitable and of decent quality by all three experts, there was no significant difference for response rate between children and adults for any of the clips, except for one. This is in contrast with a study in car drivers where higher response rates were reported for adults in three situations (out of ten) compared to children (Meyer et al., 2014). Also, child pedestrians were found to respond less often to hazardous situations compared to adults (Meir et al., 2015b, 2013; Rosenbloom et al., 2015). In line, we were not able to find differences in the number of fixations between children and adults for covert latent hazards which is in contrast with Vlakveld (2011) who found that learner drivers have more difficulties detecting covert latent hazards. This lack of difference in response rate and the number of fixations on the covert latent hazards in our study might be explained by the nature of the traffic situations, since the covert hazardous situations virtually always developed into salient hazards. Future research might therefore include more situations containing potential (covert) hazards that do not develop into actual hazards. Secondly, although our study was able to identify subtle differences between children and adults in the perception of and reaction to dangerous traffic situations, this study is limited since participants were presented with video clips on a computer screen resulting in the dissociation of perception and action. Subsequently, a hazard perception test using a bicycle simulator in a virtual environment as in Chihak et al. (2010) and Grechkin et al. (2013) might provide a more detailed understanding with respect to the differences between child and adult cyclists. Thirdly, while there are several physiological and developmental differences between children and adults, and as hazard perception is found to be related to experience, future research might consider comparing hazard perception of inexperienced and experienced child cyclists to inexperienced and experienced adult cyclists to isolate these variables. It is likely that experienced child cyclists will have a better developed situational awareness and possibly be more comparable to adult cyclists' situational awareness. This might provide us with valuable information with respect to the development of training programs for inexperienced children. Also the issue whether an adult inexperienced cyclist displays similar shortcomings compared to young cyclists might be of interest. Moreover, measurement of cycling skills and cycling experience to establish an accurate determination regarding the experience level of the participants is therefore essential. Although direct extrapolation should be done with caution, it is thought that the suboptimal scanning patterns of children may be related to the incidence of accidents. In support of this, inadequate visual search patterns were found to be one of the most prominent causal factors in car-bicycle crashes (Bao and Boyle 2009), e.g. lacking to check for other traffic participants at intersections. Although more research is to further our understanding of bicycle accidents in children, the current findings indicate that training to search for elements which could predict the hazard might be beneficial for hazard perception in children. In this respect it is promising that Meir et al. (2015a,b) reported improvements in 7–9-year-old pedestrians awareness of potential covert hazards after training compared to a control population. Therefore an adapted hazard perception training for young cyclists might improve their understanding and concepts of dangers on the road.

5. Conclusion

To our knowledge this is the first study that examined gaze behaviour in relation to hazard perception in young cyclists. We have found delayed reaction times and time until the first fixation in children compared to adults. Aside from immature cognitive abilities (Chihak et al., 2010; Grechkin et al., 2013; Langaas et al.,1998; Plumert et al., 2004; Robert et al., 2014; Yang et al., 2002) also experience-related factors (Ampofo-Boateng and Thomson 1991; Meir et al., 2015a; Meyer et al., 2014; Rosenbloom et al., 2015) contribute to poor hazard perception skills. The inefficient visual scanning patterns and the finding that children only responded to the covert latent hazards when they became salient, suggest poor situation awareness, related to slow or limited perception, comprehension and projection of the traffic situations (Meir et al., 2015a, 2013). As hazard perception does not only depend on maturity-related factors (Meyer et al., 2014), the development of a training program to detect, predict and anticipate hazardous situations in young cyclists is of interest.

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Paper 7: Hazard perception training in young cyclists improves early detection of risk: a cluster-randomised controlled trial

ABSTRACT

Introduction: Since child bicyclists are more likely to get involved in a traffic crash there is a stringent need to provide child bicyclists with tailored interventions in order to enhance their capabilities to deal with the complexity of traffic situations. The current study[37] therefore aimed to test the effectiveness of a hazard anticipation training in young bicyclists by means of eye tracking technology. **Methods:** A cluster-randomized controlled design was used in which participating schools were randomly assigned to the intervention or the control group. At first, a baseline hazard anticipation test was carried out in the intervention group (78 children; 9.56±0.38 years of age) and the control group (46 children; 9.58±0.41 years of age). Child bicyclists who participated in the intervention followed the training that consisted of two classroom sessions. In each session children were presented with video clips from the perspective of a bicyclist encountering various (potentially) dangerous traffic situations. Following the intervention, a post-test directly after the training and a retention test three weeks later were completed. The control group received the intervention after the retention test. **Results:** Trained child bicyclists were found to detect more hazards and reacted quicker compared to the control group that did not receive the training. However, the training did not result in improvements in anticipatory visual search behaviour. **Conclusion:** Trained child bicyclists seemed to have developed a better processing regarding potential dangerous situations but were not able to 'see' the hazard sooner. The potential of a brief hazard anticipation training is discussed.

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[37] This part is based on **Zeuwts L.H.R.H.**, Vansteenkiste P., Deconinck F.J.A., Cardon G., Lenoir M. (2016). Hazard perception training in young cyclists improves early detection of risk – A cluster-randomized controlled design. *Accident Analysis and Prevention. (Revised)*.

1. Introduction

Cycling is often promoted as a cheap and healthy way of transportation (Chillón et al., 2012; Davison et al., 2008). The increasing number of bicyclists in Europe (DEKRA Automobil GmbH, 2011) has strongly been associated with many positive effects for both the bicyclist and the environment (de Hartog et al. 2010; Oja et al., 2011). This increase in bicycle share however, also resulted in more bicycle accidents in Germany (Juhra et al., 2012). Furthermore, Carpentier & Nuyttens (2013) and Maring and van Schagen (1990) reported that mainly children (under the age of 14) and older cyclists (above the age of 65) are at risk. Indeed, bicycle accidents in Europe represent 7.8% of all road fatalities (European CARE report, 2015), whereas in Flanders 9- to 14-year-old children represent 10% and 14- to 19-year-old children almost 11% of all bicycle accidents (Carpentier and Nuyttens, 2013). Therefore, there is a stringent need to provide child cyclists with means for enhancing their abilities to safely deal with the complexity of dynamic traffic settings (Hill et al., 2000).

Cycling safely can be considered as a function of both motor (Ducheyne et al. 2013b; Zeuwts et al., 2015) and cognitive abilities (Briem et al., 2004). With respect to the motor abilities, previous research has shown that training of specific cycling skills has a long term effect on young children’s general cycling ability (Ducheyne et al., 2013a). For the cognitive abilities, it is known that skills such as perception, anticipation, and decision-making (Briem et al., 2004) continue to improve with experience until late childhood (Chihak et al., 2010; Plumert et al., 2011; te Velde et al., 2005). Accordingly, children’s percpetual and cognitive skills in a variety of different complex traffic situation might benefit from tailored interventions or practice too (Connelly et al., 1998; Thomson et al., 1996).

Visual search strategies and perceptual-cognitive abilities in children have been reported to be inadequate in obstacle avoidance and road-crossing tasks (Franchak and Adolph, 2010; Whitebread and Neilson, 2000). Children were shown to adopt simpler strategies when confronted with complex traffic situations (Pryde et al., 1997), have difficulties with synchronizing their actions to moving objects (Grechkin et al., 2013), make less use of their peripheral vision (Franchak and Adolph, 2010), and focus more on irrelevant stimuli compared to adults (Berard and Vallis, 2006; Day, 1975; Whitebread and Neilson, 2000). Moreover, they pay less attention to task-relevant information (Ampofo-Boateng and Thomson, 1991), have difficulties with integrating information into a holistic perspective of the situation (Underwood et al., 2007) and have a tendency to focus on the most salient factor in the environment (Ampofo-Boateng and Thomson, 1991; Thomson et al., 2005). This inadequate behaviour is likely to result in unsafe interactions with the traffic environment.

In support of this, Zeuwts et al. (2016) found that young children’s (about 10 years of age) hazard perception skills are poorer developed compared to adults. Hazard perception is the ability to read the road ahead and anticipate upon the developing situations. Hazard perception is therefore closely related to Endsley's (1995) concept of situation awareness consisting of perception, comprehension and projection of future events. Zeuwts et al. (2016) showed that young cyclists did not actively search for other road users who are hidden from view (covert hazards), which resulted in delayed reaction times with respect to the hazardous situation. Children are therefore suggested to lack the capacity to efficiently decide whether or not a situation might contain risk (comprehension) and to make predictions regarding the future events (projection) (Meir et al., 2015b, 2013; Rosenbloom et al., 2015).

Despite the overrepresentation of children in accident statistics, training interventions to improve hazard perception are to our knowledge non-existent. Just like bicycling skills may be learned (Ducheyne et al. 2013a), it can be assumed that specific training programs could aid the development of hazard perception skills and situation awareness among young inexperienced bicyclists

In driving, video-based road commentary training in young drivers (18 to 19 years of age) resulted in a similar hazard detection rate compared to more experienced drivers (±35.5 years of age; Isler et al., 2009). Consistent with this, Pradhan et al. (2005; 2006; 2009) found positive effects on drivers (16 to 21 years of age) gaze behaviour after a PC-based Risk Awareness and Perception Training. Trained drivers were reported to gaze more to relevant dangerous areas. This behaviour was also observed in situations substantially different from the training scenarios.

With respect to children, Thomson et al. (2005) reported that in an attempt to accelerate the development of pedestrian skills in 7-, 9- and 11-year-old children, interactive learning was effectively adopted to drive educational interventions. The computer-based intervention consisted of four sessions, each lasting between 30 and 40 minutes with increasing complexity. Within each training session, children were presented with nine road crossing simulations, which were embedded into a real-life scenario, e.g. a walk to the park. The instruction was to help the character on display with crossing several junctions. Each time the participant selected an unsafe gap in between the passing cars, the sound of screeching brakes was heard, the image froze and the child character's ghost departed from its body. This feedback was used to initiate a discussion with the participant. Children who were trained with a computer-simulated environment showed safer crossing behaviour – quicker crossing, better aligned crossing, missed fewer opportunities – and improved conceptual understanding. In another study, Meir et al. (2015b) evaluated the effect of a 40-minute simulator hazard perception training (the Child-pedestrians Anticipate and Act Hazard Perception Test) among 7-9-year-old child pedestrians which consisted of two individual parts. In the first part, participants were presented with 11 traffic scenarios from the perspective of a child pedestrian and had to press a button each time they encountered a dangerous situation. Then, the scenarios were replayed from a different point of view (POV). Participants were encouraged to identify and describe the hazard instigators. In the second part, children were presented with three pairs of traffic scenarios. Each pair represented the same scenario but from a different perspective. They were asked to compare between them. Trained children displayed improved awareness with respect to potential hazardous situations due to restricted field of view.

In summary, despite the evidence of positive effects of hazard perception training in young novice drivers (Crundall et al., 2010; Isler et al., 2009; Meir et al., 2014; Pradhan et al., 2009) and child pedestrians (Meir et al., 2015a), research with respect to hazard anticipation and hazard perception training amongst young cyclists is absent. Since limited complex higher order perceptual and cognitive skills in children, in particular hazard perception, situation awareness and visual search (Meyer et al., 2014; Meir et al., 2015a; Meir et al., 2015b; Rosenbloom et al., 2015; Zeuwts et al., 2016) are suggested to be associated with higher crash risk, training interventions to improve these abilities are of interest. Therefore, the aim of the current study was to test whether a hazard perception training in young bicyclists will improve child bicyclists' response rates and reaction times and result in a more efficient visual search pattern. Visual search patterns of children will be documented by means of eye tracking methodology since access to the visual information is a prerequisite for evaluating the first level of situational awareness. It is expected that the trained children will fixate the hazards sooner. However, no clear hypothesis is formulated regarding the number of fixations and dwell time.

2. Methods

2.1. Participants

In the first stage, a total number of 30 randomly selected elementary schools has been sent an invitation to participate in the study. Ultimately, only four elementary schools gave permission to conduct the hazard perception training, of which one was located in an urban, two in a suburban, and one in a rural environment. Schools were randomly assigned to the intervention or the control group which resulted in a cluster-randomized control study design. Only children with at least two years of cycling experience on the road were included for further testing since Deery (1999) and Meir et al. (2014) suggested that higher cognitive training should take place after the basic manipulation skills are obtained. According to Ducheyne et al. (2013) and Briem et al. (2004) children should be able to control their bicycle around the age of nine. Therefore, 127 fourth graders (56 girls) were recruited, of which 80 children, divided over four classes (34 girls), were allocated to the training group and 47 children, divided over three classes (24 girls), were allocated to the control group. The children of the control group received the training after the retention test. Children were given an informed consent which their parents read and signed for approval. The study protocol was approved by the Ghent University ethical committee. **Table 1** provides more information regarding the students in the intervention and control group.

Table1. Demographics regarding the intervention and control group.

	Intervention n=78	**Control n=46**
Age	9.56±0.38	9.58±0.41
Age at onset of cycling	4.32±0.87	4.32±0.87
Transportation to school		
Distance to school (km)	2.81±3.00	5.80±11.77
Minutes cycling to school	9.65±5.48	12.09±17.88
#Days to school by bicycle per week	0.97±1.53	0.72±1.28
#Days to school by foot per week	1.16±1.96	0.68±1.57
#Days to school by car per week[aa]	2.59±2.20	3.59±1.89
Minutes cycling per week	36.9±62.64	39.4±63.48

[a]$p<0.05$, [aa]$p<0.01$, [aaa]$p<0.001$

2.2. Apparatus

2.2.1. The hazard perception test for bicyclists (HPtest)

The Hazard Perception test (HPtest) is based on a modified version of the hazard perception test for bicyclists of Zeuwts et al. (2016). Because of low image quality or poor sensitivity in the original version, five clips were replaced by new improved clips. The Hptest therefore consisted of 14 film clips (with a duration of approximately 30 seconds) videoed from the perspective of a bicyclist, with a GoPro Hero2 camera (30Hz, full HD and 170° field of view). Each clip contained at least one hazardous situation. When presented with the HPtest, participants were not aware of the number of hazards and the test included a variety of typical traffic situations and road designs. Hazardous situations were classified as overt or covert hazards according to Vlakveld (2011). Overt latent hazards refer to other visible road users who might start to act dangerously over time while covert latent hazards reflect potential hazards where other road users are hidden from view e.g. vegetation on a street corner which limits proper view on a street on the right side of the bicycle path. A more detailed description of the 14 clips used in this hazard perception test can be found in **table 2**.

Table 2. Description of the hazardous situations and the types of hazards with their corresponding and correct answer.

Clip	Type	Description of the video	Timeframe	Hazard
1	Overt	A car in the opposite direction of the bicyclist is about to turn left.	4.97s	Car
2	Overt	A woman coming out of a double parked car steps onto the bicycle path from behind another car.	2.83s	Pedestrian
3	Overt	A van passes by the bicyclist. The driver indicates he is about to park in front of the bicyclist.	14.30s	Van
4	Overt	A bicyclist enters the bicycle path just in front of the other bicyclist.	5.26s	Bicyclist
5	Covert	A man enters the street from behind a van.	2.29s	Pedestrian
6	Covert	A man opens the door of his parked car and steps out of the car.	4.87s	Pedestrian
7	Covert	The view on the car coming from a street on the right side is blocked by bushes.	5.66s	Car
8	Covert	A container blocks the view on the pedestrian at a pedestrian crossing.	2.92s	Pedestrian
9	Covert	The view on a cyclists coming from the street on the right is limited.	5.87s	Bicyclist
10	Covert	A group of people is unloading a bus. A man suddenly crosses the street from behind the bus when the bicyclist is about to pass.	10.43s	Pedestrians
11	Covert	A sign and road marking indicate a bicyclist crossing. View on the crossing is limited due to parked cars and vegetation. Distracted bicyclists appear, however do not tend to cross the road.	15.58s	Bicyclist
12	Covert	The view on the street from the right is limited. A car from the right enters traffic in front of the bicyclist.	12.51s	Car
13	Covert	A van is parked on the street in front of a pedestrian crossing. A pedestrian comes from behind the van but waits for the bicyclist to pass.	5.02s	Van
14	Covert	The view on a van coming from the right is limited due to vegetation	3.43s	Van

Testing took place at the children's schools during the regular school hours. Children were called away from the classroom one at a time. When entering the testing room, children were asked to take a seat at ± 70 cm in front of the computer screen with a visual angle of 40° horizontally × 30° vertically. To measure the participant's gaze behaviour during the test, the Remote Eye tracking Device (RED) of SensoMotoric Instruments (SMI, Teltow, Germany) was used. The eye tracking device was mounted at the bottom of the 22in. computer screen which used to display the video clips with the SMI Experiment Center 3.4 software (see **figure 1**). After a brief explanation of the experiment, the eye tracking device was calibrated using a five point grid. Only calibration deviations lower than 1° were accepted. Following the calibration process, participants were told to imagine they were actually cycling the bicycle themselves and were instructed to press the mouse button (once) each time they detected a hazardous situation. A hazard was defined as each situation which required the participant to brake or steer in order to avoid a potential or imminent threat. Participants were not aware of the number of hazardous situations in the video clips. After each film clip participants were asked to indicate which hazard they had seen. Eye movements (binocular) and reaction times of the participant were recorded at 120 Hz with the iView X recording software of SMI. In the middle and at the end of the HPtest the calibration of the eye tracking device was checked.

Figure 1. A participant performing the hazard perception test.

2.2.2. Intervention

The hazard perception intervention consisted of two lessons, of approximately 50 minutes each. In these lessons, children were presented classically with video clips of dangerous traffic situations from the perspective of a child and adult bicyclist which were shown on a projection screen (1,5m × 2m) in the classroom. Video clips lasted for about 35 seconds and contained one or more (potential) hazards. All video clips for the training had previously been evaluated by three experts (driving instructors with at least 15 years of experience). Video clips which were considered useful for training were assigned to one of the themes of the lessons (**table 3**). These themes included the most prominent causes of bicycle accidents and were ranked from standard traffic situations to more complex traffic situations containing multiple dangerous situations.

When designing the hazard perception training, four principles were taken into account (Meir et al., 2014). (1) Since children are smaller and use smaller bicycles, they also perceive the environment from a different point of view than adults. For example, when bicycling along a lane of parked cars, an adult bicyclist will be able to watch over the parked cars for oncoming traffic when planning to make a turn. The child bicyclist however, is smaller and not able to check beyond the parked cars for oncoming traffic, which increases the risk for an accident when he must make a turn. Furthermore, since children have been demonstrated to rely mainly on the present visual information (salient) video clips from the perspective of a child and adult bicyclist are used to improve understanding regarding hidden hazards or situations with limited field of view. Furthermore, (2) participants were presented with video clips of dangerous traffic situations in a variety of landscapes and road designs since it has been suggested that associations between typical hazardous situations and their environment are strengthened when young novice drivers are presented with a large variety of hazardous traffic situations in their specific environment (Borowsky et al., 2009). In order to learn to anticipate potential dangerous situations (3), young bicyclists should also be familiar with traffic situations in which the hazard actually materialized (Meir et al., 2014). Child bicyclists were therefore presented with similar situations as in the HPtest, but with more hazards that actually materialized. Lastly, (4) the current HP-training combined both an active and instructional component which was suggested to generate the most effective intervention (Meir et al., 2014). The active component aimed to encourage participants to respond actively and as soon as possible to the hazardous situations by raising their hand. As soon as a child raised his or her hand, the video clip was paused and the current traffic situation was discussed. After discussion the video clip was continued until a new event occurred or until the video clip was finished. Then the video clip was replayed and the instructor provided the trainees with the correct instructions regarding the dangerous situation. These instructions were validated by three traffic experts.

Table 3. Themes of the hazard perception intervention

Lesson 1	
•	**Pedestrians:** pedestrian crossings, shared bicycle/pedestrian paths,…
•	**Parking:** cars entering parking lot, cars parking on the right side of the road, cars entering traffic,…
•	**Crossings**: street crossings, passing other road users, streets from the right side,…
Lesson 2	
•	**Junctions:** street crossings, priority lanes,…
•	**Roundabouts:** entering the roundabout, exiting the roundabout,…
•	**Bus stop:** passengers leaving the bus, passengers aiming to stop the bus,…
•	**Mixed situations**

The first lesson of the hazard perception training was performed in the class of the children approximately two days after the hazard perception test and was performed by a member of the research team with extensive teaching experience. Furthermore, the training was delivered in group sessions of 17 to 23 children. Children sat at their desks and received verbal instructions regarding the content of the intervention. A short summary of the training was provided after which children had the opportunity to ask questions. Then, video clips with different hazardous situations were shown to the children. Participants were asked to raise their hand as soon as they thought they would brake or stop to avoid a potential collision. Every time someone raised their hand, the video was paused and the respective event was discussed classically. The following questions were asked to guide the discussion: “what might happen next?”, “where did you see a possible collision?” or “what might predict a possible collision?” After the discussion, the video continued until the next event or until the end of the video clip. Subsequently, the video was replayed and the instructor provided the children with the necessary information regarding the hazardous event: where to look, what to look for, what cues might have predicted the dangerous situation or what might have happened. Furthermore, children were told what correct behaviour or actions could be undertaken.

One week after the first training session, children received the second intervention session which was followed by the post-test one or two days later. A retention-test was performed three weeks after the post-test. The control group received the training intervention after the retention-test (**figure 2**).

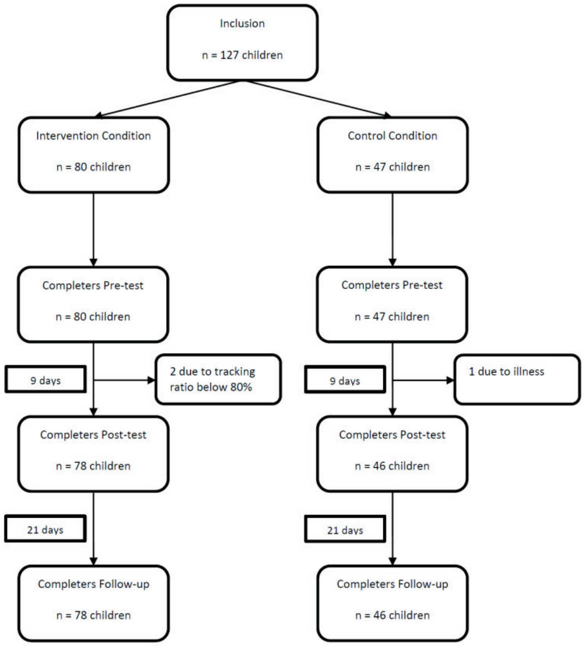

Figure 2. Overview of the intervention study and participant drop-out.

2.3. Analysis

In eye tracking there is often considerable loss of data due to eye blinking, excessive head movements or other artefacts. Therefore, prior to further analysis, tracking ratio (TR) of the gaze behaviour, i.e. the percentage of time in which gaze was accurately registered during one trial, was computed for all the participants. Participants with a TR below 80% were excluded for further analysis. This resulted in a sample size of 78 participants in the intervention group. Furthermore, one participant in the control group was excluded due to absence for the post-test (see **figure 2**).

2.3.1. Measures

2.3.1.1. Reaction time and response accuracy

Reaction times were measured relative to the critical hazard perception interval where the hazard appeared for the first time (ms) until the last time before collision (ms) was inevitable, and were exported from BeGaze 3.4 (SensoMotoric Intruments, Teltow, Germany). The critical hazard perception interval was unanimously validated by three experts. To prevent from random behaviour, reaction times within this timeframe were only included for further analysis if the participant indicated the correct hazardous situation in the short questionnaire following each clip (for the correct answers on the questions see **table 2**). *Response accuracy* was calculated and refers to the amount of correct answers within the timeframe of each clip. When a participant responded to all of the hazards correctly, he received a maximum score of 1.

2.3.1.2. Gaze behaviour

For *gaze behaviour*, the number of fixations were calculated using the 'SMI Event Detection' algorithm. A fixation was measured when the eyes remained still on the target for at least 120ms. For each video clip the hazardous events were determined and appointed as Areas Of Interest (AOIs) using the dynamic AOI-editor of the gaze analysis software package BeGaze 3.4 (SensoMotoric Instruments, Teltow, Germany). Dynamic AOIs are used to include or exclude certain areas from analysis and refer to the hazardous event or region in the video clip that the bicyclists must have seen to anticipate a potential collision. Using the BeGaze analysis tool the *number of fixations on each AOI* was calculated for each participant. The number of fixations refers to the number of glances the bicyclist made towards the hazard. The *entry time of the first fixation* on the hazard was defined as the timestamp in which the participant fixated the AOI for the first time (s), whilst *first fixation duration* was defined as the duration of the first fixation of the participant on the AOI. *Dwell time on the AOI* was calculated and defined as the total amount of time spent fixating the AOI or the sum of durations from all the fixations and saccades that hit the respective AOI.

2.4. Statistics

Differences regarding the demographics between the intervention group and the control group were estimated using an Independent-Samples T-Test (see **table 1**). The effect of the training intervention on the dependent variables was conducted using a Linear Mixed Model (LMM) analysis with repeated measures and random intercept. A LMM has the advantage over a repeated measures ANOVA because 'missing values' for cases do no result in the exclusion of the entire case. The model included two fixed effects, i.e. time (pre-test, post-test, retention-test) and group (intervention or control) and one interaction effect (time*group). Time was included as a random effect. The repeated covariance type 'diagonal' for the repeated measures and 'unstructured' for the random effect were used since both resulted in the model with the best fit (lowest AIC). Estimation was set as Restricted Maximum Likelihood (REML) and estimated marginal means for each interaction effect were obtained. Significance levels were set at $p \leq 0.05$.

3. Results

Children who followed the intervention responded significantly more often to the hazards directly after the intervention compared to the control group. This effect tended to be retained at the retention-test. Compared to the control-group, *response accuracy* in the trainees was significantly higher in the post-test as well as on the retention test. For the *reaction time* to the hazardous situations, children tended to respond faster immediately after the training. However, three weeks after the intervention children responded significantly faster compared to the control group. So, while response rate and reaction time in the control-group remained rather stable, both response rate and reaction in the intervention group improved due to the training.

Concerning *gaze behaviour* on the hazard, no training effects were found for the entry time of the first fixation or the duration of the first fixation. However, the intervention group showed a significant increase in dwell time and number of fixations on the hazard while the control group displayed a decrease for both variables on the post-test, followed by an increase towards the retention-test.

Table 4. Interaction effects for group and time with respect to mean response accuracy, reaction time (s) on the hazard, entry time of the first fixation (s) on the hazard, duration of the first fixation (s) on the hazard, dwell time on the hazard (s) on the hazard and the number of fixations on the hazard over all the clips.

	Intervention			**Control**			**[pre-post*group]**			**[pre-retention*group]**		
	Pre *N=80*	Post *N=78*	Ret *N=78*	Pre *N=47*	Post *N=46*	Ret *N=46*	β	CI	p	β	CI	p
Response Accuracy (%)	0.71±0.02	0.75±0.02	0.76±0.20	0.68±0.02	0.63±0.02	0.66±0.03	0.088	(0.02;0.15)	0.006	0.065	(-0.00;0.13)	0.099
Reaction Time (s)	4.84±0.09	4.51±0.10	4.61±0.10	5.04±0.12	5.01±0.13	5.30±0.13	-295.170	(-645.75;55.40)	0.098	-490.150	(-867.63;-112.67)	0.011
First Fixation entry time(s)	1.87±0.38	1.88±0.43	1.83±0.55	1.77±0.49	1.86±0.56	1.93±0.71	-67.278	(-238.84;104.29)	0.439	-203.817	(-412.98;5.35)	0.056
First Fixation Duration (s)	0.37±0.11	0.37±0.01	0.37±0.10	0.39±0.10	0.38±0.14	0.40±0.13	14.631	(-25.44;54.70)	0.471	-6.593	(-48.35;35.17)	0.755
Dwell Time (s)	2.92±0.56	3.02±0.66	3.49±0.56	3.80±0.73	3.18±0.86	3.61±0.74	727.145	(521.23;1014.54)	0.000	768.701	(567.50;969.91)	0.000
Number of Fixations	8.26±0.18	8.34±0.21	9.72±0.19	10.23±0.24	8.40±0.27	9.78±0.25	1.899	(1.08;2.72)	0.000	1.910	(1.15;2.67)	0.000

3.1. Response accuracy and reaction time for each clip

First, interaction effects for response accuracy and reaction times for the intervention and control group are displayed for each occasion (**fig. 3A**). With respect to ***response accuracy***, trained child bicyclists detected significantly more overt ($p < 0.05$) and covert ($p < 0.01$) latent hazards in the post-test compared to the control group. This effect disappeared in the retention-test where only a trend respecting the covert ($p < 0.1$) latent hazards was observed. For ***reaction time***, interaction effects for both the post-test ($p < 0.05$) and the retention-test ($p < 0.05$) showed improved reaction times in the trained child bicyclists compared to the control group (**fig. 3B**).

The main-effect of time for ***response accuracy*** demonstrated that trained child bicyclists significantly responded more for covert latent hazards both in the post-test ($p < 0.05$) and the retention-test ($p < 0.05$). However, the main effect for time indicated that trained bicyclists did not respond more for overt latent hazards on the post-test ($p = 0.123$). Furthermore, also the main-effect of time for ***reaction time*** showed that trained child bicyclists reacted sooner in both the post ($p < 0.01$) and retention-test ($p < 0.05$) on the covert hazards compared to the control group.

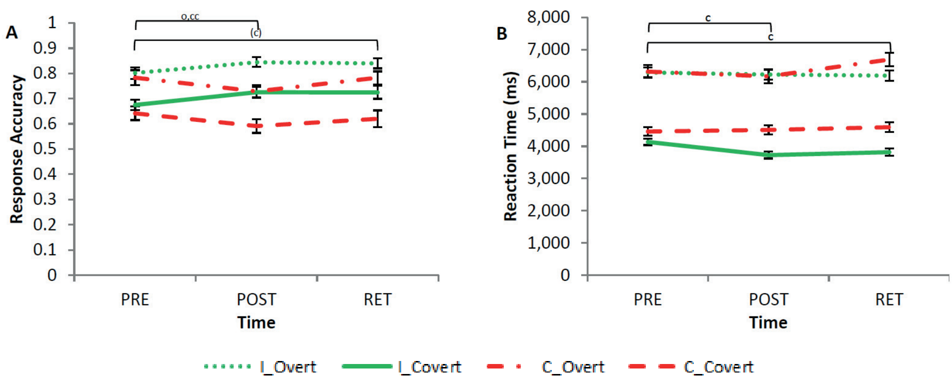

Figure 3. A) Response accuracy for the intervention (I) and control group (C) for both the overt and covert hazards over time. **B)** Reaction times for the intervention (I) and control group (C) for both the overt and covert hazards over time.
ooo = p>0.001, oo = p<0.01, o = p<0.05, (o) = trend for the overt hazards.
ccc = p>0.001, cc = p<0.01, c = p<0.05, (c) = trend for the covert hazards.

3.2. Gaze behaviour

In the second part, gaze behaviour by means of first fixation entry time, first fixation duration, dwell time and the number of fixations are provided. The interaction effect for the ***first fixation entry time*** demonstrated that trained child bicyclists fixated the overt hazards sooner compared to the control group only three weeks after the intervention (**figure 4A**). No significant effect for the first fixation entry time regarding the covert hazards was observed. For the ***first fixation duration*** on the hazard, no significant interaction effect was reported for the overt or the cover hazards after training (**figure 4B**). Regarding the interaction effect for ***dwell time*** on the hazards, trained child bicyclists increased their dwell times directly after the intervention on both the overt and the covert hazards while the control group decreased their dwell times on both types of hazards (**figure 4C**). On the retention test however, dwell times in the trained child bicyclists continued to increase while dwell times for the overt hazards slightly decreased again. At last, a significant interaction effect for the ***number of fixations*** (**figure 4D**) in the post-test and the retention-test, demonstrated an increase in the number of fixations on the covert hazards by the trained child bicyclists. Furthermore, the control group showed a decrease in the number of fixations in the post-test followed by an increase in the retention-test.

