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Department of Movement and Sports Sciences

The role of visual information in the steering behaviour of young and adult bicyclists

Pieter Vansteenkiste

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Supervisor

Prof. Dr. Matthieu Lenoir	(Ghent University)

Co-supervisors

Prof. Dr. Greet Cardon	(Ghent University)
Prof. Dr. Renaat Philippaerts	(Ghent University)

Examination board

Prof. Dr. Johan Vande Walle	(Ghent University - Chairman)
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Dr. Frederik Deconinck	(Ghent University – Reading Committee)

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TABLE OF CONTENTS

SUMMARY

In a first series of experiments, the visual behaviour during different steering tasks, and under different constraints, was investigated in an **indoor environment.** Young learner, and experienced adult bicyclists were asked to steer through narrow lanes, a curved lane, and a slalom. Participants directed their gaze to the future path about one to two seconds ahead, and moved forward using optokinetic nystagmus-like eye movements. Both cycling speed and task demand were found to affect the visual behaviour of bicyclists. Although these shifts of visual attention were in line with earlier findings in pedestrians and car drivers, they did not seem to be entirely in line with the two-level model of steering behaviour. Therefore, a redefined version of this model was proposed as the 'gaze constraints model for steering'.

During a simple linear steering task, the visual behaviour of children (between 6 and 12 years of age) was similar to that of adults. However, in a more demanding slalom task children adopted a different visual-motor strategy. Whereas adults made more use of anticipatory fixations and often looked at the functional space between two cones, children mainly focussed on the upcoming cone. These findings suggest that adults plan their route through the slalom whereas children focus on steering around one cone at the time.

In a second series of experiments, the distribution of visual attention was investigated in an **actual traffic environment** and the influence of a low quality cycling track on visual behaviour was studied. Results showed that children direct their gaze more to the environment and less to the path than adults. However, both adults and children made an apparent shift of visual attention from distant environmental regions towards more proximate road properties on the low quality cycling track.

In general, the current thesis provides insights into how visual attention of young and adult bicyclists is distributed during different steering tasks and how this is affected by individual, task, and environmental constraints. Based on the current results, a gaze constraints model for steering was proposed. Furthermore, it seems that children adapted their visual behaviour to their limited capabilities, but that children's visual behaviour changes in a similar way to changing task constraints as the visual behaviour of adults. These findings suggest that traffic rules, road infrastructure and traffic education should take into account the limited capabilities of children. However, it should be noted that this work only focussed on the lane-keeping task. Future research should therefore study the integration of these findings in the visual control of other traffic tasks such as hazard perception. A better understanding of the development of information processing of young learner bicyclists could potentially lead to better traffic education and more appropriate road infrastructure.

Additionally, a new fixation-by-fixation **analysis method** to analyze head-mounted eye tracking data was tested in this thesis. This method was found to be a good alternative to the time-consuming frame-by-frame method, provided that the areas of interest were large, and the analysis is done over an extended period of time.

SAMENVATTING

In een eerste reeks experimenten werd het visuele gedrag van fietsers onderzocht in een **indooromgeving** tijdens het uitvoeren van verschillende stuurtaken en onder verschillende condities. Onervaren jonge, en ervaren volwassen fietsers werden gevraagd om door nauwe stroken, een bocht, en een slalom te fietsen. De proefpersonen richtten hun blik voornamelijk op het wegdek op een afstand van ongeveer twee seconden voor hen en bewogen hun ogen vooruit gebruik makend van optokinetische nystagmus. Zowel fietssnelheid als de taakmoeilijkheid hadden een effect op het visuele gedrag van de fietsers. Hoewel deze veranderingen in visuele aandacht overeenstemden met eerdere bevindingen bij voetgangers en autorijders bleken deze niet volledig conform te zijn met het twee-level model voor stuurgedrag. Daarom werd een nieuwe versie van het twee-level model voorgesteld als het ‘gaze constraints’ model voor stuurgedrag.

Tijdens een eenvoudige rechtlijnige stuurtaak bleek het visuele gedrag van kinderen (tussen 6 en 12 jaar oud) gelijkaardig te zijn als dat van volwassenen. Bij een meer uitdagende slalom taak daarentegen, namen de kinderen een andere visuo-motorische strategie aan. Terwijl volwassenen meer gebruik maakten van anticiperende fixaties en vaak naar de functionele ruimte tussen twee kegels keken, besteedden kinderen voornamelijk aandacht aan de eerstvolgende kegel. Deze bevindingen suggereren dat volwassenen hun traject plannen doorheen de slalom terwijl kinderen eerder sturen rond één kegel per keer.

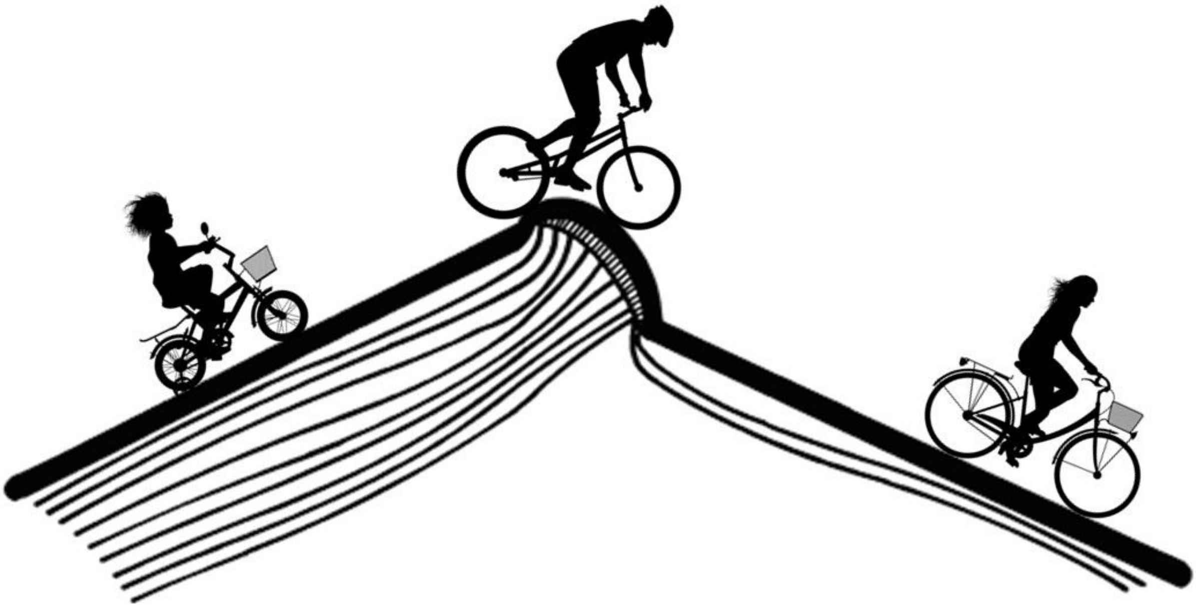
In een tweede reeks experimenten werd de verdeling van de visuele aandacht onderzocht in een **realistische verkeersomgeving** en werd de invloed van een lage kwaliteit van het fietspad op het visuele gedrag bestudeerd. Resultaten toonden aan dat kinderen meer naar de omgeving keken en minder naar het fietspad dan volwassenen. Op een fietspad van lage kwaliteit was er echter zowel bij volwassenen als bij kinderen een duidelijke verschuiving van de visuele aandacht van de ruime omgeving naar de meer nabije eigenschappen van het fietspad.

In het **algemeen** verstrekte de huidige thesis inzichten in hoe de visuele aandacht van jonge en volwassen fietsers verdeeld is gedurende verschillende stuurtaken en hoe deze aandacht wordt beïnvloed door individuele, taakgebonden, en omgevingsgebonden factoren. Op basis van de huidige resultaten werd een nieuw model voor kijkgedrag in functie van sturen voorgesteld. Daarenboven bleek dat kinderen hun visuele gedrag aanpassen aan hun beperkte capaciteiten, maar dat ze hun kijkgedrag wel op een gelijkaardige manier aanpassen aan veranderende taak- en omgevingsgebonden factoren als volwassenen. Deze bevindingen suggereren dat verkeersregels, weginfrastructuur en verkeersopleiding rekening zouden moeten houden met deze beperkte mogelijkheden van kinderen. Niettemin moet opgemerkt worden dat dit werk voornamelijk focuste op de stuurtaak in functie van ‘op het fietspad blijven’. Verder onderzoek zou deze bevindingen moeten integreren in de visuele controle van andere verkeerstaken zoals gevaarherkenning. Inzicht in de ontwikkeling van verwerkingprocessen van visuele informatie van de jonge

beginnende fietser kan mogelijks leiden tot betere verkeersopleiding en beter geschikte fietsinfrastructuur.

Tenslotte werd ook een nieuwe **fixatie-per-fixatie analyse** getest om ‘head-mounted’ oogbewegingsdata te analyseren. Deze methode werd als een geschikt alternatief bevonden voor de tijdrovende beeld-per-beeld methode, met als voorwaarde dat de ‘areas of interest’ groot waren en dat de analyse over een langere tijdspanne gebeurt.

General introduction



1. An introduction to cycling

1.1. A short history of the bicycle

Bicycles have been around since the mid 1800’s. However, these early models were quite inconvenient ‘walking machines’ and/or extremely dangerous to ride (e.g. the hobby-horse and the “ordinary” bicycle, see Fig. 1). As a result, riding these ‘bicycles’ was rather an eccentric activity than a handy way to get from A to B. Only after the development of the ‘safety bicycle’ in the late 1880’s, riding a bicycle became more convenient. With the addition of pneumatic tires some years later, the bicycle was ready to take up an important role in everyday transportations (Weiss 2010).

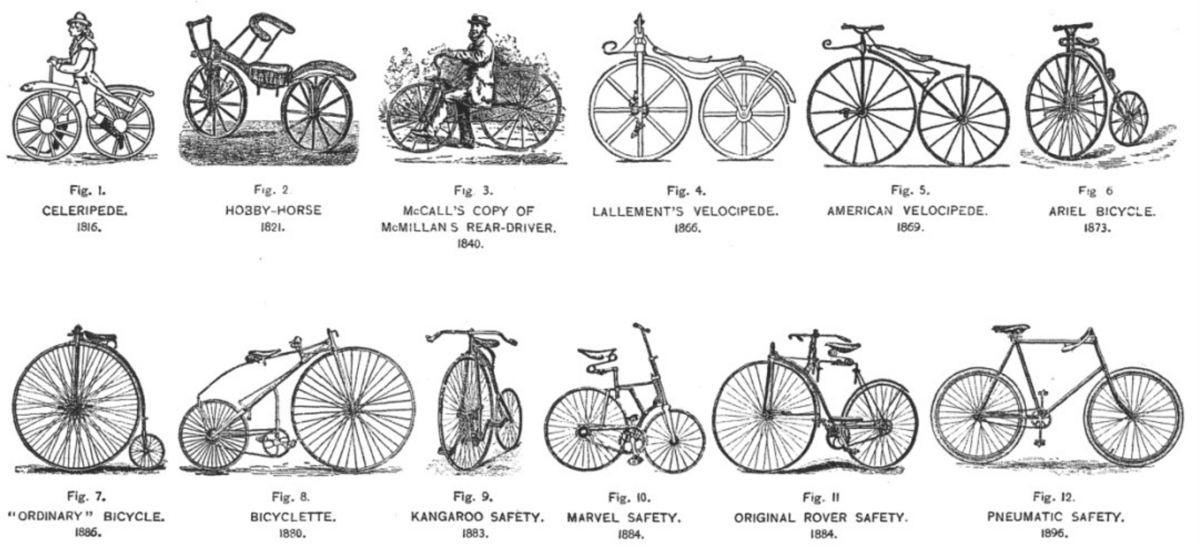


Figure 1 : The evolution of the bicycle; starting from the initial hobby horse design by Karl von Drais, from around 1820, to the final and current safety bicycle, having equally sized wheels, a chain drive and pneumatic tires, from around 1890 From : Schwab 2012.

Unfortunately, the early rise of the bicycle was put on hold by the advent of affordable cars. **Between 1950 and 1975**, many western European countries favoured cars over bicycles in their policies, leading to increasing motorization levels and a sharp decline in bicycling (Pucher & Buehler 2012). However, the car accidents, congestion, and pollution that came along with the increasing use of cars provoked a reversal of the transportation policies in many western European cities around 1975 (especially those in Germany, Denmark and the Netherlands). As a result, bicycle usage has been gradually increasing ever since.

Nowadays, a bicycle culture is thriving again, and it seems to be catching on worldwide. Cities with strong bicycle oriented transportation policies such as Amsterdam and Copenhagen are widely renowned, and other big and small cities are investigating how to make their roads more bicycle friendly. Campaigns are set up to make bicycling ‘chic’, many blogs write about the joys of bicycling, instagram and pinterest are full of trendy bicycles pictures and owners, and many books explain all possible aspects of bicycling. Furthermore bicycle racing has become a highly popular sport. Road racing, track cycling, cyclo-cross, mountain biking, and many other variations of bicycle competitions draw large crowds, especially in Europe. Together with improving bicycle infrastructure and the advent of electrical bicycles, it seems that the future for this vehicle is brighter than ever before.

> *"A bicycle can give you the feeling of freedom and speed you get from riding a motorcycle, the sense of well-being and peace you get from meditating, the health benefits you get from an afternoon in the gym, the sense of self-expression you get from learning to play guitar, and the feeling of victory you get from completing a marathon. It's an invention that was in many ways ahead of its time, and whose time has finally come."*
>
> *From 'Bike Snob'* (Weiss 2010)

1.2. Cycling : The answer to all our problems ?

In the last decennia, many studies have examined the costs and benefits of a shift from motorized to active transport. The benefits of a modal shift[1] towards active transport are numerous and are mostly based on the increase of **physical activity** that comes with it. Since walking and cycling are more likely to be sustainable in the long term than gym based exercise programs (Hillsdon et al. 1995; Carnall 2000), they are highly suitable to achieve the daily recommended amount of physical activity. These types of regular moderate intensity physical activity not only have been shown to have a positive effect on physical well being through increased general fitness and decreased cardiovascular risk (Oja et al. 2011; de Hartog et al. 2010; Hamer & Chida 2008; Shephard 2008), they are also believed to have a positive effect on **mental health** (Pinchasov et al. 2000; Lindwall et al. 2006; Rimer et al. 2012). Recreational cycling is perceived as a relaxing, fun, and social activity which has been reported to improve general emotional well being (Whitaker 2005). Furthermore, increased levels of active commuting also has an indirect effect on health due to its positive impact on the **environment**. A shift from motor vehicles to more pedestrians and bicyclists improves air quality, reduces noise pollution and lowers greenhouse gas emissions (Pucher & Buehler 2012), which in turn reduces insomnia and stress (Dora & Phillips 2000). Finally, promoting the use of bicycles has also been associated with economic benefits both for the bicyclist and for the society (Buis and Wittink 2000).

1.3. Barriers to cycling: is the fear for bicycle accidents justified?

Unfortunately, compared to car drivers who are protected by a metal cage, cyclists are very vulnerable road users. Per kilometre travelled, the fatality risk is about three times

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[1] The term 'modal shift' indicates a shift from a certain mode of transport to another

higher for bicyclists than for car drivers[2] (Van Hout & Cuyvers 2007). However, these numbers might be misleading since cars usually travel much faster. When the fatality risk is expressed in function of time spent in traffic, or per displacement, the difference between car driving and bicycling is much smaller (Van Hout & Cuyvers 2007). Nevertheless, the psychological distress associated with the actual and perceived risks of cycling in traffic are frequently reported as barriers to cycling (Horton 2007; Schepers et al. 2013; Rivara & Sattin 2011; Vandenbulcke et al. 2009).

In general, **traffic accidents** can be caused by three factors: the vehicle (e.g. broken brakes), the environment (e.g. slippery surface), and human behaviour (actions of the rider him/herself and/or other traffic participants; Elliott et al., 2007). Where, when and how bicycle accidents exactly occur depends largely on the region, population density, season, etc., and are therefore often difficult to compare. Nevertheless, some general findings can be acknowledged. Although in the last 30 years the number of bicyclists has been increasing in Europe, the number of fatal bicycle accidents has decreased by about 55% (DEKRA, 2011; ERSO, 2006). Unfortunately, some age groups are overrepresented in accident statistics. Although bicyclists of all age groups can be considered vulnerable road users, accident analyses suggest that children between 6 and 14 years of age and elder people are particularly overrepresented (See Fig 2; Carpentier and Nuyttens, 2013; DEKRA, 2011; ERSO, 2006). However, for children, this high number of bicycle accidents seems to be largely related to the higher share of bicycle trips by this group (Fig 2).

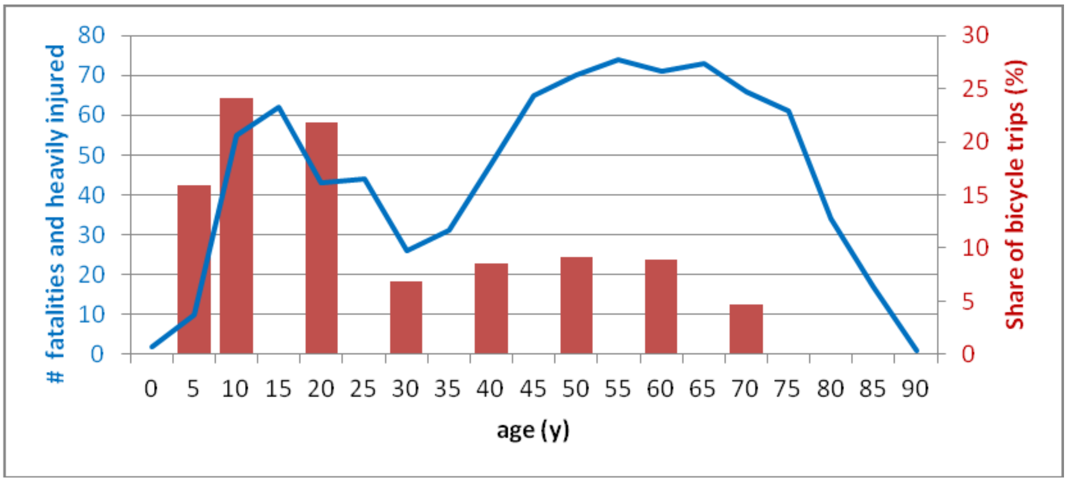

Figure 2 : Number of fatalities and heavy injuries in 2011 per age group (blue line), and the share of bicycle trips per age croup as compared to the total number of bicycle trips made in Flanders (red columns). Data from Flanders in 2011 and 2002 respectively. (Adapted from Carpentier and Nuyttens, 2013; and from Vlaams Totaalplan Fiets, 2002)

Most bicycle accidents involving **children** occur in the afternoon, when the children are cycling back home or playing outside (see Fig. 3), and do not involve other road users (Hout and Cuyvers, 2007; *ERSO*, 2006). In these so called single-bicycle accidents, the cause of the

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[2] data from Flanders, fatality risk varies over countries

accident is most often poor road quality, stunt riding, collision with an obstacle, or loss of control at low speed (Schepers & Wolt 2012; Selbst et al. 1887). However, the collisions with motorized vehicles account for almost all of the fatal injuries among children (Acton et al. 1995). Due to the large mass and higher speed, the kinetic energy of motor vehicles is much larger and a collision between a motor vehicle and a bicycle is much more likely to cause severe injuries (Wegman et al. 2012; Elvik 2010). According to Spence et al. (1993) 70% of the collisions involving cycling children are caused by the children themselves, either by violation of the road traffic law, or because of poor road sense. Analysis of the inappropriate road behaviour of young cyclists in Germany showed that 'incorrect road use and being on the wrong side of the road' were the most frequent causes of accidents (DEKRA 2011). This inappropriate road behaviour of young cyclists has been attributed to immature psychomotor skills, attention deficits and a lack of knowledge of how to manage a traffic situation with moving objects (Nixon et al. 1987; Pless et al. 2014; Hansen et al. 2005). The development of these skills and abilities will be further addressed in section 5.

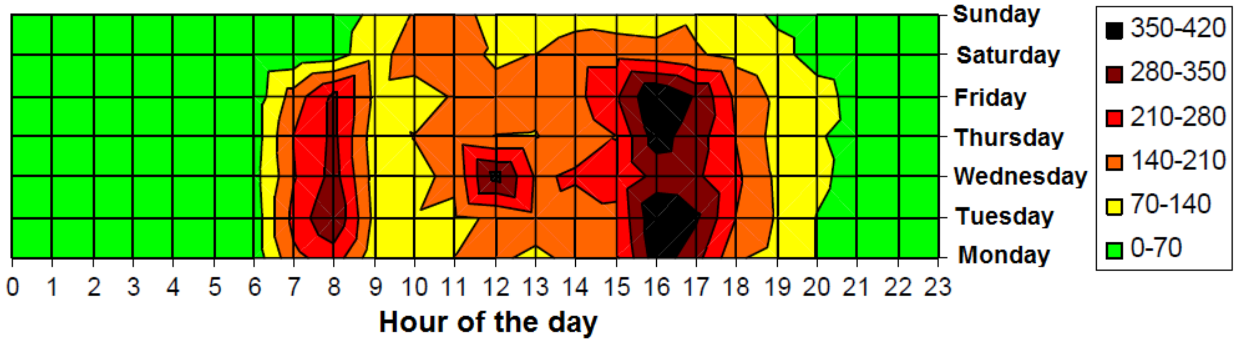

Figure 3 : bicycle accidents of children in function hour of day and day of the week
(Van Hout & Cuyvers 2007)

1.4. Risks versus benefits

Although it is undeniable that there are some disadvantages inherent to bicycling, it is generally accepted that the **health benefits of bicycling largely exceed the risks of traffic injuries** (Rabl & de Nazelle 2012; de Hartog et al. 2010). Since cycling is accessible, affordable and achievable for people of all ages, cycling has a huge potential to increase health over large populations. As national and local governments acknowledge these benefits of bicycling, they start to promote cycling and improve cycling infrastructure. Nevertheless, it is important to acknowledge the disadvantages and dangers inherent to bicycling, and to invest in improving these obstacles for cycling.

"It is hard to beat cycling when it comes to environmental, economic, and social sustainability" (Pucher & Buehler 2012)

1.5. How could research make cycling safer?

Traffic safety enhancing measures are typically classified under the three E’s of injury prevention: Enforcement, Engineering, and Education.

- **Enforcement**

Although many efforts have been made to **enforce safety measures** on car drivers and bicyclists, too many bicycle accidents are still caused by speeding, drunk driving, crossing red lights and lack of appropriate bicycle lights. However, traffic rules also have to be reconsidered where necessary. **Changing traffic policies** by lowering the maximal vehicle speed and giving priority to vulnerable road users on accident prone locations could benefit the general traffic safety. For example, the city of Ghent recently announced that the speed limit will be reduced to 30km/h for whole inner city. Accident statistics are an essential tool to identify problems in traffic safety and can contribute to better traffic policies.

- **Engineering**

Engineering can help both at preventing and reducing the damage of bicycle accidents. Providing **bicycle-specific facilities** can significantly reduce the number of bicycle accidents and injuries (Reynolds et al. 2009). With regard of safe bicycle infrastructure, insights into how bicycle accidents occur can lead to better designed infrastructure. Furthermore, innovative approaches to the design of bicycles, cars and protective gear can also lead to further reduction of the bicycle related injuries (See Fig. 4).

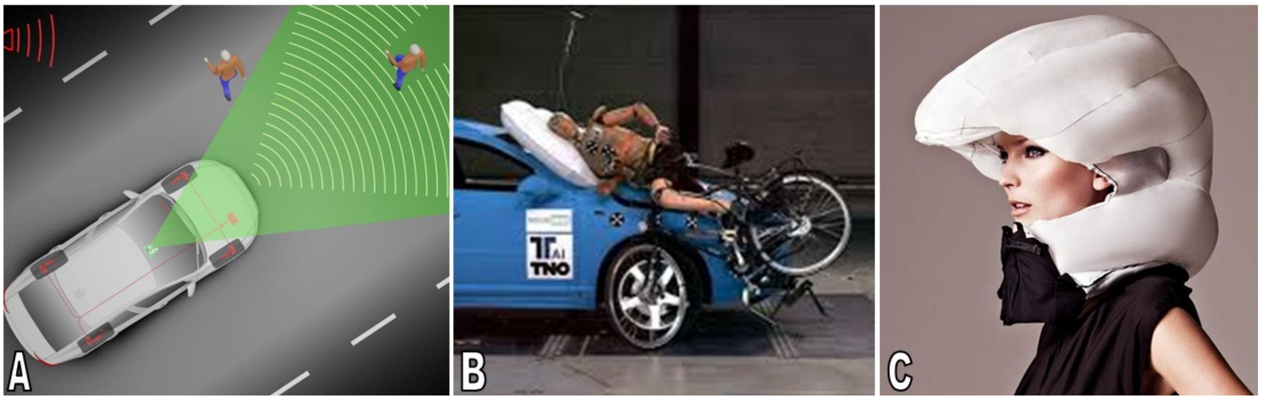

Figure 4 : examples of potential protective systems/gear. A) automatic braking system for cars (VOLVO, Göteborg, SE) B) Bicycle airbag in cars (TNO, The Hague, NL) C) Bicycle helmet with airbag (Hövding, Malmö, SE)

- **Education**

Since most accidents happen due to a human error, education and sensitization seem to be essential to improve traffic safety. In **car driving**, a driver’s licence has to be obtained, and multiple studies have examined possibilities to improve traffic skills through extra educational tools such as hazard perception trainings (Borowsky et al. 2010; Scialfa et al.

2011; Underwood et al. 2011). Since collisions with motorized vehicles cause the most severe injuries and fatalities, it is important to keep emphasizing on the protection of vulnerable road users during car driving education.

In contrast to car driving, there are no minimal motor or cognitive requirements to use a **bicycle**. Nevertheless, most schools and parents teach basic traffic rules and cycling skills to learner cyclists. Bicycle training courses have been shown to improve cycling skills at short term, and possibly also on the long term (Ducheyne, et al. 2013; Ducheyne, et al. 2013a). However, since bicycling is essentially a joint function of cognitive and motor capacities (Briem et al. 2004), traffic education should also focus on cognitive skills such as hazard perception, gap detection and risk perception.

1.6. Summary

For short displacements, researchers are almost unanimously convinced of the benefits of bicycling compared to car driving. However, as is the case for car driving, learner bicyclists seem to be more involved in traffic accidents. Accident statistics suggest that bicycle accidents of young cyclists are most often due to human behaviour, not to a failure of the bicycle or to environmental factors. More specifically, it seems that the behaviour of the children themselves is often the cause of the accidents. Although it has been suggested that attention deficits and a lack of knowledge of how to manage a traffic situations could be the cause of children’s inappropriate bicycle behaviour, research has barely focussed on the development of these perceptual-motor skills. Since perceiving the traffic environment is essential for taking safely part in it, understanding the perceptual-motor behaviour of both young and adult bicyclists is an important part of understanding bicycling behaviour.

2. The distribution of selective visual attention

In order to react appropriately to complex traffic situations, bicyclists first need to perceive and interpret the environment. In general, this can be achieved by ‘paying attention’ on the road and its users. Attention can be defined as the resource of psychic energy that we devote to the task at any time (Shinar 2007). However, since the rate at which information can be efficiently processed is limited (information processing capacity), the amount of attention that can be distributed (paid) over the multiple tasks is also limited. Due to these **limited attentional resources,** the distribution of attention is a crucial skill in traffic situations. By selecting the important, and ignoring the irrelevant objects/events, attention can be efficiently distributed in function of the traffic task. This process of mentally concentrating on specific information present in our environment is called **selective attention**. Although multiple sensory systems can provide information in function of locomotion (auditory, proprioceptive, etc.), safe traffic participation by bicycle relies primarily on visual information. Therefore, in this dissertation we focus on selective visual attention. In this section we briefly describe the mechanisms of visual information acquisition.

2.1. Eye movements

Human eyes provide a visual field of approximately 200° and 110° in the horizontal and vertical axis, respectively. However, only visual information that falls on the **fovea centralis**, a small central region on the retina, is perceived in detail. The resolution of visual information falls rapidly as receptor cells further from the fovea are triggered (see Fig. 5). Depending on how the fovea is exactly defined, its angular diameter is only between 0.3° and 2° (Leigh & Zee 2006; Aring et al. 2007; Land 2006), roughly equivalent of an adult viewing their outstretched thumbnail. Nevertheless, people are hardly aware of this narrow field of detailed vision thanks to the efficient use of various eye-movements and visual mechanisms.

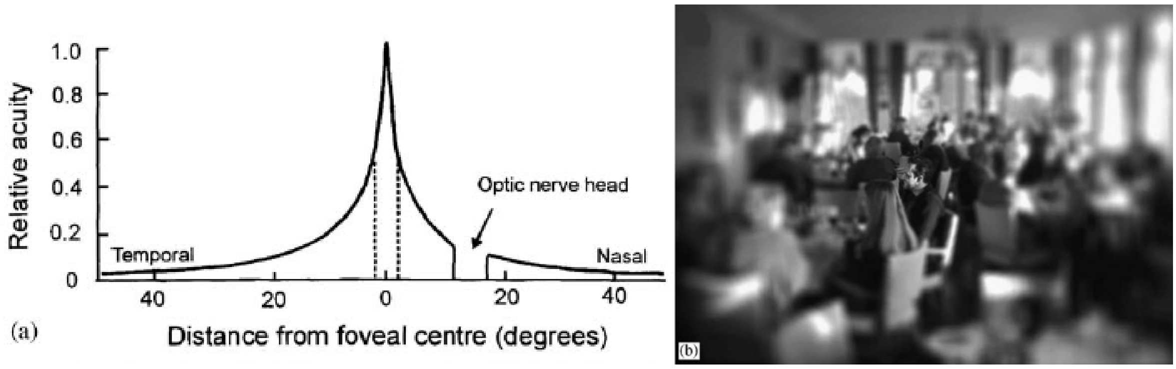

Figure 5 : **Left :** Graph of the decrease of visual acuity as the light is detected further from the fovea. The area between the dashed lines represents foveal vision, visual information from outside this region is referred to as peripheral vision. **Right :** representation of how an image is blurred by the function shown in the graph. Graph and image from (Land 2006)

To obtain a detailed view of what we want to see, we need to move the eye so that the object of interest is centred on the fovea. However, when the eye is moving, the fovea receives blurry images. Therefore, eye-movements have to be made as fast as possible. These fast eye-movements are called **saccades**, and reach speeds up to 700°/s (Carpenter 1988). Saccades are the principal way we use to relocate our direction of sight, assisted by head movements in case of large changes in visual direction (Land 2004). During everyday activities, about three saccadic eye movements are made per second. We are hardly aware of these eye movements since they are made largely unconsciously, and because visual information is suppressed during the saccades (Ross et al. 1996; Burr et al. 1994).

It takes about 20ms for the eyes to detect a change in the light reaching them. Therefore, visual information can only be taken in efficiently when the object of interest is kept stable on the retina. The moments during which the eyes are kept still relative to the object of interest are called **fixations**. Except for some micro eye movements, the eyes should be completely still during a fixation to a static object, otherwise the image would be blurred (Holmqvist et al. 2011; Duchowski 2007).

Although fixations and saccades make up for most gaze behaviour, they are not always able to efficiently capture moving images. When an object moves smoothly and not too quickly, it can be tracked using **smooth pursuit**. This type of eye movement can follow objects at about 15°/s. Above this speed, the object following smooth pursuit will be supplemented by 'catch-up saccades', or will be replaced by only saccadic eye movements (Collewijn & Tamminga 1984).

All eye movements described above are conjugate eye movements, meaning that both eyes move in the same direction. **Vergence** eye movements however, is the simultaneous movement of both eyes, but in opposite direction (disconjugate eye movements). The vergence system is responsible for generating convergent and divergent eye movements, which align the direction of sight of the two eyes to an object closer or further from the observer, respectively.

2.2. Stabilizing mechanisms

During ordinary activities, head movements and movements in the environment impede the stabilization of the image on the retina. Two stabilizing mechanisms support the stability of the visual information during fixations. The first is the **Vestibulo-Occular Reflex** (VOR). This reflex evokes eye-movements of the same speed in the opposite direction when the vestibular system detects head movements. The VOR therefore makes it possible to keep the direction of gaze on a certain point while moving the head. The second stabilization mechanism, the **OptoKinetic Reflex** (OKR), is evoked when large regions of the image move together. The OKR compensates for this shift of the visual field by rotating the eyes at the same speed in the same direction, nulling out the retinal motion. For example, when looking out of the window of a moving car or train, the OKR will cause the eyes to rotate in the same direction of backwards moving scenery, thus stabilizing the view (Niemann et al. 1999). After an eye-movement of approximately 20°, the eyes will make a saccade back to a central position in the direction of the head, and the OKR will start again. This repeating pattern of OKR and saccades back to a central position is called the OptoKinetic Nystagmus (OKN; Lappe et al. 1998).

2.3. Bottom-up vs. top down control of eye movements

Since the shifts of visual attention are usually spontaneous, it has been suggested that a large part of visual search is driven in a '**bottom-up**' manner. Bottom-up control of gaze implies that eye movements are driven by conspicuous visual features of the image in a reflexive manner (Tatler et al. 2011). However, studies have shown that even when identical stimuli are presented, gaze behaviour will be different if the subject is given a different task (Yarbus 1967; Higuchi et al. 2009; Vaeyens et al. 2007). This indicates that higher cognitive processes influence the direction of gaze, in a **top-down manner**. It is generally accepted that gaze control involves a combination of bottom-up and top-down factors (Wickens & Horrey 2009; Horrey et al. 2006), but it appears that high-level task information dominates fixation behaviour in natural behaviour (See (Land & Tatler 2009) section 9 for a more extensive explanation of this topic).

2.4. Focal and peripheral vision

In most eye movement studies, the direction of gaze is associated with the direction of visual attention. Although foveal vision is indeed crucial for many tasks, the influence of peripheral vision should not be underestimated (Assaiante & Amblard 1992; Summala et al. 1996; Marigold 2008). Whereas focal vision primarily serves object recognition, peripheral vision (or ambient vision) is associated with guidance and motor control. It is believed that the visual information from focal and peripheral vision is processed in two parallel streams : the ventral and the dorsal stream (Schieber & Schlorholtz 2009). Although these two visual systems have different functions, it should be emphasized that they normally function in synergy (Norman 2002). It is important to see focal and peripheral vision as interrelated rather than separate systems (Gugerty 2011).

3. Visual control of moving forward

Different tasks require different visual behaviour, but conversely, different visual information will also lead to different motor behaviour. Studying eye movements can therefore be an interesting way to investigate various aspects of mind and brain (van Gompel et al. 2007). Regarding human locomotion and traffic behaviour, the synergy of visual and motor behaviour can shed light on how visual information is processed, and used to guide motor actions. In the current section, the role of visual information in human locomotion is briefly reviewed.

> *"The eyes are windows of the mind"*
> (Du Laurens; 1596, in van Gompel et al., 2007)

3.1. The visual control of heading

The visual control of heading has been subject of discussion for many years, and has been discussed for both walking and driving (Wann et al. 2000; Rushton et al. 1998; Wilkie & Wann 2003a; Warren & Hannon 1990). In general, visual information can lead to the estimation of heading direction and error in two different ways. According to one theory, the **perceived visual direction** of the goal can be used to control and adjust heading. This control theory has also been referred to as egocentric control since it is based on minimizing the angle between the egocentric direction and the direction of the goal (Rushton et al. 1998). Alternatively, heading can also be controlled by monitoring the **optic flow pattern**, which is the pattern of apparent motion of the visual scene caused by the relative motion between the observer and the scene (see Fig 6). According to this approach of heading perception, heading can be controlled by keeping the focus of expansion as close to the target as possible (Gibson 1958; Beall, Andrew & Loomis, Jack 1996). Although some studies have suggested that heading is primarily controlled by perceived visual direction (Rushton et al. 1998), or by flow patterns (Wann & Swapp 2000; Wann & Land 2000), most researchers now agree that a combination of these information sources is used to judge and control heading (Wilkie & Wann 2005; Lappe et al. 1999; Warren et al. 2001; Loomis, Jack & Beall, Andrew 1998).

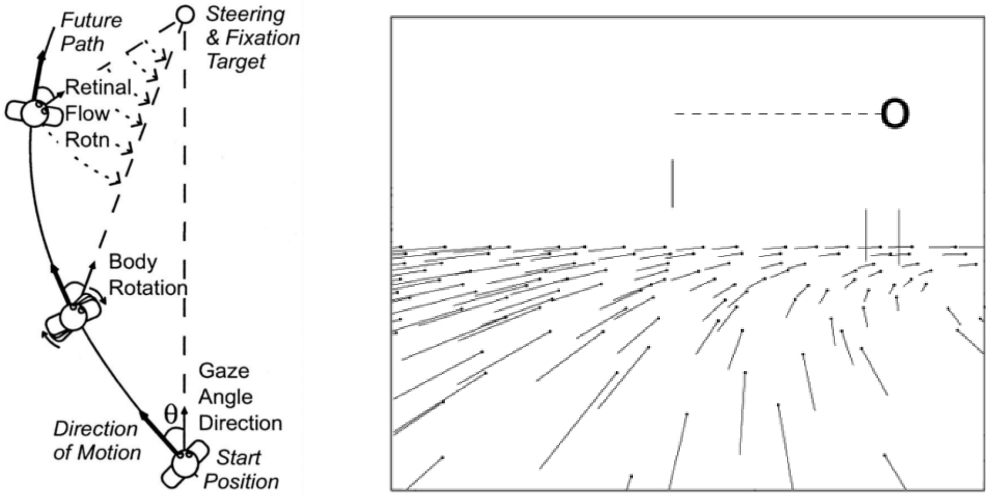

Figure 6 : **Left**: Illustration of the egocentric strategy of controlling heading. Holding the target at a constant visual angle θ as shown, would result in a curved path that overshoots the end location. **Right** : Illustration of the use of optic flow to control heading. Panels illustrate the flow arising over 0.2 s while travelling at 15 mph (or 0.1 s at 30 mph). Travelling on a curved trajectory that would carry the observer through the vertical posts, with gaze locked in a forward position. Heading and gaze eventually sweep around to be coincident with the posts. Figures from Wilkie and Wann 2005, 2003b

3.2. Gaze behaviour and locomotion on foot

During human locomotion, visual information is essential for navigation, for obstacle avoidance, and for accommodation to different surfaces (Patla 1997). When walking on a flat and object-free path, the walking task is simple enough to be executed automatically. In this case, gaze does not have to be directed to the path itself to guide footsteps and most of the visual attention can be directed to the heading direction or to other objects of interest in the environment (Turano et al. 2001; Higuchi 2013). On a more challenging terrain however, visual information is needed for obstacle avoidance and accommodation (Pelz & Rothkopf 2007), and footsteps have to be controlled more precisely. Under these more challenging circumstances, **gaze is directed about two steps ahead** to plan changes in the walking pattern, corresponding to a 'look ahead' of about 1 second (Patla & Vickers 2003; Hollands et al. 1995). Although fixating the region where steps have to be placed seems preferential, Marigold et al. (2007) have shown that peripheral vision of a suddenly appearing obstacle in the travel path can be sufficient for successful obstacle avoidance.

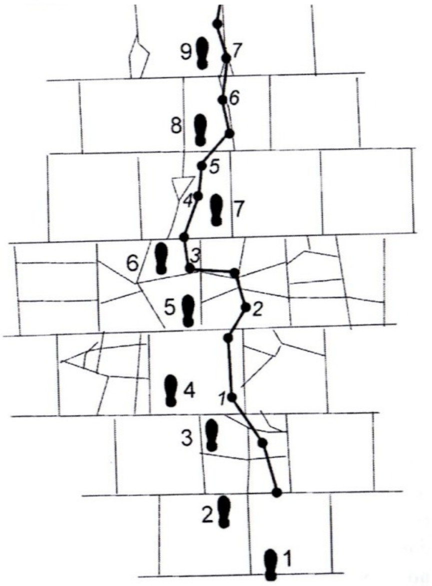

Figure 7 : Footsteps and the position of the fixations when walking across a broken paving. The participants were instructed not to step on the cracks. Dots indicate the location of a fixation and the number indicates during which footfall the fixation took place (adapted from Land and Tatler, 2009).

Patla and Vickers (2003) mentioned a specific type of path fixation during walking, called the **travel fixation**. A travel fixation occurs when gaze is held on a fixed distance about two steps in front of the body and is carried along at the speed of locomotion. As a result, the point of regard moves at the same speed as the body. During this type of fixation, optic flow lines pass through central as well as peripheral vision and are used to obtain information about the self-motion. However, since the use of travel fixations implies that the OptoKinetic Reflex (OKR) is suppressed, and only few other studies described them (Fowler & Sherk 2003; Hollands et al. 2002), their existence can be questioned. When Pelz et al. (2009) replicated the study of Patla and Vickers (2003), no travel gaze fixations were observed. Therefore, they suggested that this 'type' of fixations may have been an artefact of the instrumentation and/or the experimental setup used.