With respect to the main effects for time, no significant differences for the ***first fixation entry time*** or the ***first fixation duration*** have been reported in the trained child bicyclists. However, trained child bicyclists demonstrated significant higher ***dwell times*** on the overt hazard in the post-test ($p < 0.01$) and on the retention-test ($p < 0.05$). Regarding the covert hazards, trained child bicyclists increased their dwell times only on the retention test ($p < 0.001$). Lastly, there was no change in the ***number of fixations*** in the post-test for the trained child bicyclists. However, trained children significantly increased their number of fixations on the covert hazards in the retention-test ($p < 0.001$).

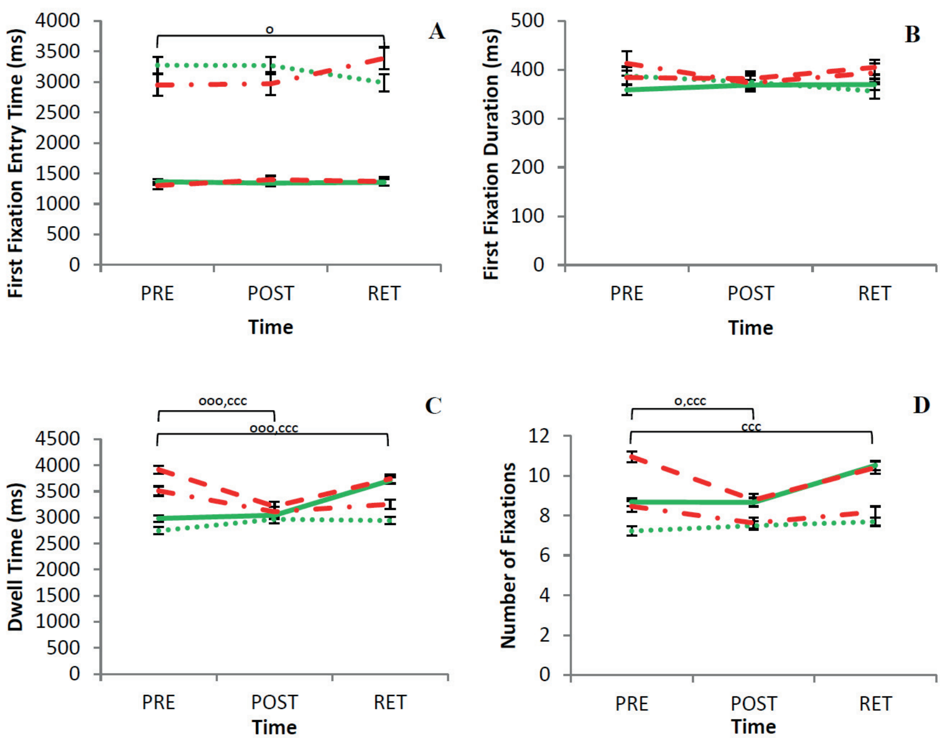

Figure 4. A) First fixation entry time for the intervention (I) and control group (C) for both the overt and covert hazards over time. **B)** First fixation duration for the intervention (I) and control group (C) for both the overt and covert hazards over time. **C)** Dwell time for the intervention (I) and control group (C) for both the overt and covert hazards over time. **D)** Number of fixations for the intervention (I) and control group (C) for both the overt and covert hazards over time.
ooo = p>0.001, oo = p<0.01, o = p<0.05, (o) = trend for the overt hazards.
ccc = p>0.001, cc = p<0.01, c = p<0.05, (c) = trend for the covert hazards.

4. Discussion

The current study aimed to investigate whether a brief intervention consisting of two classroom sessions could improve child bicyclists' ability to anticipate potentially developing hazardous traffic situations by means of improved response accuracy, reaction times and earlier detection of the hazard. Trained child bicyclists showed improved understanding regarding the potential dangerous situations compared to the control group, which is reflected by their higher response rates towards the dangerous situations and improved reaction times in the post-test. Although trained child bicyclists reacted faster to the covert hazards in the retention-test too, the interaction effect for response accuracy only tended to be significant. With respect to gaze behaviour, no clear improvements for the first fixation on the hazard were observed. However, trained child bicyclists increased their dwell times and number of fixations on the covert hazards.

Child bicyclists who participated in the training showed general improvements in response rate of ±5% compared to baseline. Especially response rate for the covert hazardous situations – in which the field of view is restricted by vegetation, buildings or other road users – significantly improved in the trained child bicyclists. With respect to the reaction times, trained children anticipated a potential hazardous event 0.32s faster on the post-test compared to the pre-test. While the intervention mainly resulted in significant improvements in reaction times for the covert latent hazards (±0.4s; minimal improvement=0.17s; maximal improvement=1.92s) directly after the training and three weeks after the training (±0.3s; minimal improvement=0.21s, maximal improvement=2.35s), reaction times for the overt latent hazards were not affected by the intervention. Our results are therefore consistent with the results of Isler et al. (2009) who reported improvements in hazard identification of comparable magnitude. Isler demonstrated that after the intervention, young-trained drivers detected significant more hazards (+4.2%) and improved their reaction time by 0.8s compared to the young control group.

As to the first fixation entry time and first fixation duration, we did not find any distinct effects which could be attributed to the intervention which is in contrast to the expectations since Zeuwts et al. (2016) reported that experienced adult bicyclists fixate sooner on the covert hazards. This implies that young trained bicyclists did not attend more to the latent hazards after the intervention. Also Vlakveld (2012) reported no superior anticipatory eye movements in experienced drivers compared to young learner and older drivers in means of entry time of the first fixation and duration of the first fixation on the hazard. Furthermore, both Hosking et al. (2010) and Huestegge et al. (2010) failed to find significant differences regarding the first fixation in inexperienced and experienced motorcycle/car drivers when scanning for hazardous situations.

On the other hand, we did find an increase in dwell time and the number of fixations on the hazardous situation, which demonstrated that trained children spent more time looking at the dangerous events. This might suggest that after training, trained children were more aware of the danger within the event and therefore keep monitoring how the situation evolves. In support of our findings, Vlakveld reported that experienced drivers showed significantly more anticipatory eye glances on three covert latent hazards (out of six) and two overt latent hazards (out of 10). Fisher et al. (2006) reported that after training, participants demonstrated an increase for anticipatory eye glances at traffic-related areas, which contained relevant information. Unfortunately, time until the first fixation on the developing hazard was not reported in this study. In contrast, a brief hazard perception intervention on visual search behaviour in young drivers resulted in reduced mean fixation durations to the developing hazard together with an increase in gaze distribution along the horizontal axis (Chapman et al. 2002). This reduction in mean fixation durations was suggested to reflect decreased perceptual capture of the hazardous situation and enhanced knowledge resulting in speeded processing of the acquired information. Meir et al. (2014) also reported reduced mean fixation durations and improved horizontal scanning after an intervention of $1^{1/2}$ hours in young novice drivers.

Learning to anticipate to dangerous traffic situations is based on improving the tight interaction between perception and action (Meir et al. 2014) and is subject to experience or practice (Ampofo-Boateng and Thomson, 1991; Plumert et al., 2011). Child-pedestrians have been reported to have difficulties in tuning perception and action indeed. Plumert et al. (2004) reported that inexperienced child bicyclists accepted similar gap sizes as experienced adult bicyclists, but hesitated longer before crossing the road. This suggests insufficient decision-making skills and a lesser-tuned perception-action coupling in young children. After some practice, however, child bicyclists' coordination of the acquired visual information with the corresponding motor actions improved resulting in faster decision-making (Plumert et al., 2004).

Despite the fact that trained child bicyclists did not improve their visual search behaviour in our study by means of earlier fixating on the hazard, trained children demonstrated increased response rates and decreased reaction times in the covert hazards, which can be attributed to extended experience and an increased sensitivity for potential hazards. It might therefore be suggested that although the intervention did not improve children's contextual knowledge regarding 'where to look', this brief intervention might have improved trained children's understanding of the hidden dangers within these type of hazards (Huestegge et al., 2010). In line, decreased reaction times after the intervention suggest that trained child bicyclists were faster in deciding whether a situation was dangerous or not, and producing a corresponding response which might result in safer behaviour. It therefore seems that the intervention increased trained child bicyclists' understanding in a variety of dangerous traffic situations (Plumert et al., 2011; Thomson et al., 2005).

A better understanding regarding the presented dangerous situations also suggest improvements in situation awareness (SA) which describes the perception of elements in the environment (level 1), comprehension of their meaning (level 2), and the projection of their status in the future (level 3) (Endsley, 1995). Correct and fast decision-making requires the formation of internal models containing prototypical information. A hazard perception training, will improve one's capacity to perceive the essential cues (level 1), the ability to integrate and comprehend the acquired information (level 2) and ultimately predict how the current situation might develop in the future (level 3). Ultimately, the decision how to cope with the dangerous situation is made and a correct action is undertaken. Although the intervention did not result in better scanning or searching for relevant cues in means of entry times, the outcomes of the brief intervention (2 hours of training) seem particularly satisfactory since the training enhanced trained child bicyclists' integration of the fixated information.

However, the intervention did not affect the perception and detection of the overt latent hazards in trained child bicyclists. Overt latent hazards refer to a situation in which another road user may start to act dangerously. Since the other road user is salient, fixations on the other road user can be the result of bottom-up processes attracting attention. Once the other road user has been noticed by the child bicyclist, he or she may realize that this road user might start to act dangerously under the given circumstances and a proper schema will be activated. Due to the saliency of the overt hazards, trained and untrained child bicyclists noticed an equal amount of overt hazards and reacted within a similar timeframe (Meir et al., 2013). The detection of covert latent hazards on the other hand, is mainly driven by top-down control and related to hazard anticipation. Detection of covert hazards without direct visual cues requires more experience and the selection of a mental schema that enables the child bicyclist to predict the development of the hazard based on the contextual aspects only (Vlakveld, 2011). Furthermore, since it has been demonstrated that children or learner drivers primarily encountered difficulties in situations with limited field of view or covert latent hazards, the current hazard anticipation training mainly focussed on these type of situations.

As the trained children tended to detect more covert hazards compared to the pre-test and reacted significantly sooner on the covert hazards three weeks after the intervention, it can be suggested that these short-term learning experiences could result in long-term training benefits (Plumert et al., 2011; Thelen and Smith, 1994; Thomson et al., 2005). Since this brief intervention already improved child bicyclists' traffic understanding, a similar (less brief) intervention could be a useful tool to add to traffic education in schools. Nevertheless, it should also be noted that a significant share of the bicycle-car accidents are caused by violation of the traffic rules or incorrect road behaviour of the bicyclist (Rijk, 2008). Appropriate traffic behaviour and knowledge of the road rules therefore should remain an important factor in traffic education.

4.1. Limitations and future research

This brief intervention improved trained child bicyclists' comprehension and decision-making skills in means of reaction times and response rates. However, there were no significant improvements in visual search behaviour regarding early detection of the hazard. This finding concurs with the suggestion that life long experience through deliberate practice is not simply captured into two hazard anticipation lessons. Improving visual search behaviour in young bicyclists might therefore require more extensive practice. Indeed, Chapman et al. (2002) suggested that visual search patterns, indicative for hazard perception skill, are only developed slowly. Recent research noted that deficiencies in visual search and hazard perception are not easily compensated by specific training programs (Huestegge et al., 2010). Future studies might therefore focus on early detection and anticipatory visual scanning in child bicyclists. For example, the integration of one-to-one tutoring might improve the effect of the intervention (Vlakveld, 2011). Especially one-to-one tutoring in a virtual environment would provide the opportunity to teach child bicyclists 'where to look' and to integrate an active component since it is suggested that the dissociation of perception and action might lead to incorrect understanding of visual search strategies (Dicks et al., 2010). It should also be noted that eye trackers only measure fixations on the hazard. Some hazards however may be detected by peripheral vision or covert attention at first, after which a saccade orients overt attention to the hazard. Therefore it remains uncertain whether onset of the first fixation is the only measure of visual anticipatory behaviour (Huestegge et al., 2010).

Although it has been suggested that young trained drivers are able to integrate the learned hazard anticipation skills into their on-road driving performance (Chapman et al. 2012). Nevertheless, it remains unclear to what extent trained child bicyclists will be able to transfer the current improvements to safer on-road behaviour questioning the ecological and external validity of our findings. When bicycling in real-life, children have to combine motor and cognitive skills into proper bicycling behaviour, which requires a considerable mental effort.

Furthermore, the current findings are also limited in generalizability due to a limited study sample. Future intervention studies might therefore consider recruiting a variety of schools from urban to city schools, including children with different social economic status. Including children with different (lower and higher) levels of bicycling experience could improve our understanding of the effect of experience.

Regarding the hazard perception test, time between the pre-test and the post-test was 9 days and between the post-test and retention-test was 21 days. It is therefore possible that time between the test session was not sufficient to overcome any effects of testing. The relative stable reaction times, response rates and gaze behaviour parameters of the control group however, suggest otherwise. In addition, the experimenters were not blinded during the experiment. However, participants received the same hazard perception test with the same instructions presented on the computer screen which decreased the potential bias for not blinding the experimenters.

At last, since this is one of the first hazard perception tests for bicyclists, it is not possible to verify our results to a golden standard. The results of the current investigation must therefore be interpreted with caution. Future research should focus on the validation of the hazard perception test and training for bicyclists prior to the integration of such tools in the traffic education lessons.

4.2. Conclusion

The current study aimed to test the effectiveness of a hazard perception training in child bicyclists of 9 to 10 years old. The hybrid intervention required child bicyclists to indicate whether a hazard was present in the video clips. This required the perception of the relevant cues in the environment (SA1), comprehension of this visual information (SA2) and predicting how the situation could develop (SA3). Trained child bicyclists detected more hazards and reacted faster compared to the control group who received the training after the testing. Although trained child bicyclists did not improve their anticipatory visual search behaviour, they did demonstrate a better processing and prediction of the potential dangerous situations which was reflected in decreased decision-times. It can therefore be concluded that even a two-hour intervention has the potential to improve hazard perception in child bicyclists.

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Part three: general discussion

The scope of this dissertation was to gather fundamental insights in the development of fundamental bicycling skills as well as gaze behaviour in real-life or when confronted with video clips of dangerous traffic situations in order to provide a more detailed understanding regarding the intrinsic factors underlying accident involvement in child bicyclists. Although this thesis adopted a comprehensive approach and comprised a wide variety of aspects regarding the intrinsic factors affecting bicycling skills in children, it also aimed to describe the visual behaviour and hazard anticipation of child bicyclists in greater detail. The first chapter of the current project focussed on the development of the fundamental motor bicycling skills in children. As interventions to improve children's bicycling skills differ in age range and often make use of different test instruments, the role of maturation and motor competence was addressed. The second chapter aimed to evaluate whether visual behaviour of bicyclists measured in real-life reflected visual behaviour measured in the lab while the third chapter aimed to address the negative effect of a low quality bicycle path on the gaze behaviour of child bicyclists. Finally, the fourth chapter of this dissertation aimed to provide a solid scientific basis for the development of a perceptual training intervention, and guidelines for traffic education in children. A hazard anticipation test was conducted to measure hazard anticipation skills of child bicyclists aged 9-10 years in a controlled (safe) laboratory environment. Consequently, a hazard anticipation training intervention was created to stimulate the learning process of safe traffic skills in child bicyclists of 9-10 years old. First, the results are discussed in more detail according to their aim. Subsequently, the methodological considerations, limitations and implications for future research of the current project are discussed.

1. Motor bicycling skills

In the introduction of this dissertation the role of motor competence for the development of more complex motor skills was emphasised. Adequately manoeuvring a bicycle is such an acquired and complex skill requiring the combination of gross motor skills such as steering, balancing, signalling and checking the shoulder. Since a substantial part of the single-bicycle crashes in children can be attributed to poor steering skills, the first aim of this dissertation addressed the role of motor competence as keystone for the development of motor bicycle skills. Subsequently the association between bicycling skills and BMI, and the contribution of age and experience is discussed more extensively.

1.1. Motor competence

In the first paper, motor competence as measured with the KörperkoordinationsTest für Kinder (Kiphard and Schilling, 2007) demonstrated a spill-over effect to the performance of bicycling skills in 9-year-old children. Children with better motor competence are therefore more likely to have better control over their bicycle. Especially more complex skills requiring the coordination of multiple body segments –when signalling or turning the head while bicycling in a straight line and tasks in which speed had to be adjusted properly such as slaloming and bicycling a circle- seem to be associated with motor competence. For example, checking the shoulder required the participant to turn the head while attempting to maintain heading on a 40cm wide track. Such extreme movements cause postural differences demanding the control over increasing degrees of freedom and muscle tension. Furthermore, when diverting gaze from the intended direction of travel to check traffic presumes that the bicyclist relies on the visual information stored in the temporal buffer to maintain heading and requires a sufficient decoupling of gaze and steering actions, which have been shown to be less attuned in children (Plumert et al., 2011). Plumert suggested that the ability to finely adjust the coupling between perception and action undergoes changes until adolescence which is supported by the finding that younger children (6 years-old) have more difficulties to maintain heading compared to their older peers (12 years-old). Also bicycling a slalom places an increasing demand on the perceptual-motor system of the child, as the gap sizes of the gate decrease near the end. The child is required to assess distance and brake accordingly to travel through the gaps safely. It therefore seems that workload increased with additional tasks, especially in for the during bicycling skills and transitional bicycling skills (see Table 4).

Table 4. Associations between motor competence and BMI with the before/after bicycling skills, during bicycling skills and the transitional bicycling skills.

	Before/after bicycling skills	During bicycling skills	Transitional bicycling skills
Motor Competence	0.056	0.412**	0.411**
BMI	-0.112	-0.353*	-0.450**

***p<0.001, **p<0.01,*p<0.05

The bicycle skills in general were positively associated with hopping for height and moving sideways as bicycling requires the coordination of strength in both upper and lower body parts for pedalling and steering and the ability to maintain balance and heading when rotating the trunk. Hopping on one leg (HH) over an increasing pile of pillows required the children to generate sufficient power to jump over the pillows as well as coordination of upper and lower limbs to maintain balance (Tveter and Holm, 2010). Strength and cooperation of the muscles in the core are therefore essential. Also in the bicycling tasks it is important to create adequate propulsion since a bicycle is a single track vehicle, it becomes self-stable at a certain speed and balance will become easier to maintain. At lower speeds however, stabilising the bicycle requires bigger steering actions and larger additional lateral knee motions to prevent from falling over to the side (Kooijman et al., 2009; Kooijman and Schwab, 2013). In the more complex tasks of the bicycle test-items (reflected by their relative lower scores) children might have decreased speed to maintain control over the task which is in line with the speed-steering workload trade-off model (Godley et al., 2004). Contradictory, decreasing speed while riding a bicycle would have resulted in more difficulties to preserve balance and resulted in deviations from the intended course, e.g. bicycling a slalom or bicycling two handed in a circle. Moreover, children who had better control over their core musculature and strength appliance in their lower and upper limbs were therefore more likely to perform better on these bicycle tasks. Indeed, this is reflected in the task of signalling left and right while bicycling in a straight line in which raising the arm caused postural adjustments and steering became more difficult with only one hand. Also braking to come to a controlled stop was associated with hopping on one leg. As coming to a stop required the child to put foot on the ground, this task required sufficient strength to maintain balance on one leg when holding a bicycle.

When moving sideways (MS), performance depended on the ability to coordinate rapid trunk rotation while stepping on the next plate as fast as possible. As MS mainly contributed to bicycling in a circle and looking left and right the latter might be explained by the additional trunk rotation to aid checking over the shoulder. Checking the shoulder required a complex coordination of head, trunk and limb movements to preserve heading and balance. Postural control is therefore extremely important which is reflected in the association with walking backwards (WB).

Although the motor quotient (MQ) in general was significantly associated with total bicycling score, jumping sideways (JS) was not. A lack of association between the bicycle test-items and the KTK test-items might be explained by the low test scores for some bicycle subskills (bicycling one handed in a circle) while on other bicycle subskills relative high test scores were obtained (bicycling over obstacles). As some test items of the bicycle test were too difficult for the nine-year-old children, it was difficult to differentiate between skilful and less skilful bicyclists and therefore harder to find an association with motor competence. On the other side of the spectrum, a similar trend is observed for the bicycle skills with high mean scores.

1.2. Body Mass Index

Children with a higher BMI performed worse for both the KTK and the bicycling skills test. This negative association between gross motor competence and BMI, reported in paper one, confirmed previous research describing the link between overweight and decreased skill levels in children (D’Hondt et al., 2012, 2011; Graf et al., 2004). As motor competence was found to be the underlying construct for more complex skills, also bicycling skills are found to be negatively influenced by increased BMI. This inverse association might be explained by the reciprocal relationship between motor competence, perceived motor competence, physical activity, physical fitness, and BMI (Robinson et al., 2015; Stodden et al., 2008). Children with lower levels of (perceived) motor competence engage less in physical activities with a negative spiral of psycho-social problems and less favourable weight status as a result. In turn, they spent less time in sport activities which might decrease their skill level, causing less proficient skills in other activities as well, e.g. bicycling. Children who engage less in bicycling, will perceive this task to be more difficult and might bicycle slower trying to maintain the balance between perceived risk and perceived capabilities (see task-difficulty homeostasis model of Fuller, 2007). It should be noted, however, that with respect to bicycling, a bicyclist only can lower his speed to a certain level as maintaining balance becomes increasingly difficult with lower speeds. It is possible that (young) bicyclists prefer to bicycle at slower speeds in certain situations in function of perceived safety, but can not due to balancing problems (see task difficulty homeostasis model of Fuller, (2007)). Furthermore, an increasing popularity of sedentary activities such as watching TV, playing computer games, and a decreasing amount of playgrounds for children only contributes to this vicious cycle of inactivity causing an even further deterioration of fundamental movement skills and a higher incidence of childhood overweight.

The negative association of BMI on bicycling skills demonstrated in paper one might also be explained from a mechanical point of view. According to the mechanical hypothesis, motor competence in children with overweight is impaired which results in difficulties with performing weight bearing tasks involving propulsion of the body (D'Hondt et al., 2012, 2011). However, bicycling is not a weight bearing task. Similar to the associations between the bicycle subskills and the KTK, BMI was mainly associated with the more difficult tasks in which the maintenance of equilibrium was harder to accomplish e.g. checking the shoulder left and right while bicycling in a straight line, bicycling in a circle, or bicycling in a slalom. Additional body movements such as turning the head or lifting the arm to signal, caused changes in the distribution of body weight, which resulted in increased momentum and more difficulties to maintain balance.

More recently, O'Neal et al. (2016) suggested that poor road crossing skills in child pedestrians with higher BMI are caused by poorer response inhibition, greater impulsivity and deficits in executive functioning. Given that body weight is carried entirely by the bicycle, the mechanical hypothesis alone might not be sufficient to explain the relation between BMI and bicycling skills. It can therefore be suggested that poorer bicycling skills in children with higher BMI might therefore also be caused by deficits in the perceptual-motor system. Gentier et al. (2013) for example found that obese children performed worse for both gross and fine motor skills suggesting deficits in perceptual-motor competence and proper movement execution. As was demonstrated in the introduction, the integration and processing of visual information is essential to drive and execute locomotion (Held and Hein, 1963; Plumert et al., 2007), especially in bicycling where travel speeds are higher and decisions have to be made faster compared to walking. Plumert et al. (2011) already reported the importance of adequately tuning perceptual information to decision-making and coming to a motor output. When bicycling on a virtual bicycle simulator, children spent more time on the curb and had less time to spare when crossing traffic gaps indicating deficits with interpreting the perceptual information and tune the motor action to the requirements of the situation. Accordingly, BMI was negatively associated with skills in which tuning of visual information to appropriate steering behaviour was more challenging. When bicycling a circle – bicycling an eight-formed track consisting of two interconnected circles – children needed to adapt speed continuously, based on their perception of visual flow in order to aid steering.

1.3. Age-related development

As motor competence was associated with bicycling skills and children's MQ was shown to improve with age (Vandorpe et al., 2011) it can be suggested that bicycling skills too are subject to age-related improvements. Indeed, our cross-sectional study in 6- to 12-year-old children demonstrated age-related improvements for the “before/after bicycling skills”, the “transitional bicycling skills” and the “during bicycling skills” (see Figure 20). Not surprisingly, younger children in the age range of 6 to 7 years-old performed worse for almost all test-items compared to the oldest age group (11 to 12 years-old). Compared to the age group of 9- to 10-year-old children, the youngest group had more difficulties with the during bicycling skills in which estimating distance and speed as well as (de)coupling perceptual information and steering behaviour were essential for performance, e.g. bicycling (one handed) in a circle, looking over the left shoulder while bicycling in a straight line, signalling left and right while bicycling in a straight line or looking left and right while bicycling in a straight line. It should be noted that especially the during bicycling skills were found to be associated with motor competence. According to Briem and colleagues (2004), young children tended to misjudge their stopping range when they were required to stop within a demarcated zone. This caused them to stop too early or too late, again suggesting difficulties with perceiving and integrating the visual information. On the other hand, the youngest children also performed worse on test-items in which mainly control over the bicycle was important, e.g. when bicycling on a sloping surface or bicycling over obstacles. In case of bicycling over the sloping surface, children primarily demonstrated difficulties with maintaining heading on the inclining surface of the plank due to difficulties with balance.

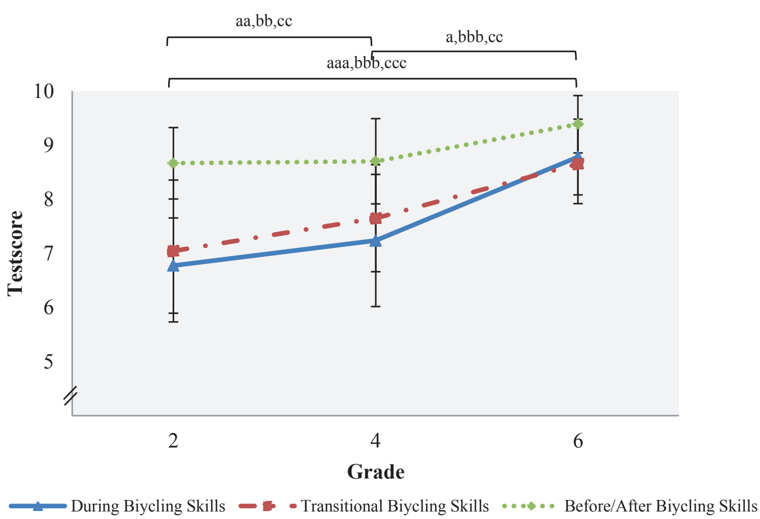

Figure 20. Testscores for the “during bicycling skills”, “transitional bicycling skills” and the “before/after bicycling skills”
^{a}($p \leq 0.05$), ^{aa}($p \leq 0.01$), ^{aaa}($p \leq 0.001$) significant different for before/after bicycling skills
^{b}($p \leq 0.05$), ^{bb}($p \leq 0.01$), ^{bbb}($p \leq 0.001$) significant different for during bicycling skills
^{c}($p \leq 0.05$), ^{cc}($p \leq 0.01$), ^{ccc}($p \leq 0.001$) significant different for transitional bicycling skills

The age group of 9- to 10-year-old children already showed some significant improvements of their bicycling skills. The older children were more proficient in maintaining their bicycle in balance when walking a slalom with the bicycle at hand, in raising their hand when signalling, shouting the right number, and making more efficient use of their brake levers. On the other hand, 9-10-year-old children still not performed as well as

11- to 12-year-old children for some of the “before/after”, “during” and “transitional bicycling skills” in which bicycling between the lines was necessary when performing additional body movements. For example, when children were required to check the shoulder, they showed difficulties with keeping the bicycle between the lines. As noticed before, turning the head caused postural changes and the body mass to redistribute which makes it more difficult to maintain balance, involuntarily influencing steering behaviour. Alternatively, Cinelli and Warren (2012) demonstrated that looking at an eccentric target at 37° to the right or to the left when walking straight forward, resulted in small but significant steering deviations from the intended path. They argued that a spatial shift of attention is cause to these small deviations according to the look where-you-want-to-go strategy (Wilkie et al., 2010). Given that the head-turns in the bicycle task were larger compared to the task of Cinelli & Warren and bicycling speeds are higher speeds compared to walking, so too did the possibility for errors to accumulate before corrective action could be undertaken.

A third hypothesis is presented in the study of Heuer (1996) by means of the tonic neck reflex. They described that there are certain risks associated with turning the head when riding a bicycle or driving a car. The tonic neck reflex contributes to voluntary activity and is accompanied by involuntary motor actions. For example, eccentric head positions cause the tonic neck reflex to produce increased flexor tonus in the contralateral muscles and increased extensor tonus in the ipsilateral arm. Since manifestation of these reflexes have also been found in healthy adults it is not unlikely that children, in full development, might display some artefacts of this reflex.

1.4. The role of experience

Children start to bicycle around the age of five. Until the age of 14, control over the bicycle and quality of movement execution enhances, with the biggest improvements until the age of ten. Around the age of eight to nine, the bicycle becomes an important mean of transportation (Rijk, 2008). More experienced bicyclists are suggested to have better control over their bicycles (Schepers, 2013). Controlling and manoeuvring the bicycle must therefore be acquired and automatized by means of extensive experience (Wierda and Brookhuis, 1991). Indeed, based on the findings in the first chapter, improvements in bicycling skills can be attributed to an age-related improvement in motor competence (Vandorpe et al., 2011). In line with this rationale, age and age to onset of bicycling were found to contribute to the development of bicycling skills. According to the power law of practice, the sooner a child learns to ride his or her bicycle, the greater her or his experience and the better his or her performance will be.

Several possible explanations for this relation can be given. A first explanation can be derived from the concept of perceived motor competence (Stodden et al., 2008). Children with better motor competence are likely to be more proficient in performing fundamental movements skills which in turn underlie performance on bicycling skills (paper one). Ducheyne et al. (2013b) reported that the performance on a bicycling test is also related to perceived motor competence which is found to be positively and inversely related to motor competence and physical activity. As a result it can be suggested that children who start to bicycle at a younger age might be endowed with better levels of motor competence which facilitates the process of learning more complex skills and endorses a positive feeling of perceived competence. Furthermore, the perceived feeling of being competent might contribute to children’s decision to ride a bicycle for recreational purposes or for transportation. Children who started to bicycle early in life will therefore have developed more experience compared to their counterparts who started to bicycle at an older age.

Somewhat contradictory to the contribution of experience is the finding that the development of bicycling skills is not enhanced by means of time spent bicycling – measured as minutes bicycling per week, which also can be considered a contributing factor to bicycling experience (paper one and two). Frequent bicyclists are likely to possess higher levels of physical fitness compared to people with a more sedentary lifestyle and therefore should have better control over their bicycle. Furthermore, more minutes bicycling per week also result in more opportunities to practice bicycle skills.