3.3. Gaze behaviour and car driving

The visual behaviour of car drivers has been studied thoroughly, both on real roads and using driving simulators. A fair amount of this research has focussed on the question of how visual information contributes to the steering behaviour. **The two-level model of driver steering behaviour** (Donges 1978), from here on referred to as the two-level model, is one of the most influential models for the visual control of steering. Although it was originally proposed as a model for steering behaviour instead of a model for gaze behaviour, its assumptions on how steering is controlled have influenced the way gaze behaviour was modelled. In short, the two-level model of driver steering behaviour can be summarized as a steering system that works on two levels: a guidance level that depicts a desired path in an anticipatory open-loop control mode, and a stabilization level whereby deviations from the desired position (lateral deviation) and the desired course (heading angle and path curvature) are detected and compensated for in a closed-loop control mode (Fig. 8).

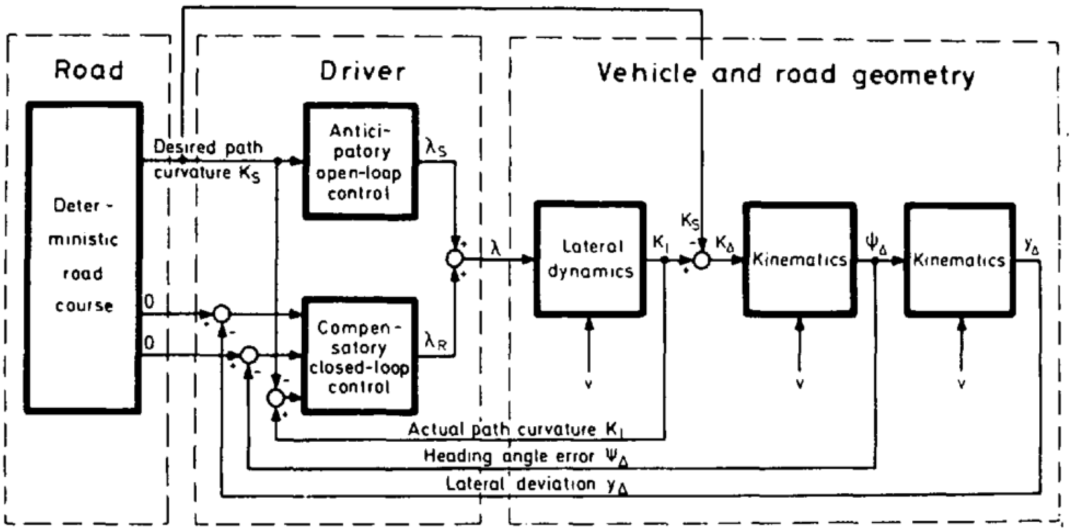

Figure 8 : A structural scheme of human steering behaviour according to the two-level model of driver steering behaviour. The guidance level is represented by anticipatory open-loop control and depicts the desired path. The stabilization level is represented by compensatory closed-loop control and formulates steering corrections based on the three feedback signals. From Donges 1978.

Although both levels in the two-level model rely on visual information, Donges (1978) only suggests that visual information is derived from 'the forward view of the road'. The question therefore remained **which parts of the road guide steering**. This research question was addressed by Land & Horwood (1995), who used a driving simulator that showed only a 1° high segment of the road to investigate how steering behaviour changed when only parts of the road were visible. They found that when only the distant part of the road was visible, the curvature was smoothly matched, but position-in-lane was not well maintained. With only the near region being visible, steering was difficult and jerky, but the position in the lane was maintained quite well. When both a near and far segments were visible, the steering accuracy was similar as when the whole road was visible. Remarkably however, drivers rarely fixated the near region, but seemed to view it peripherally while foveal gaze was directed to the distant part of the road. Land and Horwood concluded that distant parts of the road are actively looked at and provide information about the road curvature whereas nearer parts of the road are perceived peripherally an provide position-in-lane info. According to Land and Horwood, these results strongly support the two-level model of Donges (1978). Although the exact size and location of 'near' and 'far' region has been debated (Cloete & Wallis 2011; Frissen & Mars 2013; Chatziastros et al. 1999), since the publication of the paper of Land and Horwood, the guidance and the stabilization level of the two-level model have been associated with visual information from a far and a near region, respectively (Mars 2008; Lappi et al. 2013; Cloete & Wallis 2011).

Which parts of the far road region should be attended to for optimal steering during curve negotiation is a subject that is still discussed. In general, the debate is about whether gaze should be directed towards the 'tangent point' on the inside edge, or towards points on the future road to which have to be steered. Land & Lee (1994) observed that drivers systematically looked at the innermost point of a curve from the driver's point of view, which they referred to as the '**tangent point**'. The visual direction of the tangent point relative to the current heading of the vehicle is a good predictor of the road curvature, and can therefore serve as a control signal for steering (see Fig. 9). Several studies have confirmed that the inside edge close to the tangent point is often gazed at during curve negotiation (Kandil et al. 2009; Authié & Mestre 2011; Mars 2008). However, Wilkie et al. (2010) pointed out that most studies favouring the curvature matching strategy did not instruct the car drivers about the road position they should maintain. Because of the natural tendency to 'cut the corner' (Gawron & Ranney 1990) the drivers might just have been watching where they were going. Therefore a '**look where you are going'** strategy[3] was proposed for steering through curves. According to this steering strategy drivers look at a point through which they want to pass 1–2 seconds ahead of their current position (Wilkie & Wann 2003b). By using these points on the future path as 'point attractors' (Fajen & Warren 2003; Wilkie & Wann 2003a), a combination of perceptual variables such as retinal flow and visual direction is used to generate a steering response (Wilkie & Wann 2005). The 'look where you are going' strategy is in line with several studies using a wide range of experimental set-ups that confirm that gaze is usually directed in the direction of travelling (Wann & Swapp 2000; Marigold & Patla 2007; Hollands et al. 2002).

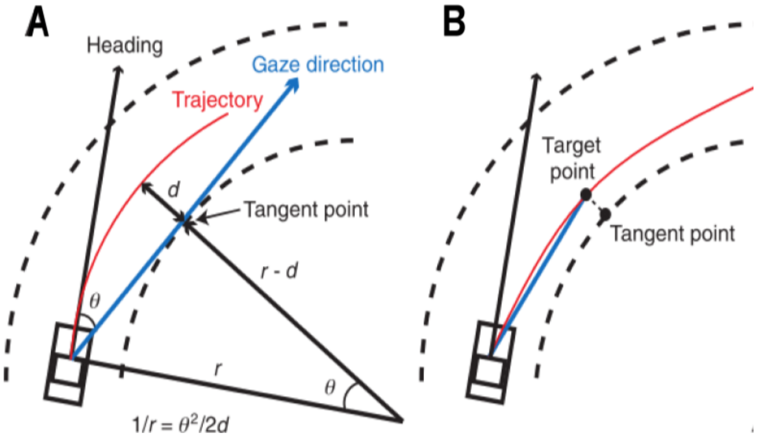

Figure 9 : Illustration of gaze behaviour (blue line) using a tangent point strategy (A) and a 'look where you are going' strategy (B) during curve negotiation (adapted from Mars 2008).

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[3] has also been referred to as 'viapoint strategy' and 'future path strategy'

4. Visual behaviour during traffic participation

The previous section described how visual information is used for lane keeping. However, traffic participation requires more than only lane-keeping. During a trip from point A to point B, a driver/cyclist also needs to make sure he is going the right direction, and looks out for traffic signs and for potential hazards. In addition, car drivers/bicyclists are also often distracted by billboards, in-vehicle technology, music, etcetera. Therefore, safe **traffic behaviour can be considered as constant multitasking between subtasks** (Johnson et al. 2014; Salvucci & Taatgen 2008). In the current section we briefly present some models that describe traffic behaviour in a broader sense than only for lane keeping.

4.1. SEEV-model

Whereas models for visual attention of drivers usually focus on lane keeping and navigation, they rarely incorporate visual behaviour in function of hazard perception. Nevertheless, these two tasks both rely primarily on visual information and have to be dealt with simultaneously. The SEEV-model is one of the few computational models of visual attention that predicts visual attention to different areas for both hazard perception and lane keeping (Horrey et al. 2006; Wickens & Horrey 2009). According to this model, visual attention is driven by two bottom-up factors, Salience and Effort, and by two top-down factors, Expectancy and Value.

Salience reflects the visual mechanism that gaze is most easily directed to conspicuous elements in the visual scene. **Effort** on the other hand, reflects the inhibition of scanning between two locations that are far apart. Gaze switches more easily between two salient features if they are close by than if a large saccade has to be made. **Expectancy** characterizes the tendency to look where task-relevant information is expected to be found. Areas with higher information bandwidth (event rate) are therefore more likely to be looked at. Finally, **value** accounts for the tendency to look at visual information that has more relevance for the task. According to the SEEV-model, the weighted influence of these four components determines the probability that a certain area of interest will be looked at. However, since some tasks are controlled using peripheral vision (such as lane keeping), the influence of ambient vision also has to be taken into account. Figure 10 shows how focal and ambient vision can be incorporated in a SEEV-model for the control of various driving tasks (Horrey et al. 2006).

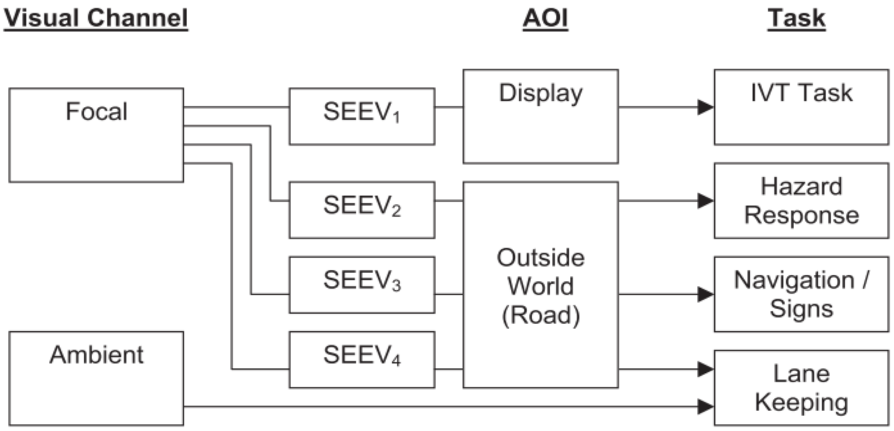

Figure 10 : conceptual model of the links between focal and ambient vision, the parameters of the SEEV model, different areas of interest (AOIs), and various steering tasks (IVT = in-vehicle technology).

4.2. Situation awareness

A concept of information processing in complex environments that gained a lot of attention in the recent years is ‘situation awareness’. Basically, situation awareness is ‘knowing what is going on’, and is acquired in three levels: perception, comprehension and projection (Ensley 1995). In the first level, **perception**, the state and dynamics of the environment are perceived without interpretation. Applied to traffic participation, this level represents perceiving important visual information for various tasks. For example, edge lines (lane keeping), an approaching bicyclist (hazard perception), the speedometer (IVT task), etc. However, only in the second level, **comprehension**, the perceived information is combined into a holistic view of the environment. The driver now understands the significance of objects and events in function of the task. For example, he/she knows what is restricted or allowed based on the traffic signs, and if he/she is driving according to these traffic rules. Finally, in the **projection** level, the future status of the environment is predicted through the knowledge and comprehension of the status and dynamics of the situation. The driver is able to anticipate on future events (Stanton et al. 2001; Salmon & Stanton 2013; Endsley 1995; Gugerty 2011). Although there are other approaches to situation awareness than this three-level approach (Stanton et al. 2001), it is a generic model with a broad theoretical construct that is widely accepted.

Poor situation awareness has been associated with many kinds of incidents, including traffic and military (Salmon & Stanton 2013). Therefore, various studies have investigated what factors affect the situation awareness (Walker et al. 2013; Underwood et al. 2013). In traffic, situation awareness has been found to differ according to many factors, including the mode of transport (Salmon et al. 2013), the road type (Walker et al. 2013), and perhaps most importantly, experience (Underwood et al. 2013).

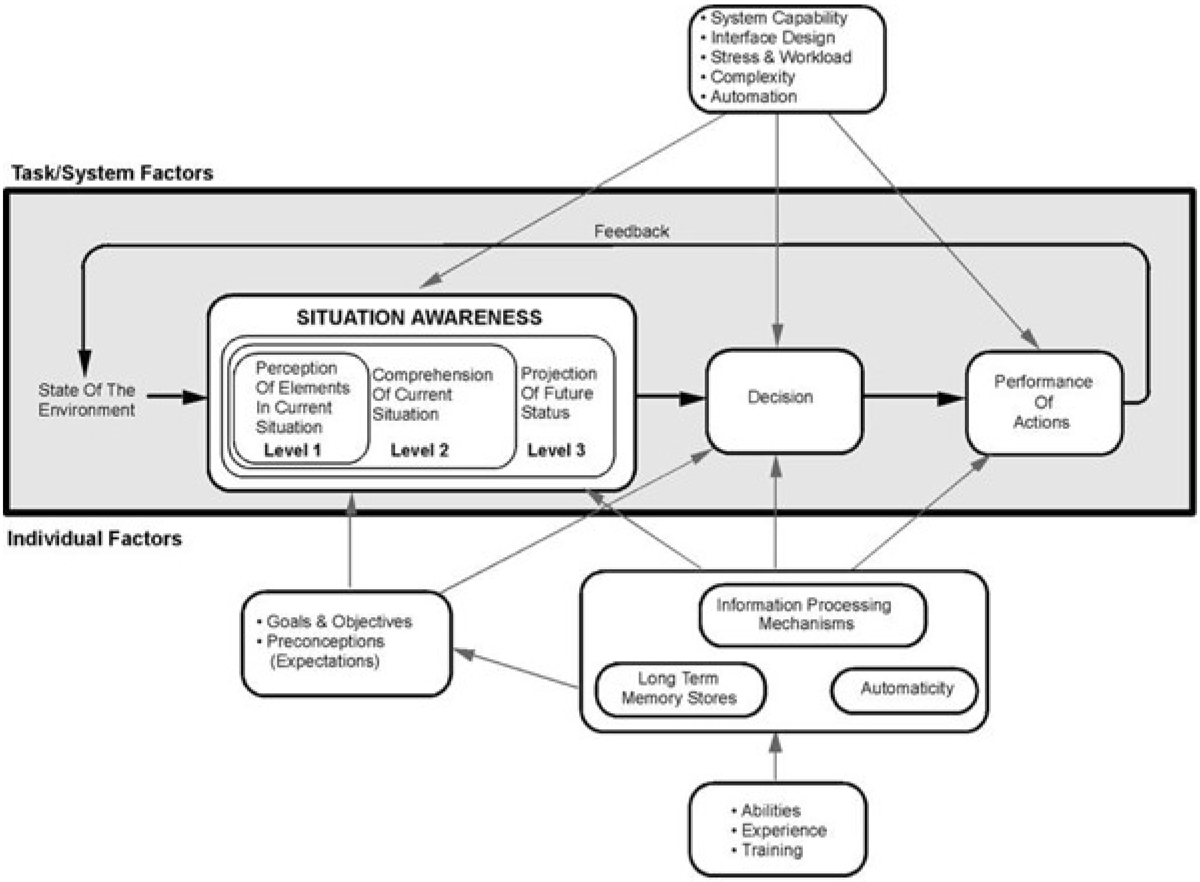

Figure 11 : A model of situation awareness in dynamic decision making (Ensley 1995)

4.3. Task-Capability Interface model

As humans have a limited attentional capacity, there is only a certain amount of attention that one can divide across the multiple traffic tasks. The Task-Capability Interface model (or short TCI model; Fuller 2005) approaches driver behaviour as a dynamic balance between the demand of the driving task and the capability of the driver. As long as the capability exceeds the demand, the task can be performed relatively easily. When the task demand approaches the driver's capability however, the driver is operating at the limits of what he/she can safely handle. Once the task demand exceeds the driver's capability he/she has no longer full control over the vehicle, and the risk of an accident increases (see Fig. 12).

The **driver's capability** is mainly restrained by the biological characteristics of the driver, and can be related to the individual constraints of the constraints approach (Newell 1986). A multitude of perceptual, cognitive and motor factors determine the level of competence of the driver. However a driver's capability is often lower than the maximal competence. Fatigue, stress, distraction, attitude, and other human factor variables can decrease the capability of the driver. The **task demand** is largely dependent on the imposed environmental and task constraints. Although the driver has little influence on many of these task and environmental constraints, the driver does have control over the trajectory and speed. Of these two, the speed choice will be predominantly used to control the level of task difficulty while driving. Slowing down buys the driver more time to take information, to process it, and to respond to it. Drivers can also use speed to increase the task load to reach an optimal level of workload. Based on the driver's perceived capability and task demand, a preferred range of task difficulty is chosen that still gives the driver some 'spare' capability. However, to choose a safe 'safety margin' the driver has to be able to adequately estimate his own capability and the task demand. Unfortunately, young drivers tend to overestimate their own capacities, which might lead to a higher accident proneness (Matthews & Moran 1986).

The TCI-model has not yet been tested for bicyclists, but the assumption that the balance between capability and task demand determines whether the vehicle is under control, seems to be applicable for bicyclists as well. However, since bicyclists are subject to different constraints (e.g. balance), some elements of the model should probably be reassessed in function of bicyclists.

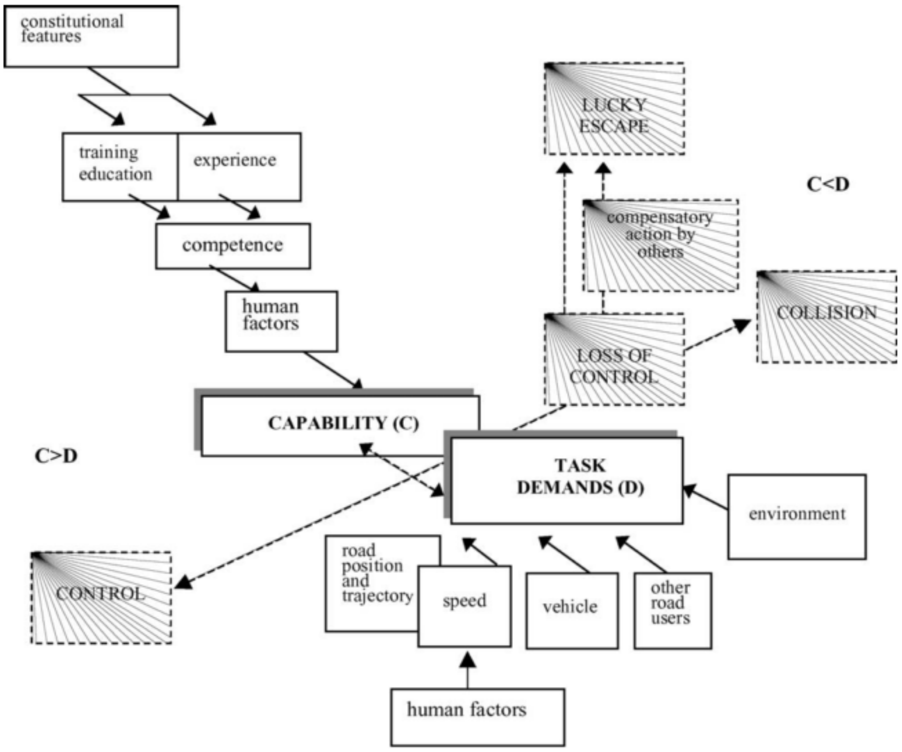

Figure 12 : The Task-Capability Interface model describes the dynamic interaction between the determinants of task demand and driver capability (Fuller 2005)

5. The development of perceptual-motor skills in function of traffic behaviour

5.1. Visual behaviour of novice car drives

Since learner **car drivers** are overrepresented in car accident statistics (Rolls & Ingham 1992), the visual behaviour of novice drivers has often been compared to that of experienced car drivers. On-road studies showed that the visual search of novice drivers is unskilled and could be considered unsafe (Mourant & Rockwell 1972). In general, novice car drivers direct a large proportion of their gaze towards the road directly in front of the vehicle, and look more often at in-vehicle objects. Experienced car drivers on the other hand, show a more pronounced horizontal visual search pattern, look more to their rear-view mirrors, and seem to make more use of their peripheral vision (Falkmer et al. 2005; Di Stasi et al. 2011; G Underwood 2007). Furthermore, experienced car drivers adapt their visual search strategy according to the complexity of the traffic situation, whereas novice car drivers tend to show a rather inflexible visual strategy (Crundall & Underwood 1998; Shinar 2008).

Next to the on-road experiments, a large proportion of the studies on visual behaviour of car drivers has been done in laboratory situations. Using video footage or simulations, the reactions of novice and experienced car drivers to specific situations can be safely and more thoroughly investigated. These tests, measuring the subjects' ability to detect and interpret hazardous situations, are referred to as **hazard perception tests**. Hazard perception studies have shown that inexperienced drivers are less likely to notice foreshadowing cues and therefore often miss the chance to anticipate on developing hazards (Scialfa et al. 2011; Crundall et al. 2013; Chapman & Underwood 1998). However, next to reacting more slowly on hazards, novice car drivers also interpret the traffic situations differently than experienced drivers (Wallis & Horswill 2007; Scialfa et al. 2012). The lower performance on these hazard perception tests of novice drivers has been attributed to slower processing of visual information (Huestegge et al. 2010) and an incomplete mental model of the dangers that can occur on certain roads (G Underwood 2007). Fortunately, hazard perception skills have also been reported to improve with training (Mcknight 2003; Mckenna & Crick 1994; Underwood et al. 2002; Isler et al. 2009). Since the poor hazard perception skills in novice drivers has been associated with elevated accident risk, some countries such as England and Australia promote these hazard perception trainings, and have incorporated a hazard perception test in the theory exam for learner drivers (Wetton et al. 2011).

5.2. The visual behaviour of learner bicyclists

Some of the findings of the studies on the development from learner to experienced car drivers could possibly also relate to the development from learner to experienced bicyclists. However, there is an important difference between learner car drivers and learner bicyclists that makes comparison problematic: cycling is a skill that is usually mastered between the age of five and ten years old. This implies that in contrast to most learner car drivers, the perceptual, motor and cognitive skills of learner cyclists are far from fully developed (Gallahue & Ozmun 2011). Therefore, children's visual and motor behaviour in traffic is not only limited by a lack of experience, but also by their immature perceptual-motor abilities.

An overview of the age at which a range of perceptual-motor abilities is believed to be mature can be found in table 1. In current section, we focus on the development of perceptual and/or motor skills in function of navigation and traffic participation.

Table 1 : Development of perceptual skills, perceptual-cognitive, and perceptual-motor skills. This list is not exhaustive.

Perceptual	Mature	Reference
Acuity (Static)	10 - 11	(Gallahue & Ozmun 2011)
Acuity (Dynamic)	11 - 12	(Gallahue & Ozmun 2011)
Depth perception	12	(Gallahue & Ozmun 2011)
Span of peripheral vision	No age difference	(Cohen & Haith 1977; Dye & Bavelier 2010)
Fixation density	15	(Aring et al. 2007)
Saccade control	3	(Kowler & Martins 1982)
Perceptual-Cognitive		
Selective attention	12	Hagen 1972
Filtering & Priming	Improvements through adulthood	(Enns & Cameron 1987)
Search ability	7	(Enns & Cameron 1987)
Processing speed	12	(Kail & Salthouse 1994)
Multiple Object Tracking	15	(Dye & Bavelier 2010)
Visual working memory	12	(Riggs et al. 2006)
Perceptual-Motor		
Visual-motor coordination	10 - 12	(Gallahue & Ozmun 2011)
Balance	11 - 13	(Assaiante & Amblard 1992; Hatzitaki et al. 2002)
Obstacle avoidance	11	(Pryde et al. 1997)

- **Cycling skills**

Cycling skills refer to the motor skills required to have sufficient control over the bicycle to cycle in traffic. These skills are often studied together with more general traffic skills such as looking over the shoulder for oncoming traffic, signalling, etcetera. The development of cycling skills in children is related to the development of general motor competence and therefore improve with age (Zeuwts et al. 2015; Ducheyne, De Bourdeaudhuij, Lenoir, Spittaels, et al. 2013b). By the age of nine most children have good steering skills, but often still have difficulties when required to steer one-handed (Ducheyne et al. 2014). However, cycling skills also improve significantly with training (Ducheyne, De Bourdeaudhuij, Lenoir & Cardon 2013; Ducheyne, De Bourdeaudhuij, Lenoir, Spittaels, et al. 2013b; Macarthur et al. 1998). Unfortunately, it is difficult to measure to what extent these bicycle skills trainings increase the safety of the children in real traffic situations (Lachapelle et al. 2013). A recent review of Richmond et al. (2014) even suggests that although educational and skills training bicycling programmes may increase knowledge of cycling safety, there is few evidence that these programmes translate into a decrease in injury rate, cycling skills or attitudes. Although many countries have bicycle skills programs, there is still a lack of scientific knowledge about the development of these cycling skills, the impact of these training programs, and their contribution to safe traffic behaviour.

- **Judging safety and attitude towards it**

Adequate cycling skills are only a first step to safe traffic participation by bike. Most of the more severe bicycle accidents do not happen due to a loss of steering control, but due to inadequate behaviour (DEKRA 2011). Therefore, the development of an appropriate **judgement of traffic safety**, and the attitude towards it, is essential for safe traffic participation. Five year old children have been found to have a different understanding of the concept of 'appropriate traffic behaviour' (Thornton et al. 1999). They seem to interpret road users' responsibility as 'not to damage things', whereas older children and adults interpret this concept as 'not to make the kind of mistakes that might cause an accident'. This different approach underpins that young children have difficulties in judging safe traffic behaviour.

The lack of appropriate safety judging skills is also evident when children have to identify a safe place to **cross the street** (Ampofo-Boateng & Thomson 1991), and is reflected in their visual behaviour. Children aged five to seven were found to fail in distinguishing between what is relevant and irrelevant to road crossing task, and failed to give adequate priority to relevant features even when the task demands that they should (Foot et al. 1999).

- **Visual-motor behaviour of young pedestrians**

During **obstacle avoidance**, children's (< 11y) motor behaviour can be described as more cautious, characterized by lower movement speeds and larger safety margins. Furthermore, children seemed to start to plan the avoidance of a second obstacle only when the first one is cleared, and seemed to rely more on visual information during obstacle avoidance than adults (Pryde et al. 1997; Berard & Vallis 2006). This latter finding was confirmed by Franchak and Adolph (2010), who found that four to eight year old children focus more on the objects that had to be dealt with than adults. Adults seemed to rely less on foveal vision and more on peripheral vision for avoiding obstacles than the children. For self-paced tasks such as obstacle avoidance, the simplified visual-motor strategies adopted by the children seem a good way to cope with their limited abilities, and allow the children to navigate safely through a complex environment.

"Successful obstacle avoidance must await maturation of the sensory systems and the motor mechanism as well as the coupling between them" (Pryde et al. 1997)

Similarly, children also have been found to use simplified visual-motor strategies in **road crossing** studies, characterized by waiting longer to cross, and making less, but longer fixations to each side of the road (Ampofo-Boateng & Thomson 1991; Whitebread & Neilson 2000). However, in contrast to obstacle avoidance tasks, road crossing is an externally paced activity. Therefore, children have more difficulties to adjust their actions in function of other moving objects such as cars (Chihak et al. 2010; Grechkin et al. 2013) and are more likely to adopt risky traffic behaviour (Connelly et al. 1998; Underwood et al. 2007). Nevertheless, with increasing age, children gradually develop away from a strategy of sampling the traffic conditions on a moment-by-moment basis and towards a strategy of making predictions (Whitebread & Neilson 1999).

6. General overview and outline of the thesis

6.1. General overview

The popularity of cycling as a mode of transportation, as recreation or as a sport seems higher than ever before. Although the health benefits of cycling are numerous, bicycles are also considered as vulnerable road users. Especially children and elder people are overrepresented in accident statistics, partly due to their higher bicycle usage, partly due to a higher accident proneness. Since safe traffic participation requires an efficient use of visual information, understanding the perceptual-motor behaviour of bicyclists is an important part of understanding bicycling behaviour.

Visual information is essential for most of the subtasks of traffic behaviour. Unfortunately, apart from road crossing studies (Plumert et al. 2004; Plumert et al. 2011), **the perceptual-motor behaviour of bicyclists is poorly documented** (Ducheyne, De Bourdeaudhuij, Lenoir, Spittaels, et al. 2013a; Zeuwts et al. 2015; Maring & van Schagen 1990). In car driving however, this topic has been widely studied. In general, these studies have mostly focussed on two topics : steering control and hazard perception. Regarding the visual behaviour of bicyclists, it could be questioned if the visual behaviour of bicyclists is comparable to that of car drivers.

Both cars and bicycles allow faster locomotion than travelling by foot and require **steering** to change direction, whereas one can make a point turn when walking and running (Hollands et al. 2002). However, there are also many important differences between car driving and cycling that might induce different visual requirements to control locomotion (Schepers & den Brinker 2011). In contrast with car drivers bicyclists have an almost unrestricted view on the environment, have a much lower travelling speed, are more subject to environmental conditions such as weather and road quality, and have to maintain balance whereas cars are stable on their own (Schwab et al. 2012). Furthermore, the comparison of learner drivers and bicyclists is even more problematic since next to a lack of experience in traffic, learner bicyclists also lack mature perceptual-motor abilities. Therefore, the transferability of the existing steering models for car driving to bicycling is questionable.

With regard of **hazard perception**, it is surprising that similar research has not yet been conducted for other road users such as cyclists. Not only might the use of hazard perception tests shed more light on the visual behaviour of bicyclists, hazard perception trainings might be even more beneficial for learner cyclists than for learner car drivers. Since learning to ride a bicycle is a skill that is acquired around the age of 6, learner bicyclists not only have few to no experience with complex traffic situations, they also lack mature perceptual-cognitive skills. These characteristics probably have an effect on the ability of learner cyclists to interpret and react to traffic situations and might be a contributing factor to their high accident proneness. A hazard perception test for cyclists could provide more insights into 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 designed infrastructure.

In general, most of the existing models and strategies for perceptual-motor behaviour in traffic (two-level model, Tangent point strategy, TCI-model, SEEV-model, etc.) are focussed on car driving. Although these models might also be applicable for bicycling, many differences between car driving and bicycling make the comparison questionable.

6.2. Research questions and outline of the thesis

In the current thesis we focus on the role of visual information in the control of bicycle steering. To investigate how visual behaviour supports steering behaviour, three simple steering tasks were isolated from other traffic tasks such as hazard perception. In these first experiments, we **investigated how visual information is used to guide bicycle steering**, and if this is in line with previous findings in the visual control of walking and car driving.

Second, the perceptual-motor behaviour of bicyclists was also investigated in a more realistic traffic setting. In these experiments, it was tested to what extent distracting factors had an effect on the visual behaviour of bicyclists.

Finally, since children have been identified as an accident prone group, current thesis also aims to **identify differences in the visual control of steering between young learner bicyclists and experienced adult bicyclists**.

Since the technology to measure gaze behaviour has undergone a large development in the recent decennia, the **first chapter** of this thesis will focus on eye tracking methodology. For the current thesis, head-mounted eye tracking devices have been used to measure eye movements. These devices have the advantage that gaze behaviour can be measured in a natural setting, but have the disadvantage that data analysis is tedious. In this first chapter a short review of the current state of eye tracking technology is presented, and a novel analysis method is tested (*paper 1*).

In **chapter two**, the perceptual-motor behaviour of bicyclists is investigated during three isolated steering tasks. These experiments were conducted in an indoor environment so the participants only had to focus on the steering task. In a first study, the visual control of lane keeping is tested while steering through straight lanes of different width (*paper 2*). The aims of this experiment were 1) to test how visual behaviour is affected by cycling speed and lane width, 2) to examine whether gaze behaviour of bicyclists is in line with the two-level model of steering, and 3) to investigate whether bicyclists use travel fixations. This experiment was repeated with eight year old children to investigate to what extent young learner bicyclists adapt their visual and motor behaviour in a similar way as adults (*paper 3*). A second steering task that was studied was curve negotiation. In this experiment we tested to what extent the existing models for curve driving also apply to cycling around a curve, and tested the influence of cycling speed on steering and gaze behaviour (*paper 4*). Unfortunately, this experiment was conducted only with adult participants. Finally, the visual control of steering was also investigated during a slalom task. Unlike steering through a straight or curved lane, a slalom task is a concatenation of steering actions, and therefore requires more anticipation. In this experiment the visual behaviour of both adults and children was investigated when cycling through three slaloms of different widths. Additionally, the participants were also asked to cycle these slaloms at three different speeds (*paper 5*).

In the **third chapter** of part 2 of this thesis, the gaze behaviour of experienced adult and young learner bicyclists was investigated in an actual traffic environment. However, for safety reasons the selected cycling route was separated from car traffic and did not include intersections or other possible hazardous sections. However, the cycling route did include two bicycle paths of different quality. By measuring the amount of visual attention towards the road region, this study investigated to what extent bicycle path quality affects the visual behaviour of bicyclists. A first exploratory experiment included only adults (*paper 6*), a second experiment included both adults and children (*paper 7*).

6.3. Situating current thesis in the cEYEcling project

The current thesis is part of a larger project in which we aim to investigate visual behaviour for both the control of steering and the detection of hazards. This research project is divided into four steps. 1) describing perceptual-motor behaviour during isolated steering tasks, 2) describing gaze behaviour in actual traffic environment, 3) developing and testing a hazard perception test for bicyclists, and 4) developing a hazard perception training for learner cyclists (See also Fig. 13). The current thesis reports the findings of the first two steps of this research project. A first explorative study with a **hazard perception test for learner bicyclists** has already been carried out and can be found in appendix A. Further research is currently focussing on developing a better hazard perception test to detect differences in the hazard perception and handling skills of young learner cyclists and experienced adult cyclists.

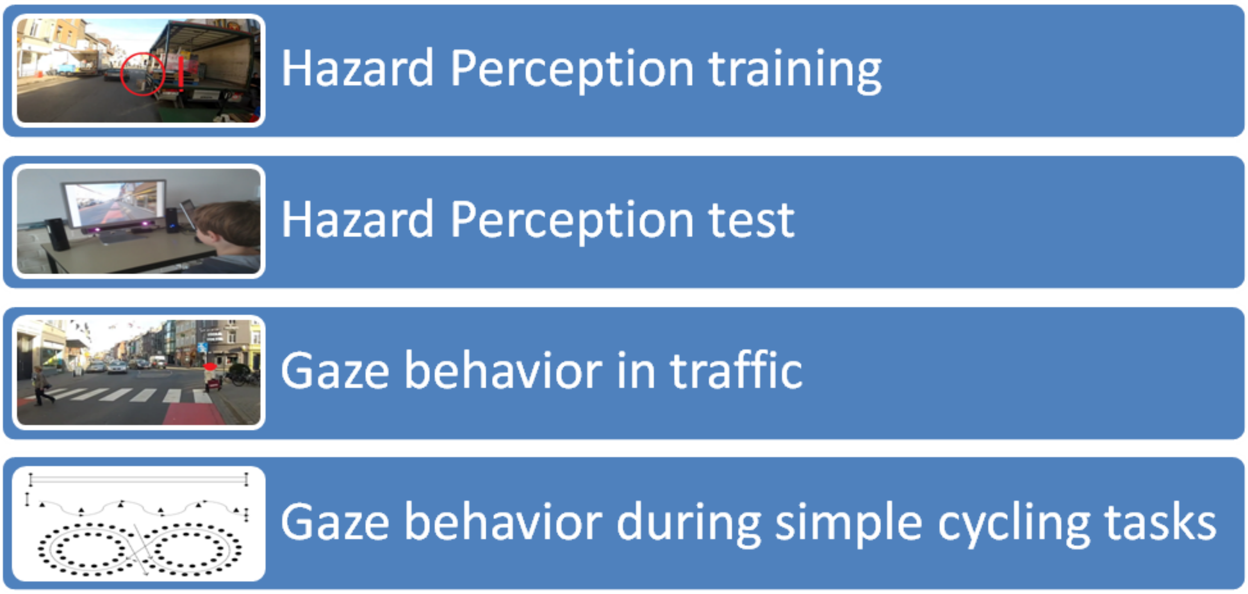

Figure 13 : overview of the four steps of the cEYEcling project

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ORIGINAL RESEARCH

Chapter 1

eye tracking methodology

In this chapter :

A short review of eye-tracking methodology is presented and a new analysis method for head mounted eye tracking data is evaluated.

Paper 1 :

MEASURING DWELL TIME PERCENTAGE FROM HEAD-MOUNTED EYE TRACKING DATA COMPARISON OF A FRAME-BY-FRAME AND A FIXATION-BY-FIXATION ANALYSIS

Vansteenkiste P, Cardon G, Philippaerts R, Lenoir M

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ABSTRACT

Although analysing software for eye-tracking data has significantly improved in the past decades, the analysis of gaze behaviour recorded with head-mounted devices is still challenging and time-consuming. Therefore, new methods have to be tested to reduce the analysis workload while maintaining accuracy and reliability. In this article, dwell time percentages to six areas of interest (AOIs), of six participants cycling on four different roads, were analysed both frame-by-frame and in a 'fixation-by-fixation' manner. The fixation-based method is similar to the classic frame-by-frame method but instead of assigning frames, fixations are assigned to one of the AOIs. Although some considerable differences in dwell time percentages towards the AOIs were found between the two methods, a Pearson correlation of 0.930 points out a good validity of the fixation-by-fixation method. For the analysis of gaze behaviour over an extended period of time, the fixation-based approach is a valuable and time-saving alternative for the classic frame-by-frame analysis.

INTRODUCTION

Recording eye movements has been done since the early 1900s, and has received increasing attention as eye-tracking technology improved in the last decades (for a history of eye tracking see Duchowski 2007; Holmqvist et al. 2011; Land 2006; van Gompel et al. 2007). Unfortunately, with an increasing variety of eye-tracking equipment, the variability in how eye-tracking data are analysed has also increased (Raschke, Blascheck, and Burch 2014). Since there is no standard procedure of how to collect, process and analyse eye movement data, comparing across multiple experiments is often difficult.

In a classic set-up for eye-tracking experiments, the participant is seated in front of a screen on which the stimuli are presented, and rests his head in front of a desk-mounted eye-tracking device. In most of these studies on eye tracking, researchers rely on algorithms to detect fixations and saccades (often called 'event detection algorithms'). Saccades are fast eye movements that redirect the orientation of the eye to a new location in the environment, and fixations are the intervals between saccades in which gaze is held almost stationary and visual information is attained (Land and Tatler 2009). The algorithms computing fixations and saccades can be divided into two groups: dispersion-based and velocity-based algorithms (Duchowski 2007, p.139). With the dispersion-based fixation detection algorithms, a fixation is detected when the pupil position stays within a certain spatially limited region (the dispersion threshold, usually between 0.5° and 2°) for a minimum duration (duration threshold, usually between 50 and 250 ms). Velocity algorithms on the other hand, typically classify eye movements above a maximum velocity as saccades, and categorise the intermittent periods as fixations. Many of these velocity-based algorithms also apply a minimal duration criteria before accepting fixations (Holmqvist et al. 2011, p.172).

These algorithms have been designed to analyse eye movement measures such as the fixation duration and the fixation frequency. Furthermore, by linking the gaze coordinates to the screen coordinates, these algorithms can also be used to analyse where the fixations were directed to. The time spent watching a certain area of interest (AOI) can be calculated relatively easy by summing the time that the gaze coordinates were within the AOI's coordinates. This measurement is usually called dwell time and is often expressed as a percentage of the total duration of a trial.

However, when using moving stimuli, the analysis becomes more complex. A first problem with moving stimuli is that, to date, the algorithms cannot detect smooth-pursuit efficiently (Holmqvist et al. 2011). This a slow eye movement that occurs when a moving object is followed. When following a slowly moving stimuli (e.g. a dot moving slowly from the left to the right side of a computer screen), several discrete fixations will be computed by the algorithms instead of one long, slowly moving, fixation. Consequently, for many studies with dynamic stimuli such as film clips, the event detection algorithms are not very reliable. Second, the coordinates of a moving AOI will change over time, which impedes the analysis of dwell time. If the same stimulus is shown to each participant, this problem can be coped with by using dynamic AOIs. By moving the AOI along with the stimulus, gaze analysis software can automatically calculate the total dwell time to that AOI. Once the dynamic AOIs are programmed for the stimulus, these settings can be used for multiple participants. Therefore, when a subject has completed the eye-tracking experiment, the experimenter can almost instantly obtain the distribution of gaze across the different AOIs.

Although the classic set-up for eye-tracking experiments has many advantages, the immobility of the desk-mounted eye-tracker is a large disadvantage, especially to investigate gaze behaviour in a natural setting (e.g. for a real-life or simulator experiment). Therefore, head-mounted eye-tracking devices have been developed. These eye-tracking devices work in the same way as desk-mounted devices, but they are attached to the head and include a 'scene camera' which films from the perspective of the participant (see Figure 1A). Instead of recording eye movements relative to a stimulus screen, eye movements are recorded onto the scene video. Therefore, head-movements have to be taken into account as well when using a head-mounted eye-tracker. As a result, data output is different for each participant. If dynamic AOIs were used to analyse head-mounted eye-tracking data, the AOIs would have to be defined for each participant separately. This can be a useful analysis method when dealing with few and rather static AOIs, but when multiple AOIs are of interest, programming the dynamic AOIs will be very time-consuming.