Surprisingly, Hansen et al. (2005) reported a similar tendency in which age at onset of bicycling is a stronger predictor for bicycling skills than the amount of time spent on the bicycle. However, it is also reported that children who learn to bicycle at a younger age (4- to 5-years-old) are at higher risk in the first two years of bicycling compared to children who learn to bicycle at an older age (6- to 7-years-old). This higher injury proneness in younger bicyclists can be attributed to immature motor skills and a lack of experience to manage complex traffic situations. It can be concluded that minutes bicycling per week in children is not a sufficient predictor for bicycling skills in children since children often live closer than ten minutes away from school and only start bicycling to school independently from the age of ten to eleven (see paper two).

1.5. Conclusion

In the first part, it was demonstrated that general motor competence underlies more complex skills such as riding a bicycle. Especially skills in which additional body movements increased task difficulty were reported to be associated with motor competence. In addition, children with a higher BMI were found to perform worse on the bicycling skills test which adds to the suggestion that motor competence, BMI and more complex skills (e.g. bicycling) are interconnected. Furthermore, children demonstrated age related improvements for the “before/after bicycling skills”, “transitional bicycling skills” and “during bicycling skills”. The youngest group performed relatively poor for the during bicycling skills or skills in which balance had to be maintained on a (small) sloping surface. Although the oldest group performed better for the during bicycling skills in which additional body movements increase task load, these skills still require attention. Lastly, the younger a child learns to rides his or her bicycle, the better his or her performance will be. This can be explained from the perspective of experience implying that a child who has learned to ride his or her bicycle at the age of four will have had more opportunities to practice her bicycling skills compared to a child who has learned to ride his bicycle at the age of six. Alternatively, from the perspective of motor competence, a child with better motor competence will be more successful in learning to ride his or her bicycle at a younger age compared to a lesser competent peer.

2. Perceptual-motor skills

Perceptual-motor behaviour involves the coupling between perception and understanding of sensory input to produce a proper motor output. Since vision is essential for the guidance of locomotion and intricately linked with action, the current dissertation primarily focusses on the visual component[38].

"Adaptive behaviour within the environment involves perceiving affordances, or possibilities for action that depend on the fit between the characteristics of the perceiver and the properties of the environment" (J.J. Gibson, 1979 in Plumert and Kearney, 2014).

Moving the self in relation to other moving objects such as bicycling through traffic or crossing a traffic filled road, requires the child to (1) perceive the relevant information from the environment, (2) make a decision and (3) synchronise his own motor movements with the acquired perceptual information. From the age of eight to nine years old, the bicycle becomes an important vehicle for transportation and the situations in which children end up, get increasingly complex. For many children up till secondary school, bicycle skills are not yet automated. The combination of bicycle control and the traffic task itself often exceeds their capacity to process all the relevant information and adapt their movements accordingly (e.g. mental workload). Studying perception and the allocation of attention in children in real traffic settings or when presented with dangerous traffic situations is therefore a prerequisite for the effective planning of road infrastructure or the development of useful educational applications.

2.1. The influence of road infrastructure

Chapter three and four demonstrated a substantial effect of the quality of the bicycle path on gaze behaviour in child and adult bicyclists. Both children and adults encountered an increased mental workload evoked by the low quality of the bicycle path which resulted in an apparent shift of attention from the distant environmental regions towards the more proximate regions. This shift in visual attention was reflected in the higher dwell times on the AOI 'road' in front of the bicyclist and can be attributed to the differences in the visual characteristics of the environment. For example, the low quality bicycle path existed of a more narrow, rugged and irregular track while the high quality bicycle path consisted of a smooth brick surface. Gaze behaviour in bicyclists on an "obstacle course" therefore seemed to be in line with the gaze behaviour of pedestrians when negotiating complex ground terrain (Marigold and Patla, 2007).

According to the speed-steering workload trade off model, the more narrow and rough bicycle track increased the steering workload and saliency (due to the irregularities) which resulted in increased attention towards the road (Godley et al., 2004). This complex ground terrain might have increased optic flow, providing

[38] With respect to the auditory component of perception in traffic, the reader is referred to 3. Methodological considerations.

the bicyclist with information regarding speed and direction of locomotion (Lappe et al., 1999; Vansteenkiste et al., 2014b).

On the other hand, Patla (1997) demonstrated that vision is essential to maintain and regulate dynamic balance and stability for efficient locomotion. Due to the lower quality of the bicycling track, the bicyclist was required to make more steering adjustments to maintain his stability and balance. This might have caused an increase in the task demands and cognitive load, resulting in higher dwell times towards the centre of the road for safe navigation. Although small adaptations in gait can be controlled by peripheral vision (Marigold et al., 2007), peripheral vision alone was not sufficient to cope with the complexity of the low quality bicycle track (Vansteenkiste et al., 2014b).

Regarding the effect of the low quality bicycle path on gaze behaviour between children and adults, one could have expected larger detrimental implications on children's visual behaviour due to the road surface than it would have had on adults' visual behaviour. Especially since children and their bicycles are smaller and should experience the poor conditions of the bicycle path to a larger extent (smaller wheel sizes increase the impact of loose stones and tree roots on rider comfort). Rather surprising, children and adults demonstrated a relatively similar shift of attention towards the road on the low quality bicycle track. No differences were found in overall fixation duration (dwell time) and the average fixation frequency, but children seemed to make shorter fixations on the low quality track than on the high quality track whereas the fixation duration of adults remained unchanged. This can be attributed to structure of the low quality track which was visually more challenging for the children (Chapman and Underwood, 1998). Nevertheless, this finding is remarkable since shorter fixation durations are believed to reflect a more developed capability to process visual information when confronted with a complex task (Whitebread and Neilson, 2000). In the road crossing task of Whitebread and colleague, more experienced adults and older children moved their focus of attention more rapidly and spent less time looking in the same direction compared to younger and less experienced children. They suggested that increased processing speed of visual information allowed more sophisticated visual search strategies to emerge.

On the high quality bicycle path, children spent generally more time looking at the surroundings and the side of the road whereas adults spent more time looking towards the road. The finding that children spent more time watching at the surroundings and the side concurs with the suggestion that children had difficulties to distinguish between what is relevant from irrelevant for safe travel. Foot et al. (1999) and Whitebread and Neilson (2000) demonstrated that children often fail to give adequate priority to relevant road features which concurs with papers five, six and seven regarding hazard anticipation. The low quality bicycle track increased mental workload resulting in a smaller functional field of view. Furthermore, children had difficulties with selecting the task relevant features in traffic and are therefore less likely to notice more distant hazards since the major task is to maintain balance and stability and prevent from bicycling into a pothole or joint between stones. In other words, the alertness of child bicyclists to hazards is even more impeded compared to adult bicyclists. This was also reflected in a more narrow distribution of the eye movements along the x-axis on the low quality track, in line with the narrowing of visual search behaviour in car driving (Chapman and Underwood, 1998). de Geus et al. (2012) consequently suggested that road quality might also contribute indirectly to bicycling accidents which confirms the importance of well-maintained bicycling infrastructure.

Alternatively, children have also been found to make less use of their peripheral vision to guide actions (Franchak and Adolph, 2010). This less efficient use of peripheral vision might also be a reason why children looked more to the surroundings and the side of the road compared to adults. Whereas adults were able to process some of the peripheral cues without actively looking at them, children were more likely to actually fixate elements in this AOI. For example, whereas adults predominantly controlled lane keeping by using peripheral vision (see Land and Horwood, 1995), children might have fixated the edges of the track more often to ascertain proper lane keeping (Franchak et al., 2011).

According to the speed-steering workload trade-off model (Godley et al., 2004) and the task-difficulty homeostasis model (Fuller, 2007) it could have been expected that children would adjust their speed more to the narrower lane width and the low quality of the bicycle path compared to adults. Especially since young child bicyclists were shown to have more difficulties with maintaining balance compared to older bicyclists (paper two). Although children bicycled slower than adults on both bicycling tracks, the difference in bicycling speed was not larger on the low quality track than on the high quality track. By increasing their attentiveness to task-relevant stimuli (i.e. more attention to the road), the participants increased their capability, and could deal more easily with the higher task demand of the low quality track. As a result, there was no need to adapt bicycling speed to the environmental constraints imposed by the lower quality of the bicycling track.

Based on the results of visual behaviour when bicycling in real-life (paper four), it can be concluded that children do not yet possess the motor and perceptual-motor bicycling skills that characterize adult bicycling behaviour which is reflected in lower movement times and a different visual behaviour (Assaiante, 2011; Chihak et al., 2010; Hatzitaki et al., 2002; Plumert et al., 2011). Apparently it seems that children adopted a simpler and more cautious (visual) strategy. Pryde et al. demonstrated in 1997 that only when all elements of the sensory and the motor system as well as the coupling between them, are sufficiently developed, they can be integrated into an adult-like strategy for perceptual-motor behaviour. Nevertheless, for both the children and the adults, increasing their attentiveness to task-relevant stimuli was adequate to cope with the increased task difficulty on the low quality track, and no speed adjustments were required. An alternative explanation however, is that the difference in bicycling speed might be due simply to the fact that children’s bicycles are smaller than adult bicycles.

2.2. Hazard anticipation

Hazard perception or hazard anticipation has been defined as the ability to detect, process or evaluate and respond to a dangerous situation in traffic (Crundall et al., 2012), it is closely related to the concept of situation awareness and requires the capability to detect and use anticipatory cues which might provide more time to prevent from colliding with other traffic participants. Based on schemata in long term memory stores, the detection of hazards in experienced bicyclists is therefore primarily driven by top-down control. This implies that the bicyclists’ eyes are directed to the area where (s)he expects a potential hazard to materialize. Given that young bicyclists have limited perceptual-motor skills, the evaluation of hazard anticipation skills in is essential. Due to ethological considerations and internal validity, it not possible to present child and adult bicyclists with real-life dangerous traffic situations. The current dissertation therefore developed the first hazard anticipation test (paper 5 and 6) and training (paper 7) for bicyclists. Both the test and the training were based on video clips from the perspective of a bicyclist. Next to the gaze behaviour of child and adult bicyclists, reaction times and correct response rates were measured. The effect of the hazard anticipation training intervention and the influence of both maturation and experience are discussed.

2.2.1. Perception of hazards in child bicyclists

In the exploratory hazard anticipation test (paper 5), children and adults were presented with three different tasks: (1) observing the traffic situations, (2) answering a question after the video clip and (3) pressing a response button as soon as a hazardous event appeared in which a potential collision could occur. In general, the exploratory study did not find any differences in the total number of fixations made by children and adults on the hazard which was in contrast to what we expected. However, adults spent more time fixating – longer dwell times - the cars in the first and the second part of the test, suggesting that they are more aware of the potential danger caused by the presence of cars due to their own vulnerability as a bicyclist. Similar findings were reported in car driving where experienced drivers paid more attention to potential dangers involving the behaviour of other road users (Underwood 2007). According to these findings it can be suggested that children have difficulties to pay attention to the features which might create a dangerous situation. Indeed, Barton (2006) described that children have difficulties with selective – the ability to focus on a specific element - and dividing – the ability to divide attention among multiple elements - attention[39]. To our surprise children spent an equal amount of time looking at traffic signs in the video clips which was most likely due to a 'traffic education week' the week before the tests were carried out. Since it is known that traffic education has a strong short term effect (van Schagen and Brookhuis, 1994), this focus on traffic signs was most likely the reason why children spent as much time looking to the traffic signs as the adults.

Since this was, to our knowledge, the first exploratory study regarding visual behaviour and traffic situations in child bicyclists (aside from gap acceptance studies) only the general distribution of visual attention by means of dwell time (%) and number of fixations were of interest. The areas of interest were only assigned according to their physical location (i.e. cars, road,…) instead of their (potential) hazardousness. Despite a relatively small study sample and nature of the video clips in the exploratory study, results were already indicative for further and more detailed evaluation of hazard anticipation in child bicyclists. The improved hazard anticipation test (paper 6) therefore examined visual behaviour of young bicyclists more extensively by means of onset of the first fixation on the hazard (an estimate for the detection of the hazard – SA1), duration of the first fixation on the hazard, dwell time on the hazard and the number of fixations on the hazard (processing of the hazard – SA2). Since children tend to rely on clear visible cues to judge whether a hazard is dangerous or not

[39] In Barton (2006) a four-part model for selective attention was adopted: (1) orienting, (2) filtering, (3) searching and (4) expecting. (1) *Orienting* refers to directing attention towards a stimulus and occurs reflexively or covertly. Children become more proficient in orienting attention between the ages 5 – 10. (2) *Filtering* refers to the ability to focus on one stimulus only. This skill has been suggested to become adult-like around the age of 12. (3) *Searching* arrives from the combination of orienting and filtering, f.e. when moving attention from one relevant stimulus to the next. Searching has been reported to approach adult-like efficiency around the age of 11. (4) *Predicting* consists of anticipating a stimulus based on past experiences or cues. Predicting consists of two subcomponents: priming and prompting. *Priming* refers to an informational cue which might guide attention. For example, looking in the direction from where the bus might emerge after checking the timetable. *Prompting* refers to the retention of cues in memory for later use. For example, after a child has learned to cross the street on a crosswalk or other safe location, it will search for a crosswalk before crossing the street.

(e.g. approaching cars), they might have difficulties to detect developing and hidden latent hazards. Therefore a distinction between overt and covert hazards was made (Crundall et al. 2012; Vlakveld 2011).

As children showed higher response latencies and delayed fixation onset on these covert hazards, it can be concluded that child bicyclists have difficulties with attending to the relevant information in the traffic environment. The inefficient visual scanning strategies of children can be attributed to maturation on one hand and experience on the other hand.

2.2.1.1. Maturation

Children are limited to what they can deal with since the central nervous system of children has not yet fully developed. Children's inefficient visual scanning behaviour might therefore partly be attributed to the immaturity of the visual, perceptual-cognitive and perceptual-motor system (Langaas et al., 1998; Robert et al., 2014). It has for example been reported that the ability to control saccades or the capacity to control smooth pursuit movements are not yet fully mature at the age of nine. Delayed onset of the first fixations on the hazardous situation can therefore be a result from the combination of difficulties with saccade control and the ability to sustain attention and predictive control (Kowler, 2011; Land, 2006). Furthermore, smaller dwell times in children might be attributed to difficulties with smooth pursuit since they are not yet capable of following moving targets efficiently and predicting future events (Hoffman et al., 1980). This is consistent with the findings of Grechkin et al. (2013) who showed that children persistently underestimate time to contact of gap interception with the oncoming car (in a virtual environment). Not only the eye movement system, but also the executive and cognitive abilities develop well into adolescence as a function of maturation of the nervous system. Foot et al. (1999) and Barton (2006) reported that immature psychological processes contribute to difficulties with dividing attention between various causes of danger, concentration and coordinating observation and action (Plumert et al., 2011). Stevens et al. (2013), for example, have indicated that typically developing children with lower levels of inhibitory control timed their entry into the roadway less carefully and ended up with less time to spare when crossing the road. Moreover, young children have a different understanding regarding the concept of danger compared to their older peers (Dunbar et al., 1999). Young children rated risky behaviour based on their criteria of "*not to damage things*" while older children used a "*not to make the kind of mistake that might cause an accident*" criteria. As a result, a situation in which risky behaviour was depicted but no accident occurred, young children will rate this situation as not dangerous while older children will often rate this situation as dangerous (Thornton et al., 1999).

2.2.1.2. The role of experience

Children's inefficient visual scanning behaviour by means of shorter dwell times and later fixating the hazardous event, however, cannot be explained from immaturity of the visual and cognitive system alone. The ability to select the relevant sources of information, judge whether the situation is potentially dangerous or not and come to the decision to cross or to wait is dependent on experience too (Meir et al., 2013; Sahlberg et al., 2015). Indeed, child bicyclists consistently fixated the events of interest shorter compared to more experienced adult bicyclists suggesting that child bicyclists were less aware of other road users. Children also fixated later on the cues predicting the covert latent hazards which attributes to the concept of situation awareness (Endsley 1995; Salmon et al. 2014). Situation awareness is defined as the perception of the elements in the environment within a volume of time and space (level1), the comprehension of their meaning (level 2) and the projection of their status in the near future (level 3) and is based upon schemata (Endsley, 1995). Adult bicyclists already have developed a more extended "database" of mental templates or schemata based on previous experiences. This extended database drives the visual system automatically via top-down control to the relevant sources of information in the environment and facilitates decision-making when confronted with certain traffic situations.

Limited experience in child bicyclists, however, will restrict their capacity to perceive the important cues (SA level 1) which was reflected in delayed fixations on the hazardous event. In other words, when cycling, the child bicyclist does not routinely search traffic for hazards. Meir et al. (2013) and Ampofo-Boateng and Thomson (1991) reported that young pedestrians demonstrated difficulties with detecting possible hazards that are not physically present at the moment of crossing and traffic elements such as blind summits, obscuring obstacles and complex junctions were not recognised. As a result, children tended to focus only on the hazard when salient, instead of scanning the areas that could contain relevant information on hazards. Furthermore, it has been reported that young bicyclists are slower in detecting hazards in their peripheral vision and are more easily distracted by irrelevant information which might result in the missing of important safety cues. Since child bicyclists often failed to anticipate a hazardous situation (see footnote 39; priming and prompting), this strengthens the belief that children lack the required specific mental models based and are less likely to search for the essential visual cues (Barton, 2006).

According to the second level of situation awareness (SA level 2), little to no experience with traffic will result in a poor internal representation of the specific traffic situation and will cause difficulties to transfer the little knowledge to other context specific situations (Salmon et al. 2014). For example, a child might have an internal representation of an intersection but it does not necessarily include cars, motorcyclists or other road users. As the child never experienced a dangerous traffic situation at the intersection before, he or she does not actively search for the relevant elements which could predict a potential hazard, and ignores other irrelevant stimuli. Tolmie et al. (1998) demonstrated that younger children had more difficulties with differentiating between traffic relevant and irrelevant features and therefore encountered difficulties with attuning their performance to the task requirements. It can therefore be concluded that the children often lack the capacity to select the relevant cues and subsequently comprehend whether or not a cue contains potential risk.

In the final stage of situation awareness (SA level 3) it is cause to the bicyclist to integrate the visual information into a holistic appreciation of the situation and compare this internal presentation to the existent schemata stored in their long term memory. Based on this comparison, the bicyclist attempts to predict how the situation might develop. The accuracy with which this prediction is made depends on their previous experiences and internal models. Since adults have already encountered a variety of dangerous traffic situations, they have developed a more extensive database of mental templates (internal models or schemata, according to Endsley), which in turn facilitates the decision-making process. Younger children however are more inclined to display an idiosyncratic perspective, assessing the hazard on a single characteristic instead of integrating information from different parts of the environment (Whitebread and Neilson, 2000). The notion that child bicyclists have lesser developed levels of situation awareness is strengthened by their inability to answer the non-traffic related questions properly (paper 5).

In addition, longer dwell times on the hazard in more experienced or older bicyclists might reject the theory of attentional capture (Underwood et al., 2005). Underwood showed that learner and novice drivers had longer fixations on the hazardous event when driving. As a consequence, attention is directed to the hazard or "captured" by this event, while inspection of other events in the periphery decreased. In other words, target fixations resulted in some kind of tunnel vision. Attentional capture is therefore considered to contribute to poor hazard perception skills in learner drivers since they are unaware of other potential hazards in their close surroundings. Paramount to this, we reported older and more experienced bicyclists to show longer dwell times on the hazards, suggesting a better understanding regarding the nature of the events. Adults are more likely to keep an eye on the event of interest in order to follow its development.

In conclusion, young novice drivers who are considered to possess a mature visual system, still have difficulties with identifying the locations from where potential hazards might emerge and scan these areas considerably less often compared to more experienced drivers. Furthermore, road crossing studies in young pedestrians showed that children base their judgments exclusively on the presence of cars that are visible (Meir et al., 2013; Pollatsek et al., 2006b). Accordingly, child bicyclists in the current dissertation demonstrated an inefficient visual scanning behaviour when presented with the covert hazards which required a better understanding and comprehension of the situation. This adds to the belief that hazard anticipation and situation awareness in children does not just emerge as a function of maturation but is dependent upon experience too.

2.2.2. Reaction time and response rate to hazards in child bicyclists

To our surprise both studies regarding hazard anticipation reported no difference for response rate (correct answers) towards the hazards between child and adult bicyclists. It must therefore be concluded that children detected an equal amount of hazards in the presented video clips. On the other hand, adults did systematically show shorter response latencies to the hazards in the presented video clips, especially when the video clips contained a potential hazard which was caused by limited visibility or required a better understanding of the situation. This concurs with the finding that children detected the hazard later compared to adults, suggesting that children only pressed the response button when the hazard became visible or salient.

Delayed decision-making and reaction times to the hazardous situation in non-experienced bicyclists can, similar to the delayed onset of the first fixations, be attributed to a lack of traffic-related experience and knowledge (Underwood 2007; Scialfa et al. 2011; Crundall et al. 2013; Chapman et al. 2002; Hosking et al. 2010). Although situation awareness itself does not include the anticipatory actions themselves, it precedes decision-making and action guidance (Endsley 1995). Schemata are closely associated to scripts in the long term memory stores (see Figure 21) which in turn drive automatic decision-making and provide action guidance. More extended knowledge or memory representations, and experience through deliberate practice tightens the connection between these scripts and schemata resulting in more automated and efficient decision and improved reaction times (Endsley 1995; Salmon et al. 2014).

Furthermore, since child bicyclists have been found to be less adept at coordinating their own movements with movements of other traffic participants, or adjusting their decision to fit their actions, early detection of potential sources of danger is therefore essential in order to "buy" more time for adapting their behaviour to the requirements of the situation (Plumert and Kearney, 2014). However, since child bicyclists in the current thesis failed to detect the relevant cues, which makes them more accident prone, these findings underlines the need for training interventions.

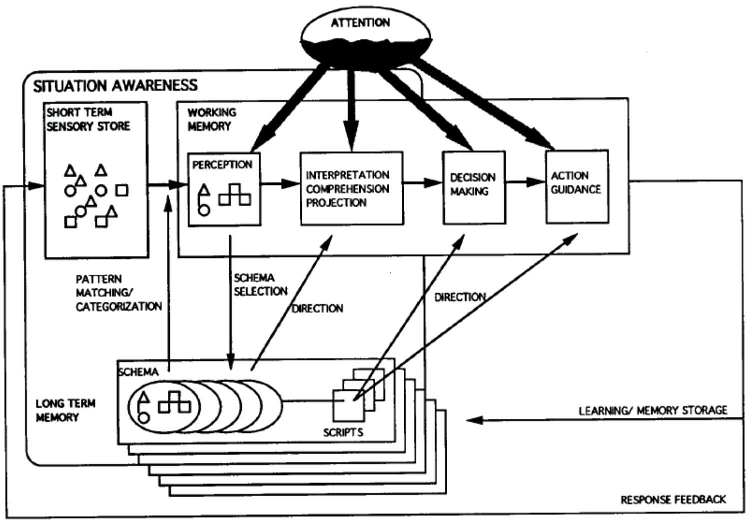

Figure 21. Model of situation awareness mechanisms (Endsley, 1995).

2.3. The effect of hazard anticipation training

A recent meta-analysis conducted by Schwebel et al. (2014) reported that repeated practice in vivo or in simulation at the complex cognitive-perceptual task of judging traffic can be effective. Learning has been based on ecological theories (Grechkin et al., 2013; Plumert et al., 2004) – children judge the affordance of traffic gaps and determine when it is safe to move their body through a gap – or on cognitive theories (Barton, 2006; Thomson et al., 2005; Schwebel et al., 2016) – children estimate distance and speed and complete rapid cognitive processing to estimate the safety of the gap. Regardless the theories, judging traffic is a challenging process for a young mind (Schwebel et al., 2016). In the last paper the effect of a brief hazard perception training intervention in nine-year-old-child bicyclists was therefore described. The brief training intervention itself consisted of two one hour classroom sessions in which the children were presented with traffic situations containing potentially dangerous traffic situations. The situations in these video clips typically developed into almost unavoidable dangerous events in which the bicyclist had to undertake an evasive action to prevent from colliding with another road user. As for the active-practical component, each time one of the students detected a hazard, the video was immediately paused and discussed classically. Then the video was played again and students received feedback regarding the elements which might have predicted the cue, what to look for, and how to react. To exclude a test-retest effect, the video clips in the hazard perception test contained similar concepts as in the video clips of the training but were filmed in different environments and with other traffic participants (Pollatsek et al., 2009).

After the intervention, child bicyclists significantly improved for the number of hazards they detected as well as the time in which they responded to the hazardous event. The effect of the training was strongest for the covert latent hazards which required more extensive knowledge and experience. Despite the previous hazard perception studies in this dissertation found superior anticipatory eye movements in more experienced adult bicyclists, no such improvements in anticipatory visual search behaviour could be attributed to the intervention.

In line with the current findings, Hosking et al. (2010) and Huestegge et al. (2010) failed to find significant differences for the first fixation when scanning for hazardous situations in learner and experienced drivers. In contrast, Alberti et al. (2012) reported decreased detection times to spot the hazard in inexperienced drivers after a relatively short practice with a riding simulator and Pollatsek et al. (2006b) demonstrated that a PC-based hazard perception training can be successful to improve the time window in which learner drivers fixated the area where a potential hazard might emerge. It can therefore be concluded that that the current hazard perception training was insufficient to provide child bicyclists with more efficient means to detect the relevant cues or improve child bicyclists' contextual knowledge regarding 'where to look'. On the other hand, the intervention tended to increase dwell time and the number of fixations on the potential hazardous situation which might suggest a better understanding of the danger within the situation and the necessity to maintain focus on the developing event. As the more experienced bicyclists demonstrated longer dwell times on the hazard, this can be considered a positive learning effect. Nevertheless, results should be interpreted with caution since the interaction effects for the eye movements are influenced by variations in the control group for the pre, post and retention test.

Anticipating dangerous traffic situations is subject to the tight interaction between perception and action (Meir et al. 2014) which improves with experience or repeated practice (Ampofo-Boateng and Thomson, 1991; Plumert et al., 2011). Plumert et al. (2004) demonstrated less developed decision-making skills and an insufficient perception-action coupling in young bicyclists. Their decision-making skills however, significantly improved after some practice as the coordination of the visual information with the corresponding motor actions enhanced. This strengthens the belief that a short training might improve child bicyclists' perceptual-motor skills. After our hazard perception training, child bicyclists already demonstrated increased response rates and decreased reaction times for the covert hazards. Since child bicyclists did not improve their visual search behaviour in our study by means of earlier detection times, it can be suggested that this brief intervention extended trainees' experience and knowledge for these types of hazards. When the trained child bicyclists noticed the presence of a dangerous situation, their extended knowledge base (mental templates) resulted in a faster and more automated decision whether a situation was dangerous or not (Plumert et al., 2011; Schwebel et al., 2016a; Thomson et al., 2005). It can be suggested that our hazard anticipation training therefore accelerated decision-making as a result from improvements in situation awareness (SA) by means of a better understanding of the situation (level 2), and the projection of the situations' status in the future (level 3) (Endsley, 1995).

2.4. Auditory perception in traffic

Although the current dissertation primarily focused on visual perception in traffic[40], orienting attention based on auditory perception can be considered crucial as well for safe navigation, especially in bicyclists. Bicyclists share the road with faster-moving cars and often find themselves amidst traffic approaching from various directions. As bicyclists' auditory perception is not limited by, for example a cars' exterior, they are more likely to rely on auditory cues compared to car drivers. The detection, identification and localisation of traffic (e.g. the sound of an approaching/receding vehicle) aid the bicyclist to interpret the traffic situation, paths

[40] Though it must be noted that video clips in the hazard perception test included sound.

of motion and timely anticipate the forthcoming events (cfr. situation awareness). When vision is limited or obstructed, auditory stimuli of approaching vehicles are frequently the first cues to be noticed (Barton et al., 2012; Stelling-Konczak et al., 2016). Child pedestrians, however, still make significantly more mistakes in determining the distance to an approaching car or the direction from which a vehicle approaches (Barton et al., 2013; Pfeffer and Barnecutt, 1996). Although detection of the vehicles improved with increasing speeds, localisation accuracy of the vehicles decreased. The skills to identify, localize, and determine the direction of the approaching improves with age, but it remains uncertain when traffic related auditory perception skills in children reaches adult-levels.

2.5. Conclusion

In the second part of this dissertation, it has been demonstrated that child bicyclists display simpler perceptual motor strategies compared to more experienced adult bicyclists when bicycling in real-life or when presented with a hazard anticipation test. When bicycling on a high quality bicycle path, child bicyclists spent a considerable amount of time looking at task irrelevant items suggesting that they lack the ability to distinguish traffic relevant from irrelevant items due to a lack of experience. Furthermore, when bicycling on low quality bicycle path, child bicyclists spent most of the time looking in front of their bicycle to monitor the bicycle path. This implies that child bicyclists have less time to scan the environment for oncoming traffic which might result in higher accident proneness. Indeed, when child bicyclists were presented with a hazard anticipation test consisting of video clips from the perspective of a bicyclist, child bicyclists demonstrated a more idiosyncratic appreciation of the situation, rather than a holistic appreciation of the situation. Child bicyclists detected the covert latent hazards later and reacted later to these hidden hazards compared to more experienced adult bicyclists. It therefore seems that bicyclists have incomplete and immature situation awareness which is suggested to improve with experience. Consequently, a brief hazard anticipation training for child bicyclists effectively improved trained child bicyclists’ sensitivity and response latencies regarding covert latent hazards. It can therefore be suggested that a hazard anticipation test and hazard anticipation training could be useful tools for testing and training or for traffic education in schools.

3. Methodological considerations

3.1. The bicycle test

Since the practical bicycle test was constructed in agreement with experts and validated by Ducheyne et al. (2013), the bicycle test can be considered a valid and reliable tool for evaluating bicycle skills in nine-year old children. Some of the test-items, however, were too difficult to successfully differentiate between grades, while others were too easy. When using the bicycle skills test of Ducheyne et al., 2013, some of the test items should therefore be carefully reconsidered. For example, lane width of the circles should be in relation to lane width of common bicycle paths.

As bicycling skills are found to be age-related, future research might also focus on the development of bicycling skills in children making the transition from elementary school to secondary school. Where elementary schools are often located in the proximity of the children's homes, pupils mostly have to cover greater distances to their secondary school, in turn influencing their bicycling behaviour and experience (Cardon et al., 2012).

Although children from a randomly selected typical Flemish school were tested, our results are limited in generalizability. Since the development of bicycling skills might be specific for region, country and culture, this offers opportunities for future research. Also a more effective enquiry of time spent bicycling might provide a more accurate estimation of children's bicycling behaviour and experience. For example, a "bicycling journal", by GPS or pedometer over a prolonged period would improve the estimation of bicycling behaviour. Moreover, in recent studies the value of a bicycling route planner was suggested.

3.2. Validity of visual search

Since studies regarding visual behaviour often make use of pictures or movies in restricted laboratory settings, generalisation of visual behaviour measured in the lab towards the real world has been questioned as the evaluation of expertise and visual attention is often context dependent. As this dissertation aimed to develop an 'off-line' educational package, validation of visual behaviour is essential to ensure that visual behaviour in lab conditions reflects visual behaviour in real-life to some extent. In other words, the trade-off between ecological validity and internal validity of gaze behaviour in real-life and the laboratory is of major importance for generalisation and effectiveness of the educational package. The methodological considerations when dealing with visual behaviour measured in the laboratory were therefore described. Furthermore, the current dissertation made use of multiple eye tracking methods and devices. Since these devices offer different advantages and disadvantages, the following section will discuss some of the recurrent limitations regarding (1) remote and (2) head mounted eye tracking research.