Figure 1 : Participant on bicycle wearing the head-mounted eye-tracking device (SMI). Inset: frontal view of eye tracker

When researchers are interested in gaze behaviour in a natural setting, an experiment with a head-mounted eye-tracker and manual frame-by-frame fixation detection analysis is almost inevitable. This method consists of replaying the 'gaze overlay video' frame-by-frame, manually deciding when a fixation or saccade ends and/or starts and identifying the AOI in which the fixation took place. This direct inspection method has been described by

Duchowski (2007) as ‘rather tedious but surprisingly effective’ and has been successfully used by several researchers (Patla and Vickers 2003; Singer et al. 1998; Vansteenkiste et al. 2013).

Multiple analysing methods have been used in an attempt to speed up the analysis of head-mounted eye-tracking data. Some experimenters choose to use only eye movement measurements such as fixation duration, fixation frequency, and horizontal and vertical variance of eye movements (Mann et al. 2007; Pelz and Canosa 2001; Vaeyens et al. 2007). Although these measurements have the advantage that they can be obtained quite fast and give a general view of the eye movements made during the experiment, some disadvantages have to be taken into account. First, this analysis method does not result in any measures about actual gaze location; only eye movements are reported. Since gaze behaviour is also dependent on head and body movements, the eye movements do not necessarily reflect gaze behaviour. In a dynamic setting, such as sports or urban traffic, one can make many eye movements to keep looking at the same object, or conversely, make very few eye movements and yet get to see various stimuli. Second, since smooth pursuit will often be detected as multiple fixations, the results could be biased by the use of smooth pursuit. Finally, fixations are usually acquired using dispersion-based algorithms. This makes the comparison across different experiments difficult because the settings of the algorithm influence the number and duration of fixations that will be detected (Holmqvist et al. 2011, 158).

Fixation duration and frequency is not of interest for all eye-tracking studies. When dwell time to the different AOIs is the main focus of an experiment, it is easier to only assign the gaze location of each frame to one of the AOIs. With this frame-by-frame gaze location analysis, no judgements have to be made whether a small displacement of the gaze has to be coded as a new fixation or not, only its location has to be judged. To reduce the processing time, a ‘time-window’ is often selected in which the response to a discrete event is expected. This way, only a part of the eye-tracking data has to be analysed (Franchak and Adolph 2010; Vansteenkiste et al. 2014). Despite these efforts, however, head-mounted eye-tracking data are still very time-consuming (Franchak et al. 2011).

Although head-mounted eye tracking is in many studies the most appropriate tool to measure gaze behaviour, the tedious data processing is a major holdback and many researchers chose a screen-based eye-tracking design instead of a real-life experiment. Unfortunately, gaze behaviour when watching video simulations does not always reflect a natural gaze behaviour (Dicks, Button, and Davids 2010; Foulsham, Walker, and Kingstone 2011; Tatler et al. 2011). With head- mounted eye trackers becoming increasingly portable, affordable and easy to use, their popularity grows too. As a result, the need for quick analysis tools also increases. Therefore, some eye-tracking manufacturers now offer new analysis tools that claim to reduce the analysis workload of head-mounted eye-tracking experiments by analysing gaze fixation by fixation instead of frame by frame.

In this article, we test the validity of a fixation-by-fixation analysis method to calculate dwell time percentage. Although fixation-detection algorithms are not designed for head-mounted eye-tracking recordings, when dwell time to different AOIs is the research topic, they might be used to reduce the analysis workload. To know the pattern in which AOIs have been looked at, and how much time is spent looking at them, exact durations of individual fixations are not essential. Therefore, the outcome of a fixation-by-fixation analysis should be similar to that of a frame-by-frame gaze location analysis and as a consequence be a valid tool for analysing dwell time of head-mounted eye-tracking experiments.

METHODS

A data-set, collected in the scope of a previous study and analysed with the frame-by-frame gaze location method (Vansteenkiste et al. 2014)[4], was re-analysed using a fixation-by-fixation analysis and the results of both methods were compared. The fixation-based analysis was performed by another researcher 10 months after the original analysis. To test the inter-rater reliability, 1/6th of the frame-by-frame analysis was re-analysed. Comparison of the dwell time percentages resulted in a single measures intra-class correlation of 0.98. This high inter-rater reliability suggests that only few of the possible differences between fixation-by-fixation and frame-by-frame analysis are to be attributed to an inter-rater variability.

Participants

In the original study, 10 participants (22 – 24 years of age, students of the department movement and sports sciences from Ghent University) took part and signed the informed consent form which was approved by the Ghent University hospital ethical committee. Participants were only included in the study if their tracking ratio (% of time eye movements was actually measured) was higher than 80% and had a good pre- and post-calibration. This procedure left only six participants (1♂, 5♀) for further analysis. All participants used their bicycle on a daily basis for transportation and had normal or corrected-to-normal vision.

Materials

Gaze location was recorded using the head-mounted eye-tracking device of SensoMotoric Instruments GmbH (SMI, Teltow, Germany). The system is mounted on a baseball cap and has a 1° accuracy (left eye, 50 Hz). A scene video was recorded at 25 Hz by a camera with 3.6 mm lens, placed next to the eye-tracking camera. The scene video had a horizontal and vertical field of view of approximately 33°. The two cameras were connected to a notebook (Lenovo X201; 1.4 kg, Lenovo Group Ltd., Beijing, China) which was worn in a backpack. Both scene videos and eye-tracking recordings were saved using SMI's software IViewX.

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[4] This study can be found in chapter three of the current thesis

Set-up and procedure

After a short briefing about the experiment, participants were asked to put on the baseball cap with the eye tracker and secure it with a strap (Figure 1). A five-point calibration was performed indoors and for each participant the saddle of the bike (female model city bike) was adjusted to the participant's height. After a familiarisation trial, participants were asked to cycle the same route at preferred speed until the test leaders, who cycled behind, instructed to stop. At three moments during the test, the participant was asked to stop, and a calibration check was performed by instructing the participant to watch certain objects in the environment. After the test, a final indoor calibration check was done and the data were saved. Since sunlight may disturb the infrared-signal of the eye-tracking system, all tests were performed in overcast weather.

The cycling route was a 4 km tour in the city of Ghent, Belgium, which included a similar low-quality and a high-quality cycling track on the sides of a river and a high- and low-quality road with tramways. The whole experimental procedure took approximately 45 minutes per subject.

Data analysis

Based on landmarks on the route, four trajectories of about 120 m (± 25 s) were selected for analysis. Participants were unaware of which parts of the route would be used for analysis.

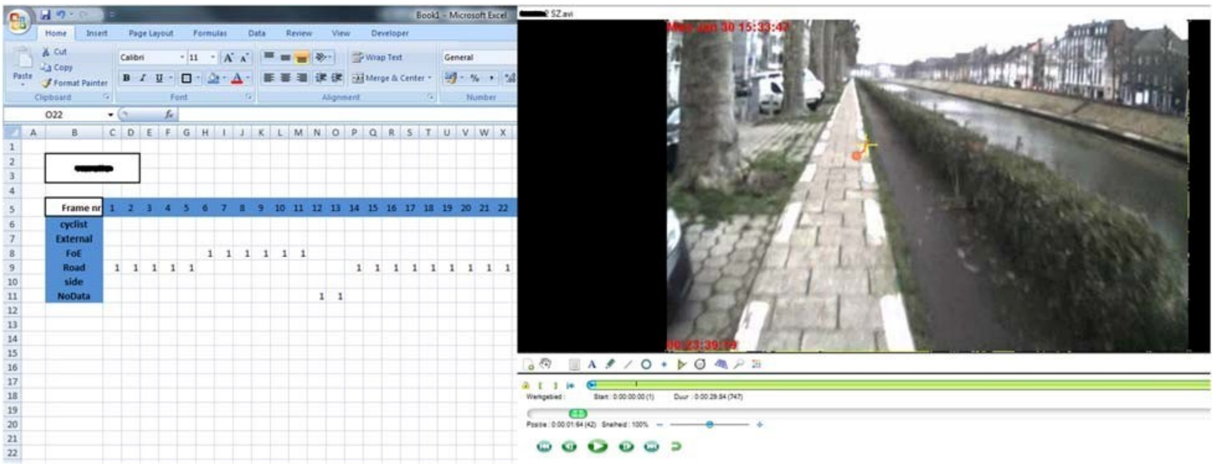
Gaze was categorised into five possible AOIs: Road, Side, External, Focus of Expansion (FoE) and Cyclist. A sketch of how these AOIs were spread across the scene video of one of the trajectories can be found in Figure 2. Since the experiment was executed on public roads in a city known for its high number of bicycle users, the experimenters could not ensure identical traffic situations for all participants. Therefore, the AOI 'Cyclist', which represents gaze to all other cyclists on the cycling track, was not equally present for all participants. The total time spent watching each AOI per trajectory was called the dwell time. By dividing dwell time by the duration of the trial dwell time percentage to each AOI was calculated.

The difference between 100% and the sum of the dwell time percentage to the five AOIs was called 'NoData'. This measure represents saccades between AOIs, blinks and data loss (no eye-tracking signal, or gaze outside of the scene video) during the experiment.

Figure 2 : Screen shot of the gaze-overlay video with AOIs superimposed. Note that this figure is only a sketch of the AOIs, and this grid was not used to determine the fixation location. Each of the fixations/frames was assigned manually to one of these AOIs, or to a fifth AOI 'Cyclist', as described in Section 2

Frame-by-frame analysis

For the frame-by-frame analysis, videos with overlay gaze cursor were coded frame-by-frame to assign gaze location to one of the AOIs (Figure 3). When no gaze cursor was available, or it did not stay within one AOI for at least two consecutive frames, the frames were coded as NoData. Dwell time percentage to each AOI was calculated in Excel by dividing the amount of frames assigned to an AOI by the number of frames analysed in that trial.



[redacted]

Frame nr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
cyclist																						
External																						
FoE						1	1	1	1	1	1											
Road	1	1	1	1	1									1	1	1	1	1	1	1	1	1
side																						
NoData												1	1									

Figure 3 : Example of frame-by-frame procedure: at the left an Excel file for data coding; at the right video analysing software (in this case Kinovea)

Fixation-by-fixation analysis

For the fixation-based analysis, fixations were detected with the 'SMI Event Detection' algorithm and superimposed on the scene video using the BeGaze 3.2 analysis software of SMI (unfortunately, SMI currently does not disclose details about the algorithm). This scene video with superimposed fixations was then used to analyse the fixations one-by-one and assign them to the same AOIs as in the frame-by-frame analysis. For the current experiment, this was done using the function ‘Semantic Gaze Mapping’ in BeGaze 3.2 (Figure 4; this can also be done manually by adding the fixation duration of each fixation to the total dwell time of the corresponding AOI). Dwell time percentage (‘sum of the duration of fixations and saccades that hit the AOI’ (SMI 2012) of each AOI was calculated in BeGaze and saved in an Excel sheet. A percentage of ‘NoData’ was calculated by subtracting the sum of all dwell time percentages from 100%.

Figure 4 : Example of fixation-based procedure: at the right the video is shown with fixation marker, at the left six possible AOIs are shown to which the fixations can be assigned (print screen of BeGaze 3.2).

Comparison

Both analysis methods resulted in 144 dwell time percentages (6 participants X 4 trials X 6 AOIs). Descriptive statistics of the relative and the absolute differences between the dwell time percentages of the frame-by-frame analysis and the fixation-by-fixation analysis were calculated and compared using Microsoft Excel. Relative difference is the dwell time percentage of the fixation-by-fixation method compared with the frame-by-frame method. Negative relative differences therefore indicate that dwell time percentages were lower in the fixation-based method than in the frame-by-frame method. Absolute differences, however, are the absolute values of the relative difference and therefore represent the differences between the two methods regardless the direction of the difference. Whereas the absolute differences indicate the magnitude of the differences in dwell time % between the two methods, the relative differences also informs to what extent these differences affect the average dwell time %. To compare the average dwell time percentages between the two analysis methods, a paired samples t-test was also run per AOI. The significance level for this test was set at $p \leq 0.05$.

The validity of the fixation-by-fixation method compared with the frame-by-frame method was tested using a Pearson correlation test. To compare the results of the two methods per AOI, six separate Pearson correlations were also run. Since eye-tracking data of only six subjects were used for this test, the significance level was set at $p \leq 0.01$ to reduce the chance of type 1 errors.

RESULTS

An overview of the size of the dwell time percentages per analysis method for each of the four trials can be found in Figure 5. The descriptive statistics of the differences between the frame-by-frame analysis and the fixation-by-fixation analysis show an average relative difference of 0.00 ± 7.46% (median = 0.00) and an average absolute difference of 5.24 ± 5.29%. However, the frequency distribution in Table 1 and the box-plot in Figure 6 show that the average absolute difference is biased by a few extreme values. This is also reflected by a lower median (3.64) compared with the average. The descriptive statistics of the relative and the absolute differences per AOI can be found in Table 2. This table shows that there are some considerable differences between the two analysis methods. t-Tests revealed that these differences tended to be significant for the AOIs 'External' (t = 2.353; p = 0.028), 'FoE' (t = 2.555; p = 0.018) and 'Road' (t = 2 1.938; p = 0.065), but no significant differences were found for the AOIs 'Cyclist' (t = -1.660; p = 0.111), 'Side' (t = -1.471; p = 0.155) and 'NoData' (t = 0.785; p = 0.440). The dwell time percentage to 'External' and 'FoE' tended to be higher in the fixation-by-fixation analysis, while the dwell time percentage to 'Road' tended to be higher with the frame-by-frame method.

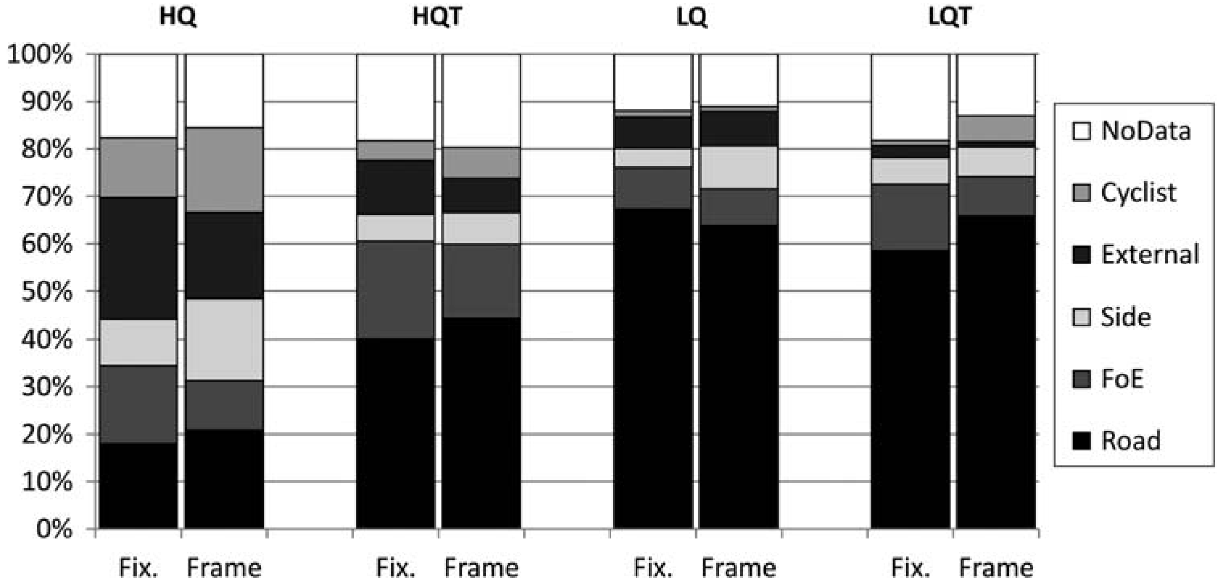


Figure 5 : Average dwell time percentages for each AOI per trial, using fixation-based analysis and frame-by-frame analysis. Fix., fixation-by-fixation analysis; Frame, frame-by-frame analysis; HQ, high quality road; HQT, high quality road with tram rails; LQ, low quality road; LQT, low quality road with tram rails.

Table 1 : Frequency distribution of the relative and the absolute differences between the frame-by-frame and the fixation-by-fixation analysis. Note: Negative relative differences indicate lower dwell time percentage in the fixation-based method than in the frame-by-frame method.

Relative difference			Absolute difference		
Range (%)	Frequency	%	Range (%)	Frequency	%
[-26, -22]	1	1%	[0, 2]	54	38%
[-22, -18]	1	1%	[2, 4]	21	15%
[-18, -14]	2	1%	[4, 6]	16	11%
[-14, -10]	6	4%	[6, 8]	14	10%
[-10, -6]	18	13%	[8, 10]	17	12%
[-6, -2]	16	11%	[10, 12]	6	4%
[-2, 2]	54	38%	[12, 14]	6	4%
[2, 6]	21	15%	[14, 16]	4	3%
[6, 10]	13	9%	[16, 18]	2	1%
[10, 14]	6	4%	[18, 20]	1	1%
[14, 18]	4	3%	[20, 22]	0	0%
[18, 22]	0	0%	[22, 24]	0	0%
[22,26]	2	1%	[24, 26]	3	2%
Total	144	100%	Total	144	100%

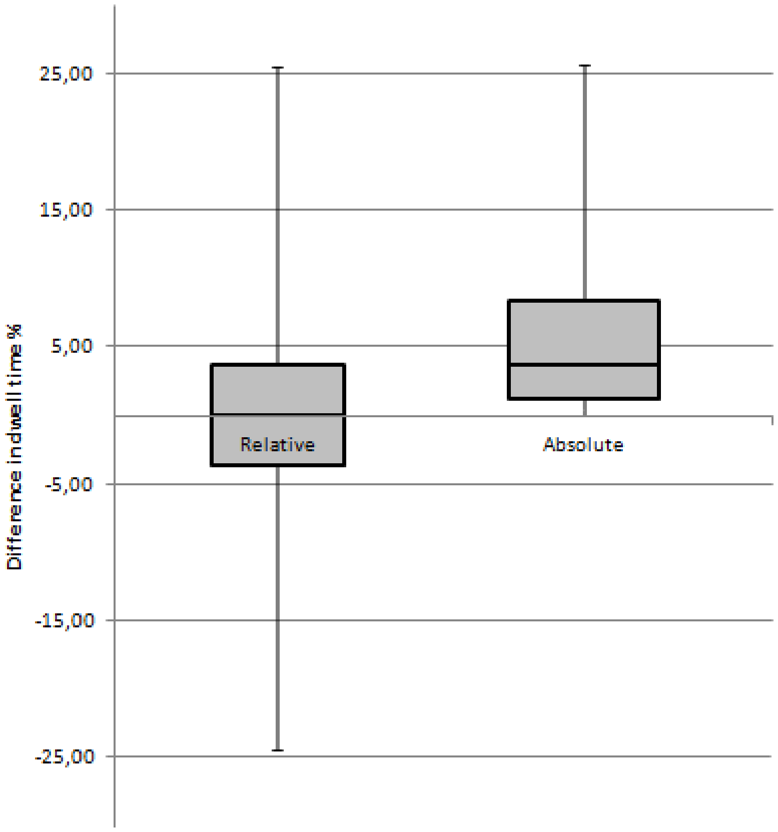


Figure 6 : Box-plot of the relative and the absolute differences in dwell time percentage between the results of the frame-by-frame and the fixation-by-fixation analysis. Negative relative differences indicate lower dwell time percentage in the fixation-based method than in the frame-by-frame method.

Table 2 : Descriptive statistics of the relative differences and the absolute differences in dwell time % between two methods per AOI.

	Cyclist	External	FoE	Road	Side	NoData
	Relative difference					
average	-2,95 ± 6,01	3,07 ± 6,50	4,41 ± 5,75	-2,74 ± 9,17	-3,50 ± 5,11	1,72 ± 7,80
Q1	-8,64	-0,38	-0,11	-6,97	-6,69	-2,25
Median	0,00	0,46	3,67	-4,29	-1,25	2,21
Q3	0,00	4,11	8,19	2,36	-0,21	5,32
Min	-18,59	-3,62	-8,92	-24,48	-16,26	-12,17
Max	9,31	24,69	15,63	14,54	2,36	25,57
	Absolute difference					
average	4,34 ± 5,06	4,03 ± 5,93	5,56 ± 4,60	7,66 ± 5,54	4,07 ± 4,66	5,78 ± 5,38
Q1	0,00	0,42	1,86	4,23	0,95	2,85
Median	2,05	1,82	4,08	6,77	1,71	4,63
Q3	9,36	4,11	8,49	8,83	6,69	6,70
Min	0,00	0,00	0,00	0,30	0,07	0,23
Max	18,59	24,69	15,63	24,48	16,26	25,57

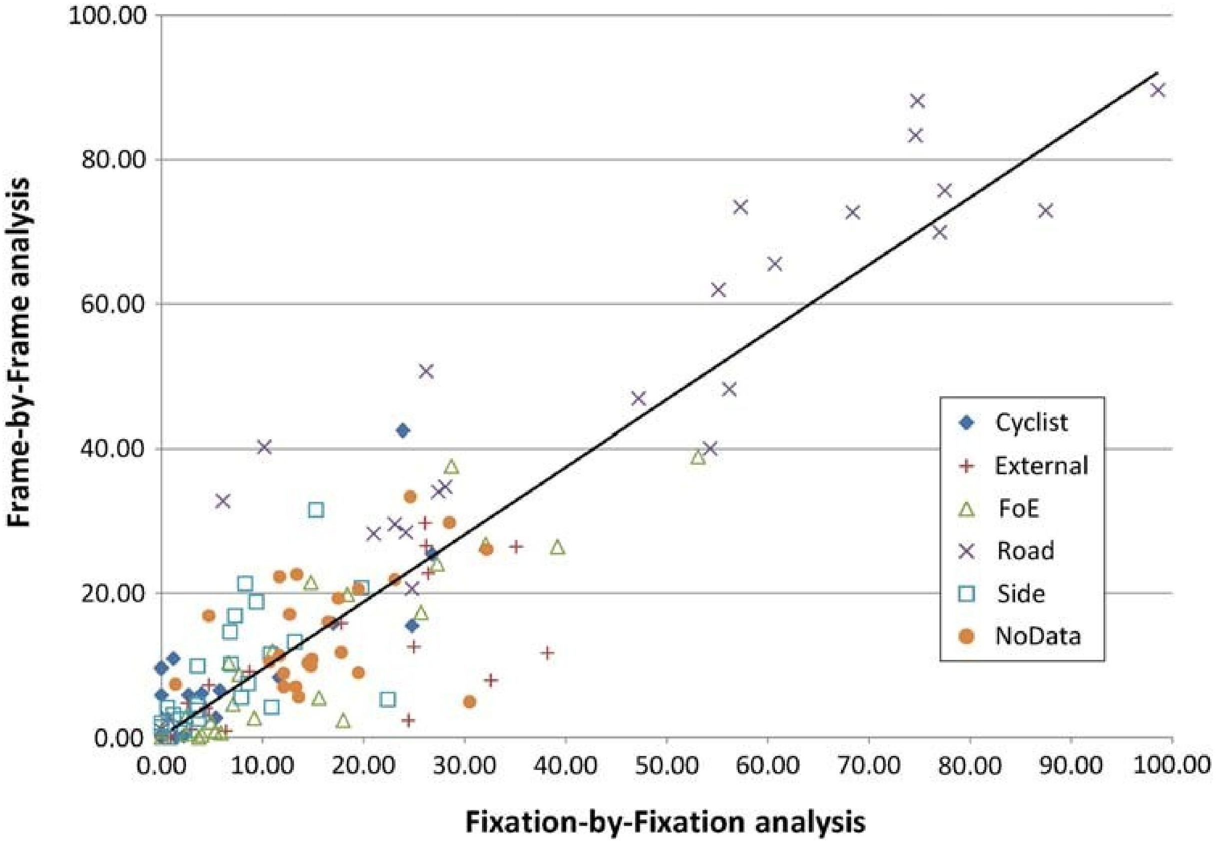


Figure 7 : Scatter plot of gaze percentages per AOI of both the analysis methods. The black line represents the overall trend line.

The Pearson correlation test revealed a significant ($p < 0.001$) Pearson correlation coefficient of 0.930 for the overall comparison of the frame-by-frame and fixation-by-fixation analysis. A scatter plot of the dwell time percentages per AOI can be found in Figure 7. The analysis per AOI showed high correlations between the two methods for the AOIs 'Road' ($r = 0.916$; $p < 0.001$), 'FoE' ($r = 0.896$; $p < 0.001$), 'Cyclist' ($r = 0.813$; $p < 0.001$) and 'External' ($r = 0.765$; $p < 0.001$). The correlation between the two methods was only moderate for the AOIs 'Side' ($r = 0.596$; $p = 0.002$) and 'NoData' ($r = 0.455$; $p = 0.026$).

DISCUSSION

The high correlation of the dwell time percentages suggests a good validity for the fixation-by-fixation analysis compared with the frame-by-frame analysis, which is accepted as a good analysis method for head-mounted eye-tracking data. The overview of the results of both methods in Figure 5 confirms that both methods yield very similar results. Nevertheless, some considerable differences between the dwell time percentages of the fixation-by-fixation analysis and the frame-by- frame analysis were found as well.

The analyses per AOI showed lower correlations than the overall correlation, especially for the AOIs 'Side' and 'NoData'. In general, the lower correlation coefficients per AOI were probably due to the fact that these correlations were based on less data. The observation that the most fixated AOI 'Road' shows the highest correlation between the two methods is in line with this idea. Still, the lower correlations between the two methods for 'NoData' and for dwell time to the side of the road were remarkable. The low and non-significant correlation between the two methods for 'NoData' was probably due to the fact that this measure was calculated slightly differently in both methods. Regarding the AOI 'Side', the lower correlation is rather surprising. Since the AOI 'Side' was similar in size and as static as the other AOIs, it is unlikely that the lower correlation is caused by the different analysis method, because if it was, the correlations for all AOIs should be low, not only for 'Side'. However, during the analysis of the data, the few times that there was minor discussion about the AOI to which a fixation should be appointed, it usually involved the AOI 'Side'. Although the inter-rater reliability was very high, it was not perfect. Therefore, it is possible that the few inter-rater differences mostly involved the AOI 'Side' and affected the correlation for this AOI. A small inter-rater difference could have caused the less systematic allocation of fixations to the AOI 'Side' in both methods, and therefore could have led to the lower correlation for the AOI 'Side'. These few inter-rater differences might also have caused the few large differences in dwell time percentage between the two analysis methods (Table 1).

Although the correlation between the two analysis methods was high, the absolute differences in dwell time percentage were found to be more than 4% in almost half of the data. Furthermore, the fixation-by-fixation analysis seemed to result in slightly higher dwell time percentages for some AOIs compared with the frame-by-frame analysis. Nevertheless, when looking at the general outcome of the two analysis methods in Figure 5, these differences did not seem to alter the final results of the experiment. With a good correlation between the two analysis methods and very similar average results, it seems that the overall validity of the fixation-by-fixation analysis was very good compared with the frame-by-frame analysis, but that some considerable differences in individual data points have to be taken into account. However, the differences between the two analysis methods in this article are not only due to errors of the fixation-by-fixation analysis. In this article, we used the frame-by-frame gaze location analysis as the reference method. Unfortunately, this analysis method has never been compared with a frame-by-frame fixation detection analysis using both gaze overlay video and eye-movements video, which is considered the most reliable method for gaze analysis. Therefore, the considerable differences between the two analysis methods in this article are possibly due to errors in both of them.

To investigate the distribution of gaze over different AOIs, the errors in dwell time percentage caused by the fixation- by-fixation analysis method will hardly affect the final results (cf. Figure 5). Therefore, the fixation-by-fixation analysis method is suitable to get a general overview of dwell time percentages towards several AOIs over an extended period of time. This fixation-by-fixation method could be of use for a growing group of scientists who are interested in using eye tracking in dynamic real-life situations (e.g. in traffic and sports; Authié and Mestre 2011; Mann et al. 2007; Underwood et al. 2005; Vaeyens et al. 2007). It should be mentioned, however, that the fixation-by-fixation approach is probably not suitable for all head-mounted eye-tracking experiments. This article tested the fixation-by-fixation method successfully to get a general overview of the distribution of gaze in a traffic environment. However, AOIs were rather large, and gaze behaviour was analysed for an extended period of time. Therefore, small errors in the number of fixations and in fixation duration will hardly affect the general dwell time to each AOI, as long as fixations are located within the correct AOI. In many sport situations, however, the environment is not only more dynamic than in traffic, an extra task, such as handling a ball, is often involved. Therefore, many sports scientists focus on a specific event and analyse only the actions preceding it (Cañal-Bruland, Mooren, and Savelsbergh 2011; Savelsbergh et al. 2005). For these detailed analyses, where individual fixation durations are taken into account, both the frame-by-frame gaze location analysis and the fixation-by-fixation analysis might not be the most adequate analysis methods. When analysing only a few seconds and small AOIs are used, dwell time will be increasingly dependent on the quality of the fixation-detection algorithm and errors in individual data points will have an increasingly large effect on the overall results. Therefore, for a detailed analysis of gaze behaviour, the frame-by- frame fixation detection method still seems the most appropriate analysis.

When investigating dwell time percentages, the advantage of the fixation-by-fixation analysis is that it can be done much faster than with a frame-by-frame approach. With a scene camera of the eye-tracker working at 25 Hz, a recording of, in this study, 25 seconds leads to 625 frames to be analysed frame-by-frame. Considering that humans make two to three fixations per second (Kowler 2011; Lappe and Hoffman 2000), with a fixation-by-fixation analysis only 50 – 75 fixations have to be assigned to the correct AOI for the same recording. Of course, frames are often analysed not one by one, but rather as a string of frames towards an AOI. Still, the fixation-by-fixation method was much more convenient, especially when gaze shifted a lot between the multiple AOIs. For this experiment, using the fixation-by-fixation method reduced analysis time by factor 9 (from ±54 to ±6 seconds of analysis, per second of eye-tracking data). Taking into account that the frame-by-frame gaze location analysis used in this article is already faster than the frame-by-frame fixation detection method, these results approach the increase of efficiency of data analysis by factor 10 – 50, as advertised by eye-tracking software developers (e.g. SMI).

In the current investigation, we tested to which extent two gaze analysis methods to calculate dwell time percentage resulted in comparable results. Although we showed that the fixation-based method is a valuable method, we also suggested it might not be the most appropriate analysis tool for some experimental set-ups. Choosing the right analysis method could save a lot of processing time, but could possibly also alter the results. Therefore, further research is necessary to test the fixation-by-fixation method in various settings. More generally however, there is still a large need for more standardised procedures for head-mounted gaze analysis.

CONCLUSIONS

When the general distribution of attention towards multiple AOIs over an extended period is the main research interest, the use of dwell time and a fixation-based approach seems the most suitable analysis method at the moment.

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Chapter 2

Visual-motor behaviour during isolated steering tasks

In this chapter :

2.1. Cycling on a straight narrow lane

The gaze and steering behaviour of adults and children steering through narrow straight lanes is investigated.

2.2. Cycling around a curve

The effect of cycling speed on gaze and steering behaviour of adults negotiating a semicircular lane is investigated.

2.3. Cycling a slalom

The gaze behaviour of adults and children while cycling through a slalom is investigated.

2.1 Cycling on a straight narrow lane

Paper 2

THE VISUAL CONTROL OF BICYCLE STEERING: THE EFFECTS OF SPEED AND PATH WIDTH

Vansteenkiste P, Cardon G, D'Hondt E, Philippaerts R, Lenoir M

Accident Analysis and Prevention 51 (2013) 222-227

ABSTRACT

Although cycling is a widespread form of transportation, little is known about the visual behaviour of bicycle users. This study examined whether the visual behaviour of cyclists can be explained by the two level model of steering described for car driving, and how it is influenced by cycling speed and lane width. In addition, this study investigated whether travel fixations, described during walking, can also be found during a cycling task. Twelve adult participants were asked to cycle three 15 m long cycling lanes of 10, 25 and 40 cm wide at three different self-selected speeds (i.e., slow, preferred and fast). Participants' gaze behaviour was recorded at 50 Hz using a head mounted eye tracker and the resulting scene video with overlay gaze cursor was analysed frame by frame. Four types of fixations were distinguished: (1) travel fixations, (2) fixations inside the cycling lane (path), (3) fixations to the final metre of the lane (goal), and (4) fixations outside of the cycling lane (external). Participants were found to mainly watch the path (41%) and goal (40%) region while very few travel fixations were made (<5%). Instead of travel fixations, an OptoKinetic Nystagmus was revealed when looking at the near path. Large variability between subjects in fixation location suggests that different strategies were used. Wider lanes resulted in a shift of gaze towards the end of the lane and to external regions, whereas higher cycling speeds resulted in a more distant gaze behaviour and more travel fixations. To conclude, the two-level model of steering as described for car driving is not fully in line with our findings during cycling, but the assumption that both the near and the far region is necessary for efficient steering seems valid. A new model for visual behaviour during goal directed locomotion is presented.

INTRODUCTION

Goal directed locomotion is usually guided by information from task specific visual search patterns (Ballard and Hayhoe, 2010). Both in car driving and walking, eye movements have been studied to understand how humans use vision for obstacle avoidance and safe navigation (Marigold et al., 2007; Patla and Greig, 2006; Hildreth et al., 2000; Mourant and Rockwell, 1972; Underwood et al., 2003; Falkmer and Gregersen, 2005). Unfortunately, despite the fact that cycling is a wide-spread form of transportation and is often recommended as a healthy and economic way to do so (Rabl and de Nazelle, 2012), little is known about the visual behaviour of cyclists. With increased use of bicycles for transportation, the number of bicycle accidents also increased (Juhra et al., 2012). Therefore, greater insight in the visual behaviour of cyclists is essential for effective traffic education and infrastructural planning.

In car driving, gaze behaviour can be best described by the two-level model of steering (Donges, 1978; Land and Horwood 1995). According to this model, two visual regions are used for efficient steering. First, a distant point on the travel path is used for controlling heading. On a straight road this is usually the vanishing point, a leading car or a point to which the car has to be steered (Salvucci and Gray, 2004; Land and Lee, 1994). On curved roads, the 'tangent point' has been identified as an important visual cue. This is the point on the inside edge of the bend which protrudes the most in the road and has been shown to be closely linked to the drivers steering behaviour (Land and Lee, 1994; Mars, 2008; Kandil et al., 2009). The second region described in the two-level model is the near road region. This region includes the road and its markings in the immediate proximity of the car and plays an important role for lane keeping. However, this near region is rarely fixated. Instead of switching gaze from far road to near road regions, car drivers tend to fixate mainly the far road and attend to the near road peripherally for position-in-lane feedback. This gaze strategy has been shown to be efficient for multiple steering tasks, such as corrective steering, lane changing and curve negotiation (Salvucci and Gray, 2004).

The two-level model has not yet been explicitly tested for walking but some studies in real-world scene perception also use the distinction between near and far regions (Foulsham et al., 2011; Pelz and Rothkopf, 2007). In contrast to car driving, the near path region is frequently gazed at during walking (±30% of the time) and only few fixations (<10%) are made to the distant path (Foulsham et al., 2011). On an uneven pathway, proportion of gaze to the near path even increases up to 75% (Pelz and Rothkopf, 2007). This 'path-watching' phenomenon can be explained by pedestrians being more dependent on path quality for maintaining dynamic balance, in contrast to car drivers. The fact that pedestrians also spend more time looking at regions irrelevant for the control of locomotion, such as the scenery (Turano et al., 2003), is probably due to the lower speeds at which they travel. At lower speeds, more time is available to anticipate and react to possible hazards, which leads to a lower task demand.

Patla and Vickers (2003) mentioned a specific type of near path fixation during walking, called the travel fixation. A travel fixation occurs when gaze is held on a fixed distance about two steps in front of the body and is carried along at the speed of locomotion. As a result, the point of regard moves at the same speed as the body. During this type of fixation optic flow lines pass through central as well as peripheral vision and are used to obtain information about the self-motion. However, generalization of travel fixations to other forms of locomotion can be questioned since they have been observed in only a few other studies (Fowler and Sherk, 2003; Hollands et al., 2002). In addition, the use of travel fixations would mean that the OptoKinetic Reflex (OKR) is suppressed. This OKR is a reflexive eye movement that stabilizes the retinal image by adapting the eye movement velocity to that of the retinal image (Lappe and Hoffman, 2000; Miles, 1998). When moving forward at a constant speed, the environment is perceived as a constant radial optic flow. Without eye movements adapted to the speed of the optic flow, visual pick-up would be blurry. Therefore, a series of optokinetic eye movements is elicited (Solomon and Cohen, 1992; Lappe et al., 1998; Knapp et al., 2008; Niemann et al., 1999). This series of OKR's is called OptoKinetic Nystagmus (OKN) and has been described during simulated rectilinear self motion in the monkey and humans (Lappe et al., 1998; Niemann et al., 1999) and recently also during car driving (Authié and Mestre, 2011). To our knowledge, however, neither travel fixations nor OKN have been described for cycling.

The first aim of this study was to test the influence of these constraints on gaze behaviour by imposing three cycling speeds and three lane widths (i.e., a smaller path). It was expected that higher cycling speeds and lower task demands would result in a more distant visual behaviour. The second aim of this experiment is to examine whether the visual behaviour of cyclists can be explained by the two-level model of steering. If this model can be applied to cycling as for driving, cyclists would mainly look at distant points while they maintain centred in the lane by attending the proximal pathway peripherally. However, Land and Horwood (1995) noted that at lower speeds (<12 m/s) the near-road information is adequate on its own. In addition, Pelz and Rothkopf (2007) showed that when task demands were higher, vision shifted towards the near region. Finally, the third aim of this study was to investigate whether travel fixations are made or an OKN is elicited when looking at the path during a in situ linear cycling task.

MATERIALS AND METHODS

Subjects

A convenience sample of nineteen participants took part in the experiment and were recruited from Ghent University's students and staff. Twelve participants aged 21–28 (five females) whose tracking ratio of eye movements (i.e., the time that direction of gaze could be determined/duration of trial) was at least 85% and for whom pre and post calibration were good, were selected for further analysis. All participants had normal or corrected-to-normal vision and all used their bicycle on regular basis for transportation.

Apparatus

Eye movements were recorded using the IviewX Head mounted Eye tracking Device (SMI, Teltow GER). An infra red eye camera was mounted on a baseball cap and recorded the left eye movements at 50 Hz using pupil position and corneal reflex. A scene camera with 3.6 mm lens, placed next to the eye camera recorded video images at 25 Hz with a horizontal and vertical field of view of approximately 33◦. Both cameras were connected to a notebook which was worn in a backpack. Video and eye tracking data were combined using SMI's software BeGaze 3.0. The system has a spatial accuracy of 1◦.

Set up and procedure

The experimental set up is shown in Fig. 1. Cycling lanes of 10 cm (narrow), 25 cm (middle) and 40 cm (wide) of width and 15 m of length were marked on the floor with a white tape. Two mechanical gates at the start and at the end of the lane gave a visual signal when the cyclist passed through. A line marked the start of the 15 m run-up before the first gate and an overview camera (25 Hz, Full HD) stood 4 m behind the second gate to record the cyclist and the signals of the mechanical gates. After calibration, participants were given one familiarization trial for each lane. Subsequently, the test leader (A on Fig. 1) asked the participant to cycle through one of the lanes at self-selected low, preferred or high speed without crossing the edge lines. A start signal was given to the cyclist by a second test leader (B on Fig. 1) using a clapperboard. This signal was also used for synchronizing eye tracking data with the video images of the overview camera. Nine conditions (3 lanes × 3 speeds) were carried out in a randomized order. After the last condition a calibration check was done. All tests were done in a gymnasium with a parquet floor and with a standard city bicycle (women's model) rented from the university bicycle service. Saddle height was adjusted for each participant so that they could reach the ground with the tips of their feet while being seated on it.