3.2.1. (Dis)similarities of visual search in the lab and in real-life

In paper three, it was demonstrated that (dis)similarities between gaze behaviour in the lab and real-life strongly depended on the nature of the task, task-complexity and task demands (Dunbar et al., 2001; Egan, 2012; Jovancevic et al., 2006). Indeed, visual search in real-life and in the lab showed relative similar distributions towards the AOIs when task demands were higher, e.g. when bicycling on a low quality bicycle path. Bicycling on the LQ bicycle path required continuous monitoring of the bicycle path for direct control and safe travel (Vansteenkiste et al., 2014b, 2013). Both in real-life (71,92%) as in the laboratory (45,50%) gaze is therefore predominantly driven towards the road. Although dwell times on the road were lower in the lab due to lower task constraints (no need to control the bicycle), the road was the longest fixated AOI. These findings concur with 't Hart et al. (2009) and Foulsham et al. (2011), who suggested a more pronounced bias of gaze allocation towards the travel path in real-life compared to the laboratory conditions which might be attributed to the decreased task demands as monitoring the road is not a prerequisite of safe travel in the lab condition. In support of the current findings, Tatler (2009) concluded that gaze behaviour is guided by top-down processes when and where it is needed in real-world active tasks, while Land (2009) reported that gaze in both passive and active visual tasks is controlled by top-down instructions. Alternatively, participants engaging in the laboratory condition were told to behave as they normally would when bicycling in the real world. Participants were therefore aware of the task demands resulting in a top-down influence of task requirements on gaze behaviour ('t Hart et al., 2009; Foulsham et al., 2011).

Nonetheless, there were also some substantial differences between visual search behaviour in the lab and gaze behaviour in real-life which must be considered for interpretation of the hazard anticipation studies and intervention study. E.g. (1) participants fixated more on the road when actually bicycling whereas participants fixated more towards (2) the focus of expansion in the lab condition. These differences in visual search behaviour could be attributed to several factors described in the following sections.

3.2.1.1. Ventral and dorsal stream

Although we attempted to sustain the natural link between perception and action, it was not possible to synchronize the video clips with the bicycle ergometer (paper three). Due to separated visual pathways for perception (ventral stream) and action (dorsal stream)[41], however, disruption between perception and action in abstracted laboratory-based studies has been demonstrated to influence visual perception significantly (Milner and Goodale, 2008, 2005). Bootsma (1989) argued that this disruption between perception and action, might result in disproportionately increased use of ventral stream processing for vision. Another key study performed by Dicks et al. (2010) who repeated the study of Savelsbergh et al. (2005), demonstrated that a video simulation task requiring only a button-press or the manipulation of a joystick instead of a sport-specific response to a visual stimulus may be insufficient for evaluating an athlete's contextual dependent visual search behaviour. With respect to the hazard perception studies (paper five and six) and training intervention (paper seven), these findings might limit generalizability and ecological validity of visual behaviour measured in the lab.

3.2.1.2. Screen size

The smaller screen size in the laboratory might have also resulted in substantial differences in visual search behaviour with respect to the real-world. Indeed, when video clips were presented on a computer screen with a visual angle of 40° (paper five, six and seven) or on a projection screen with a visual angle of 53° (paper three), this resulted in a smaller environment which had to be monitored by the participant. Consequently, participants could acquire all the necessary information from central vision alone, eliminating the need for

[41] Also see 3.3.1. Focal and peripheral vision.

peripheral vision. When bicycling in the real world, however, gaze is often attracted to cues in the periphery which are relevant for safe navigation. Moreover, AOIs in the laboratory study were much smaller compared to the real world which in turn might have caused a misinterpretation of the reported gaze behaviour. On the other hand, when dwell time percentages towards the road and the side of the road from the video simulation (paper three) were combined, the amount of time spent fixating the travel path between the two conditions became increasingly similar.

3.2.1.3. Context dependency

The context in which the particular expertise has been built often determines the nature of the collected information, which information is processed, and the linkage between information and action (’t Hart et al., 2009). According to the theory of situation awareness, schemata are based upon experience, drive gaze to the relevant cues via top-down control and regulate the processing of visual information to select an appropriate response. Presenting children with video clips is contextually different from real traffic since one does not have to monitor the quality of the road or experience the vibrations caused by the bicycle path. Moreover, a potential collision does not cause any harm to the participant which might have altered gaze behaviour significantly.

3.2.1.4. Centrality bias

Due to a framing effect of the monitor, Egan (2012) reported that a “centrality bias” – a strong tendency to fixate the centre of the screen – might account up to 56% of eye movements when viewing static images. However this central bias tended to be weaker when participants were presented with continuous video clips (Tatler et al. 2011). Conform to Egan (2012) and Tatler et al. (2011), participants appeared to fixate the focus of expansion substantially more often in the video simulation task compared to cycling in real-life (paper three). Notwithstanding that horizontal gaze distribution only appeared to differ between road types and not condition, vertical gaze distribution in the video simulation task was considerably denser compared to the real-life cycling task. Less extensive scanning in the vertical plane can likely be attributed to the reduced visual angle lab. This central bias might even be more pronounced when watching video clips on a smaller computer screen, for example when presented with a hazard perception test.

3.2.1.5. Head-centered video clips

The video clips which were used for the hazard anticipation test (papers five, six and seven) were obtained from the head-centered GoPRO-camera or form the environmental camera of the eye tracker (sample rate: 30Hz; paper three). According to the study of ’t Hart et al. (2009), this implies that observers’ visual scanning in the lab condition was restricted since their gaze is directed to the places in the environment that the wearer of the camera attended to. Also contrast sensitivity and the resolution of the projections should be considered. On the other hand, when collecting the video clips for the hazard anticipation test, bicyclists were instructed to keep their head a still as possible when cycling through traffic (without endangering themselves). Furthermore, some video clips for the test and training intervention were recorded with the GoPRO-camera mounted in the center of the steering bar.

3.2.1.6. Recurring issues with head mounted eye tracking research

With the fixation-by-fixation method or "semantic gaze mapping method" which was used in the real-life bicycling studies (papers three and four), data analysis workload was reduced significantly since the researcher attributes fixations to predefined AOIs. This allows the researcher to conduct much longer experiments. Moreover, *"semantic gaze mapping"* is less subjective than manual frame-by-frame fixation detection. In manual frame-by-frame analysis, however, the start and ending of a fixation is determined by the researcher. This provides the opportunity to detect irregularities or errors in the data, to detect smooth pursuit and to analyse the data in full detail.

Given that the fixation-by-fixation method relies on the algorithms provided by the software manufacturer, there has been discussion about the reliability and validity of these algorithms. Questions arise whether such fixation detection algorithms can effectively make the difference between long smooth pursuit fixations or multiple fixations (Holmqvist et al., 2011). In addition, when analysing the data, the researcher must be aware that he is analysing partially processed data instead of the raw data which makes it harder to detect irregularities and errors. Finally, when the experiment contains small AOIs or high speed stimuli it is questionable whether this method is still reliable. The researcher must therefore carefully reconsider the analysis method in function of the conducted experiment. A combination of multiple gaze measures might provide a better understanding regarding the gaze behaviour throughout the experiments.

Aside from the used method, also the eye-tracking hardware struggles with recurring issues such as calibration issues when tracking eye movements outdoor. Since head mounted eye tracking devices only provide a measure of the eye tracking precision under ideal and artificial conditions, many environmental and personal factors influence the eye tracking accuracy when measuring accuracy in real-life (Holmqvist et al., 2011). Furthermore eye tacking accuracy is often measured at one fixed distance which might result in a parallax effect. Parallax errors result from the scene camera and eye camera not being on the same line and increases when an object is closer or further from the distance which was used for the calibration. To counter calibration issues a calibration grid with concentric circles at different distances could improve calibration and provide a measure of eye tracking accuracy (Vansteenkiste, 2015). However, according to the manufacturer, the Eye Tracking Glasses (papers three and four) should compensate for the parallax effect.

Also data loss due to disturbing factors such as problems with calibration, or problems with the eye tracking devices often result in low tracking ratio. Tracking ratio describes the time the eye tracker is able to record the position of the eye. When the position of the eye falls outside the range of the scene video or is unstable for at least 80ms, the eye movements are not included in the measure of eye movement data and could therefore result in data loss or biased data despite a high tracking ratio.

3.2.2. The hazard anticipation test

3.2.2.1. Quality of the video clips

The video clips in the hazard perception studies and the training were found to be relevant and of decent quality by three experts in the field of hazard perception. Nevertheless, none of the clips reached a significant difference in response rate between children and adults. Also Vlakveld (2011) reported no difference in clicks on the latent hazards. Together with a lack of difference for the number of fixations between children and adults on covert latent hazards the sensitivity for some of the clips might be questioned. In contrast, child pedestrians were found to respond less often to hazardous events than adults when presented with road-crossing situations (Meir et al., 2015b, 2013; Meyer et al., 2014; Rosenbloom et al., 2015) and learner drivers have been reported to demonstrate more difficulties detecting covert latent hazards (Konstantopoulos et al., 2010).

The inability of our hazard perception test to differentiate between learner and more experienced cyclists for response rate and the number of fixations on the covert hazards can possibly be attributed to the saliency of the used traffic situations. The covert hazardous situations nearly always developed into salient hazards. Including more subtle potential hazards in which no actual hazard occurred might provide a better hazard anticipation test. However, the exploratory study with a wide range of video clips in a small population of experienced cyclists concluded that when hazards were not salient, they did not react for the situation as they seem to find the danger not imminent enough to respond. Cyclists possibly felt confident that they still could brake when a hazard appeared as cycling occurs at significant lower speeds compared to driving. Furthermore, the video clips did not respond to the braking actions of the participant and were presented on a relatively small screen which might have decreased the sense of reality. Presentation of the video clips on a larger screen, while being seated on a bicycle might improve the feeling of being "immersed" in traffic.

3.2.2.2. Experience

Children are not yet physiologically and mentally mature and develop further throughout adolescence (Chihak et al., 2014; Plumert et al., 2011). Since hazard perception is found to be related to experience, it is likely that experienced child cyclists will have a better developed situational awareness and possibly be more comparable to adult cyclists' situational awareness. Differentiating between inexperienced and experienced child cyclists to isolate maturity could provide us with valuable information with respect to the development of training programs. Measurement of cycling skills and cycling experience to establish an accurate determination regarding the experience level of the participants is therefore essential.

3.2.2.3. Visual or auditory problems

For the studies in this dissertation, it can not be excluded whether children with visual or auditory problems participated in one of the studies. As parents were required to sign an informed consent, fill out a questionnaire and were informed regarding the testing protocol for each investigation, we assume that parents or teachers would have informed the researchers.

3.3. Training intervention

To evaluate the effect size of the hazard anticipation intervention presented in paper seven, it is essential to compare the improvements with the results of other hazard anticipation studies. The intervention resulted in significant improvements for the amount of detected hazards (±5%) in the post-test and the retention test. Furthermore, also improvements in the reaction times for the covert latent hazards directly after the training (±0.5s; minimal improvement=0.17s; maximal improvement=1.92s) and three weeks after the training (±0.3s; minimal improvement=0.21s, maximal improvement=2.35s) have been reported. The results are therefore of comparable magnitude to the results of Isler et al. (2009). After an intervention in young novice drivers, Isler reported that the trainees identified significant more hazards (+4.2%) and improved their reaction time by 0.8s compared to the young-control group. In line, an intervention study in child pedestrians conducted by Meir et al.

(2015a) resulted in a decrease of mean crossing decision-time by 0.6s. However, Sahlberg et al. (2015) reported more spectacular improvements in response latency after child bicyclists were trained with a learning game for situation awareness. After the learning game, children responded up to 5% more hazards and 1,5 to 2s faster directly after the intervention and up to ±10% more hazards and 2,2s faster on the third test occasion. Nevertheless it can be concluded that the improvements in reaction time after the intervention lie within the expected range since children were shown to respond ±0.6s later compared to adults for the covert latent hazards (paper six).

3.4. Conclusion

It can be concluded that bicycling in real-life is more demanding than bicycling in the laboratory. Since actual steering, navigating and other sensory stimuli in the lab were eliminated, this might have had certain implications on gaze behaviour. In favour of internal validity and ethical reasons, ecological validity is therefore often suppressed. Nevertheless, it has also been demonstrated that gaze behaviour in the lab - under certain task constraints, f.e. by means of a hazard anticipation task - might predict gaze behaviour in real-life to some extent. Children displayed a significant lesser extended visual search behaviour and were less likely to gaze towards the hazardous events since they were less aware of the task demands.

4. General conclusion

Bicycle related accidents are among the most common causes of children's physical injuries (Briem et al., 2004; Lammar, 2005; Van Hout and Cuyvers, 2007). In general, three groups of factors involved in traffic accidents can be identified: external factors (road architecture, sings and signalization, other traffic participants…), the bicycle itself (lights, brakes, maintenance…), and intrinsic factors that influence the behaviour of the bicyclist. Large part of the bicycle accidents in children appear to be related to factors within the bicyclist: motor skills such as bicycle riding skills and perceptual-motor skills such as hazard anticipation (Ducheyne et al., 2013; Ormel et al., 2009; Vansteenkiste et al., 2014, 2013). Given that these intrinsic factors are not well documented in the scientific literature, the current dissertation aimed to address the development of (perceptual-) motor skills child bicyclists. Although this thesis adopted a comprehensive approach and focussed on a variety of aspects, we also aimed to explore the fundamental characteristics for safe bicycling behaviour in depth. Given that a large part of the bicycle accidents are caused by risky behaviour of car drivers as well, it should be noted that education of young bicyclists alone will not solve the traffic problem.

In the early stages of learning to ride a bicycle, attention is mainly directed towards the control of the bicycle itself. Therefore this dissertation was the first to evaluate the influence of motor competence on bicycling skills. In line with our hypothesis, it was found that actual motor competence acts a keystone to the development of more complex skills such as bicycling (paper one). Especially complex skills in which correct steering behaviour and additional body movements such as signalling or turning the head were combined, required more proficient coordination of the upper and lower body parts. The results are therefore in line with theoretical models of motor development describing a spill-over effect from a general construct, e.g. motor competence, to the development of more complex skills such as bicycling. Since motor competence is a stable trait from the age of six (Ahnert, 2005; Vandorpe et al., 2011), this dissertation emphasised the importance of proper motor skill development in young children. The necessity to carefully monitor and stimulate motor skill development by means of sport activities, physical activities or free play has been demonstrated to be even more important since increasing BMI index was found to be negatively associated with motor competence and bicycling skills. The results presented in this thesis therefore concur with the developmental perspective of Stodden et al. (2008) in which the reciprocal relationship between motor competence and BMI has been described. Next to general motor competence, the evaluation of bicycling skills in children of different age groups was of interest. According to the model of motor development we hypothesized that bicycling skills would enhance with age. With increasing age, bicycling skills enhanced significantly, which was reflected in better scores for the bicycling skills in which more complex additional body movements were required (paper two). Furthermore, the younger a child learns to control his or her bicycle, the better their performance will be according to the power law of practice (Wierda and Brookhuis, 1991). Moreover, this might also be related to motor competence.

The ability to control one's bicycle is unfortunately no guarantee for safe traffic participation. Once a child masters his bicycle, it will also need to develop specific perceptual-motor skills to actively and safely participate in traffic (Briem et al., 2004; SWOV, 2012). During this learning process, bicycling skills are progressively automated and a shift of attention from the bike and its immediate surroundings to the wider environment occurs (Helsen et al., 2005). Due to this shift of attention, the bicyclist should be able to pay better attention to traffic signs, other traffic participants, dangerous traffic situations and participate in traffic in a safer manner. As research regarding the perceptual-motor skills in child bicyclists remains rather scarce, the current dissertation was the first to evaluate child bicyclists' visual behaviour when bicycling in real-life by means of eye tracking methodology. It was hypothesized that children's visual behaviour will be affected more by the quality of the bicycle path compared to adults (paper three). Although the magnitude of the shift of visual attention towards the road when bicycling on a low quality bicycle track was similar to that of adults, children tended to focus more on the side of the road or on other road users. Given that children seemed to focus more on task irrelevant regions and travelled at considerable lower speeds, the real-life bicycling study demonstrated that child bicyclists displayed a simpler perceptual-motor strategy compared to adults. This might imply that children are less likely to notice dangerous obstacles on the low quality bicycle path. Consequently, it can be suggested that children seemed to lack a sufficient understanding of the task demands when bicycling in traffic.

In order to evaluate child bicyclists' awareness of potential hazards in traffic, a novel hazard anticipation test was created (paper five and six). This test presented children with video clips of potential dangerous situations. Such a test has a number of important benefits: (1) it allows evaluating children's behaviour when presented with dangerous traffic situations without endangering them, (2) internal validity and (3) children do not have to control their bicycle which decreases cognitive load. According to studies in driving and pedestrians, it was expected that child bicyclists would demonstrate poorer hazard anticipation skills by means of increased response latency and entry time of the first fixation on the potential hazard. In line with our expectations, it was demonstrated that young (±10 years of age) children's hazard anticipation skills and situation awareness were poorly developed compared to adults, both by means of visual behaviour and reaction times. Even when the motor component was absent and could not interfere with attention, young bicyclists did not actively search for other road users who were hidden from view (covert hazards) or were less likely to scan the areas from where a road user possibly could emerge. Anticipation of potential dangerous situations requires the child bicyclist to approach situations from the perspective of other traffic participants (theory of mind) which is more difficult for children. To fathom covert hazards, one has to form an internal representation of a traffic participant who is not (yet) visible. Child bicyclists, however, only reacted when the hazard became visible or salient. Children were therefore suggested to lack the contextual knowledge and mental schemata enabling the bicyclist to search for the relevant cues of the potentially hazardous situation (SA1: perception), to efficiently decide whether or not the situation contained risk (SA2: comprehension) and to make predictions regarding the future development of the situation (SA3: projection) (Meir et al., 2015b, 2013; Rosenbloom et al., 2015). The more experience a bicyclist gains, the more automated and faster the processing of the perceptual information in the working memory occurs. In addition, as the capacity of the working memory is limited, more elaborated schemata will also decrease cognitive load. Grace to scripts which are tightly linked to the schemata, decision making and action are facilitated which results in enhanced anticipation of the (potential) dangerous event.

To provide child bicyclists with means for enhancing their abilities to safely deal with the complexity of dynamic traffic settings and learn to anticipate a variety of potentially dangerous traffic situations, a brief hazard perception training intervention was developed (paper seven). We hypothesized that the training would improve hazard anticipation skills in child bicyclists by means of higher response rates to the hazards and lower response latencies and first fixation latencies. Although the intervention was not sufficient to teach children where to look for potential hazards that are not momentarily and physically present, trained children were found to detect more hazards and reacted quicker to the covert hazards. It can therefore be suggested that the brief intervention improved children's processing of the potential hazards due to increased experience with potentially dangerous situations and better developed mental models which is reflected in the higher response rates and decreased response latencies. The current thesis therefore stressed that a hazard anticipation test and training can be useful tools for traffic education by parents, schools or caregivers.

It should also be noted that, although, child bicyclists demonstrated better motor bicycling skills the younger they start practising, it remains questionable at what age children should start participating in traffic. As it has been suggested that they only start to master their bicycling skills around the age of nine, grace to the development of motor and cognitive abilities (Briem et al., 2004; Ducheyne, 2013), nine-year-old child bicyclists may not be ready for traffic participation. Moreover, it was demonstrated that children's bicycling skills, especially the more complex skills, improve at least to the age of twelve (paper two). Cognitive workload in younger children might therefore be (too) high as controlling the bicycle in more complex situations will absorb all attentional resources. For example, a child bicyclist who does not sufficiently master the skill to adequately steer his bicycle with one hand and look over the shoulder, will experience high levels of perceived task difficulty when he needs to signal and check his shoulder in a real traffic situation. Subsequently, the child bicyclist might lose his heading when attempting to perceive traffic or fail to see the oncoming hazards. In order to lower the perceived task difficulty, the child can decrease bicycling speed only to a certain threshold. In addition, learning from experiences is more difficult when mental workload is high. Because young bicyclists also performed poor on a hazard anticipation test in which the motor component of bicycling was absent, training of hazard anticipation and motor bicycling skills is of major importance. Training of bicycling skills might enhance the capabilities of the bicyclist, resulting in enhanced perceived capabilities and more automated control over the bicycle. Furthermore, hazard anticipation training might improve children's schemata in long term memory stores which benefit decision-making and anticipation. Improvements in both motor and perceptual-motor abilities might therefore reduce workload and benefit safe traffic behaviour. Accordingly, hazard perception training could/should start early enough to provide children with a head start.

The methodological considerations whether studies regarding visual behaviour making use of movies in restricted laboratory settings or classrooms can be transferred towards the real world have been addressed in paper three. Comparison of visual behaviour in participants, bicycling a bicycle track of high and low quality in real-life and in the lab, demonstrated increasing resemblance with increasing task load. When task load was high, for example when bicycling on a bicycle track of low quality or in heavy traffic, attention was directed towards the task-relevant information since there was few time for corrections. When task load was low however, bicyclists had more time to focus on irrelevant or salient characteristics in the environment. A correct understanding of the task demands remains essential for properly dividing attention. This implies that under certain task constraints, lab experiments making use of video clips, for example hazard perception, could provide valuable information regarding gaze behaviour in real-life, especially in more demanding tasks.

5. Strengths and limitations

The following section describes the strengths and limitations of the studies which were described in this thesis will be briefly discussed.

5.1. Strengths

This dissertation aimed to provide a better understanding regarding the motor and perceptual-motor skills in child bicyclists. Especially since a certain amount of bicycle accidents in children can be attributed to poor motor bicycling skills. First of all, to our knowledge this was the first study to evaluate the influence of actual motor competence on bicycling skills (paper one). Since also BMI was found to be related to bicycling skills, this thesis added value to theoretical models regarding motor development which have suggested that MC, BMI and more complex skills are interrelated (Stodden et al., 2008; Robinson et al., 2015). Furthermore, this dissertation was the first to compare bicycling skills of three different age groups in detail with a validated testing instrument (paper two). The results provide useful insights regarding the age-related development of bicycling skills in children and can be used to develop tailored training interventions.

Secondly, this thesis was the first to evaluate perceptual-motor skills and visual search strategies in child bicyclist in a real-life environment by using a mobile head mounted eye tracker (paper four). While riding on a bicycle path of low quality and high quality children's eye movements were tracked and compared to more experienced adult bicyclists. Given that many bicycle path are in poor condition, it is important to document the impact of poor road condition on perceptual-motor behaviour. Furthermore, this thesis was one of the first to demonstrate that visual behaviour in traffic, when bicycling on a mounted bicycle in the laboratory and bicycling the same route in real-life, is relatively similar with increasing task demands (paper three).

Thirdly, one of the major strengths of this dissertation was that it evaluated hazard anticipation in child bicyclists using eye tracking methodology and was developed together with three experts. In the test, participants were presented with video clips of dangerous traffic situations, implying that hazard anticipation skills can be measured in a safe setting. The development of such a test sets new standards for testing of perceptual-motor skills in child bicyclists. It was demonstrated that children lack the necessary experience and hazard perception skills to anticipate dangerous traffic situations which adds value to previous research in child pedestrians. Poorly developed schemata which aid the process of understanding the perceived visual information and coming to an appropriate decision were suggested to underlie the shortcomings in child bicyclists.

A fourth major strength of the current thesis is the hazard anticipation training. To improve child bicyclists impoverished hazard anticipation skills, we developed a novel and brief hazard perception training for child bicyclists which consisted of video clips of dangerous traffic situations. The training was carefully developed in cooperation with an expert panel. After the intervention, trained child bicyclists effectively reported more covert latent hazards and reacted sooner compared to the control group. Therefore this was the first study to demonstrate that child bicyclists' perceptual-motor skills by means of hazard perception and situation awareness could be improved with a brief hazard perception intervention. According to the findings of this dissertation, practical implications for parents, education in schools and policy makers are provided.

5.2. Limitations

It is important to consider certain limitation when interpreting the results of the current dissertation. Although some limitations regarding the test-items already have already been addressed in the methodological considerations, general limitations regarding this thesis are discussed. For all studies in this thesis, generalizability of the findings is limited due to the nature and size of the sample population. In paper one, two, five and six, for example, only one school was tested in each study. Correlates such as socio-economic status, localisation of the school (e.g. city, (sub)-urban) and the rather small sample sizes might therefore have their implications on the results. Regarding the sample size in paper one for example, only few participants were classified as overweight or obese. In study seven on the other hand, randomization of the participating children was limited to the schools that were willing to participate in the training. This might have resulted in an increased risk for an unbalanced design or cluster-effect. However, to avoid contamination between the experimental and the control group, school should be used as the unit of randomization (Chillón et al., 2012). Furthermore, as no exclusion criteria were used for any of the studies, it can not be excluded that children with an auditory, visual or developmental disorder participated in one of the studies. As parents were required to sign an informed consent for participation of their child, we assumed that parents would have told the researchers regarding potential problems.

With respect to hazard anticipation, since this dissertation was one of the first to develop a hazard perception test and training for child bicyclists, it was not possible to verify the outcomes to a golden standard. Although we attempted to compare our results with previous research in child pedestrians and learner drivers, it important to note that the results of paper five, six and seven must be interpreted with caution. Future research should focus on the validation of the hazard perception test and training for bicyclists prior to the integration of such tools in the traffic education lessons. Also internal consistency of the hazard perception test should be taken into consideration. Furthermore, it remains unclear to what extent trained child bicyclists will be able to transfer the current improvements to safer on-road behaviour questioning the ecological and external validity of our findings. When bicycling in real-life, children have to combine motor and cognitive skills into proper bicycling behaviour, which requires a considerable mental effort.

Regarding the tracking of visual behaviour, eye trackers only measure fixations. Peripheral vision for lane keeping, attending to other bicyclists or pedestrians (papers three and four) is not taken into account. It is also possible that a foreshadowing element predicting a potential hazard (papers five, six and seven), may be detected by peripheral vision or covert attention at first, after which a saccade orients overt attention to the hazard. It is therefore important to note that visual anticipatory behaviour measured by means of fixations alone does not provide the full spectrum of visual attention. Furthermore, it could be questioned whether adults and children acted natural during the eye tracking experiments (papers three to seven). The question whether participants alter their visual behaviour or not when they are aware that their eye movements are being recorded is a recurring concern in all eye tracking experiments.

A final limitation regarding the studies in nine-year-old children (paper one, two, five, six and seven) concerns the cross-sectional design. Although these studies provided valuable evidence for understanding and evaluation of the (perceptual-) motor bicycling skills in children, longitudinal studies are required to provide causal evidence.

6. Practical implications

In this dissertation motor bicycling skills have been shown to be associated with motor competence and BMI and improve with age and experience. Furthermore, child bicyclists tended to exhibit simpler and less flexible visual search strategies both in real-life or when perceiving video clips of hazardous traffic situations. Based on the findings of the current research project, the practical implications for policy makers, teachers as well as primary prevention measures regarding bicycle and traffic education are discussed.

6.1. Extrinsic factors

6.1.1. Environmental factors

In the real-life bicycling study (paper four), it was demonstrated that the quality of the bicycle infrastructure plays an important role in the distribution of visual attention when bicycling. To encourage more bicycling by means of home-school transportation in children, or bicycle use for short trips, decent maintenance of infrastructure is essential. Especially for children who suffer lower motor competence, are less confident and have less control over their bicycle. Policy makers should aim to increase comfort by avoiding potholes in the middle of bicycle tracks, small poles or concrete blocks to divert traffic, and other obstacles with which the bicyclist could collide. Therefore a high-quality asphalt or smooth concrete surface are preferred over tiles or cobblestones (Van Hout et al., 2011). Furthermore, Pucher and colleagues (2010) reported in their review that new bike lanes are associated with higher levels of bicycle commuting which in turn improves physical activity and bicycle experience. High quality bicycle tracks could also reduce the amount of single bicycle accidents and consequently decrease healthcare costs.

Not only the quality of the bicycle infrastructure, but also their localisation to motorised traffic has been indicated as an important factor for (perceived) safety (Pucher et al., 2010; Van Hout et al., 2011). Since children are found to display less skilful perceptual-motor bicycle skills and are less confident bicyclists, separated bicycle paths are preferred above shared bicycle lanes[42]. Although parents indicated that a curb is a sufficient alternative to a hedge, children preferred bicycle tracks separated from motorised traffic by a hedge rather than a curb or no separation at all. As accessing the bicycle track over the curb was perceived to be more difficult in younger children (Ghekiere et al., 2015), this results from their poorer developed bicycle skills such as riding over a sloping surface or bicycling over obstacles. Furthermore, this dissertation demonstrated that children have difficulties with detecting covert dangerous situations for example when parked cars limit view. Therefore policymaker must carefully consider the place of the bicycle path with respect to parking places.

Unfortunately, separated bicycle lanes are not always possible due to limited space. When applying on-road bicycle lanes, policy makers should ascertain that bicycle lanes are marked in such a way that no confusion

[42] Pucher & Buehler (2012) reported that bicycle infrastructure can be classified into (1) shared streets and shared lanes with no clear dedicated bicycle space, (2) bike lanes which are separated by roadway striping, (3) separated bicycle paths, physically separated from the road by a curb or parked cars and (4) standalone bicycle paths referring to shared-use bicycle paths in a park or along a rail corridor.

regarding the place of each road user could possibly occur. On-road bicycle lanes should be marked with high contrasting colour and sufficient lane markings in order to alert the motorists for bicyclists and clearly indicate where child bicyclists should ride. Especially since child bicyclists have been reported to enter traffic without looking properly (Lammar, 2005). In case of an intersection, bike boxes, marked with a high contrasting colour and advanced stop lines, in front of the vehicle lane might improve visibility of the bicyclists for other road users and give them a head start when the lights turn green. Schreiber and colleagues (2015) postulated several recommendations regarding the construction of intersections which are relevant in light of the current findings. For example, obstructions to visibility at intersections must be removed, the bicyclist's field of view must be clear so he can make a shoulder check, decrease the complexity at intersections and quality of the bicycle paths at intersections must be of high quality so that a bicyclist can attribute all his attention to negotiating traffic. Furthermore, bicyclists must be aware that they are not always visible to other road users and should adapt their behaviour accordingly. Also driver assistance systems could help to prevent bicycle crashes at intersections. Such systems detect approaching bicyclists when the driver is making a turn at low speed which might aid the driver to anticipate. More information regarding the impact of infrastructure on bicycling injuries and crashes can be found in the review of Reynolds and colleagues (2009) or Pucher and colleagues (2010).

Figure 22. On the left, a bicycle track separated from traffic by a curb. In the middle a bicycle track separated by a curb and a parking. On the right, a bike box which is a marked area for bicyclists at intersections (Pucher et al., 2010).

It is case to create a bicycle-friendly environment for children. Policy makers should aim to implement traffic calming measures in residential neighbourhoods, around the schools and approach traffic from the perspective of the vulnerable road user rather than from the perspective of car drivers. Or to cite Pucher and Buehler (2012, p.142) *"Danger is imposed on the bicyclist and not the other way around. Bicycling is a benign activity that often takes place in dangerous environments"*. Since younger children have lesser control over their bicycle and approach traffic from an idiosyncratic perspective, creating bicycle friendly environments for children require the implementation of safe connections between homes, schools and recreational facilities. A special bicycle network for children with adapted infrastructure and signs to guide children to their destinations might improve (perceived; both of parents and children) safety and bicycle use. A good example can be found in the east-west-route in Ghent which passes through car free streets, connects important locations and consists of high quality, sufficiently wide and comfortable bicycle infrastructure (Fietsersbond, 2014). Pucher and Buehler (2012) described that "child ribbons" or "*kindlint"* which interconnect important destinations to children such as playgrounds or schools improved bicycle safety significantly. Key for such interventions, is the siting of the interconnected facilities, for which applies that close is better than far. For example, bicycling on a "bicycle boulevard", a "bicycle high-way" or a "bicycle street" in which the whole street has been assigned to the bicyclist and motorised transport should remain behind the bicyclists, are traffic calming measures to improve safety of the child bicyclists and connect destinations with each other.