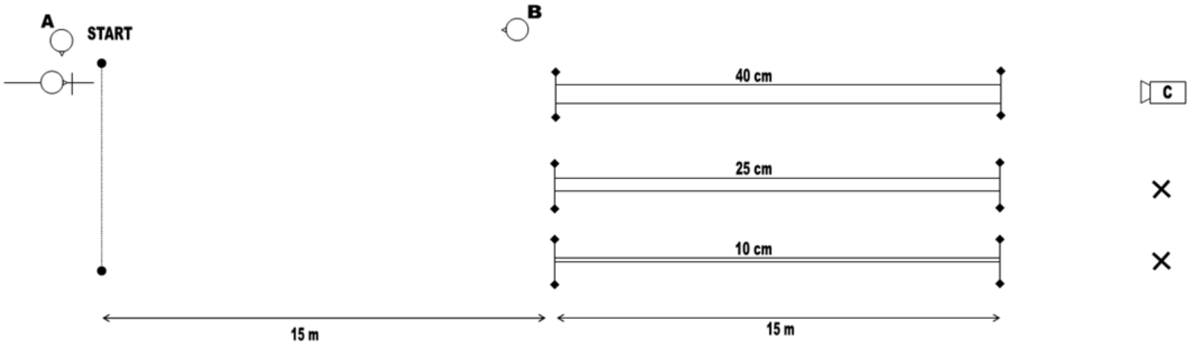

Figure 1 : Experimental set-up. (A) test leader that gives instructions to the participant; (B) test leader with clapperboard; (C) and (X) places of overview camera

Data analysis

Performance variables were cycling speed (v = (15 m/cycling time from gate 1 to gate 2 in s) × 3.6) expressed in km/h and the cycling time inside the edge lines, expressed as a percentage of total cycling time (in-lane%). The in-lane cycling time was visually obtained from the overview camera at the end of the lane. For each trial the video data with overlay gaze cursor were exported from BeGaze 3.0. These videos were analysed frame by frame in Kinovea to measure fixation duration, fixation type, and fixation location. A fixation was defined as the cursor being steady for at least three consecutive frames (120 ms) and ended when a saccade was made. This “direct inspection” method has been reported to be time-consuming but very effective for head mounted eye trackers (Duchowski, 2007, p. 138). Single measure intraclass correlation was calculated on 8.33% of the data to test the intrarater reliability. Results demonstrated a high intrarater reliability for both the number of fixations (R = 0.856) and the fixation duration (R = 0.902). Travel fixations were denoted when “gaze was held stable in front on the travel surface and moved at the speed of locomotion” (Patla and Vickers, 1997). All other fixations were divided into fixations on the cycling path (Path), on the final metre of the cycling lane (goal) and on areas outside of the travel path (external). A total fixation percent-age (TotFix%) was calculated by dividing the total fixation duration of a trial by the duration of that trial. Fixation time of each fixation type (Fix%) was expressed as a percentage of the total fixation time (%Travel, %Path, %Goal and %External).

Statistics

Effects of self-imposed cycling speed and lane width on actual cycling speed, in-lane% and TotFix% were analysed using a repeated measures ANOVA, including two within subject factors with each of them consisting of three sublevels (i.e., speed: slow, preferred, fast; width: narrow, middle and wide). For analysis of the effect of speed and width on Fix%, a similar repeated measures ANOVA was used but the four types of fixations were added as separate measures. For comparison of the Fix% of the four types of fixation, a repeated measures ANOVA was done with three within subject factors (width, speed and fixation type). Significant differences ($p < 0.05$) were further analysed using pairwise comparisons.

RESULTS

Table 1 provides an overview of both descriptive and comparative statistics.

Cycling speed, in-lane% and total fixation%

Cycling speed increased from the slow to the fast condition ($p < 0.001$) and participants cycled faster on the wide lane as compared with the narrow lane ($p < 0.045$). Cycling speed on the middle lane appeared to be lower than on the wide lane and higher than on narrow lane but these differences did not reach significance ($p = 0.070$ and $p = 0.085$, respectively). In-lane% was significantly lower on the narrow lane than on the middle ($p < 0.001$) and on the wide lane (p < 0.001). No difference between middle and wide lane speeds were found (p = 0.060). Cycling speed did not influence the in-lane%. TotFix% at low speed (74 ± 11%) was significantly higher than in preferred speed (68 ± 13%; p = 0.003) and high speed (66 ± 17%; p = 0.014). No interaction between speed and width and no effect of lane width were found on TotFix%.

Table 1 : Mean values and Standard Deviations for cycling speed, in-lane%, TotFix%, %path, %Travel, %goal and %external. F-value, (degrees of freedom) and significance are given for effect of lane Width, cycling Speed and Width*Speed

	Narrow			Middle			Wide			F-value (df) and p		
	Slow	Preferred	Fast	Slow	Preferred	Fast	Slow	Preferred	Fast	Width	Speed	W * P
speed (km/h)												
Mean	8,48	11,97	16,76	8,66	12,19	17,08	8,81	12,50	17,76	4.607 (22)	63.225 (22)	0.544 (44)
SD	2,22	2,04	2,95	2,25	1,86	2,97	2,27	2,03	3,62	0.021	< 0.001	0.704
in-lane%												
Mean	57%	65%	61%	98%	99%	100%	100%	100%	100%	53.256 (22)	0.639 (22)	0.582 (44)
SD	20%	22%	26%	5%	3%	1%	0%	0%	0%	< 0.001	0.512	0.556
total fix%												
Mean	73%	67%	69%	77%	72%	70%	71%	66%	60%	2.174 (10)	9.457 (10)	0.182 (8)
SD	12%	14%	17%	4%	9%	15%	13%	17%	20%	0.165	0.005	0.941
% Path fix												
Mean	69%	50%	47%	51%	36%	27%	31%	31%	25%	19.670 (22)	5.172 (22)	1.239 (44)
SD	17%	25%	27%	32%	25%	29%	32%	29%	31%	< 0.001	0.014	0.308
% Travel fix												
Mean	1%	4%	4%	1%	2%	5%	1%	2%	7%	0.109 (22)	5.220 (22)	0.478 (44)
SD	2%	10%	8%	3%	3%	7%	3%	4%	10%	0.897	0.014	0.752
% Goal												
Mean	24%	35%	39%	37%	46%	53%	45%	38%	43%	6.049 (22)	1.898 (22)	1.472 (44)
SD	16%	24%	24%	24%	20%	25%	25%	18%	27%	0.008	0.174	0.227
% External												
Mean	6%	11%	10%	10%	16%	14%	24%	29%	26%	8.089 (22)	0.882 (22)	0.029 (44)
SD	8%	15%	15%	17%	19%	20%	24%	26%	25%	0.002	0.428	0.998

Fixation location

Overall, the Fix% of the four fixation types was different (F3,9 = 411.459; p < 0.001). Path (41 ± 30%) and goal fixations (40 ± 23%) were the dominant types of fixations, followed by external fixations (16 ± 13%; p < 0.05) and travel fixations (3 ± 6%; p < 0.05). Both lane width ($F_{8,38}$ = 4.432; p = 0.001) and cycling speed ($F_{8,38}$ = 2.384; p = 0.034) had an effect on fixation location but no interaction between lane width and cycling speed was found ($F_{16,126}$ = 0.577; p = 0.896) (Fig. 2). Percentage of gaze towards the Path was higher when cycling at slow speed than at preferred (p = 0.040) and fast speed (p = 0.013). No difference in %Path was found between preferred and fast cycling speed (p = 0.288). Percentage of travel gaze at fast speed was significantly higher than at slow speed (p = 0.003), whereas no difference was found for preferred speed as compared to slow (p = 0.208) or fast speed (p = 0.133).

Percentage of goal fixations was lower at slow than at fast speed but this difference did not reach significance (p = 0.084). The percentage goal fixations at preferred speed was not significantly different from than that at high (p = 0.254) and at low speed (p = 0.427). No effect of cycling speed was found for %External fixations (p > 0.100). Looking to the path (%Path fix) increased as the lane was more narrow (p < 0.050) while %Goal was lower on the narrow lane than on the wider lanes (p < 0.050). No significant difference in %Goal was found between the wide and the middle lane (p = 0.340). Percentage external fixations were higher on the wide lane as compared to both the middle (p = 0.003) and narrow lane (p = 0.014). No difference in %External was found between the middle and the narrow lane (p = 0.237) and no effect of lane width on %Travel was found (p > 0.100).

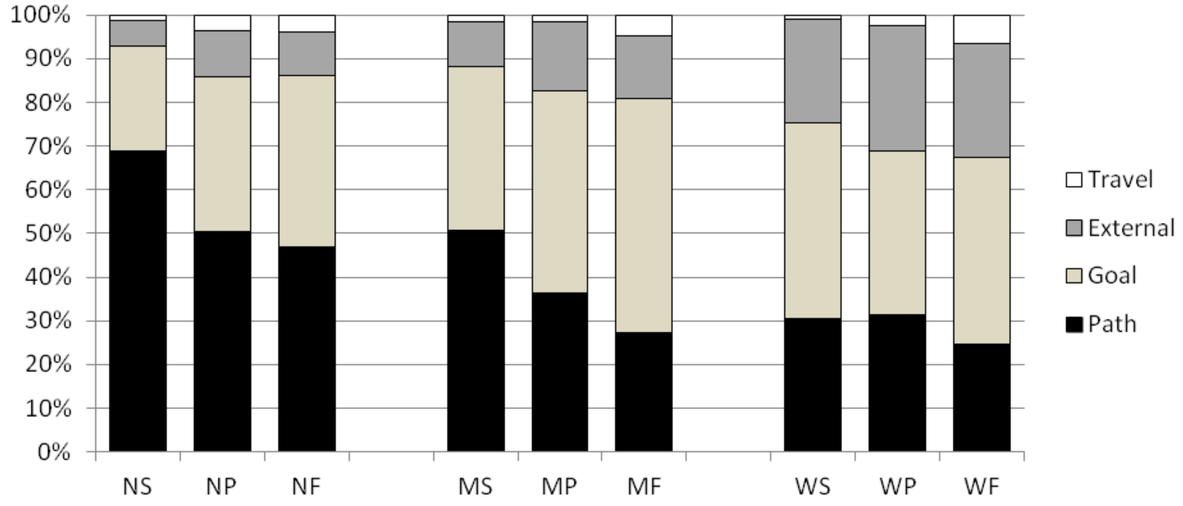

Figure 2 **:** Distribution of the four fixation types at different path widths (Narrow – Middle – Wide) and speeds (Slow – Preferred – Fast). For values and significance, see text and Table 1

Travel fixations versus OptoKinetic Nystagmus

Only 3% of all fixations were categorized as travel fixations. Instead of travel fixations, OKN was revealed when participants watched the path. An example of how the OKN can be observed in the Y-coordinates (vertical axis) of the gaze is given in Fig. 3 (participant BC), with each ‘sawtooth’ representing an OKR followed by a regressive saccade. If this participant would have made mainly travel fixations, the graph would show multiple horizontal lines. The Y-coordinates of participant Y show a typical ‘goal-watching’ behaviour.

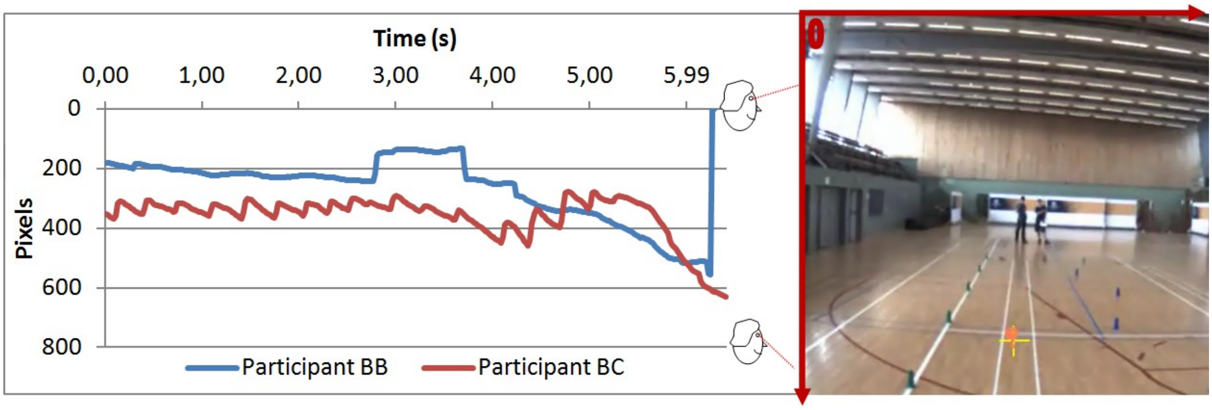

Figure 3 : Y coordinates of gaze of two participants while cycling on the 15m track. Participant BC looks at the path while OKN takes place and looks at the final gate about 1/2s before he reaches it ('path-watching'). Participant BB looks at the final gate from the beginning, makes a shift towards an external region and then looks back at the final gate until he reaches it ('goal-watching').

DISCUSSION

The overall aim of this paper was to investigate to what extent visual strategies documented for car drivers and pedestrians also hold for cycling. Our study results showed that participants mainly watched the path and the goal region but proportions were subject to lane width and cycling speed. Few travel fixations were measured, instead an OptoKinetic Nystagmus was revealed.

Although not instructed to do so, participants cycled slightly faster when the cycling lane was wider. This effect of lane width on travelling speed has been previously described in car driving (McLean and Hoffman, 1972) and can be explained by the speed-steering workload trade-off. According to this concept, higher speeds and more narrow lanes both require a higher mental effort to keep the vehicle in lane. Therefore, speed will be adjusted according to the width of the cycling lane to keep the mental workload at a reasonable level for keeping the vehicle in position (Godley et al., 2004). Adjustment of speed to the task difficulty is also called task difficulty homeostasis and is an essential part of the task–capability interface (TCI) model. According to this model driving behaviour can be described by the interaction between the determinants of task demand and the driver's capability (Fuller, 2005; Fuller et al., 2008). The TCI-model was designed for car driving behaviour but from our data seems to be applicable for cycling behaviour as well.

Results of the gaze location analysis indicated a visual behaviour that was similar to that of pedestrians, with gaze directed to the path as well as to the goal area (Patla and Vickers, 2003; Turano et al., 2001; Foulsham et al., 2011). In contrast to the two-level model of steering during car driving, the near region was actively looked at. As Land and Horwood (1995) suggested, at lower speeds the near region seems to be sufficient for both stability and guidance. However, the high standard deviation of the fixation location suggests notable individual differences. In some trials, a visual behaviour resembling the two-level model of steering was revealed, characterized by prolonged fixations to the goal. In other trials gaze was directed primarily to the near path or even to external regions. It has been frequently shown that visual behaviour is highly task dependent (Yarbus, 1967; Marigold and Patla, 2007; Ballard and Hayhoe, 2010). The present results however suggest that large individual differences can also exist within the same task. In other words, multiple visual strategies can lead to the same visual information and an associated motor action. The observed variation of visual behaviour could be due to the specific task characteristics (i.e., self-imposed speed, lane width, etc.) or to a combination of individual differences such as cycling skills (balance and steering control (Ducheyne et al., 2013), perception of the task, visual dependency, etc.). An example of the visual behaviour during 'goal-watching' and 'path-watching' is shown in Fig. 3. Notwithstanding the individual differences, participants shifted their attention towards the goal at higher speeds, towards the near pathway on narrow lanes and more towards irrelevant areas on wider lanes.

Since human action is associated with a visual-motor delay (Hayhoe and Ballard, 2005; Land, 2006), a visual buffer of 0.80–2.00 s is used in locomotion (Land and Furneaux, 1997; Wilkie and Wann, 2003; Wilkie et al., 2008). Considering a visual buffer of 1 s, participants in our current experiment should have looked approximately 2.5 m in front of them in the slowest condition. In the preferred and high speed condition however, the same visual buffer will lead to look-ahead fixations at a distance of 3.3 and 4.7 m respectively. With gaze often stabilized on the goal once it is within the range of the visual buffer, larger look-ahead fixations will lead to a higher proportion of goal fixations. In other words, the higher proportions of goal fixations in the faster conditions are not necessarily the result of a different visual strategy but rather of the same visual buffer that got larger spatial dimensions as cycling speed was higher.

The effect of wider lane width on the visual behaviour could be explained by the lower task demand that it induces. It has been shown that selective attention to relevant stimuli is indicative for the information needs (Hughes and Cole, 1988; de Waard, 1996). So it is reasonable to suggest that less demanding situations will lead to a less restricted visual search pattern, and therefore to more task-irrelevant fixations. On the wide lanes participants can probably keep the bicycle on the track by using primarily the peripheral vision, analogous to the two-level model. But as the demands of traffic situations increase, the use of the peripheral vision will drop in favour of the information uptake by the fovea (Miura, 1987). So when the lane gets more narrow, peripheral vision is no longer sufficient for the lane keeping task and gaze will be directed closer to the bicycle. This shift of attention is similar to that during walking, where vision is also directed more to the path itself when the task becomes more demanding (Pelz and Rothkopf, 2007). Although in the study of Pelz and Rothkopf the higher task demand for walking is mainly due to a higher need for balance and that of cycling in the current study rather to a need for finer steering adjustments, both could be seen as a need for more direct control.

A new gaze constraints model for goal directed locomotion is presented in Fig. 4. Similar to the two-level model of steering, it relies on the assumption that both the far region (guidance) and the near region (lane-keeping) are necessary for efficient steering. Different from the two-level model is that the current model is applicable to multiple forms of locomotion and predicts how gaze behaviour changes under different task and environmental constraints. The gaze constraints model assumes that reaching a goal in a safe manner requires: (1) direct control for stability and vehicle control and (2) anticipation for guidance and hazard perception. The need for direct control is characterized by close gaze behaviour (the 'near' region). This need increases with task complexity, and decreases with automatisation and/or mastery of the vehicle. The need for anticipation on the other hand is characterized by distant gaze behaviour (the 'far' region) and increases with speed as well as the extent to which the environment is unpredictable. Together with an increasing need for both direct control and anticipation, the attentional demand and mental workload will also increase, leaving less room for irrelevant gaze behaviour. Similar to the use of the two-level model (Salvucci and Gray, 2004), the near region will be attended peripherally and/or with intermittent fixations when the need for anticipation is higher than the need for direct control. When the need for direct control is highest, vision will be more similar to that of pedestrians on rough surface (Marigold and Patla, 2007), with gaze primarily directed to the near path with occasionally shifts to the distant regions.

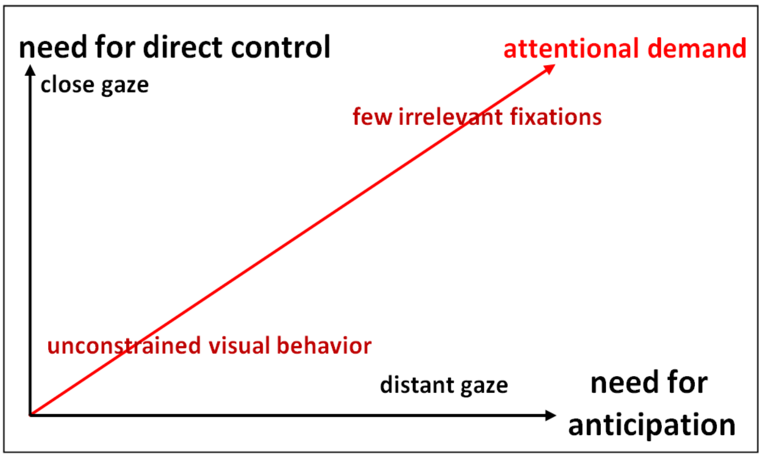

Figure 4 : Gaze constraints model for goal directed locomotion. The synergy of the need for direct control (task complexity, capability, ...) and the need for anticipation (unpredictability of environment, speed, ...) determines the gaze direction and attentional demand of the person in locomotion

The third aim of the present experiment was to find out whether travel fixations were used or an OptoKinetic Nystagmus (OKN) could be revealed. In contrast to previous findings of Patla and Vickers (2003) during walking, few travel fixations were observed during a cycling task. Alternatively, as was found for curve driving by Authié and Mestre (2011) gaze towards the path directly in front of the participants was subject to an OptoKinetic Nystagmus (OKN). To our knowledge the current paper is the first study to report the OKN in a non-simulated locomotion experiment. Results also disprove two of the suggestions made by Authié et al. (2011). They suggested that OKN may not have been observed in other studies due to an insufficient temporal resolution of the eye tracking systems being used as well as to the lower speeds of locomotion. In the current experiment, however, OKN was observed even though the temporal resolution of the eye tracker was 50 Hz and cycling speeds were between 6 and 26 km/h. Another possibility is that the methodology used for analysing eye movements determined whether or not OKN can be detected. Since eye movement data analysis is time-consuming, many researchers rely on analysis software for fixation duration, location, etc. Unfortunately, this software usually does not detect smooth pursuit, which is an essential part of the OKN. Therefore, this particular visual behaviour might be missed out. This difference in methodology could also explain why few travel fixations were observed in the current study. If we look at the raw data of gaze (i.e., frame by frame eye movements) it seems as there is a 'travel gaze behaviour' in that way that gaze stays within a certain array in front of the body but keeps moving back and forth as a result of the OKN. If processed data (i.e., per fixation) of the analysis software are used, fixations keep reappearing on the same distance of the cyclist. Still, some travel fixations were observed, especially at higher speeds. These could be caused by a failing optokinetic reflex at higher travelling speeds or could be due to the gain ratio between gaze velocity and optical flow velocity being lower than one. OKR gain falls below unity at stimulus speeds exceeding 30◦/s (Howard and Ohmi, 1984). Similarly, Authié & Mestre (2011) also reported gains of 0.66. A low gain of the OKR could have led to a visual behaviour resembling travel fixations. An alternative explanation is that these observations were the result of the frame-by-frame analysis. At higher travelling speeds, eye movements were somewhat more troubled and could have lead to a higher chance of falsely appointing a fixation as a travel fixation.