Child bicyclists also indicated speed limitations to be favourable for perceived safety. Speed restrictions to 30km/h in the proximity of the children's bicycle network or neighbourhood streets and up to 15 km/h in home zones or "*woonerf*" could benefit all residents. Furthermore, such speed regulations might improve the amount of bicycling, in turn, enhancing physical activity in children and regular practice of their bicycling skills. Another example presented in Pucher et al. (2010) reported that *ciclovias* initiated higher levels of bicycle use. Ciclovias or *car-free days* are free recreational events where streets are temporarily closed for motorised vehicles and the road is reserved for bicyclists, pedestrians, roller-bladers,… These events offer the opportunity for children to learn and improve their bicycle skills in real-life settings. Accordingly, Ducheyne et al. (2013b) stressed the importance of a free-play environment. The researchers reported that children living in a lower residential neighbourhood performed better on the bicycle skills test while cycle frequency did not had a mediating effect. It was therefore suggested that six to ten year old children develop bicycling skills rather during leisure time activities in which the bicycle is used as a toy than when bicycling to school (Arnberg et al., 1978).

6.1.2. Parental factors

Getting more children on their bicycles, parental safety concerns regarding infrastructure and education should be addressed. Parents have indicated that their children are allowed to bicycle when a safe network of bicycle routes would exist (Pucher et al., 2010; Pucher and Buehler, 2012). Policy makers should therefore consider to lower traffic volume, apply speed limitations and improve connectivity between destinations, which are essential infrastructural adaptations in order to provide safe conditions for bicycling and improve parental perceived safety. Furthermore, Parental perceived motor competence of the child has been shown to play an important role in the prediction of fundamental movement skills in children (Raudsepp and Päll, 2006). Given that FMS are a prerequisite for more complex skills such as bicycling (Ducheyne et al., 2013b) demonstrated that parental perceived motor competence explained 10% of children's bicycling skills. Rigorous safety education and bicycle skills training are key to improve children's skills and parental perceived ratings of their children's abilities. Safe bicycling can be part of primary education in schools, lessons physical education, or non-profit local governmental organisations. However, also parents should invest time in teaching their children correct road attitudes and bicycle skills.

6.1.3. Bicycle related factors

To improve safety and control over the bicycle in children, it is important that parents adjust the bicycle to their child's abilities and physical characteristics. When young children encounter more difficulties with maintaining balance or stopping appropriately, lowering saddle height to ensure children with lower motor competence can touch the ground with both feet could improve bicycle control and confidence of the child. Alternatively bicycle size too needs to be considered. When selecting a bicycle with wheels or frame too small or large, control over the bicycle might be hampered resulting from lowered speeds due to poor posture and foot placement on the pedals. Furthermore, when a bike is too big and wheels too large, the saddle has to be lowered and sufficient power production might be more difficult. As a result the child will have more difficulties to control the bicycle as well. Also manageable brake levers, easy to squeeze and reach, are possible modifications to the bicycle which simplify bicycle handling and improve control and safety.

6.1.4. Other traffic participants

This thesis aimed to develop a better understanding regarding the intrinsic factors (e.g. hazard perception, experience, motor competence etc.) related to traffic accidents from the perspective of the child bicyclists. Although this work focussed on providing child bicyclists with means to cope with traffic, bicycle accidents often have a multidimensional cause. It must, for example, not be forgotten that a large amount of the accidents are caused by risky or inattentive driving behaviour of drivers. It would be a mistake to assume that education of young bicyclists alone would be the solution to bicycle accidents. For example, consider a bicyclist riding on a bicycle-suggestion path. A driver wants to advance in front of the bicyclist but realizes he will not be able to pass the bicyclist in time before the approaching car arrives. Unaware of the danger they can cause to the bicyclist, the driver moves to the side. The bicyclist is expelled to the gutter and falls. As sufficient training of young bicyclists might decrease accident statistics by three or four percentage points, it also requires serious efforts of car drivers to further decrease accident statistics with bicyclists. Education of motorists regarding safe road attitudes, vulnerable road users' rights and awareness of bicyclists is essential too (Pucher et al., 1999). Cycling policies should therefore compel motorists to respect vulnerable road-users.

6.2. Internal factors

6.2.1. Physical activity and motor competence

Given that motor competence is a relatively stable trait from the age of six (Ahnert, 2005) and FMS also have bearing on to other more complex tasks (see paper one) and participation in sport activities later in life (Stodden et al., 2008; Riethmuller, et al., 2009; Reilly, 2010; Lopes et al., 2012; Vandorpe et al., 2012b) promotion of physical activity and active leisure time activities in (pre-)school children is extremely important. Because young children increasingly engage in sedentary activities (computer, TV, tablets, etc.), they hardly reach the appropriate amount of daily physical activity resulting in a higher incidence of childhood overweight. Especially children with lower motor competence are at higher risk to become overweight and require special attention (Stodden et al., 2008). Schepers (2012) for example, suggested that bicyclists with an athletic build can more easily avoid an obstacle at the last moment while obese bicyclists will have more problems to avoid the obstacle. Parents, schools and caregivers should therefore stimulate children to engage in free and unstructured play, outdoor activities, sports or any other physical activities for at least 60 min/day which preferably involve large-muscle groups. For example, creating a stimulating playground in schools, afterschool physical activities, activity diaries,… Also introducing one day a week in which children are encouraged to come by bicycle rather than by car. However, not only teachers or schools, but also parents bear responsibility. parents should stimulate their children to play outside, join sport clubs or scouts and use active transport for short trips (Lopes et al., 2012). Goodway and colleagues (2014) demonstrated that participating in free and unstructured (outdoor) play or physical activities helped children to get used to an active and healthy lifestyle which stimulates the development of FMS. Furthermore, it has been demonstrated that promotion of an active and healthy lifestyle during childhood may stimulate a healthier lifestyle later in life, stimulate (perceived) motor competence and physical activity (Robinson et al., 2015).

However, not only the amount of physical activity is important. As there is a transfer from motor competence to bicycling skills (paper one), this highlights the importance that children must be stimulated to *"move"* qualitatively and in a wide variety of settings. Motor competence is based upon nurture (previous experiences in preschool), which refers to environmental factors, and nature (the stage of development), which refers to intra-personal factors. It is important that children can between choose activities that they love and for which they have acquired the appropriate building blocks. Children with high motor competence should be stimulated towards competitive sports in order to increase their potential. Children with lower motor competence on the other hand should be stimulated to practice and develop their FMS so they can participate in a variety of sports and games. Children need to explore different ways of moving and experience a wide variety of skills, and appropriate feedback to develop a broad base of fundamental movement skills such as hanging, catching, climbing or jumping. Especially in pre-schoolers because of the high plasticity of the nervous system and the brain (Logan et al., 2012; Riethmuller et al., 2009; Vandorpe, 2011). School-based and community-based programs are therefore needed to enhance the quality and levels of motor skill development. A non-competitive, challenging environment with sufficient equipment and daily physical activity routines are required. Furthermore, it is essential to match the activities to the child and not the other way around (Weiss, 1993). Teachers need to provide children with modified tasks, so skills can be practiced at different levels of difficulty. For example, when throwing a ball, the teacher can provide targets at different distances, or varying sizes of balls. To conclude, it is essential that children are offered a wide variety of activities which they love to do, in a variety of settings, to stimulate a broad fundamental movement skill base and increase their skilfulness.

6.2.2. Education

The current dissertation demonstrated that younger children do not yet possess the practical skills and knowledge which are required for safe bicycling in traffic. Child bicyclists were also demonstrated to adopt simpler perceptual-motor strategies to cope with complex dynamic traffic situations. Based on these findings, it is suggested that traffic education for young bicyclists should focus on four essential elements: (1) the development of motoral bicycle skills, (2) knowledge and attitudes (3) hazard perception and (4) integration of these components into on-road experience. We suggest that these elements should be combined and modified into appropriate traffic lessons for each grade. Furthermore, this is a plea for more traffic education in school. Children should be, as it were, "*immersed"* in traffic. In the following part, we describe the potential of each element.

6.2.2.1. Motor bicycle skills

Recently Ducheyne and colleagues (2013b) developed a valid tool to evaluate bicycle skills in nine year old children. The researchers demonstrated that a four-session (45min/session) training program effectively improved the motor bicycle skills in the nine year old children (Ducheyne et al. 2014). Accordingly, training programs can for example be implemented as part of the lessons physical education or can be subject to an annual bicycle-project week in schools. It is key to let children practice a wide variety of skills, in a wide variety of settings. For example, bicycling over all kinds of sloping surfaces, performing different slaloms, or bicycling along a playground and picking up objects form a table and handing them over to a fellow bicyclist. Extensive practice results in automating of these different skills. Automation of skills will enable children to focus more on the environment, for example, when bicycle in traffic (Helsen et al., 2005). However, not only schools but also parents should supervise that the learned skills are practiced and mastered accordingly.

Starting with the motor bicycle skills in the first grade, educators should start with relatively easy skills and progress to more complex skills. For example, mounting and dismounting the bicycle in different settings, walking with the bicycle at hand on a variety of terrains. When proceeding to riding the bicycle, children should learn to control their bicycle on a variety of ground terrains, different levels of sloping surfaces and maintain heading when bicycling through a range of lane widths. It should be noted that although children might demonstrate sufficient control over their bicycle when practicing these relatively easy skills on school playgrounds or closed roadblocks, these settings are inherently different from real dynamic traffic situations where interaction with other road users affects behaviour. Parents are therefore advised to accompany their children and encourage them to practice their skills in closed road blocks and home zones.

When children gain better control over their bicycle with increasing experience and/or age (physical and mental development), training programs should include more complex skills which require additional body movements. For example checking the shoulder or signalling. Ultimately, complex skills can be combined such as signalling and checking the shoulder at the same time or performing those skills when attempting to maintain heading. Nevertheless, teachers should bear in mind that previously learned bicycling skills should be practised over and over again to become automated.

6.2.2.2. Knowledge and attitudes

Next to the ability to control a vehicle, it is essential that children acquire sufficient knowledge and a correct, safe and defensive bicycling behaviour in traffic. With traffic education during childhood, the foundation for traffic knowledge, -skills and –attitudes in adulthood is formed. Children must learn their place on the road. As young children (up to nine years old) are allowed to ride their bicycle on the pavement in Belgium, older children must ride their bicycle on the bicycle path engaging in more dynamic interaction with other traffic participants. Furthermore, the meaning of relevant traffic signs and rules to the child bicyclist and traffic lights must therefore be coupled to the correct behaviour. For example stopping in time when a light turns red or granting priority to vehicles coming from the right. Briem et al. (2004) demonstrated accordingly that younger children have difficulties to interpret relevant traffic signals in time. When growing older boys displayed riskier behaviour due to increased confidence and decreased fear for adverse consequences of risky bicycle behaviour. Girls on the other hand missed more traffic signals compared to boys.

Consequently, teachers should focus on knowledge regarding traffic signs and traffic rules too. A session in a traffic theme park might learn children correct attitudes, how to apply the traffic rules and learn how to correctly behave in traffic. A variety of non-profit organisations already offers packages for schools to create a miniature traffic setting on the schools playground in which knowledge of priority rules and traffic signs can be applied. In addition, policy makers should consider placing adapted traffic signs for children by means of height.

6.2.2.3. Hazard anticipation and training

When children have mastered the motor bicycling skills to control their bicycle sufficiently and have acquired respectable knowledge and attitudes, traffic education should transfer its focus to hazard anticipation. Indeed, it has been demonstrated that compared to adults, children often lack the experience to deal with dangerous traffic situations by means of detecting (e.g. visually and auditory) and selecting the relevant information to anticipate the dangerous events accordingly (paper five and six). Given certain modifications[43], the hazard anticipation test for child bicyclists, presented in this dissertation, can be used as an effective tool to measure and evaluate hazard anticipation skills in child bicyclists prior to a training intervention. For example, a useable and attracting hazard anticipation test that measures response rate and response latencies can easily be provided on a CD-ROM or as an application for tablets. In cooperation with game developers, a game can be created with an avatar to guide the participant and provide instructions or feedback. Such a program might be used in classrooms or at home to evaluate children's hazard anticipation skills.

Furthermore, also the hazard anticipation training for young bicyclists was found to provide an effective and promising tool for extending children's traffic related experience. Although the intervention presented in this dissertation provides a solid basis for future research that should aim to enhance child bicyclists' hazard anticipation, the current training program is not yet suitable for mass-distribution. The intervention requires the addition of video clips with correct feedback and instructions in order to improve children's visual search strategies and situation awareness as well. As was mentioned above, the development of a learning game for PC or tablet, might offer opportunities for traffic education (see 5.3. Future research). On the other hand, such a training program can also be used classically. We suggest that such training interventions start in the first year of primary school since traffic education can be considered a lifelong learning process and should be reinforced consistently. Only when hazard anticipation becomes automated due to deliberate and extensive practice, children will learn to "what to look at" and create an understanding of the situation.

It should be noted, however, that hazard anticipation alone can not guarantee safe traffic behaviour. The use of video clips offers a novel method for traffic education in school. Although training programs should include real-life sessions as well, the use of video clips offers the opportunity to make children experience dangerous traffic situations, how to anticipate, and how to react on these situations without endangering them. In addition, using video clips is less time consuming and requires less organisation compared to planning an excursion.

6.2.2.4. Integrated training

Despite our effort to create the most realistic training intervention within our possibilities, it appeared that the intervention did not elicit improved visual search strategies in child bicyclists. Children remained to operate from a more idiosyncratic perspective and reacted mainly when the hazard became visible. More ecological valid and practical programs to consolidate the transfer of the acquired motor skills, knowledge and hazard anticipation skills to real-life situations must therefore be an essential part of each bicycle education

[43] Some of the video clips in the hazard anticipation test lack the sensitivity to differentiate between children and adults. The addition of qualitative clips to improve the discriminative power of the hazard anticipation test should be considered. Furthermore, it is also essential to validate the current hazard anticipation test and training.

program. For example, an on-road training course under parent/teacher supervision in which hazardous situations are discussed and correct behaviour is discussed classically could be useful (Foot et al., 2006). Teachers or parents could take the children to similar places as in the hazard anticipation training to strengthen the link between classroom education and real-life. Especially since it was demonstrated that young children's ability to transfer and apply their extended knowledge to improved behaviour is poor (Ampofo-Boateng and Thomson, 1991; Zeedyk et al., 2002). An alternative example in Flanders is presented by the Flemish Institute for Traffic Engineering or *"Vlaamse Stichting Verkeerskunde"*. To acquire a certificate which indicates a child is able to bicycle independently and safely through traffic, they have to perform a bicycle exam in the sixth grade. This exam consists of several on-road skills such as cornering, making a left turn or providing priority. Furthermore, this exam is carried out in real traffic in close proximity of the school with which neighbourhood the children are familiar with. Extending this exam with hazard anticipation training could result in a quite complete traffic education program. Accordingly, we plea for more hours of traffic education in schools combining the four elements we described in the previous part.

6.3. Future research

6.3.1. Virtual reality

Regarding the hazard anticipation test in the current dissertation, a variety of videoed dangerous traffic situations were used. Although it was demonstrated that visual behaviour in the lab might provide useful information with respect to visual behaviour in real-life (paper three), several methodological limitations should be taken into account (described in Part 3. Methodological considerations). To increase ecological validity in laboratory studies, future studies therefore might want to consider a virtual reality environment which offers the possibility to synchronize the bicyclists' behaviour with the video stimuli. At the University of Iowa, USA, such a high fidelity real-time bicycle simulator was constructed. This simulator consists of a mounted bicycle on a stationary frame. The bicycle is positioned between three 3m wide × 2.5m high screens forming a three-walled room. Two projectors provide participants with 270° non-stereoscopic visual imagery while four speakers provide traffic sounds. The pedals, handlebars and handbrakes are all functional and a friction-drive flywheel is connected to the rear wheel taking ground resistance, wind resistance, mass and inertia into consideration. Steering angle and wheel speed are combined with terrain information to ensure a realistic trajectory through the immersive virtual environment (Babu et al., 2011; Chihak et al., 2010; Grechkin et al., 2013; Plumert et al., 2011, 2007; Plumert and Kearney, 2014; Stevens et al., 2013).

Figure 23. Picture from the bicycle simulator at the University of Iowa. Visual angles are correct from the rider's viewpoint (Nikolas et al., 2016).

6.3.2. Valorisation

After some modifications, the current hazard anticipation test and hazard anticipation training might provide valuable tools for evaluating training hazard anticipation in young bicyclists. Future research might aim to develop a (1) "PC-based/tablet-based and stand-alone" situation awareness test and (2) a PC-based/tablet-based learning game (Figure 24) to improve situation awareness and hazard anticipation in children. At the university of Helsinki in Finland for example, Sahlberg and colleagues (2015) developed a learning game for improving situation awareness in child bicyclists. The learning game consisted of 40 video clips in which the participants were required to point out the targets where/from where a hazard might occur by touching on the touchscreen. When a target was hit, a green circle appeared around the target and a sound was played. When the participants missed a target, the video stopped and a red circle around the target appeared together with warning sound was played. When they hit an area where there was no target, a smaller circle appeared. The training of Sahlberg only took 20 minutes. In line with the results from our hazard anticipation training study (paper seven), the learning game resulted in improved reaction times and situation awareness in children who received the training suggesting that hazard perception does not only depend on maturity-related factors but can be stimulated with qualitative traffic education. Unfortunately, only response rate and reaction times were reported but eye movements were not, no distinction was made between the types of hazardous events (covert and overt hazards), and also the control group (adults) increased its response rate and reaction times to the hazards. Furthermore, no feedback was given to the children regarding the dangerous situations included in the learning game. A future project might therefore aim to construct a similar but more expanded learning game in which children receive expert feedback regarding the occurring situations.

Figure 24. Two screenshots from the learning game for situation awareness in child-bicyclists of Sahlberg et al. (2015). Picture a) presents a screenshot in which the participant has hit a target whereas picture b) represents a screenshot in which the participant has missed a target .

Schwebel and colleagues (2016a) on the other hand constructed a mobile virtual pedestrian environment to teach child-pedestrians about road safety. A total number of 6 training sessions were provided with a duration of 15 minutes/session. After an intense training course of one week, the system could be moved to another location. The virtual training was effective to improve processing speed and decision-making about the safety of gaps (Figure 25).

Figure 25. Picture of the mobile virtual pedestrian environment (Schwebel et al., 2016a)

6.3.3. Auditory perception

Given that auditory perception skills are imperative for safe traffic participation too and child pedestrians are less adept at making approach decisions, position determinations and evaluate speed and direction of approach of oncoming vehicles, future research in hazard perception should measure auditory perception as well. Particularly in bicyclists as they, above all, rely on auditory information. Furthermore, training interventions aiming to improve child bicyclists' hazard anticipation should incorporate auditory traffic perception in the intervention (Barton et al., 2013). Future research might also investigate the impact of electric cars on child bicyclists' hazard perception skills. Stelling-Konczak et al. (2016) reported recently that adult bicyclists have more difficulties detecting, localizing, and determining the direction of approaching/receding electric vehicles compared to conventional vehicles. As child bicyclist have less experience with traffic and electric cars, accident risk might increase. Future hazard perception interventions should therefore pay attention to the potential danger of electric cars.

6.3.4. Target populations

Future (longitudinal) research might consider to include participants with different levels of experience within age groups in order to strengthen the relationship between experience and hazard perception. Objectively measuring baseline cycling experience and the integration of experienced and inexperienced adults could improve our understanding of the effect of experience. Although age has been reported as a risk factor, little is known of *why*. Furthermore, another risk factor for bicycle injuries is gender (Barton, 2006). Boys are reported to display more risky behaviour when cycling around a traffic playschool while girls missed more traffic related signals (Briem et al. 2004). In addition, O'Neal et al. (2016) reported that girls were more cautious when crossing the roads but waited longer before crossing resulting in more missed opportunities (Stevens et al., 2013). It can therefore be assumed that differences between boys and girls are likely to occur.

As this thesis focused on 'healthy' child bicyclists in general, future research should investigate the impact of children with neurodevelopmental disorders, temperamental control disorders, visual or auditory impairments on hazard perception skills. Youth with neurodevelopmental disorders such as Attention-deficit hyperactivity disorder (ADHD) are at high risk for unintentional injury. Nikolas et al., (2016) demonstrated that children with ADHD have more difficulties with modulating their behaviour in relation to changing environments, experience more close calls when crossing the road and demonstrate poorer timing entering traffic when crossing due to difficulties with planning and regulating perceptual-motor actions. Examining hazard anticipation in such target groups is therefore of particular interest in order to provide children with neurodevelopmental disorders with effective means to enhance their road crossing skills and bicycle behaviour. Similarly, to children with ADHD, O'Neal et al. (2016) suggested that also children suffering from overweight or obesity display less proficient road crossing skills compared to normal weighted peers due to deficits in executive functioning such as impulsivity, disinhibition or selective attention (Chaddock et al., 2011). Overweight children had more collision, waited less before crossing and have a smaller temporal buffer between themselves and the approaching car. Since paper one demonstrated that children with high BMI have poorer bicycle skills and Gentier et al. (2013) reported overweight children to have qualitative poor fine and gross motor skills arriving from restricted processing and integration of sensory information. Describing the hazard anticipation skills in overweight children might therefore be on interest in future research. In addition, Ducheyne et al. (2013b) demonstrated that children with a lower social economic status (SES) perform worse on the bicycling skills test. Future hazard perception studies should therefore investigate whether children with low SES, perform worse compared to children with higher SES.

At last, future research should investigate the impact of visual or auditory impairments on hazard perception in child bicyclists. It can be suggested that are at greater risk for being involved in an accident. Children with auditory processing disorders (APD), for example, are suggested to have difficulties with general auditory processing, working memory, executive attention, processing speed and alerting attention (De Wit et al., 2015).

6.3.5. How much practice is needed?

Lastly, child bicyclists were shown to improve their hazard anticipation skills after a brief intervention training. Similar to our intervention, Thomson and colleagues (2005) presented child pedestrians with four sessions of 30 to 40 minutes, Tolmie and colleagues presented children with four sessions of 25 to 30 minutes and Schwebel et al. (2016a) used an intervention consisting of six session of 15 minutes. Although children improved their efficiency and skill in all cases, it remains unknown how much practice is needed to reach adult levels which offers opportunities for future research. Since learning how to deal with traffic can be considered a lifelong learning process, and traffic education in childhood forms the foundation for traffic knowledge and skills in adulthood, we suggest that schools increase the amount of qualitative traffic education as suggested in section 5.2.2. Education. Longitudinal future research should therefore focus on the effect of training and experience on accident involvement and long-term improvements in hazard perception and bicycling skills. In addition, bicycling is considered the joint function of motor and perceptual bicycling skills and strongly dependent on age (Briem et al., 2004). Based on the findings of the current research project it can be stated that the younger a child learns to ride his/her bicycle, the better his/her motor bicycle skills are. Hazard anticipation skills in child bicyclists, on the other hand, were less developed compared to adult bicyclists and only slightly improved by training. It can be suggested that developmental related psychological aspects, such as the ability of children to put themselves in the place of other traffic participants (theory of mind), limit child bicyclists to fathom covert hazards. Given that the current research was cross-sectional, longitudinal research should further determine if these developmental aspects are mainly influenced by age or experience in order to evaluate whether traffic it is better to start traffic participation at older ages.

6.3.6. Mental fatigue

Mental fatigue refers to a psychobiological state due to sustained periods of demanding cognitive activity. This results in a feeling of tiredness and has a negative impact on the ability to maintain attention, decision making, identify and respond to meaningful cues in the environment (Boksem and Tops, 2008; Smith et al., 2016). Given that children spend a whole day in class, paying attention to teachers, this might induce mental fatigue. Since research in everyday activities (Hockey et al., 2000), handball (Laborde and Raab, 2013), or soccer (Smith et al., 2016) have demonstrated that decision-making skills in mentally fatigued participants were impaired, future research might aim to examine the effect of mental fatigue on hazard anticipation in children after a long day of school.

References

't Hart, B.M., Vockeroth, J., Schumann, F., Bartl, K., Schneider, E., König, P., Einhäuser, W., 2009. Gaze allocation in natural stimuli: Comparing free exploration to head-fixed viewing conditions. Vis. cogn. 17, 1132–1158.

Açik, A., Sarwary, A., Schultze-Kraft, R., Onat, S., König, P., 2010. Developmental changes in natural viewing behavior: Bottomup and top-down differences between children, young adults and older adults. Front. Psychol. 1, 1–14.

Adolphe, R.M., Vickers, J.N., Laplante, G., 1997. The effects of training visual attention on gaze behaviour and accuracy: A pilot study. Int. J. Sport. Vis. 4, 28–33.

Ahnert, J., 2005. Motorische Entwicklung vom Vorschul- bis ins frühe Erwachsenenalter - Einflussfaktoren und Prognostizierbarkeit [Motor development from the preschool period until early adulthood: Moderating factors and predictability]. Unpublished doctoral thesis, Universität Würzburg.

Alberti, C.F., Gamberini, L., Spagnolli, A., Varotto, D., Semenzato, L., 2012. Using an eye-tracker to assess the effectiveness of a three-dimensional riding simulator in increasing hazard perception. Cyberpsychol. Behav. Soc. Netw. 15, 274–6.

Altmann, G.T.M., Kamide, Y., 2007. The real-time mediation of visual attention by language and world knowledge: Linking anticipatory (and other) eye movements to linguistic processing. J. Mem. Lang. 57, 502–518.

Ampofo-Boateng, K., Thomson, J.A., 1991. Children's perception of safety and danger on the road. Br. J. Psychol. 82, 487–505.

Angelaki, D.E., Hess, B.J.M., 2005. Self-motion-induced eye movements: effects on visual acuity and navigation. Nat. Rev. Neurosci. 6, 966–76.

Aring, E., Grönlund, M.A., Hellström, A., Ygge, J., 2007. Visual fixation development in children. Graefes Arch. Clin. Exp. Ophthalmol. 245, 1659–65.

Armstrong, K.M., Fitzgerald, J.K., Moore, T., 2006. Changes in Visual Receptive Fields with Microstimulation of Frontal Cortex. Neuron 50, 791–798.

Arnberg, P., Ohlson, E., Westerberg, W., Oström, C., 1978. The ability of preschool- and school children to manoeuvre their bicycles. Linköping, Sweden.

Assaiante, C., 2011. Action and representation of action during childhood and adolescence: a functional approach. Neurophysiol. Clin. 42, 43–51.

Authié, C.N., Mestre, D.R., 2012. Path curvature discrimination: dependence on gaze direction and optical flow speed. PLoS One 7, e31479.

Babu, S. V., Grechkin, T.Y., Chihak, B., Ziemer, C., Kearney, J.K., Cremer, J.F., Plumert, J.M., 2011. An immersive virtual peer for studying social influences on child cyclists' road-crossing behavior. IEEE Trans. Vis. Comput. Graph. 17, 14–25.

Baldwin, C.L., 2012. Auditory Cognition and Human Performance: Research and Applications. CRC Press - Taylor & Francis Group, Boca Raton, FL.

Ballard, D.H., Hayhoe, M.M., 2010. Modelling the role of task in the control of gaze. Vis. cogn. 17, 1185–1204.

Bao, S., Boyle, L.N., 2009. Age-related differences in visual scanning at median-divided highway intersections in rural areas. Accid. Anal. Prev. 41, 146–52.

Bardy, B.G., Laurent, M., 1989. Use of peripheral vision in the decision to brake. Percept. Mot. Skills 69, 163–166.

Bardy, B.G., Warren W. H., J., Kay, B.A., 1973. The role of central and peripheral vision in postural control during walking. Percept. Organ. 61, 213–253.

Barnett, L.M., van Beurden, E., Morgan, P.J., Brooks, L.O., Beard, J.R., 2009. Childhood motor skill proficiency as a predictor of adolescent physical activity. J. Adolesc. Health 44, 252–9.

Barton, B.K., 2006. Integrating selective attention into developmental pedestrian safety research. Can. Psychol. 47, 203–210.

Barton, B.K., Lew, R., Kovesdi, C., Cottrell, N.D., Ulrich, T., 2013. Developmental differences in auditory detection and localization of approaching vehicles. Accid. Anal. Prev. 53, 1–8.

Barton, B.K., Ulrich, T.A., Lew, R., 2012. Auditory detection and localization of approaching vehicles. Accid. Anal. Prev. 49, 347–353.

Berard, J.R., Vallis, L.A., 2006. Characteristics of single and double obstacle avoidance strategies: a comparison between adults and children. Exp. Brain Res. 175, 21–31.

Best, J.R., Miller, P.H., Jones, L.L., 2009. Executive Functions after Age 5: Changes and Correlates. Dev. Rev. 29, 180–200.

Bjorklund, D.F., Harnishfeger, K.K., 1990. The Resources Construct in Cognitive Development: Diverse Sources of Evidence and a Theory of inefficient Inhibition. Dev. Rev. 71, 48–71.

Boksem, M.A.S., Tops, M., 2008. Mental fatigue: costs and benefits. Brain Res. Rev. 59, 125–39.

Boothroyd, A., 1997. Auditory development of the hearing child. Scand. Audiol. 46, 9–16.

Bootsma, R.J., 1989. Accuracy of perceptual processes subserving different perception-action systems. Q. J. Exp. Psychol. A. 41, 489–500.

Borowsky, A., Oron-Gilad, T., Parmet, Y., 2009. Age and skill differences in classifying hazardous traffic scenes. Transp. Res. Part F Traffic Psychol. Behav. 12, 277–287.

Borowsky, A., Shinar, D., Oron-Gilad, T., 2010. Age, skill, and hazard perception in driving. Accid. Anal. Prev. 42, 1240–9.

Branca, F., Nikogosian, H., Lobstein, T., 2007. The Challenge of Obesity in the WHO European Region and the Strategies for Response, World Health Organization Reg. Off. Eur. Copenhagen.

Briem, V., Radeborg, K., Salo, I., Bengtsson, H., 2004. Developmental Aspects of Children's Behavior and Safety While Cycling. J. Pediatr. Psychol. 29, 369–377.

Bucci, M.P., Seassau, M., Pia, M., Magali, B., 2012. Saccadic eye movements in children: a developmental study. Exp. Brain Res. 222, 21–30.

Burton, A.W., Miller, D., 1998. Movement skill assessment. Human Kinetics, Champaign, IL.

Button, C., Croft, J., 2009. Visual Search Strategies of Cricket Batsmen. Auckland, New Zealand.

Cardon, G.M., Maes L, R.D., Haerens, L.L., De Bourdeaudhuij I, M.M., 2012. Bicycling to school during the transition from childhood into adolescence: a six-year longitudinal study. Pediatr. Exerc. Sci. 24, 369–83.

Carpentier, A., Nuyttens, N., 2013. Jaarrapport Verkeersveiligheid 2011: Analyse van de verkeersveiligheidsindicatoren in Vlaanderen tot en met 2011 [Annual Report of road safety 2011: Analysis of road safety indicators in Flanders until 2011]. Brussel.

Casajus, J.A., Leiva, M.T., Villarroya, A., Legaz, A., Moreno, L.A., 2007. Physical Performance and School Physical Education in Overweight Spanish Children. Ann. Nutr. Metab. 51, 288–296.

Chaddock, L., Pontifex, M.B., Hillman, C.H., Kramer, A.F., 2011. A Review of the Relation of Aerobic Fitness and Physical Activity to Brain Structure and Function in Children. J. Int. Neuropsychol. Soc. 17, 975–985.

Chapman, P., Underwood, G., Roberts, K., 2002. Visual search patterns in trained and untrained novice drivers. Transp. Res. Part F Traffic Psychol. Behav. 5, 157–167.

Chapman, P.R., Underwood, G., 1998. Visual search of driving situations: danger and experience. Perception 27, 951–64.

Chattington, M., Wilson, M., Ashford, D., Marple-Horvat, D.E., 2007. Eye-steering coordination in natural driving. Exp. Brain Res. 180, 1–14.

Chihak, B.J., Grechkin, T.Y., Kearney, J.K., Cremer, J.F., Plumert, J.M., 2014. How children and adults learn to intercept moving gaps. J. Exp. Child Psychol. 122, 134–152.

Chihak, B.J., Plumert, J.M., Ziemer, C.J., Babu, S., Grechkin, T., Cremer, J.F., Kearney, J.K., 2010. Synchronizing self and object movement: how child and adult cyclists intercept moving gaps in a virtual environment. J. Exp. Psychol. Hum. Percept. Perform. 36, 1535–52.

Chillón, P., Ortega, F.B., Ruiz, J.R., Evenson, K.R., Labayen, I., Martínez-Vizcaino, V., Hurtig-Wennlöf, A., Veidebaum, T., Sjöström, M., 2012. Bicycling to school is associated with improvements in physical fitness over a 6-year follow-up period in Swedish children. Prev. Med. (Baltim). 55, 108–12.

Cinelli, M., Warren, W.H., 2012. Do walkers follow their heads? Investigating the role of head rotation in locomotor control. Exp. Brain Res. 219, 175–90.

Clark, J.E., Metcalfe, J.S., 2002. The mountain of motor development: A metaphor, in: Clark, J.E., Humphrey, J. (Eds.), Motor Development: Research and Reviews. NASPE Publications, Reston, VA, pp. 163–190.

Clarke, D.D., Ward, P., Truman, W., 2005. Voluntary risk taking and skill deficits in young driver accidents in the UK. Accid. Anal. Prev. 37, 523–529.

Cole, T.J., Bellizzi, M.C., Flegal, K.M., Dietz, W.H., 2000. Establishing a standard definition for child overweight and obesity worldwide: international survey. Br. J. Sports Med. 320, 1–6.

Collewijn, H., Martins, A.J., Steinman, R.M., 1981. Natural retinal image motion: origin and change. Ann. N. Y. Acad. Sci. 374, 312–29.

Colwell, J., Culverwell, A., 2002. An examination of the relationship between cycle training, cycle accidents, attitudes and cycling behaviour among children. Ergonomics 45, 640–8.

Connelly, M.L., Conaglen, H.M.M., Parsonson, B.S.S., Isler, R.B.B., Connelly, M.L.L., Conaglen, H.M.M., Parsonson, B.S.S., Isler, R.B.B., Connelly, M.L.L., Conaglen, H.M.M., Parsonson, B.S.S., Isler, R.B.B., 1998. Child Pedestrians' Crossing Gap Thresholds. Accid. Anal. Prev. 30, 443–53.

Cools, W., Martelaer, K. De, Samaey, C., Andries, C., 2009. Movement skill assessment of typically developing preschool children: a review of seven movement skill assessment tools. J. Sports Sci. Med. 8, 154–68.

Cooper, A.R., Andersen, L.B., Wedderkopp, N., Page, A.S., Froberg, K., 2005. Physical activity levels of children who walk, cycle, or are driven to school. Am. J. Prev. Med. 29, 179–84.

Cooper, A.R., Wedderkopp, N., Wang, H., Andersen, L.B., Froberg, K., Page, A.S., 2006. Active travel to school and cardiovascular fitness in Danish children and adolescents. Med. Sci. Sports Exerc. 38, 1724–31.

Corden, T.E., Tripathy, N., Pierce, S.E., Katcher, M.L., 2005. The role of the health care professional in bicycle safety. Winsconsin Med. J. 104, 35–8.

Crundall, D., Andrews, B., van Loon, E., Chapman, P., 2010. Commentary training improves responsiveness to hazards in a driving simulator. Accid. Anal. Prev. 42, 2117–24.

Crundall, D., Chapman, P., Phelps, N., Underwood, G., 2003. Eye movements and hazard perception in police pursuit and emergency response driving. J. Exp. Psychol. Appl. 9, 163–74.

Crundall, D., Chapman, P., Trawley, S., Collins, L., van Loon, E., Andrews, B., Underwood, G., 2012. Some hazards are more attractive than others: drivers of varying experience respond differently to different types of hazard. Accid. Anal. Prev. 45, 600–9.

Crundall, D., van Loon, E., Stedmon, A.W., Crundall, E., 2013. Motorcycling experience and hazard perception. Accid. Anal. Prev. 50, 456–64.

Crundall, D.E., Underwood, G., 1998. Effects of experience and processing demands on visual information acquisition in drivers. Ergonomics 41, 448–458.

D'Hondt, E., Deforche, B., De Bourdeaudhuij, I., Lenoir, M., 2009. Relationship between motor skill and body mass index in 5- to 10-year-old children. Adapt. Phys. Activ. Q. 26, 21–37.

D'Hondt, E., Deforche, B., Gentier, I., De Bourdeaudhuij, I., Vaeyens, R., Philippaerts, R., Lenoir, M., 2012. A longitudinal analysis of gross motor coordination in overweight and obese children versus normal-weight peers. Int. J. Obes. 37, 1–7.

D'Hondt, E., Deforche, B., Vaeyens, R., Vandorpe, B., Vandendriessche, J., Pion, J., Philippaerts, R., Bourdeaudhuij, I., Lenoir, M., 2011. Gross motor coordination in relation to weight status and age in 5- to 12-year-old boys and girls: A cross-sectional study. Int. J. Pediatr. Obes. 32, 556–564.

DaCota, 2013. Children in road traffic. Brussels.

Davison, K.K., Werder, J.L., Lawson, C.T., 2008. Children's Active Commuting to School: Current Knowledge and Future Directions. Public Heal. Res. Pract. Policy 5, 1–11.

Day, M., 1975. Developmental trends in visual scanning. Adv. Child Dev. Behav. 10, 153–193.

de Geus, B., Vandenbulcke, G., Int Panis, L., Thomas, I., Degraeuwe, B., Cumps, E., Aertsens, J., Torfs, R., Meeusen, R., 2012. A prospective cohort study on minor accidents involving commuter cyclists in Belgium. Accid. Anal. Prev. 45, 683–93.

de Hartog, J.J., Boogaard, H., Nijland, H., Hoek, G., 2010. Do the health benefits of cycling outweigh the risks? Environ. Health Perspect. 118, 1109–16.

de Jong, P., 2012. The health impact of mandatory bicycle helmet laws. Risk Anal. 32, 782–90.

De Wit, E., Visser-Bochane, M.I., Steenbergen, B., van Dijk, P., van der Schans, C.P., Luinge, M.R., 2015. Characteristics of Auditory Processing Disorders: A Systematic Review. J. Speech, Lang. Hear. Res. 59, 384–413.

Deery, H. a, 1999. Hazard and Risk Perception among Young Novice Drivers. J. Safety Res. 30, 225–236.

DEKRA Automobil GmbH, 2011. Road safety report 2011 - pedestrians and cyclists. Stuttgart.

Dicks, M., Button, C., Davids, K., 2010. Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. Atten. Percept. Psychophys. 72, 706–720.

Donges, E., 1978. A Two-Level Model of Driver Steering Behavior 2.

Ducheyne, F., 2013. Cycling to school: correlates, cycling skills and effectiveness of cycle training on cycling skills and levels of cycling to school. Ghent University.

Ducheyne, F., De Bourdeaudhuij, I., Lenoir, M., Cardon, G., 2013a. Does a cycle training course improve cycling skills in children? Accid. Anal. Prev. 59, 38–45.

Ducheyne, F., De Bourdeaudhuij, I., Lenoir, M., Cardon, G., 2012. Test-retest reliability and validity of a child and parental questionnaire on specific determinants of cycling to school. Pediatr. Exerc. Sci. 24, 289–311.

Ducheyne, F., De Bourdeaudhuij, I., Lenoir, M., Spittaels, H., Cardon, G., 2013b. Children's cycling skills: Development of a test and determination of individual and environmental correlates. Accid. Anal. Prev. 50, 688–97.

Duchowski, A.T., 2007. Eye Tracking Methodology: Theory and Practice, Second. ed. Springer, London.

Dunbar, G., Hill, R., Lewis, V., 2001. Children's attentional skills and road behavior. J. Exp. Psychol. Appl. 7, 227–234.

Dunbar, G., Lewis, V., Hill, R., 1999. Control processes and road-crossing skills. Psychologist 12, 398–399.

Egan, C.D., 2012. Children's gaze behaviour at real-world and simulated road crossings. Edinburgh Napier University.

Ekstrom, L.B., Roelfsema, P.R., Arsenault, J.T., Vanduffel, W., 2008. Bottom-Up Dependent Gating of Frontal Signals in Early Visual Cortex 321, 414–417.

Elvik, R., 2011. Publication bias and time-trend bias in meta-analysis of bicycle helmet efficacy: A re-analysis of Attewell, Glase and McFadden, 2001. Accid. Anal. Prev. 43, 1245–1251.

Elvik, R., 2010. Why some road safety problems are more difficult to solve than others. Accid. Anal. Prev. 42, 1089–1096.

Endsley, M.R., 1995. Towards a theory of situation awareness in dynamic systems. Hum. Factors 37, 32–64.

Enns, J.T., Cameron, S., 1987. Selective attention in young children: The relations between visual search, filtering, and priming. J. Exp. Child Psychol. 44, 38–63.

European Commission, 2015. Traffic Safety Basic Facts on Cyclists 2015.

European Communities, 2006. Better health for all: Promoting active lifestyles and improved nutrition. Brussels.

Fajen, B.R., Warren, W.H., 2003. Behavioral dynamics of steering, obstable avoidance, and route selection. J. Exp. Psychol. Hum. Percept. Perform. 29, 343–362.

Falkmer, T., Gregersen, N.P., Torbjörn, F., 2005. A Comparison of Eye Movement Behavior of Inexperienced and Experienced Drivers in Real Traffice Environments. Optom. Vis. Sci. 82, 732–739.

Fietsberaad, 2013. Feiten over de elektrische fiets. Fietsberaadpublicatie 24. Utrecht.

Fietsersbond, 2014. Fietsroutes in Vlaanderen: Goede Praktijkvoorbeelden [Bicycle Routes in Flanders: Practical Examples]. Brussels.

Fietsersbond Vzw, 2006. Fietsen is (g)een kinderspel. Spelenderwijs beter leren fietsen [Bicycling is not a childgame. Learning to bicycle], 2nd ed. Drukkerij De Bie, Berchem.

Foot, H., Thomson, J.A., Tolmie, A.K., Whelan, K.M., Morrison, S., Sarvary, P., 2006. Children's understanding of drivers' intentions. Br. J. Dev. Psychol. 24, 681–700.

Foot, H.C., Tolmie, A., Thomson, J., Mclaren, B., Kirstie, W.W., Whelan, K., 1999. Recognising the hazards. Psychologist 12, 400–402.

Foulsham, T., Walker, E., Kingstone, A., 2011. The where, what and when of gaze allocation in the lab and the natural environment. Vision Res. 51, 1920–31.

Franchak, J.M., Adolph, K.E., 2010. Visually guided navigation: head-mounted eye-tracking of natural locomotion in children and adults. Vision Res. 50, 2766–74.

Friedburg, C., Allen, C.P., Mason, P.J., Lamb, T.D., 2004. Contribution of cone photoreceptors and post-receptoral mechanisms to the human photopic electroretinogram. J. Physiol. 556, 819–34.

Fuller, R., 2007. Driver Training and Assessment : Implications of the Task-Difficulty Homeostasis Model, in: Dorn, L. (Ed.), Driver Behaviour and Training Vol. 3. Ashgate, Dublin, pp. 337–367.

Fuller, R., 2005. Towards a general theory of driver behaviour. Accid. Anal. Prev. 37, 461–72.

Furneaux, S., Land, M.F., 1999. The effects of skill on the eye-hand span during musical sight-reading. Proc. Biol. Sci. 266, 2435–2440.

Gabbard, C., 2008. Lifelong motor development, 5th ed. CA: Pearson Benjamin Cummings, San Fransico.

Gallahue, D.L., Ozmun, J.C., 2005. Understanding Motor Development: Infants, Children, Adolescents, Adults. McGraw-Hill.

Gårder, P., Leden, L., Pulkkinen, U., 1998. Measuring the Safety Effect of Raised Bicycle Crossings Using a New Research Methodology. Transp. Res. Rec. 1636, 64–70.

Gentier, I., Augustijn, M., Deforche, B., Tanghe, A., De Bourdeaudhuij, I., Lenoir, M., D'Hondt, E., 2013. A comparative study of performance in simple and choice reaction time tasks between obese and healthy-weight children. Res. Dev. Disabil. 34, 2635–2641.

Gentier, I., D'Hondt, E., Shultz, S., Deforche, B., Augustijn, M., Hoorne, S., Verlaecke, K., De Bourdeaudhuij, I., Lenoir, M., 2013. Fine and gross motor skills differ between healthy-weight and obese children. Res. Dev. Disabil. 34, 4043–4051.

Ghekiere, A., Deforche, B., Mertens, L., Bourdeaudhuij, I. De, 2015. Creating Cycling-Friendly Environments for Children : Which Micro-Scale Factors Are Most Important ? An Experimental Study Using Manipulated Photographs Creating Cycling-Friendly Environments for Children : Which Micro-Scale Factors Are Most Important ? A. PLoS One 10, e0143302.

Gibson, J.J., 1958. Visually controlled locomotion and visual orientation in animals. Br. J. Psychol. 49, 182–194.

Gill, S. V., Hung, Y.-C., 2014. Effects of overweight and obese body mass on motor planning and motor skills during obstacle crossing in children. Res. Dev. Disabil. 35, 46–53.

Godley, S.T., Triggs, T.J., Fildes, B.N., 2004. Perceptual lane width, wide perceptual road centre markings and driving speeds. Ergonomics 47, 237–56.

Goodale, M.A., Milner, A.D., 1992. Separate visual pathways for perception and action. TINS 15, 20–25.

Goodway, J.D., Famelia, R., Bakhtiar, S., 2014. Future Directions in Physical Education & Sport: Developing Fundamental Motor Competence in the Early Years Is Paramount to Lifelong Physical Activity. Asian Soc. Sci. 10, 44–55.

Google, 2016. Google Self-Driving Car Project Monthly Report June 2016.

Graf, C., Koch, B., Kretschmann-Kandel, E., Falkowski, G., Christ, H., Coburger, S., Lehmacher, W., Bjarnason-Wehrens, B., Platen, P., Tokarski, W., Predel, H.G., Dordel, S., 2004. Correlation between BMI, leisure habits and motor abilities in childhood (CHILT-project). Int. J. Obes. Relat. Metab. Disord. 28, 22–6.

Grechkin, T.Y., Chihak, B.J., Cremer, J.F., Kearney, J.K., Plumert, J.M., 2013. Perceiving and acting on complex affordances: How children and adults bicycle across two lanes of opposing traffic. J. Exp. Psychol. Hum. Percept. Perform. 39, 23–36.

Gregersen, N.P., Bjurulf, P., 1996. Young novice drivers: Towards a model of their accident involvement. Accid. Anal. Prev. 28, 229–241.

Gugerty, L., 2011. Situation Awareness in Driving, in: Fisher, D.L., Rizzo, M., Caird, J.K., Lee, J.D. (Eds.), Handbook of Driving Simulation for Engineering, Medicine, and Psychology. CRC Press, pp. 265–272.

Hale, S., 1990. A global developmental trend in cognitive processing speed. Child Dev. 61, 653–663.

Hansen, K.S., Eide, G.E., Omenaas, E., Engesaeter, L.B., Viste, A., Engesæter, L.B., Viste, A., 2005. Bicycle-related injuries among young children related to age at debut of cycling. Accid. Anal. Prev. 37, 71–5.

Harris, M.A., Reynolds, C.C.O., Winters, M., Cripton, P.A., Shen, H., Chipman, M.L., Cusimano, M.D., Babul, S., Brubacher, J.R., Friedman, S.M., Hunte, G., Monro, M., Vernich, L., Teschke, K., 2013. Comparing the effects of infrastructure on bicycling injury at intersections and non-intersections using a case-crossover design. Inj. Prev. 19, 303–310.

Hatzitaki, V., Zisi, V., Kollias, I., Kioumourtzolgou, E., 2002. Perceptual-motor contributions to static and dynamic balance control in children. J. Mot. Behav. 34, 161–170.

Hayhoe, M., Ballard, D., 2005. Eye movements in natural behavior. Trends Cogn. Sci. 9, 188–94.

Hayhoe, M.M., Mruczek, R., Pelz, J.B., 2003. Visual memory and motor planning in a natural task 49–63.

Haywood, K.M., Getchell, N., 2009. Life Span Motor Development, Fifth. ed. Human Kinetics, Champaign, IL.

Heesch, K.C., Garrard, J., Sahlqvist, S., 2011. Incidence, severity and correlates of bicycling injuries in a sample of cyclists in Queensland, Australia. Accid. Anal. Prev. 43, 2085–92.

Held, R., Hein, a, 1963. Movement-Produced Stimulation in the Development of Visually Guided Behavior. J. Comp. Physiol. Psychol. 56, 872–6.

Helo, A., Pannasch, S., Sirri, L., Rämä, P., 2014. The maturation of eye movement behavior: scene viewing characteristics in children and adults. Vision Res. 103, 83–91.

Helsen, P.W., Lavrysen, A., Pauwels, P.J., 2005. Integratie van Theorie en Praktijk in de Verkeersopvoeding Door School en Ouders: Een wetenschappelijke verantwoording bij het project [Integration of Theorie and Practice in Traffic Education by School and Parents: A Scientific Approach]. Leuven.

Henderson, J., 2003. Human gaze control during real-world scene perception. Trends Cogn. Sci. 7, 498–504.

Herlihy, D. V., 2006. Bicycle: The History, First. ed. Yale University Press, Taunton, Mass.

Heuer, H., 1996. Coordination, in: Heuer, H., Keele, S.W. (Eds.), Handbook of Perception and Action. Vol. 2 Motor Skills. Academic Press, London, pp. 121–180.

Hildreth, E.C., Beusmans, J.M., Boer, E.R., Royden, C.S., 2000. From vision to action: experiments and models of steering control during driving. J. Exp. Psychol. Hum. Percept. Perform. 26, 1106–32.

Hill, R., Lewis, V., Dunbar, G., 2000. Young children's concepts of danger. Br. J. Dev. Psychol. 18, 103–119.

Hockey, G.R.J., John Maule, a., Clough, P.J., Bdzola, L., 2000. Effects of negative mood states on risk in everyday decision making. Cogn. Emot. 14, 823–855.

Hollands, M. a, Marple-Horvat, D.E., 1996. Visually guided stepping under conditions of step cycle-related denial of visual information. Exp. Brain Res. 109, 343–356.

Holm, I., Tveter, A.T., Fredriksen, P.M., Vøllestad, N., 2009. A normative sample of gait and hopping on one leg parameters in children 7-12 years of age. Gait Posture 29, 317–321.

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., van de Weijer, J., 2011. Eye tracking: A Comprehensive Guide To Methods And Measures, first. ed. Oxford University Press.

Horrey, W.J., Wickens, C.D., Consalus, K.P., 2006. Modeling drivers' visual attention allocation while interacting with in-vehicle technologies. J. Exp. Psychol. Appl. 12, 67–78.

Horsley, M., Eliot, M., Knight, B.A., Reilly, R., 2014. Current Trend in Eye Tracking Research, First. ed, Igarss 2014. Springer London.

Hosking, S.G., Liu, C.C., Bayly, M., 2010. The visual search patterns and hazard responses of experienced and inexperienced motorcycle riders. Accid. Anal. Prev. 42, 196–202.

Huestegge, L., Skottke, E.-M., Anders, S., Müsseler, J., Debus, G., 2010. The development of hazard perception: Dissociation of visual orientation and hazard processing. Transp. Res. Part F Traffic Psychol. Behav. 13, 1–8.

Iivonen, S., Sääkslahti, A.K., Laukkanen, A., 2015. A review of studies using the Körperkoordinationstest für Kinder (KTK). Eur. J. Adapt. Phys. Act. 8, 18–36.

Irving, E.L., Steinbach, M.J., Lillakas, L., Babu, R.J., Hutchings, N., 2006. Horizontal saccade dynamics across the human life span. Investig. Ophthalmol. Vis. Sci. 47, 2478–2484.

Irving, E.L., Tajik-Parvinchi, D.J., Lillakas, L., González, E.G., Steinbach, M.J., 2009. Mixed pro and antisaccade performance in children and adults. Brain Res. 1255, 67–74.

Isler, R.B., Starkey, N.J., Williamson, A.R., 2009. Video-based road commentary training improves hazard perception of young drivers in a dual task. Accid. Anal. Prev. 41, 445–52.

Itti, L., Koch, C., 2000. A saliency-based search mechanism for overt and covert hifts of visual attention. Vision Res. 40, 1489–1506.

Jacobsen, P., 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. Inj. Prev. 9, 205–209.

Jacobsen, P.L., Racioppi, F., Rutter, H., 2009. Who owns the roads? How motorised traffic discourages walking and bicycling. Inj. Prev. 15, 369–373.

Janssens, D., Declercq, K., Wets, G., 2012. Onderzoek Verplaatsingsgedrag Vlaanderen [Reasearch Transportation Behaviour Flanders]. Hasselt.

Jovancevic, J., Sullivan, B., Hayhoe, M., 2006. Control of attention and gaze in complex environments. J. Vis. 6, 1431–1450.

Juhra, C., Wieskötter, B., Chu, K., Trost, L., Weiss, U., Messerschmidt, M., Malczyk, A., Heckwolf, M., Raschke, M., 2012. Bicycle accidents - Do we only see the tip of the iceberg?: A prospective multi-centre study in a large German city combining medical and police data. Injury 43, 2026–34.

Kandil, F.I., Rotter, A., Lappe, M., 2009. Driving is smoother and more stable when using the tangent point. J. Vis. 9, 1–11.

Karkhaneh, M., Rowe, B.H., Saunders, L.D., Voaklander, D.C., Hagel, B.E., 2013. Trends in head injuries associated with mandatory bicycle helmet legislation targeting children and adolescents. Accid. Anal. Prev. 59, 206–12.

Kelders, W.P. a, Kleinrensink, G.J., van der Geest, J.N., Feenstra, L., de Zeeuw, C.I., Frens, M. a, 2003. Compensatory increase of the cervico-ocular reflex with age in healthy humans. J. Physiol. 553, 311–7.

Kemeny, A., Panerai, F., 2003. Evaluating perception in driving simulation experiments. Trends Cogn. Sci. 7, 31–37.

Kiphard, E.J., Schilling, F., 2007. Körperkoordinationstest für Kinder. 2. Überarbeitete und ergängtze auflage [Body coordinations test for children. 2. Revised and supplemented edition]. Weinheim: Beltz Test GmbH.

Knudsen, E.I., 2007. Fundamental components of attention. Annu. Rev. Neurosci. 30, 57–78.

Konstantopoulos, P., Chapman, P., Crundall, D., 2012. Exploring the ability to identify visual search differences when observing drivers' eye movements. Transp. Res. Part F Traffic Psychol. Behav. 15, 378–386.

Konstantopoulos, P., Chapman, P., Crundall, D., 2010. Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving. Accid. Anal. Prev. 42, 827–34.

Kooijman, J.D.G., Schwab, A.L., Moore, J.K., 2009. Some Observations on Human Control of a Bicycle, in: Proceedings of the ASME 2009 International Design and Engineering Technical Conferences & Computers and Information in Engineering Conference. Asme, California, pp. 2021–2028.

Kooijman, J.D.G., Schwab, a. L., 2013. A review on bicycle and motorcycle rider control with a perspective on handling qualities. Veh. Syst. Dyn. 51, 1722–1764.

Kowler, E., 2011. Eye movements: the past 25 years. Vision Res. 51, 1457–83.

Kowler, E., 2007. The stability of Gaze and its Implications for Vision, in: Eye Movements: A Window on Mind and Brain. pp. 71–92.

Laborde, S., Raab, M., 2013. The Tale of Hearts and Reason: The Influence of Mood on Decision Making. J. Sport Exerc. Psychol. 35, 339–357.

Lachapelle, U., Noland, R.B., Von Hagen, L.A., 2013. Teaching children about bicycle safety: An evaluation of the New Jersey Bike School program. Accid. Anal. Prev. 52C, 237–249.

Lammar, P., 2005. Letsels, blootstelling en risicofactoren voor kinderen als zwakke weggebruiker (fietser of voetganger) [Injuries, Exposure, and Risk Factors in Children as Vulnerable Road User (Bicyclist or Pedestrian)]. Steunpunt Verkeersveiligheid, Hasselt.

Land, M.F., 2009. Vision, eye movements, and natural behavior. Vis. Neurosci. 26, 51–62.

Land, M.F., 2006. Eye movements and the control of actions in everyday life. Prog. Retin. Eye Res. 25, 296–324.

Land, M.F., 2004. The coordination of rotations of the eyes, head and trunk in saccadic turns produced in natural situations. Exp. Brain Res. 159, 151–60.

Land, M.F., 1999. Motion and vision: why animals move their eyes. J. Comp. Physiol. A. 185, 341–52.

Land, M.F., Horwood, J., 1995. which parts of the road guide steering. Nature 377, 339–340.

Land, M.F., Lee, D.N., 1994. Where we look when we steer. Nature 369, 742–744.

Land, M.F., Tatler, B.W., 2009. Looking and Acting: Vision and Eye Movements in Natural Behaviour, First Edit. ed. Oxford University Press, Oxford.

Langaas, T., Mon-Williams, M., P. Wann, J., Pascal, E., Thompson, C., 1998. Eye movements, prematurity and developmental co-ordination disorder. Vision Res. 38, 1817–1826.

Lappe, M., Bremmer, F., van den Berg, A.V., 1999. Perception of self-motion from visual flow. Trends Cogn. Sci. 3, 329–336.

Lappe, M., Hoffmann, K.-P., 2000. Optic flow and eye movements. Int. Rev. Neurobiol. 44, 29–47.

Lappe, M., Pekel, M., Hoffmann, K.P., 1998. Optokinetic eye movements elicited by radial optic flow in the macaque monkey. J. Neurophysiol. 79, 1461–80.

Laurent, M., Paul, P., Cavallo, V., 1988. How is the gait regulated when the head is traveling faster than the legs? J. Mot. Behav. 20, 301–316.

Leblanc, J.C., Huybers, S., 2004. Improving bicycle safety: The role of paediatricians and family physicians. Paediatr. Child Health 9, 315–318.

Lee, J.D., 2008. Fifty Years of Driving Safety Research. Hum. Factors J. Hum. Factors Ergon. Soc. 50, 521–528.

Lehtonen, E., Sahlberg, H., Rovamo, E., Summala, H., 2016. Learning game for training child bicyclists' situation awareness. Accid. Anal. Prev. 1–12.

Liu, C.C., Hosking, S.G., Lenné, M.G., 2009. Hazard perception abilities of experienced and novice motorcyclists: An interactive simulator experiment. Transp. Res. Part F Traffic Psychol. Behav. 12, 325–334.

Logan, S.W., Robinson, L.E., Wilson, A.E., Lucas, W.A., 2012. Getting the fundamentals of movement: a meta-analysis of the effectiveness of motor skill interventions in children. Child. Care. Health Dev. 38, 305–15.

Lopes, V.P., Stodden, D.F., Bianchi, M.M., Maia, J. a R., Rodrigues, L.P., 2012. Correlation between BMI and motor coordination in children. J. Sci. Med. Sport 15, 38–43.

Luna, B., Garver, K.E., Urban, T.A., Lazar, N.A., Sweeney, J.A., 2004. Maturation of cognitive processes from late childhood to adulthood. Child Dev. 75, 1357–1372.

Luna, B., Velanova, K., Geier, C.F., 2009. Development of eye-movement control. Brain Cogn. 68, 293–308.

Macarthur, C., Parkin, P.C., Sidky, M., Wallace, W., 1998. Evaluation of a bicycle skills training program for young children: a randomized controlled trial. Inj. Prev. 4, 116–21.

Magill, R.A., 2007. Motor learning and control, 8th ed. McGraw-Hill, New York, USA.

Mann, D.T.Y., Williams, M.A., Ward, P., Janelle, C.M., 2007. Perceptual-Cognitive Expertise in Sport: A Meta-

Analysis. J. Sport Exerc. Psychol. 29, 457–78.

Marigold, D.S., 2008. Role of peripheral visual cues in online visual guidance of locomotion. Exerc. Sport Sci. Rev. 36, 145–51.

Marigold, D.S., Patla, a E., 2007. Gaze fixation patterns for negotiating complex ground terrain. Neuroscience 144, 302–13.

Marigold, D.S., Weerdesteyn, V., Patla, A.E., Duysens, J., 2007. Keep looking ahead? Re-direction of visual fixation does not always occur during an unpredictable obstacle avoidance task. Exp. Brain Res. 176, 32–42.

Maring, W., van Schagen, I., 1990. Age dependence of attitudes and knowledge in cyclists. Accid. Anal. Prev. 22, 127–136.

Mars, F., 2008. Driving around bends with manipulated eye-steering coordination. J. Vis. 8, 1–11.

Martinez-Conde, S., Macknik, S.L., Troncoso, X.G., Dyar, T.A., 2006. Microsaccades counteract visual fading during fixation. Neuron 49, 297–305.

Matthews, C.E., Jurj, A.L., Shu, X.O., Li, H.L., Yang, G., Li, Q., Gao, Y.T., Zheng, W., 2007. Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese women. Am. J. Epidemiol. 165, 1343–1350.

Mckenna, F., Crick, J., 1997. Developments in hazard perception, Trl Report 297. Berkshire, UK.

McKnight, A.J., McKnight, A.S., 2003. Young Novice Drivers: Careless or Clueless? Accid. Anal. Prev. 35, 921–5.

McLaughlin, K.A., Glang, A., 2010. The effectiveness of a bicycle safety program for improving safety-related knowledge and behavior in young elementary students. J. Pediatr. Psychol. 35, 343–353.

Meir, A., Borowsky, A., Oron-Gilad, T., 2014. Formation and Evaluation of Act and Anticipate Hazard Perception Training (AAHPT) intervention for young novice drivers. Traffic Inj. Prev. 15, 172–80.

Meir, A., Oron-Gilad, T., Parmet, Y., 2015a. Can child-pedestrians' hazard perception skills be enhanced? Accid. Anal. Prev. 83, 101–110.

Meir, A., Oron-Gilad, T., Parmet, Y., 2015b. Are child-pedestrians able to identify hazardous traffic situations? Measuring their abilities in a virtual reality environment. Saf. Sci. 80, 33–40.

Meir, A., Parmet, Y., Oron-Gilad, T., 2013. Towards understanding child-pedestrians' hazard perception abilities in a mixed reality dynamic environment. Transp. Res. Part F Traffic Psychol. Behav. 20, 90–107.

Memmert, D., Simons, D.J., Grimme, T., 2009. The relationship between visual attention and expertise in sports. Psychol. Sport Exerc. 10, 146–151.

Meyer, S., Sagberg, F., Torquato, R., 2014. Traffic hazard perception among children. Transp. Res. Part F Traffic Psychol. Behav. 26, 190–198.

Milner, A.D., Goodale, M.A., 2008. Two visual systems re-viewed. Neuropsychologia 46, 774–85.

Milner, A.D., Goodale, M.A., 2005. The Visual Brain in Action, Second. ed. Oxford University Press, Oxford.

Møller, M., Hels, T., 2008. Cyclists' perception of risk in roundabouts. Accid. Anal. Prev. 40, 1055–1062.

Montagne, G., Bastin, J., Jacobs, D.M., 2008. What is visual anticipation and how much does it rely on the dorsal stream? Int. J. Sport Psychol. 39, 149–156.

Mourant, R.R., Rockwell, T.H., 1972. Strategies of Visual Search by Novice and Experienced Drivers. Hum. Factors 14, 325–335.

Mourant, R.R., Rockwell, T.H., 1970. Mapping eye-movement patterns to the visual scene in driving: an exploratory study. Hum. Factors 12, 81–7.

Murray, W.S., van Gompel, R.P.G., Fischer, M.H., Hill, R.L., 2007. Eye Movements: A Window on Mind and Brain, First Edit. ed. Elsevier.

Niemann, T., Lappe, M., Büscher, A., Hoffmann, K.P., 1999. Ocular responses to radial optic flow and single accelerated targets in humans. Vision Res. 39, 1359–71.

Nikolas, M.A., Elmore, A.L., Franzen, L., O'Neal, E., Kearney, J.K., Plumert, J.M., 2016. Risky bicycling behavior among youth with and without attention-deficit hyperactivity disorder. J. Child Psychol. Psychiatry 57, 141–148.

Nixon, J., Clacher, R., Pearn, J., Corcoran, A., 1987. Bicycle accidents in childhood. Br. Med. J. 294, 1267–1269.

Norman, D.A., Shallice, T., 1986. Attention to Action. Conscious. Self-Regulation 4, 1–18.

O'Neal, E.E., Plumert, J.M., McClure, L.A., Schwebel, D.C., 2016. The role of Body Mass Index in child pedestrian injury risk. Accid. Anal. Prev. 90, 29–35.

Oja, P., Titze, S., Bauman, a, de Geus, B., Krenn, P., Reger-Nash, B., Kohlberger, T., 2011. Health benefits of cycling: a systematic review. Scand. J. Med. Sci. Sports 21, 496–509.

Ormel, W., Klein Wolt, K., den Hertog, P., 2009. Enkelvoudige fietsongevallen. Een LIS-vervolgonderzoek [Single bicycle accidents. A LIS-follow-up study].".

Paas, F., van Gog, T., Sweller, J., 2010. Cognitive load theory: New conceptualizations, specifications, and integrated research perspectives. Educ. Psychol. Rev. 22, 115–121.

Parkin, J., Wardman, M., Page, M., 2008. Estimation of the determinents of bicycle mode share for the journey to work using census data. Transportation (Amst). 35, 93–109.

Patla, A.E., 1997. Understanding the roles of vision in the control of human locomotion. Gait Posture 5, 54–69.

Patla, A.E., Vickers, J.N., 2003. How far ahead do we look when required to step on specific locations in the travel path during locomotion? Exp. Brain Res. 148, 133–8.

Patla, A.E., Vickers, J.N., 1997. Where and when do we look as we approach and step over an obstacle in the travel path? Neuroreport 8, 3661–5.

Payne, V.G., Isaacs, L.D., 1995. Human Motor Development: A Lifespan Approach, Third. ed. Mayfield.

Pelz, D.C., Krupat, E., 1974. Caution profile and driving record of undergraduate males. Accid. Anal. Prev. 6, 45–58.

Pelz, J., Hayhoe, M., Loeber, R., 2001. The coordination of eye, head, and hand movements in a natural task. Exp. Brain Res. 139, 266–277.

Pelz, J.B., Rothkopf, C., 2007. Oculomotor behavior in natural and man-made environments, in: Eye Movements: A Window on Mind and Brain. pp. 661–676.

Pfeffer, K., Barnecutt, P., 1996. Children's auditory perception of movement of traffic sounds. Child. Care. Health Dev. 22, 129–137.

Pitcairn, T., Edlmann, T., 2000. Individual differences in road crossing ability in young children and adults. Br. J. Psychol. 91, 391–410.

Plumert, J.M., 2003. Children's overestimation of their physical abilities: Links to injury proneness, in: Savelsbergh, G.J.P., Davids, K., van der Kamp, J., Bennet, S.J. (Eds.), Development of Movement Co-Ordination in Children: Applications in the Field of Ergonomics, Health Sciences and Sport. Routledge, London, p. 274.

Plumert, J.M., Kearney, J.K., 2014. Linking Decisions and Actions in Dynamic Environments: How Child and

Adult Cyclists Cross Roads With Traffic. Ecol. Psychol. 26, 125–133.

Plumert, J.M., Kearney, J.K., Cremer, J.F., 2007. Children's road crossing: A window into perceptual-motor development. Curr. Dir. Psychol. Sci. 16, 255–258.

Plumert, J.M., Kearney, J.K., Cremer, J.F., 2004. Children's perception of gap affordances: bicycling across traffic-filled intersections in an immersive virtual environment. Child Dev. 75, 1243–53.

Plumert, J.M., Kearney, J.K., Cremer, J.F., Recker, K.M., Strutt, J., 2011. Changes in children's perception-action tuning over short time scales: bicycling across traffic-filled intersections in a virtual environment. J. Exp. Child Psychol. 108, 322–37.

Pollatsek, A., Fisher, D.L., Pradhan, A., 2006a. Identifying and Remedying Failures of Selective Attention in Younger Drivers. Curr. Dir. Psychol. Sci. 15, 255–259.

Pollatsek, A., Narayanaan, V., Pradhan, A., Fisher, D.L., 2006b. Using Eye Movements to Evaluate a PC-Based Risk Aware- ness and Perception Training Program on a Driving Simulator. Hum. Factors 48, 447–464.

Pollatsek, A.K.P.A., Fisher, M.K.D.L., Pradhan, a K., Knodler, M., Fisher, D.L., Pollatsek, A.K.P.A., Knodler, M., Fisher, D.L., 2009. Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? Ergonomics 52, 657–73.

Posner, M.I., 1980. Orienting of attention Posner. Q. J. Exp. Psychol. 1 32, 3–25.

Pradhan, A.K., Fisher, D.L., Pollatsek, A., Fisher L, D., 2005. The effects of pc-based training on novice drivers' risk awareness in a driving simulator. Proc. Third Int. Driv. Symp. Hum. Factors Driv. Assessment, Train. Veh. Des. 1, 81–87.

Pradhan, A.K., Hammel, K.R., DeRamus, R., Pollatsek, A., Noyce, D.A., Fisher, D.L., 2003. The Use of Eye Movements to Evaluate the Effects of Driver Age on Risk Perception in an Advanced Driving Simulator. Washington, p. 14.

Pradhan, A.K., Pollatsek, A., Knodler, M., Fisher, D.L., 2009. Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? Ergonomics 52, 657–73.

Pryde, K.M., Roy, E.A., Patla, A.E., 1997. Age-related trends in locomotor ability and obstacle avoidance. Hum. Mov. Sci. 16, 507–516.

Pucher, J., Buehler, R., 2012. City Cycling, First. ed. MIT Press, London.

Pucher, J., Dill, J., Handy, S., 2010. Infrastructure, programs, and policies to increase bicycling: an international review. Prev. Med. (Baltim). 50 Suppl 1, S106-25.

Pucher, J., Komanoff, C., Schimek, P., 1999. Bicycling renaissance in North America ? Recent trends and alternative policies to promote bicycling. Transp. Res. Part A Policy Pract. 33, 625–654.

Raudsepp, L., Päll, P., 2006. Motor Skills and Outside-School Physical Activity of Elementary School Children 426–435.

Reilly, J.J., 2010. Low levels of objectively measured physical activity in preschoolers in child care. Med. Sci. Sports Exerc. 42, 502–507.

Reynolds, C.C.O., Harris, M.A., Teschke, K., Cripton, P. a, Winters, M., 2009. The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. Environ. Health 8, 47.

Riethmuller, A.M., Jones, R., Okely, A.D., 2009. Efficacy of interventions to improve motor development in young children: a systematic review. Pediatrics 124, e782-92.

Rijk, A., 2008. Verkeersveiligheid van kinderen: Een ongevallenanalyse en literatuurstudie [Traffic Safety in Children: An Accident Analysis and Litarature Study]. Leidschendam.

Risko, E.F., Laidlaw, K., Freeth, M., Foulsham, T., Kingstone, A., 2012. Social attention with real versus reel stimuli: toward an empirical approach to concerns about ecological validity. Front. Hum. Neurosci. 6, 1–11.

Rivara, F.P., Thompson, D.C., Patterson, M.Q., Thompson, R.S., 1998. Bicycle-related injuries: helmets, education, and legislation. Annu. Rev. Public Health 19, 293–318.

Rivara, F.P., Thompson, D.C., Thompson, R.S., 1997. Epidemiology of bicycle injuries and risk factors for serious injury. Inj. Prev. 3, 110–4.

Rizzolatti, G., Luppino, G., Umana, F., 2001. The cortical motor system. Neuron 31, 889–901.

Robert, M.P., Ingster-Moati, I., Albuisson, E., Cabrol, D., Golse, B., Vaivre-Douret, L., 2014. Vertical and horizontal smooth pursuit eye movements in children with developmental coordination disorder. Dev. Med. Child Neurol. 56, 595–600.

Robertshaw, K.D., Wilkie, R.M., 2008. Does gaze influence steering around a bend? J. Vis. 8, 1–13.

Robinson, L.E., Stodden, D.F., Barnett, L.M., Lopes, V.P., Logan, S.W., Rodrigues, L.P., D’Hondt, E., 2015. Motor Competence and its Effect on Positive Developmental Trajectories of Health. Sport. Med. 45, 1273–1284.

Rosenbloom, T., Mandel, R., Rosner, Y., Eldror, E., 2015. Hazard perception test for pedestrians. Accid. Anal. Prev. 79, 160–169.

Rushton, S.K., Harris, J.M., Lloyd, M.R., Wann, J.P., 1998. Guidance of locomotion on foot uses perceived target location rather than optic flow. Curr. Biol. 8, 1191–4.

Sahlberg, H., Lehtonen, E., Rovamo, E., Summala, H., Paper, C., 2015. Learning game for training child bicyclists ’ situational awareness for better hazard perception, in: International Cycling Conference. Hannover, Germany, pp. 1–19.

Salman, M.S., Sharpe, J.A., Lillakas, L., Dennis, M., Steinbach, M.J., 2006. Smooth pursuit eye movements in children. Exp. Brain Res. 169, 139–143.

Salmon, P.M., Lenne, M.G., Walker, G.H., Stanton, N. a, Filtness, A., 2014. Exploring schema-driven differences in situation awareness between road users: an on-road study of driver, cyclist and motorcyclist situation awareness. Ergonomics 1–20.

Salmon, P.M., Stanton, N. a., 2013. Situation awareness and safety: Contribution or confusion? Situation awareness and safety editorial. Saf. Sci. 56, 1–5.

Salmon, P.M., Stanton, N. a., Young, K.L., 2012. Situation awareness on the road: review, theoretical and methodological issues, and future directions. Theor. Issues Ergon. Sci. 13, 472–492.

Salvucci, D.D., Gray, R., 2004. A two-point visual control model of steering. Perception 33, 1233–1248.

Savelsbergh, G.J.P., Van der Kamp, J., Williams, a M., Ward, P., 2005. Anticipation and visual search behaviour in expert soccer goalkeepers. Ergonomics 48, 1686–97.

Savelsbergh, G.J.P., Williams, A.M., Van der Kamp, J., Ward, P., 2002. Visual search, anticipation and expertise in soccer goalkeepers. J. Sports Sci. 20, 279–87.

Savill, T., Bryan-Brown, K., Harland, G., 1996. The Effectiveness of Child Cycle Training Schemes. Berkshire.

Schepers, P., 2013. A safer road environment for cyclists. SWOV, Leidschendam.

Schepers, P., 2012. Does more cycling also reduce the risk of single-bicycle crashes? Inj. Prev. 18, 240–5.

Schepers, P., Wolt, K.K., 2012. Single-bicycle crash types and characteristics, in: Cycling Research International. pp. 1–17.

Scherf, K.S., Sweeney, J.A., Luna, B., 2006. Brain basis of developmental change in visuospatial working memory. J. Cogn. Neurosci. 18, 1045–1058.

Schmidt, R.A., Wrisberg, C.A., 2004. Motor Learning and Performance: A problem-based approach to learning, 3th ed. Human Kinetics, Champaign, IL.

Schoeters, A., Carpentier, A., Briers, S., 2014. Jaarrapport Verkeersveiligheid 2014: Analyse van verkeersveiligheidsindicatoren in Vlaanderen tot en met 2014. Hasselt.

Schreiber, M., Ortlepp, J., Butterwegge, P., Gehlert, T., 2015. Designing Safe Intersections: Determinants of Accidents Involving Cyclists and Turning Vehicles and Strategies for Their Reduction, in: Gerike, R., Parkin, J. (Eds.), Cycling Futures: From Research into Practice. Ashgate Publishing Limited, Farnham, pp. 155–182.

Schwab, A.L., 2012. Bicycling safety and the lateral stability of the bicycle. Proceedings, Int. Cycl. Saf. Conf. 2012 1–5.

Schwab, A.L., Kooijman, J.D.G., 2011. A review on handling aspects in bicycle and motorcycle control, in: Proceedings of the ASME 2011 International Design Engineering Technical Conferences & COputers and Information in Engineering Conference. p. 11.

Schwebel, D.C., Barton, B.K., Shen, J., Wells, H.L., Bogar, A., Heath, G., McCullough, D., 2014. Systematic review and meta-analysis of behavioral interventions to improve child pedestrian safety. J. Pediatr. Psychol. 39, 826–845.

Schwebel, D.C., Combs, T., Rodriguez, D., Severson, J., Sisiopiku, V., 2016a. Community-based pedestrian safety training in virtual reality: A pragmatic trial. Accid. Anal. Prev. 86, 9–15.

Schwebel, D.C., Shen, J., McClure, L.A., 2016b. How do children learn to cross the street? The process of pedestrian safety training. Traffic Inj. Prev. 1–30.

Scialfa, C.T., Borkenhagen, D., Lyon, J., Deschênes, M., Horswill, M., Wetton, M., 2012. The effects of driving experience on responses to a static hazard perception test. Accid. Anal. Prev. 45, 547–53.

Scialfa, C.T., Deschênes, M.C., Ference, J., Boone, J., Horswill, M.S., Wetton, M., 2011. A hazard perception test for novice drivers. Accid. Anal. Prev. 43, 204–8.

Seefeldt, V., 1980. developmental motor patterns: implications for elementary school physical education, in: Nadeau, C., Holliwel, K., Roberts, G. (Eds.), Psychology of Motor Behaviour and Sport. Champaign, IL, pp. 314–323.

Shephard, R.J., 2008. Is active commuting the answer to population health? Sport. Med. 38, 751–758.

Silverans, P., Goldenbeld, C., 2015. Themadossier verkeersveiligheid nr. 2: Fietsers. Brussel, België.

Simpson, A.H., Mineiro, J., 1992. Prevention of bicycle accidents. Injury 23, 171–3.

Smith, M.R., Zeuwts, L., Lenoir, M., Hens, N., De Jong, L.M.S., Coutts, A.J., 2016. Mental fatigue impairs soccer-specific decision-making skill. J. Sports Sci. 414, 1–8.

Smits-engelsman, B.C.M., Henderson, S.E., 1998. The assessment of children with Developmental Coordination Disorders in the Netherlands : The relationship between the Movement Assessment Battery for rperkoordinations Test f Children and the K o ur Kinder 17, 699–709.

Spence, L.J., Dykes, E.H., Bohn, D.J., Wesson, D.E., 1993. Fatal bicycle accidents in children: a plea for prevention. J. Pediatr. Surg. 28, 214–216.

Stanton, N.A., Chambers, P.R.., Piggott, J., 2001. Situational awareness and safety. Saf. Sci. 39, 189–204.

Stelling-Konczak, A., Hagenzieker, M., Commandeur, J.J.F., Agterberg, M.J.H., van Wee, B., 2016. Auditory localisation of conventional and electric cars: Laboratory results and implications for cycling safety. Transp. Res. Part F Traffic Psychol. Behav. 41, 227–242.

Stevens, E., Plumert, J.M., Cremer, J.F., Kearney, J.K., 2013. Preadolescent temperament and risky behavior: bicycling across traffic-filled intersections in a virtual environment. J. Pediatr. Psychol. 38, 285–295.

Stichting Vlaamse Schoolsport, 2008. Meester op de fiets. Fietsvaardigheidstraining in uw school [Master on the Bike. Bicycle skills training in your school]. Belgisch Instituut voor de Verkeersveiligheid, Brussel.

Stichting Vlaamse Schoolsport, 2005. Meester op de fiets. Fietsvaardigheidstraining in uw school [Master on the Bike. Bicycle Skill Training in School], first. ed. Belgisch Instituut voor de Verkeersveiligheid, Brussels.

Stodden, D.F., Goodway, J.D., Langendorfer, S.J., Roberton, M.A., Rudisill, M.E., Garcia, C., Garcia, L.E., 2012. A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity : An Emergent Relationship 37–41.

Stodden, D.F., Goodway, J.D., Langendorfer, S.J., Roberton, M.A., Rudisill, M.E., Garcia, C., Garcia, L.E., 2008. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship.pdf. Quest 60, 290–305.

Summala, H., Lamble, D., Laakso, M., 1998. Driving experience and perception of the lead car's braking when looking at in-car targets. Accid. Anal. Prev. 30, 401–7.

Summala, H., Pasanen, E., Räsänen, M., Sievänen, J., 1996. Bicycle accidents and drivers' visual search at left and right turns. Accid. Anal. Prev. 28, 147–53.

SWOV, 2012. Traffic education for children 4-12 years old. Leidschendam.

Tamm, L., Menon, V., Reiss, A.L., 2002. Maturation of brain function associated with response inhibition. J. Am. Acad. Child Adolesc. Psychiatry 20, 1231–1238.

Tatler, B.W., 2009. Current understanding of eye guidance. Vis. cogn. 17, 777–789.

Tatler, B.W., Hayhoe, M.M., Land, M.F., Ballard, D.H., 2011. Eye guidance in natural vision: Reinterpreting salience. J. Vis. 11, 1–23.

te Velde, A.F., van der Kamp, J., Barela, J.A., Savelsbergh, G.J.P., 2005. Visual timing and adaptive behavior in a road-crossing simulation study. Accid. Anal. Prev. 37, 399–406.

te Velde, A.F., van der Kamp, J., Savelsbergh, G., 2003. Road-crossing behaviour in young children, in: Savelsbergh, G., Davids, K., van der Kamp, J., Bennet, S.J. (Eds.), Development of Movement Co-Ordination in Children: Applications in the Field of Ergonomics, Health Sciences and Sport. Routledge, London, p. 274.

Thelen, E., Smith, L.B., 1994. A Dynamical Systems Approach to the Development of Action and Perception. MIT Press, Cambridge.

Thomson, J.A., Ampofo-Boateng, K., Pitcairn, T., Grieve, R., Lee, D.N., Demetre, J.D., 1992. Behavioural group training of children to find safe routes to cross the road. Br. J. Educ. Psychol. 62, 173–183.

Thomson, J.A., Tolmie, A., Foot, H.C., Mclaren, B., 1996. Child Development and the Aims of Road Safety Education: A Review and Analysis. Road Saf. Res. Rep. 1–8.

Thomson, J., Tolmie, A., Foot, H., Whelan, K.M., 2005. Influence of virtual reality training on the roadside crossin judgements of child pedestrians. J. Exp. Psychol. 11, 175–186.

Thornton, S., Pearson, A., Andree, K., Rodgers, N., 1999. Taking the child's perspective seriously. Psychologist 12, 393–394.

Tolmie, A., Thomson, J.A., Foot, H.C., McLaren, B., Whelan, K.M., 1998. Problems of attention and visual search in the context of child pedestrian behavior. Road safety research report no. 8. London.

Trapp, G.S., Giles-Corti, B., Christian, H.E., Bulsara, M., Timperio, A.F., McCormack, G.R., Villaneuva, K.P., 2011. On your bike! a cross-sectional study of the individual, social and environmental correlates of cycling to school. Int. J. Behav. Nutr. Phys. Act. 8, 123–133.

Trick, L.M., Enns, J.T., 1998. Lifespan changes in attention: The visual search task. Cogn. Dev. 13, 369–386.

Triesch, J., Ballard, D.H., Hayhoe, M.M., Sullivan, B.T., 2003. What you see is what you need. J. Vis. 3, 86–94.

Turano, K. a, Geruschat, D.R., Baker, F.H., Stahl, J.W., Shapiro, M.D., 2001. Direction of gaze while walking a simple route: persons with normal vision and persons with retinitis pigmentosa. Optom. Vis. Sci. 78, 667–75.

Tveter, A.T., Holm, I., 2010. Influence of thigh muscle strength and balance on hop length in one-legged hopping in children aged 7-12 years. Gait Posture 32, 259–262.

Underwood, G., Chapman, P., Bowden, K., Crundall, D., 2002a. Visual search while driving: skill and awareness during inspection of the scene. Transp. Res. Part F Traffic Psychol. Behav. 5, 87–97.

Underwood, G., Crundall, D., Chapman, P., 2011. Driving simulator validation with hazard perception. Transp. Res. Part F Traffic Psychol. Behav. 14, 435–446.

Underwood, G., Crundall, D., Chapman, P., 2002b. Selective searching while driving: the role of experience in hazard detection and general surveillance. Ergonomics 45, 1–12.

Underwood, G., Ngai, A., Underwood, J., 2012. Driving experience and situation awareness in hazard detection. Saf. Sci. 1–7.

Underwood, G., Phelps, N., Wright, C., van Loon, E., Galpin, A., 2005. Eye fixation scanpaths of younger and older drivers in a hazard perception task. Ophthalmic Physiol. Opt. 25, 346–56.

Underwood, J., Dillon, G., Farnsworth, B., Twiner, A., 2007. Reading the road: The influence of age and sex on child pedestrians' perceptions of road risk. Br. J. Psychol. 98, 93–110.

van der Kamp, J., Savelsbergh, G.J.P., Rosengren, K.S., 2001. The Separation of Action and Perception and the Issue of Affordances. Ecol. Psychol. 13, 167–172.

Van Houcke, H., Gabriels, D., De Smedt, T., 2009. FietsIEfieTS. Mechelen: Jan Peumans.

Van Hout, K., Brijs, T., Daniels, S., Hermans, E., 2011. Fietsinfrastructuur: Effecten op Verkeersveiligheid [Bicycle Infrastructure: Effects on Traffic Safety]. Hasselt.

Van Hout, K., Cuyvers, R., 2007. De risico' s van fietsen: Feiten, cijfers en vaststellingen [The Risks of Bicycling: Facts, Numbers and Statement]. Diepenbeek Hasselt.

Van Merriënboer, J.J.G., Sweller, J., 2005. Cognitive load theory and complex learning: Recent developments and future directions, Educational Psychology Review.

van Schagen, I.N., Brookhuis, K. a, 1994. Training young cyclists to cope with dynamic traffic situations. Accid. Anal. Prev. 26, 223–230.

Vandorpe, B., 2011. The contribution of motor coordination to sports participation in school-aged children and to talent identification in young female gymnasts. Ghent University.

Vandorpe, B., Vandendriessche, J., Lefevre, J., Pion, J., Vaeyens, R., Matthys, S., Philippaerts, R., Lenoir, M., 2011. The KörperkoordinationsTest für Kinder: reference values and suitability for 6-12-year-old children in Flanders. Scand. J. Med. Sci. Sports 21, 378–388.

Vandorpe, B., Vandendriessche, J., Vaeyens, R., Pion, J., Matthys, S., Lefevre, J., Philippaerts, R., Lenoir, M., 2012a. Relationship between sports participation and the level of motor coordination in childhood: a longitudinal approach. J. Sci. Med. Sport 15, 220–5.

Vandorpe, B., Vandendriessche, J.B., Vaeyens, R., Pion, J., Lefevre, J., Philippaerts, R.M., Lenoir, M., 2012b. The value of a non-sport-specific motor test battery in predicting performance in young female gymnasts. J. Sports Sci. 30, 497–505.

Vansteenkiste, P., 2015. The role of visual information in the steering behaviour of young and adult bicyclists. Ghent University.

Vansteenkiste, P., Cardon, G., D'Hondt, E., Philippaerts, R., Lenoir, M., 2013. The visual control of bicycle steering: The effects of speed and path width. Accid. Anal. Prev. 51, 222–227.

Vansteenkiste, P., Cardon, G., Lenoir, M., 2015. Visual guidance during bicycle steering through narrow lanes: A study in children. Accid. Anal. Prev. 78, 8–13.

Vansteenkiste, P., Cardon, G., Lenoir, M., n.d. Visually guided steering of young and adult bicyclsts during a slalom task. Accid. Anal. Prev.

Vansteenkiste, P., Van Hamme, D., Veelaert, P., Philippaerts, R., Cardon, G., Lenoir, M., 2014a. Cycling around a curve: The effect of cycling speed on steering and gaze behavior. PLoS One 9, 1–11.

Vansteenkiste, P., Zeuwts, L., Cardon, G., Philippaerts, R., Lenoir, M., 2014b. The implications of low quality bicycle paths on gaze behavior of cyclists: A field test. Transp. Res. Part F Traffic Psychol. Behav. 23, 81–87.

Vedul-Kjelsas, V., Stensdotter, A., 2013. Motor competence in 11-year-old boys and girls. Scand. J. Educ. Res. 57, 561–570.

Vickers, J.N., 2007. Perception, Cognition, and Decision Training. The Quiet Eye in Action, First. ed. Human Kinetics.

Violanti, J.M., Marshall, J.R., 1996. Cellular phones and traffic accidents: an epidemiological approach. Accid. Anal. Prev. 28, 265–270.

Vlakveld, W., 2011. Hazard anticipation of young novice drivers. SWOV, Hilversum.

Vlakveld, W.P., 2014. A comparative study of two desktop hazard perception tasks suitable for mass testing in which scores are not based on response latencies. Transp. Res. Part F 22, 218–231.

Walker, I., 2007. Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender. Accid. Anal. Prev. 39, 417–425.

Wallis, T.S. a, Horswill, M.S., 2007. Using fuzzy signal detection theory to determine why experienced and trained drivers respond faster than novices in a hazard perception test. Accid. Anal. Prev. 39, 1177–85.

Warren, W.H., Hannon, D.J., 1990. Eye movements and optical flow. J. Opt. Soc. Am. A. 7, 160–9.

Warren, W.H., Kay, B. a, Zosh, W.D., Duchon, a P., Sahuc, S., 2001. Optic flow is used to control human walking. Nat. Neurosci. 4, 213–6.

Webman, R., Dultz, L. a, Simon, R.J., Todd, S.R., Slaughter, D., Jacko, S., Bholat, O., Wall, S., Wilson, C., Levine, D. a, Roe, M., Pachter, H.L., Frangos, S.G., 2013. Helmet use is associated with safer bicycling behaviors and reduced hospital resource use following injury. J. Trauma Acute Care Surg. 75, 877–81.

Weiss, M., 1993. Psychological effects of intensive sport participation on children and youth: self-esteem and motivation, in: Intensive Participation in Children's Sports. Human Kinetics Publishers, Champaign, IL, pp. 39–69.

Wetton, M.A., Horswill, M.S., Hatherly, C., Wood, J.M., Pachana, N.A., Anstey, K.J., 2010. The development and validation of two complementary measures of drivers' hazard perception ability. Accid. Anal. Prev. 42, 1232–9.

Wetton, M. a, Hill, A., Horswill, M.S., 2011. The development and validation of a hazard perception test for use in driver licensing. Accid. Anal. Prev. 43, 1759–70.

Whitebread, D., Neilson, K., 2000. The contribution of visual search strategies to the development of pedestrian skills by 4-11 year-old children. Br. J. Educ. Psychol. 70 Pt 4, 539–57.

WHO, 2007. Increasing Physical Activity Reduces Risk of Heart Disease and Diabetes.

WHO, 2005. WHO Air Quality Guidelines. Global Update 2005. Copenhagen:WHO Regional Office for Europe.

Wierda, M., Brookhuis, K.A., 1991. Analysis of Cycling Skill: A cognitive Approach. Appl. Cogn. Psychol. 5, 113–122.

Wilkie, R., Wann, J., 2003. Controlling steering and judging heading: retinal flow, visual direction, and extraretinal information. J. Exp. Psychol. Hum. Percept. Perform. 29, 363–78.

Wilkie, R., Wann, J.P., Allison, R.S., 2008. Active gaze, visual look-ahead and locomotor control. J. Exp. Psychol. Hum. Percept. Perform. 34.

Wilkie, R.M., Kountouriotis, G.K., Merat, N., Wann, J.P., 2010. Using vision to control locomotion: looking where you want to go. Exp. Brain Res. 204, 539–47.

Wilkie, R.M., Wann, J.P., 2005. The role of visual and nonvisual information in the control of locomotion. J. Exp. Psychol. Hum. Percept. Perform. 31, 901–11.

Williams, A.M., Davids, K., Williams, J.G., 2005. Visual Perception & Action in Sport, Second. ed. Taylor & Francis, London.

Williams, A.M., Ward, P., Knowles, J.M., Smeeton, N.J., 2002. Anticipation skill in a real-world task: Measurement, training, and transfer in tennis. J. Exp. Psychol. Appl. 8, 259–270.

Wolfe, J.M., 1994. Visual search in continuous, naturalistic stimuli. Vision Res. 34, 1187–1195.

Wrotniak, B.H., Epstein, L.H., Dorn, J.M., Jones, K.E., Kondilis, V.A., 2006. The relationship between motor proficiency and physical activity in children. Pediatrics 118, e1758-65.

Wulf, G., 2007. Attention and Motor Skill Learning, First Edit. ed. Human Kinetics, Stanningley.

Zeedyk, M.S., Wallace, L., Spry, L., 2002. Stop, look, listen, and think? What young children really do when crossing the road. Accid. Anal. Prev. 34, 43–50.

Zeuwts, L., Ducheyne, F., Vansteenkiste, P., D'Hondt, E., Cardon, G., Lenoir, M., 2015. Associations between cycling skill, general motor competence and body mass index in 9-year-old children. Ergonomics 1–12.

Zeuwts, L., Vansteenkiste, P., Deconinck, F.J.A., Cardon, G., Lenoir, M., 2016. Hazard perception in young cyclists and adult cyclists. Accid. Anal. Prev. In Press.

Curriculum Vitae

List of publications and presentations

A1 - Publications

1. Vansteenkiste P, **Zeuwts L**, Cardon G, Philippaerts R, Lenoir M (2014). The implications of low quality bicycle paths on gaze behavior of cyclists: a field test. *Transportation Research Part F: Traffic Psychology and Behaviour,* 23, 81-87. DOI: 10.1016/j.trf.2013.12.019
   IF: 1.473
2. Vansteenkiste P, Vaeyens R, **Zeuwts L**, Philippaerts R, Lenoir M (2014). Cue usage in volleyball: a time course comparison of elite, intermediate and novice female players. *Biology of Sport*, 31, 295-302 DOI: 10.5604/20831862.1127288
   IF: 0.789
3. **Zeuwts L**, Ducheyne F, Vansteenkiste P, Cardon G, Lenoir M (2015). Associations between cycling skill, general motor competence and body mass index in 9-year-old children. E*rgonomics* , 58(1), 160-171 DOI: 10.1080/00140139.2014.961971
   IF: 1.608
4. **Zeuwts L**, Vansteenkiste P, Cardon G, Lenoir M (2016). Development of cycling skills in 7 to 12-year-old children. *Traffic Injury Prevention*. Epub ahead of print, DOI 10.1080/15389588.2016.1143553
   IF: 1.413
5. Smith, M.R**., Zeuwts, L**., Lenoir, M., Hens, N., De Jong, L.M.S., Coutts, A.J., (2016). Mental fatigue impairs soccer-specific decision-making skill. J. Sports Sci. 0414, 1–8. DOI: 10.1080/02640414.2016.1156241
   IF: 2.416
6. **Zeuwts L**, Vansteenkiste P, Deconinck F, Cardon G, Lenoir M (2016). Hazard perception in young and adult bicyclists. *Accident Analysis and Prevention.* Epub ahead of print, DOI: 10.1016/j.aap.2016.04.034.
   IF: 2.070
7. **Zeuwts L**[1], Vansteenkiste P[1], Cardon G, Lenoir M (2016). A hazard-perception test for cycling children: an exploratory study. *Transportation Research Part F*, 41, part B, 182-194. DOI: 10.1016/j.trf.2016.05.001
   IF: 1.473
8. **Zeuwts L.H.R.H.**, Vansteenkiste P., Deconinck F.J.A., Cardon G., Lenoir M. (2016). Hazard perception training in young cyclists improves early detection of risk – A cluster-randomized controlled design. *Accident Analysis and Prevention. (Revised)*
   IF: 2.070
9. Vansteenkiste P[1], **Zeuwts L**[1], Cardon G, Lenoir M (2016). The implications of low quality bicycle paths on gaze behavior of cyclists : a field test. *Transportation Research Part F. (Submitted)*
   IF: 1.473
10. **Zeuwts L**[1], Vansteenkiste P[1], Cardon G, Lenoir M (2016). Is gaze behaviour in a laboratory context similar to that in real-life: A study in bicyclists *Transportation Research Part F. (Accepted)*
    IF: 1.473
11. Rozilee N, Decroix M, **Zeuwts L**, Deconick F, Lenoir M, Vansteenkiste P. (2016) Expert-novice differences in visual behaviour during alpine slalom skiing. *Research Quarterly for Exercise and Sport (Submitted)*
    IF: 1.702
12. **Zeuwts L**, Koppo K, Cardon G, Lenoir M. (2016) The ability to correct an on-going action: accuracy and correction time in elite fencing. *Archives of Buddo (Submitted)*
    IF: 1.310
13. **Zeuwts L**, Cardon G, Lenoir M. (2016) The effect of a hazard perception training intervention child bicyclists. *Transportation Research Part F (Submitted)*
    IF: 1.473

C3 – Presentations at national and international conferences

1. Vansteenkiste P, **Zeuwts L**, Cardon G, Lenoir M (2013) A hazard perception test for cycling children : an exploratory study. *Conference abstract + Poster presentation at Eye Tracking South Africa (29-31/08, Cape Town – South Africa)*
2. Vansteenkiste P, **Zeuwts L**, Cardon G, Lenoir M (2013) A hazard perception test for cycling children: an exploratory study. *Conference abstract + Poster presentation at VK-symposium (13/12, Leuven - Belgium)*
3. **Zeuwts L**, Debuyck G, Vansteenkiste P, Cardon G, Lenoir M (2013) Is there a difference in visual search patterns between watching video clips of fencers on a computer screen and reacting on them on a life-sized screen? *Conference abstract + Poster presentation* at Eye Tracking South Africa, 81-81 *(29-31/08, Cape Town – South Africa)*
4. **Zeuwts L**, Debuyck G, Vansteenkiste P, Cardon G, Lenoir M (2013) Is there a difference in visual search patterns between watching video clips of fencers on a computer screen and reacting on them on a life-sized screen? *Conference talk + Conference abstract at ECEM (11-16/08, Lund - Sweden).*
5. **Zeuwts L**, Cardon G, Lenoir M, (2016) Risicopersceptie bij jonge, minder ervaren fietsers. Conference talk at "*Fietscongres Gent*" (*07/06/2016, Ghent - Belgium*).

C4 – Other publications

1. Zeuwts L, Cardon, G, Lenoir M (2016) Kinderen herkennen de gevaren in het verkeer onvoldoende. *Press Release Ghent University* (23/06/2016).

Media appearances

1. Zeuwts L, Cardon G, Lenoir M, MNM (radio). Kinderen herkennen gevaren in het verkeer onvoldoende (23/06/2016).
2. De serrist Nr. 3. Kinderen herkennen gevaren in het verkeer onvoldoende: Doctoraatsonderzoeker ontwikkelde een veelbelovende visuele training. *Jean-Pierre Dubois* (28/07/2016).
3. Het Nieuwsblad. Jonge fietsers stuurloos in het verkeer (2/07/2016).
4. Het Laatste Nieuws. Vlaamse onderzoeker ontwikkelt nieuwe training. In 2 uur leert kind al veiliger fietsen (2/07/2016)

Supervised master dissertations

1. Thielens Zino & Seeuws Jonas (2013-2015) 'Hazard Perception' in jonge volwassen en expert fietsers
2. Van Eetvelde Maarten (2013-2015) 'Hazard Perception' in jonge volwassen en expert fietsers: De ontwikkeling van een Hazard Perception test
3. Baetslé Sarah & De Poorter Catharina (2013-2015) De invloed van de kwaliteit van het wegdek op het visueel stuurgedrag bij kinderen en volwassenen
4. Baetslé Lisa (2013-2015) Invloed van fietservaring en fietsvaardigheden op het visueel stuurgedrag bij kinderen afhankelijk van de kwaliteit van het fietspad
5. Tinel Mathilde & Van Gheluwe Annelies (2014-2016) Ontwikkeling van een hazard perception training voor jonge fietsers
6. De Pauw Mattias & Alleman Gerti (2014-2016) Jonge fietsers worden expert door hazard perception training
7. Minnebo Jane & Lambrights Karlien (2014-2016) Ontwikkeling van een hazard perception training voor jonge fietsers

Appendix

Table 1. Interaction effects for group and time regarding the mean response rate for each individual video clip and the overt and covert latent hazards.

		Intervention			**Control**			**[pre-post*group]**			**[pre-retention*group]**		
		Pre	*Post*	Retention	Pre	Post	Retention	β	CI	p	β	CI	p
2	overt	0.62±0.06	0.59±0.06	0.56±0.06	0.50±0.07	0.33±0.07	0.43±0.07	0.148	(-0.09;0.39)	.227	0.014	(-0.24;0.26)	.913
15	covert	0.82±0.04	0.78±0.04	0.87±0.04	0.83±0.06	0.91±0.05	0.87±0.05	-0.125	(-0.3;0.05)	.151	0.008	(-0.18;0.20)	.935
25	covert	0.95±0.03	0.88±0.04	0.85±0.04	0.93±0.03	0.89±0.05	0.87±0.05	-0.021	(-0.14;0.1)	.730	-0.037	(-0.19;0.11)	.621
31	covert	0.14±0.04	0.37±0.05	0.40±0.05	0.11±0.05	0.09±0.06	0.09±0.06	0.253	(0.09;0.42)	.003	0.278	(0.09;0.47)	.004
40	covert	0.36±0.05	0.46±0.06	0.62±0.06	0.30±0.07	0.41±0.07	0.39±0.07	-0.006	(-0.24;0.22)	.958	0.169	(-0.05;0.39)	.134
46	overt	0.69±0.05	0.87±0.04	0.94±0.04	0.74±0.07	0.74±0.06	0.76±0.05	0.179	(-0.02;0.38)	.076	0.222	(0.04;0.41)	.020
48	overt	0.96±0.02	0.97±0.02	0.96±0.02	0.98±0.03	0.96±0.03	1.00±0.02	0.035	(-0.09;0.12)	.402	-0.022	(-0.11;0.07)	.626
54	covert	0.71±0.05	0.73±0.05	0.64±0.06	0.67±0..07	0.57±0.07	0.50±0.07	0.134	(-0.09;0.36)	.233	0.110	(-0.12;0.34)	.355
101	covert	0.77±0.05	0.88±0.04	0.82±0.04	0.76±0.06	0.74±0.05	0.78±0.06	0.137	(-0.08;0.35)	.205	0.030	(-0.19;0.25)	.789
131	overt	0.94±0.03	0.90±0.03	0.90±0.03	0.91±0.04	0.89±0.05	0.93±0.04	-0.017	(-0.16;0.12)	.815	-0.060	(-0.21;0.09)	.424
193	covert	0.77±0.05	0.63±0.06	0.59±0.05	0.70±0.06	0.43±0.07	0.63±0.07	0.120	(-0.11;0.35)	.298	-0.114	(-0.32;0.09)	.275
762	covert	0.71±0.05	0.76±0.05	0.86±0.05	0.63±0.07	0.50±0.07	0.57±0.06	0.182	(-0.02;0.38)	.078	0.219	(0.02;0.42)	.030
874	covert	0.64±0.05	0.77±0.05	0.76±0.05	0.67±0.07	0.61±0.07	0.65±0.07	0.193	(-0.02;0.41)	.077	0.137	(-0.07;0.34)	.183
902	covert	0.88±0.04	0.90±0.04	0.85±0.04	0.78±0.05	0.76±0.05	0.83±0.05	0.035	(-0.14;0.2)	.688	-0.082	(-0.24;0.08)	.310
	Overt	0.80±0.04	0.83±0.04	0.84±0.04	0.78±0.05	0.73±0.05	0.78±0.05	0.097.	(0.01;0.19)	.034	0.038	(-0.05;0.13)	.390
	Covert	0.67±0.05	0.72±0.05	0.72±0.05	0.64±0.06	0.59±0.06	0.62±0.06	0.100	(0.03;0.17)	.005	0.072	(-0.01;0.16)	.099

Table 2. Interaction effects for group and time regarding the mean reaction time (s) for each individual clip and the overt and covert latent hazards.

		Intervention			Control			[pre-post*group]			[pre-retention*group]		
		Pre	*Post*	Retention	Pre	Post	Retention	β	CI	p	β	CI	p
2	overt	9.28±0.45	10.41±0.41	10.32±0.38	11.05±0.66	10.13±0.72	11.52±0.56	2,050.640	(-71.35;4172.63)	.058	567.002	(-1566.80;2700.81)	.599
15	covert	3.53±0.44	3.52±0.14	4.06±0.19	4.64±0.56	4.91±0.17	5.10±0.25	-246.034	(-1494.63;1002.56)	.698	111.466	(-1238.16;1461.09)	.871
25	covert	9.10±0.14	7.84±0.22	8.05±0.21	8.95±0.18	8.95±0.28	9.28±0.27	-1,262.549	(-2068.53;-456.57)	.002	-1,396.208	(-2137.72;-654.69)	.000
31	covert	11.81±0.45	10.32±0.61	11.09±0.41	12.04±0.7	12.36±1.64	11.66±1.10	-2,007.158	(-6121.23;2106.92)	.327	-327.433	(-2901.04;2246.18)	.793
40	covert	3.86±0.26	1.94±0.32	1.51±0.24	3.95±0.37	2.16±0.44	3.04±0.38	-137.174	(-1448.08;1173.73)	.835	-1,451.932	(-2736.26;-167.61)	.027
46	overt	3.31±0.08	3.06±0.08	3.11±0.08	3.00±0.10	3.38±0.12	3.45±0.11	-627.079	(-1008.09;-246.07)	.001	-641.449	(-992.60;-290.30)	.000
48	overt	11.21±0.18	11.16±0.09	11.36±0.14	10.68±0.24	11.07±0.12	11.82±0.18	-442.326	(-844.44;178.39)	.161	-998.846	(-1752.46;-245.23)	.010
54	covert	2.34±0.08	1.84±0.13	1.77±0.17	2.51±0.11	2.37±0.19	2.33±0.25	-361.699	(-844.44;121.04)	.139	-407.158	(-978.67;164.36)	.160
101	covert	0.99±0.04	0.82±0.07	0.77±0.09	0.96±0.05	1.17±0.10	1.18±0.11	-377.695	(-606.94;-148.45)	.001	-443.771	(-691.03;-196.52)	.001
131	overt	1.31±0.04	1.23±0.05	1.32±0.06	1.53±0.05	1.66±0.06	1.56±0.08	-209.828	(-368.82;-50.84)	.010	-22.334	(-230.35;185.68)	.832
193	covert	3.17±0.10	2.66±0.08	2.95±0.13	3.52±0.14	3.22±0.12	3.67±0.17	-198.729	(-614.95;217.49)	.346	-362.152	(-855.69;131.39)	.148
762	covert	4.56±0.10	4.27±0.12	3.87±0.13	5.03±0.14	5.19±0.19	5.33±0.21	-456.091	(-971.43;59.24)	.082	-991.251	(-1546.15;-436.35)	.001
874	covert	1.71±0.08	1.41±0.07	1.34±0.09	1.50±0.10	1.60±0.11	1.58±0.12	-405.326	(-745.62;-65.03)	.020	-451.879	(-852.75;-51.01)	.028
902	covert	4.56±0.13	4.43±0.16	4.45±0.15	4.43±0.18	4.84±0.22	4.67±0.20	-545.920	(-1232.61;140.77)	.118	-353.388	(-1011.34;304.57)	.290
	Overt	6.29±0.15	6.22±0.16	6.19±0.16	6.31±0.20	6.16±0.21	6.69±0.21	82.773	(-484.01;649.56)	.773	-474.930	(-1165.30;215.44)	.176
	Covert	4.13±0.10	3.73±0.11	3.82±0.11	4.46±0.14	4.51±0.14	4.59±0.15	-457.538	(-899.74;-15.34)	.043	-448.059	(-888.44;-7.68)	.046

Table 3. Interaction effects for group and time regarding entry time of the first fixation (s) on the hazard for each video clip and the overt and covert latent hazards.

		Intervention			**Control**			**[pre-post*group]**			**[pre-retention*group]**		
		Pre	*Post*	Retention	Pre	Post	Retention	β	CI	p	β	CI	p
2	overt	3.71±0.23	3.76±0.27	3.62±0.25	3.12±0.29	3.53±0.35	3.98±0.33	-370.753	(-1360.29;618.78)	.460	-960.127	(-1909.12;-11.14)	.047
15	covert	1.47±0.06	1.27±0.06	1.41±0.07	1.43±0.08	1.34±0.08	1.48±0.09	-116.918	(-380.33;146.50)	.381	-116.267	(-402.47;169.94)	.423
25	covert	0.65±0.06	0.75±0.09	0.88±0.11	0.43±0.07	0.59±0.11	0.71±0.14	-63.013	(-398.86;272.83)	.711	-52.297	(-436.17;331.58)	.788
31	covert	1.09±0.19	1.44±0.21	1.49±0.22	1.01±0.25	1.15±0.26	1.33±0.29	215.007	(-642.53;1072.54)	.621	89.326	(-865.41;1044.06)	.853
40	covert	0.79±0.10	0.75±0.09	0.67±0.08	0.94±0.13	0.89±0.12	0.69±0.10	-.350	(-403.83;403.13)	.999	131.529	(-290.20;553.26)	.538
46	overt	1.96±0.13	2.03±0.11	2.16±0.11	1.52±0.15	1.55±0.15	1.71±0.14	30.310	(-481.15;541.77)	.907	.376	(-486.69;487.44)	.999
48	overt	6.22±0.40	6.45±0.38	5.42±0.41	6.48±0.52	6.46±0.49	7.02±0.54	245.925	(-354.87;2140.39)	.798	-1,348.178	(-3061.75;365.39)	.122
54	covert	1.15±0.06	1.04±0.06	0.99±0.07	1.03±0.08	1.03±0.08	1.08±0.08	-105.442	(-354.87;143.99)	.403	-213.031	(-488.95;62.89)	.129
101	covert	0.51±0.04	0.45±0.04	0.43±0.03	0.50±0.05	0.52±0.05	0.49±0.04	-80.371	(-263.20;102.46)	.386	-64.960	(-228.45;98.53)	.433
131	overt	0.77±0.04	0.64±0.04	0.69±0.04	0.72±0.05	0.79±0.05	0.67±0.05	-196.106	(-381.87;-10.34)	.039	-29.079	(-199.49;141.33)	.736
193	covert	0.89±0.07	0.81±0.07	0.88±0.09	0.72±0.10	0.74±0.09	1.02±0.11	-104.998	(-419.32;209.32)	.509	-308.353	(-670.92;54.22)	.095
762	covert	2.89±0.10	2.89±0.11	2.93±0.12	2.78±0.12	2.87±0.15	2.87±0.16	-90.450	(-557.90;377)	.702	-48.972	(-528.48;430.53)	.840
874	covert	0.49±0.04	0.54±0.05	0.48±0.05	0.37±0.05	0.45±0.06	0.39±0.06	-22.359	(-195.26;150.54)	.798	-15.174	(-202.54;172.19)	.873
902	covert	3.53±0.09	3.32±0.12	3.28±0.12	3.74±0.12	3.74±0.15	3.60±0.15	-208.881	(-666.73;248.97)	.368	-101.530	(-557.78;354.72)	.660
	Overt	3.27±0.13	3.27±0.14	2.99±0.14	2.95±0.17	2.97±0.19	3.39±0.18	-27.554	(-653.21;598.11)	.931	-725.873	(-1292.65;-159.10)	.012
	Covert	1.36±0.04	1.34±0.05	1.35±0.05	1.30±0.06	1.40±0.06	1.37±0.07	-115.267	(-312.59;82.06)	.250	-78.046	(-283.48;127.39)	.453

Table 4. Interaction effects for group and time regarding mean duration of the first fixation (s) on the hazard for each video clip and the overt and covert latent hazards.

		Intervention			**Control**			**[pre-post*group]**			**[pre-retention*group]**		
		Pre	Post	Retention	Pre	Post	Retention	β	CI	p	β	CI	p
2	overt	0.34±0.03	0.33±0.02	0.34±0.03	0.38±0.04	0.32±0.03	0.36±0.03	41.991	(-66.24;150.22)	.444	13.054	(-100.15;126.26)	.820
15	covert	0.40±0.03	0.43±0.03	0.45±0.04	0.42±0.03	0.44±0.04	0.53±0.05	9.346	(-125.18;143.87)	.891	-63.165	(-202.29;75.96)	.370
25	covert	0.34±0.03	0.36±0.03	0.35±0.04	0.36±0.04	0.35±0.04	0.44±0.05	24.104	(-121.38;169.59)	.743	-80.660	(-241.55;80.23)	.323
31	covert	0.26±0.02	0.27±0.02	0.26±0.02	0.33±0.03	0.30±0.02	0.28±0.02	41.627	(-49.51;132.76)	.368	47.003	(-40.00;134.00)	.287
40	covert	0.38±0.03	0.39±0.04	0.44±0.03	0.41±0.04	0.47±0.05	0.44±0.04	-49.506	(-184.99;85.98)	.471	23.972	(-109.55;157.49)	.723
46	overt	0.34±0.03	0.37±0.03	0.40±0.03	0.39±0.04	0.45±0.04	0.41±0.04	-39.293	(-183.58;105.00)	.591	37.982	(-97.72;173.69)	.580
48	overt	0.35±0.04	0.31±0.02	0.28±0.02	0.37±0.05	0.27±0.03	0.33±0.03	65.962	(-78.68;200.13)	.332	-32.685	(-172.60;107.23)	.645
54	covert	0.40±0.04	0.34±0.02	0.34±0.02	0.41±0.05	0.30±0.03	0.35±0.03	56.379	(-78.68;191.44)	.410	-5.841	(-152.36;140.67)	.937
101	covert	0.48±0.03	0.51±0.03	0.45±0.03	0.44±0.04	0.52±0.04	0.47±0.04	-51.016	(-169.34;67.30)	.395	-56.501	(-183.93;70.93)	.382
131	overt	0.52±0.03	0.49±0.02	0.41±0.02	0.52±0.04	0.49±0.03	0.48±0.03	6.096	(-117.08;129.27)	.922	-60.285	(-168.62;48.05)	.273
193	covert	0.49±0.03	0.46±0.04	0.50±0.03	0.52±0.04	0.53±0.05	0.46±0.04	-34.178	(-184.59;116.24)	.654	79.148	(-58.72;217.01)	.258
762	covert	0.32±0.02	0.31±0.02	0.29±0.02	0.33±0.03	0.37±0.03	0.39±0.03	-50.364	(-149.81;49.08)	.318	-93.082	(-201.23;15.07)	.091
874	covert	0.32±0.02	0.38±0.03	0.40±0.03	0.37±0.03	0.38±0.03	0.42±0.03	49.848	(-47.03;146.73)	.310	27.676	(-80.86;136.21)	.615
902	covert	0.23±0.01	0.24±0.02	0.24±0.01	0.25±0.02	0.24±0.02	0.26±0.02	24.469	(-40.12;89.06)	.455	9.210	(-51.29;69.71)	.764
	Overt	0.39±0.02	0.37±0.01	0.36±0.01	0.41±0.02	0.37±0.02	0.39±0.02	27.324	(-38.43;93.07)	.412	-12.320	(-83.82;59.18)	.734
	Covert	0.36±0.01	0.37±0.01	0.37±0.01	0.38±0.01	0.38±0.01	0.40±0.02	11.718	(-29.76;53.19)	.577	-10.249	(-54.74;34.25)	.649

Table 5. Interaction effects for group and time regarding mean dwell time (s) on the hazard for each video clip and the overt and covert latent hazards.

		Intervention			Control			[pre-post*group]			[pre-retention*group]		
		Pre	Post	Retention	Pre	Post	Retention	β	CI	p	β	CI	p
2	overt	6.93±0.19	7.08±0.21	7.15±0.22	8.33±0.24	7.38±0.28	7.40±0.29	1,092.765	(314.44;1871.09)	.006	1,149.966	(334.78;1965.16)	.006
15	covert	2.71±0.19	2.81±0.21	8.79±0.23	9.38±0.24	3.31±0.27	8.20±0.29	6,169.607	(5483.66;6855.56)	.000	7,266.555	(6410.58;8122.53)	.000
25	covert	5.27±0.19	6.09±0.20	6.15±0.20	5.90±0.24	6.42±0.26	6.44±0.26	304.601	(-414.41;1023.61)	.403	335.435	(-331.97;1002.84)	.322
31	covert	6.52±0.26	6.37±0.29	6.73±0.29	7.37±0.34	6.95±0.38	6.53±0.37	277.340	(-746.54;1301.22)	.593	1,053.114	(-11.71;2117.94)	.053
40	covert	3.07±0.11	3.33±0.12	3.26±0.12	3.35±0.15	3.16±0.15	3.47±0.15	451.373	(-42.87;945.62)	.073	74.599	(-392.53;541.72)	.752
46	overt	1.45±0.11	2.00±0.09	2.10±0.09	2.62±0.15	2.20±0.12	2.51±0.11	961.478	(559.81;1363.15)	.000	754.775	(319.33;1190.22)	.001
48	overt	0.97±0.07	1.10±0.07	0.94±0.08	1.22±0.09	1.18±0.09	1.24±0.10	163.970	(-210.54;455.37)	.267	-53.084	(-323.57;217.40)	.698
54	covert	1.21±0.08	1.21±0.08	1.08±0.09	1.50±0.11	1.37±0.10	1.43±0.11	137.834	(-210.54;486.21)	.435	-57.310	(-375.22;260.60)	.722
101	covert	1.45±0.05	1.34±0.06	1.37±0.05	1.55±0.06	1.33±0.08	1.45±0.06	106.856	(-119.35;333.06)	.351	16.023	(-174.92;206.97)	.868
131	overt	1.64±0.06	1.72±0.07	1.57±0.07	1.88±0.08	1.68±0.09	1.88±0.09	275.174	(-2.35;552.69)	.052	-62.870	(-348.42;222.68)	.664
193	covert	3.45±0.08	3.44±0.11	3.39±0.10	3.74±0.11	3.54±0.14	3.50±0.13	186.502	(-241.32;614.33)	.390	171.706	(-234.27;577.69)	.404
762	covert	2.44±0.09	2.28±0.11	2.33±0.11	2.59±0.12	2.45±0.14	2.42±0.15	-27.496	(-434.32;379.33)	.894	61.571	(-344.79;467.94)	.765
874	covert	2.08±0.06	2.04±0.08	2.26±0.07	2.23±0.07	2.12±0.10	2.28±0.09	65.415	(-215.72;346.55)	.646	123.709	(-160.84;408.26)	.391
902	covert	1.63±0.05	1.71±0.08	1.78±0.07	1.54±0.07	1.63±0.10	1.73±0.09	-6.739	(-284.51;271.03)	.962	-26.518	(-285.41;232.37)	.840
	Overt	2.75±0.07	2.97±0.08	2.94±0.07	3.51±0.09	3.11±0.10	3.26±0.09	618.852	(362.66;875.04)	.000	447.197	(175.99;718.41)	.001
	Covert	2.98±0.06	3.05±0.07	3.71±0.06	3.92±0.08	3.21±0.09	3.75±0.08	767.888	(521.23;1014.55)	.000	901.888	(673.45;1130.33)	.000

Table 6. Interaction effects for group and time regarding the mean number of fixations on the hazard for each video clip and the overt and covert latent hazards.

		Intervention			Control			[pre-post*group]			[pre-retention*group]		
		Pre	Post	Retention	Pre	Post	Retention	β	CI	p	β	CI	p
2	overt	17.18±0.65	16.38±0.62	17.35±0.66	18.59±0.85	17.00±0.81	18.04±0.86	.783	(-2.06;3.63)	.586	.710	(-2.01;3.43)	.606
15	covert	7.16±0.66	7.36±0.72	24.82±0.80	24.87±0.85	9.05±0.94	22.20±1.03	16.009	(13.14;18.88)	.000	20.338	(17.40;23.28)	.000
25	covert	15.18±0.59	16.36±0.70	17.18±0.68	16.74±0.76	17.57±0.90	17.35±0.88	.351	(-2.28;2.99)	.793	1.391	(-1.04;3.82)	.260
31	covert	18.68±0.87	19.35±1.04	19.19±0.88	20.07±1.14	18.24±1.35	18.09±1.15	2.492	(-1.22;6.20)	.186	2.491	(-0.63;5.61)	.117
40	covert	8.85±0.40	8.39±0.35	8.35±0.36	9.22±0.52	8.20±0.45	9.13±0.47	.564	(-1.14;2.27)	.515	-.413	(-1.96;1.13)	.598
46	overt	4.45±0.36	5.69±0.27	5.99±0.28	6.59±0.47	4.89±0.35	6.24±0.37	2.940	(1.61;4.27)	.000	1.886	(0.43;3.34)	.012
48	overt	2.97±0.24	3.49±0.24	3.12±0.24	3.96±0.32	3.61±0.31	3.87±0.31	.862	(-0.16;1.89)	.098	.228	(-0.74;1.19)	.641
54	covert	2.91±0.23	3.49±0.23	3.12±0.23	4.21±0.30	3.99±0.31	3.92±0.31	.795	(-0.16;1.75)	.103	.501	(-0.46;1.46)	.305
101	covert	4.00±0.20	3.62±0.22	3.86±0.21	4.15±0.26	3.17±0.28	3.98±0.28	.595	(-0.32;1.51)	.199	.033	(-0.84;0.91)	.941
131	overt	4.32±0.18	4.45±0.21	4.35±0.22	4.72±0.24	4.33±0.28	4.61±0.28	.518	(-0.42;1.45)	.275	.134	(-0.75;1.02)	.764
193	covert	8.31±0.25	8.20±0.31	7.85±0.29	8.11±0.33	7.65±0.40	8.33±0.38	.347	(-0.93;1.62)	.591	-.679	(-2.00;0.64)	.309
762	covert	7.01±0.28	6.63±0.30	6.75±0.32	6.93±0.36	6.77±0.39	6.92±0.41	-.215	(-1.49;1.06)	.739	-.250	(-1.64;1.14)	.723
874	covert	7.32±0.26	6.53±0.31	7.28±0.28	7.43±0.34	6.43±0.40	6.74±0.37	.214	(-1.05;1.48)	.738	.657	(-0.57;1.88)	.290
902	covert	7.76±0.27	7.28±0.35	7.59±0.33	7.96±0.35	7.46±0.45	7.96±0.43	.024	(-1.37;1.42)	.973	-.167	(-1.40;1.07)	.790
	Overt	7.23±0.22	7.50±0.21	7.70±0.21	8.46±0.28	7.62±0.27	8.19±0.28	1.106	(0.17;2.04)	.020	.740	(-0.22;1.70)	.130
	Covert	8.68±0.21	8.66±0.23	10.52±0.23	10.94±0.27	8.78±0.30	10.41±0.31	2.144	(1.25;3.04)	.000	2.379	(1.48;3.27)	.000

Table 5. Main effects (p-values) for time (pre-post and pre-retention) for response rate (RR), reaction time (RT), FF (entry time of the first fixation), duration of the first fixation (Ffdur), dwell time (DT), and fixation count (FC) for the intervention group respectively.

	[time=pre-post]						[time=pre-retention]					
clip	RR	RT	FF	Ffdur	DT	FC	RR	RT	FF	Ffdur	DT	FC
2	0.731	0.050	0.884	0.780	0.534	0.361	0.507	0.092	0.745	0.969	0.382	0.842
15	0.468	0.971	0.014	0.457	0.633	0.793	0.376	0.198	0.438	0.251	0.000	0.000
25	0.081	0.000	0.369	0.653	0.000	0.150	0.027	0.000	0.059	0.908	0.000	0.009
31	0.000	0.054	0.185	0.814	0.643	0.562	0.000	0.147	0.168	0.844	0.517	0.595
40	0.150	0.000	0.734	0.825	0.093	0.385	0.000	0.000	0.365	0.202	0.197	0.295
46	0.004	0.035	0.704	0.570	0.000	0.003	0.000	0.068	0.223	0.173	0.000	0.001
48	0.610	0.799	0.690	0.377	0.163	0.106	1.000	0.540	0.131	0.097	0.739	0.636
54	0.708	0.001	0.174	0.186	0.998	0.048	0.375	0.001	0.078	0.170	0.176	0.481
101	0.081	0.017	0.243	0.408	0.110	0.175	0.446	0.004	0.106	0.521	0.165	0.601
131	0.376	0.132	0.031	0.478	0.392	0.661	0.402	0.840	0.159	0.003	0.430	0.925
193	0.045	0.000	0.390	0.549	0.904	0.781	0.005	0.163	0.949	0.686	0.595	0.257
762	0.413	0.042	0.967	0.734	0.195	0.338	0.012	0.000	0.802	0.375	0.387	0.542
874	0.055	0.004	0.285	0.040	0.598	0.046	0.066	0.003	0.974	0.019	0.042	0.919
902	0.807	0.500	0.151	0.420	0.368	0.272	0.434	0.555	0.086	0.344	0.055	0.662
overt	0.123	0.707	0.974	0.524	0.007	0.353	0.637	0.637	0.101	0.155	0.022	0.116
covert	0.020	0.003	0.731	0.458	0.406	0.952	0.021	0.021	0.859	0.428	0.000	0.000