The presented study is a first step towards understanding the visual behaviour of cyclists. However, the current experiment only tested the model in an indoor, distraction-free environment, and visual behaviour was analysed on a track of only 15 m long. This set-up might have been too pragmatic to encounter some variations of in-traffic gaze behaviour. Furthermore, it should be taken into account that even the largest lane width used in current experiment is still much narrower than a real cycling lane, which is about 1.5m wide. Therefore, further research is necessary to test if our proposed model is applicable in more open and realistic settings and if the OKN is also elicited in free cycling situations. Nevertheless, even on this short track, the effects of path width and cycling speed were apparent. Together with hazard perception and decision making, more insights into the visual behaviour of bicyclists could lead to primary prevention measures such as better infrastructure and adapted traffic education for children and adults.

CONCLUSION

Bicycle users adapted their cycling speed to the lane width in accordance to the speed-steering workload trade-off. Visual behaviour of the participants could only partly be explained by the two-level model. Participants shifted their attention towards the goal at higher speeds, towards the near pathway on narrow lanes and more towards irrelevant areas on wider lanes. Based on these findings, a gaze constraints model for goal directed locomotion was presented. Finally, few travel fixations were found, instead an OptoKinetic Nystagmus was revealed.

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Paper 3

VISUAL GUIDANCE DURING BICYCLE STEERING THROUGH NARROW LANES
A STUDY IN CHILDREN

Vansteenkiste P, Cardon G, Lenoir M

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ABSTRACT

Recently, Vansteenkiste et al. (2013) explored how visual behaviour guides bicycle steering when cycling at different speeds through 15m long lanes of 10, 25 and 40 cm wide. Participants were found to shift their gaze direction towards the end of the lanes at higher speeds, towards the near pathway on narrow lanes and more towards irrelevant areas on wider lanes. To investigate to what extent young learner bicyclists adapt their visual behaviour in a similar way as adults, the experiment was repeated with seven eight-year-old children, and results were compared to the adult data. Children were found to cycle slower through narrow lanes than adults. However, with increasing lane width and cycling speed, children made the same shifts of visual gaze direction as the adults. These results suggest that for a simple precision steering task, children are able to adopt a similar visual-motor strategy as adults, provided that they cycle at their own pace.

INTRODUCTION

Although bicyclists of all age groups can be considered vulnerable road users, accident analyses have shown that children under the age of 15 and elder people over 65 are particularly at risk (Carpentier and Nuyttens, 2013; DEKRA, 2011). The higher accident proneness of children has been linked to the fact that they are still developing the motor and cognitive skills essential for safe traffic participation. Regarding the motor skills required for safe cycling, multiple studies have documented the development of cycling skills, and the effects of cycling skills training programs (Ducheyne et al., 2013; Macarthur et al., 1998; Zeuwts et al., 2015). The development of cognitive skills in traffic safety such as visual attention, judgment and decision making however, has mostly been described in pedestrians and car drivers (Land and Horwood, 1995; Mcknight, 2003; Oxley et al., 2005; Salvucci and Gray, 2004; Underwood et al., 2007).

For example, pedestrians should be able to detect the presence of traffic, make judgements about it, and co-ordinate their actions to it, to safely cross a street (Geruschat et al., 2003; Whitebread and Neilson, 2000). Studies have showed that children younger than ten have problems with all three of these actions. They adopt different visual search strategies, featured by a limited use of peripheral vision, watching irrelevant areas in their field of view, and less switching between relevant cues compared to adults. As a result, they need more time to make decisions and have difficulties in synchronizing themselves with moving objects (Ampofo-Boateng and Thomson, 1991; Chihak et al., 2010; Franchak and Adolph, 2010; Plumert et al., 2007; Thomson et al., 1996; Whitebread and Neilson, 2000). In contrast to the relatively well documented visual behaviour in young pedestrians, it remains unclear to what extent these less developed cognitive skills affect the cycling behaviour of learner cyclists.

Recently, Vansteenkiste et al. explored how visual behaviour guides bicycle steering in a simple bicycling tasks (Vansteenkiste et al., 2013). In this experiment, adults were asked to steer at three different speeds through 15m long narrow straight lanes of different widths. The results showed that although there were considerable individual differences in where participants looked, participants shifted their gaze direction towards the end of the lanes at higher speeds, towards the near pathway on narrow lanes and more towards irrelevant areas on wider lanes. However, while this task-specificity of gaze behaviour seems obvious for adults, and has been described in many other visual-motor tasks (Land and Hayhoe, 2001; Land, 2006; Pelz and Rothkopf, 2007; Vaeyens et al., 2007; Vansteenkiste et al., 2014; Yarbus, 1967), it is not known whether children exhibit the same task-specific adaptations in visual behaviour.

To investigate if young learner bicyclists adapt their visual behaviour in a similar way to adults, the experiment of Vansteenkiste et al. (2013) was repeated with eight year old children, and compared to the adult data. Taking into account the differences in visual behaviour between adults and children, we expected that children would spend more time watching irrelevant areas (Whitebread and Neilson, 2000) and focus less on the goal region than adults (Franchak and Adolph, 2010; see also Vansteenkiste et al. 2013, and the section 'data analysis' of current paper').

MATERIAL AND METHODS

Subjects

Seventeen children were recruited by disseminating a request for volunteers via elementary schools in the neighbourhood of Ghent University. All children who participated were accompanied by at least one of their parents, who read and signed the informed consent. With the approval of the parents, all children received a small incentive (i.e. a toy of approximately €5) after the experiment. Similar to the previous study, participants were only included in the analysis if they had a Tracking Ratio (TR = percentage of time that direction of gaze could be determined relative to the duration of trial) of at least 85% and good pre and post calibration. Eye tracking data for seven children met these criteria. These children (3♂, 4♀) were 8.29 ± 0.95 years old and had a TR of 95 ± 3%. According to parental report, the children could already cycle without side wheels for 3.43 ± 1.37 years but had little to no experience in cycling independently in traffic. All children had normal or corrected-to-normal vision.

Apparatus

Eye movements were recorded using the Head mounted Eye tracking Device (HED, SensoMotoric Instruments, Teltow GER). The system consists of an infra red eye camera that recorded the left eye movements at 50 Hz, and a scene camera that recorded the viewpoint of the participant at 25 Hz. Both cameras were mounted on a baseball cap and connected to a notebook (Lenovo X201; 1.4 kg, Lenovo Group Ltd., Beijing, China) which was worn in a backpack. Eye tracking data and video data of the scene camera were saved using SMI's software iViewX. The system was calibrated using a five-point calibration and has an accuracy of 1° (SensoMotoric Instruments, 2012).

Set up and procedure

The experimental set up and the data procedure were identical to the first study (Vansteenkiste et al., 2013). In a gymnasium with a parquet floor, cycling lanes of 10 cm (Narrow), 25 cm (Middle) and 40 cm (Wide) of width and 15m of length were marked on the floor with a white tape, and a starting line was marked 15m before the start of the lanes (see Fig 1). Two mechanical gates were placed at the start and at the end of the lane and gave a visual signal when the cyclist passed through. This signal and the participants cycling performance were filmed by an overview camera (25Hz, Full HD), which stood four meter behind the second gate.

The children were asked to bring their own bicycle, and if necessary the saddle was adjusted to the participant's height. Each participant was then given one familiarization trial for each lane. For the calibration of the eye tracker, participants were asked to sit down and look subsequently to five reference points without moving their head. Since children often had troubles holding still, an experimenter helped them by supporting their heads. When the eye-tracker was calibrated and the recording unit was put in the backpack, the participants were positioned at the start line for the actual experiment.

One of the experimenters (A on fig.1) instructed the participant to cycle through one of the lanes at low, preferred or high speed without crossing the edge lines. A start signal was given by a second experimenter using a clapperboard (B on fig.1). This signal was also used for synchronizing eye tracking data with the video images of the overview camera. Nine conditions (3 lanes x 3 speed) were carried out in a randomized order and after the last condition a calibration check was done.

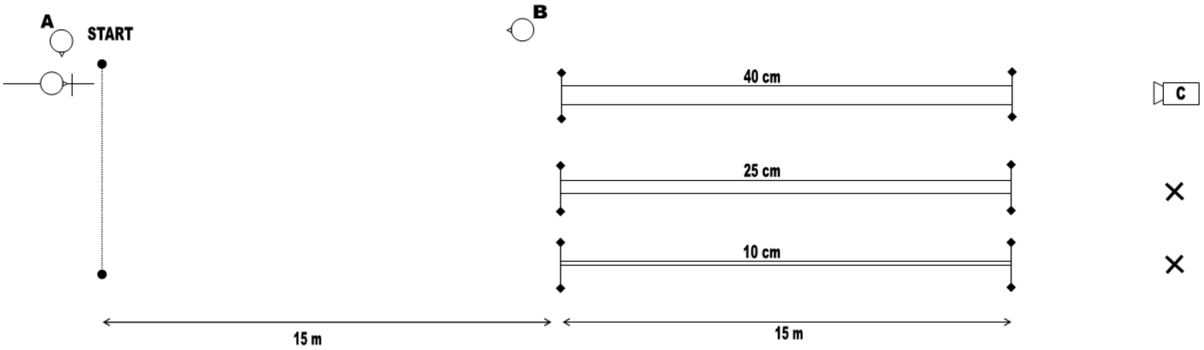

Figure 1 : Experimental set-up. (A) Experimenter who gives instructions to the participant; (B) experimenter with clapperboard, (C) and (X) places of overview camera

Data analysis

The data of the adults in the first study were used to compare with the data of the children in the current study. The data analysis of the children was identical to that of the adults in the first study (Vansteenkiste et al., 2013).

Using the signals from the mechanical gates, the average cycling speed (km/h) on the 15m lane was calculated. Steering precision was expressed as the percentage of time the participant cycled inside the edge lines and was visually obtained from the overview camera at the end of the lane. To analyze gaze behaviour, the video data with overlay gaze cursor were exported from BeGaze for each trial. These videos were then analyzed frame by frame in Kinovea to measure fixation duration, fixation type, and fixation location. A fixation was defined when the cursor was steady for at least three consecutive frames (120ms) and ended when a saccade was initiated. This “direct inspection” method has been reported to be time-consuming but very effective for head mounted eye trackers (Duchowski 2007, p138).

Four ‘types’ of fixations were distinguished. Travel fixations were defined when “gaze was stabilized at a constant distance in front of the participants’ body and moved in the same direction and at the same speed” (Hollands et al., 2002; Patla and Vickers, 1997). The other fixations, which were directed to an object or specific location, were categorized according to the fixation location: fixations on the cycling path (Path), on the final meter of the cycling lane (Goal) and on areas outside of the travel path (External). A total fixation percentage (TotFix%) was calculated by dividing the sum of all fixation durations of a trial by the duration of that trial. Fixation time of each fixation type (Fix%) was expressed as a percentage of the total fixation time (%path, %travel, %goal and %external). The same experimenters who analyzed the gaze behaviour of the adults now analyzed the gaze behaviour of the children. Therefore the intrarater reliability of the previous experiment is the same as for the current experiment : a Single Measure Intraclass Correlation of 0.856 for number of fixations and 0.902 for fixation duration.

Statistics

Age-related differences in Cycling speed, steering precision and TotFix% were analyzed using repeated measures ANOVA tests consisting of two within factors (Speed and Width) with each three levels (resp. Slow, Preferred, Fast and Narrow, Middle, Wide), and with age group as between factor. Age-related differences in fixation location were investigated using a similar repeated measures MANOVA, but with the four types of fixations as measures. Interaction effects between age and speed and/or width were further investigated with independent samples t-tests. Non-significant interaction effects are not mentioned.

Since the adaptations in steering and visual behaviour of children and adults to different speeds and lane widths is the focus of the current experiment, analyses of the effects of cycling speed and lane width are done separately for adults and children, regardless of an age*speed or age*width interaction effect or not. The effects of speed and width on cycling speed, steering precision and TotFix% were investigated using a repeated measures ANOVA tests with speed and width as two within factors. For the effect of speed and width on fixation location, a repeated measures ANOVA tests was also carried out, but with the four types of fixations as measures. Finally, to compare the four types of fixations with each other, a repeated measures ANOVA was carried out with three within factors (width, speed and fixation type). Post hoc tests were performed using the Bonferroni correction for pairwise comparison and significance level was set at 0.05 for all analyses.

RESULTS

For an overview of the results see table 1 and table 2.

Cycling Speed, in-lane% and total fixation%

On average, adults cycled significantly faster than the children ($F_{1,17} = 8.026$; $p = 0.011$). For both adults and children, cycling speed increased significantly as they were asked to cycle faster ($F_{2,22} = 63.225$; $p < 0.001$ and $F_{2,12} = 44.469$; $p < 0.001$, respectively). Nevertheless, a significant age*speed interaction ($F_{2,34} = 7.721$; $p = 0.009$) showed that the difference in cycling speed between adults and children increased as they were asked to cycle faster (see also Figure 2). A significant effect of lane width was found for both adults and children ($F_{2,22}$ = 4.607; p = 0.043 and $F_{2,12}$ = 14.154; p = 0.001, respectively), but only few of these differences reached significance in the pairwise comparison (see Table 1 for significances).

Table 1 : Results of cycling speed, in-line% and total fixation% per speed and width for adults (A) and children (C). * indicates significant differences between adults and children. Same superscript letters indicate significant differences between speed or width conditions.

		Average	Slow	Preferred	Fast	Narrow	Middle	Wide
Speed (km/h)	Adults *	12,69 ± 4,29	8,65 ± 2,18^{a}	12,22 ± 1,93^{a}	17,2 ± 3,13^{a}	12,4 ± 4,18	12,64 ± 4,21	13,02 ± 4,57
	Children	10,35 ± 2,40	8,37 ± 1,54^{b}	9,96 ± 1,38^{b}	12,71 ± 1,86^{b}	9,92 ± 2,23^{c}	10,29 ± 2,41	10,83 ± 2,58^{c}
Steering Precision (%)	Adults	86,58 ± 22,23	81,14 ± 23,08	89,48 ± 20,68	88,64 ± 23,38	60,57 ± 22,21^{d,e}	98,85 ± 3,44^{d}	100,00 ± 0,00^{e}
	Children	84,55 ± 22,55	81,69 ± 28,58	86,52 ± 20,02	85,44 ± 18,58	58,13 ± 20,67^{f,g}	96,43 ± 5,98^{f}	99,10 ± 3,23^{g}
TotFix%	Adults	69,44 ± 14,33	74,65 ± 10,67^{h,i}	66,96 ± 13,4^{h}	66,23 ± 17,38^{i}	69,6 ± 14,17	73,87 ± 10,63	65,24 ± 16,95
	Children	66,43 ± 9,75	68,18 ± 9,97	64,75 ± 9,68	66,35 ± 9,77	64,06 ± 9,25	67,68 ± 10,92	67,55 ± 9,01

No significant difference in steering precision was found between the adults and the children ($F_{1,17}$ = 0.570; p = 0.461). Speed did not have an effect on the steering precision of both adults and children ($F_{2,22}$ = 0.633; p = 0.537 and $F_{2,12}$ = 0.776; p = 0.482, respectively), but lane width did ($F_{2,22}$ = 53.158; p < 0.001 and $F_{2,12}$ = 86.789; p < 0.001, respectively). Both groups managed significantly less to stay inside of the narrow lane than in the middle and wide lane.

TotFix% of the children was not significantly different than that of the adults ($F_{1,17}$ = 0.683; p = 0.420). The TotFix% of the children did not change with increasing speed ($F_{2,12}$ = 0.863; p = 0.446) or lane width ($F_{2,12}$ = 1.942; p = 0.186). The TotFix% of the adults also did not change with increasing lane width ($F_{2,22}$ = 2.286; p = 0.127), but adults had a significantly higher TotFix% in the slow condition compared to the preferred and fast condition ($F_{2,22}$ = 5.345; p = 0.022).

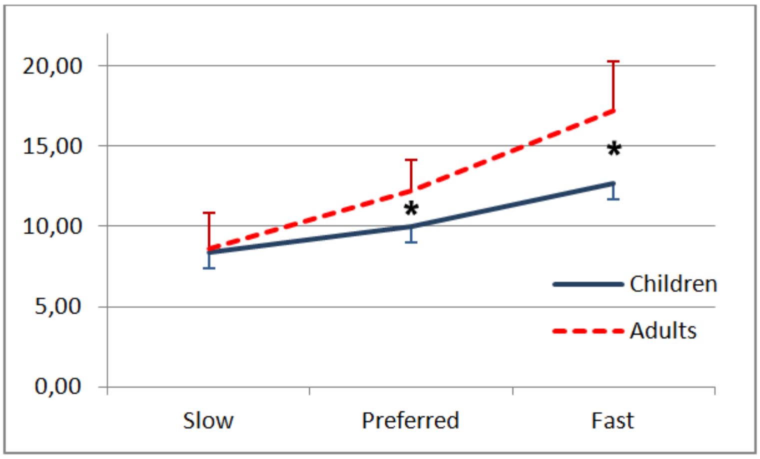

Figure 2 : Cycling speed of children and adults over the three speed conditions. Independent T-tests showed adults cycled significantly faster than children in the preferred and fast cycling speed conditions, but not in the slow speed condition. * indicates significant difference (p < 0.05) between children and adults.

Fixation location

Compared to the adults, children did not spend more or less time watching the path region ($F_{1,17}$ = 0.711; p = 0.411), the goal region ($F_{1,17}$ = 0.052; p = 0.822) or external regions ($F_{1,17}$ = 0.790; p = 0.387), nor made more or less travel fixations ($F_{1,17}$ = 0.132; p = 0.720). For both the children and the adults, path and goal fixations were the dominant types of fixations, and very few travel fixations were detected (see Figure 3).

Cycling speed had a significant effect on path ($F_{2,22}$ = 5.172; p = 0.014) and travel fixations ($F_{2,22}$ = 5.22; p = 0.026) for the adults, and on path ($F_{2,22}$ = 13.989; p = 0.001) and external fixations ($F_{2,22}$ = 5.568; p = 0.047) for the children. In general, percentage of path fixations decreased as cycling speed increased. As cycling speed increased adults also made more travel fixations, and children looked more to external regions. However, not all of these differences were significant (see Table 2 for details).

Lane width had a significant effect on the percentage of gaze towards path, goal and external for both adults ($F_{2,22}$ = 19.670 and p < 0.001; $F_{2,22}$ = 6.049 and p = 0.008; $F_{2,22}$ = 8.089 and p = 0.008, respectively) and children ($F_{2,12}$ = 9.800 and p = 0.003; $F_{2,12}$ = 4.635 and p = 0.033; $F_{2,12}$ = 5.340 and p = 0.022). On wider lanes, both adults and children spent less time watching the lane itself and more time watching external regions. Again, however, not all of these differences were significant, see Table 2 for details.

Table 2 : Mean values and standard deviations of gaze percentages of both adults (A) and children (C) per cycling speed and lane width. Same superscript letters indicate significant differences between speed or width conditions.

		Average	Slow	Preferred	Fast	Narrow	Middle	Wide
% Path	A	40,82 ± 30,06	50,11 ± 31,53^{a}	39,38 ± 26,67	32,98 ± 30,03^{a}	55,45 ± 24,77^{b}	38,16 ± 29,43^{b}	28,85 ± 30,11^{b}
	C	33,18 ± 23,03	44,76 ± 23,69^{c}	33,57 ± 20,70	21,20 ± 19,03^{c}	44,88 ± 18,98^{d,e}	30,51 ± 25,24^{d}	24,14 ± 20,23^{e}
% Goal	A	40,08 ± 23,33	35,33 ± 23,23	39,80 ± 20,66	45,11 ± 25,47	32,83 ± 21,89^{f}	45,69 ± 23,37^{f}	41,71 ± 23,46
	C	41,51 ± 22,03	36,05 ± 18,39	41,09 ± 23,25	47,39 ± 23,63	33,30 ± 17,85^{g}	48,03 ± 22,45^{g}	43,20 ± 23,75
% External	A	16,14 ± 20,39	13,31 ± 19,02	18,31 ± 21,47	16,80 ± 20,86	8,80 ± 13,05^{h}	13,51 ± 18,38^{i}	26,11 ± 24,45^{h,i}
	C	21,77 ± 21,40	14,03 ± 19,89	23,30 ± 21,70	27,99 ± 21,14	17,22 ± 19,92	18,44 ± 17,22	29,66 ± 25,04
% Travel	A	2,96 ± 6,12	1,25 ± 2,42^{j}	2,52 ± 6,08	5,11 ± 7,97^{j}	2,92 ± 7,08	2,64 ± 4,75	3,32 ± 6,45
	C	3,54 ± 6,85	5,16 ± 9,38	2,05 ± 4,20	3,41 ± 5,90	4,60 ± 6,94	3,03 ± 6,89	3,00 ± 6,95

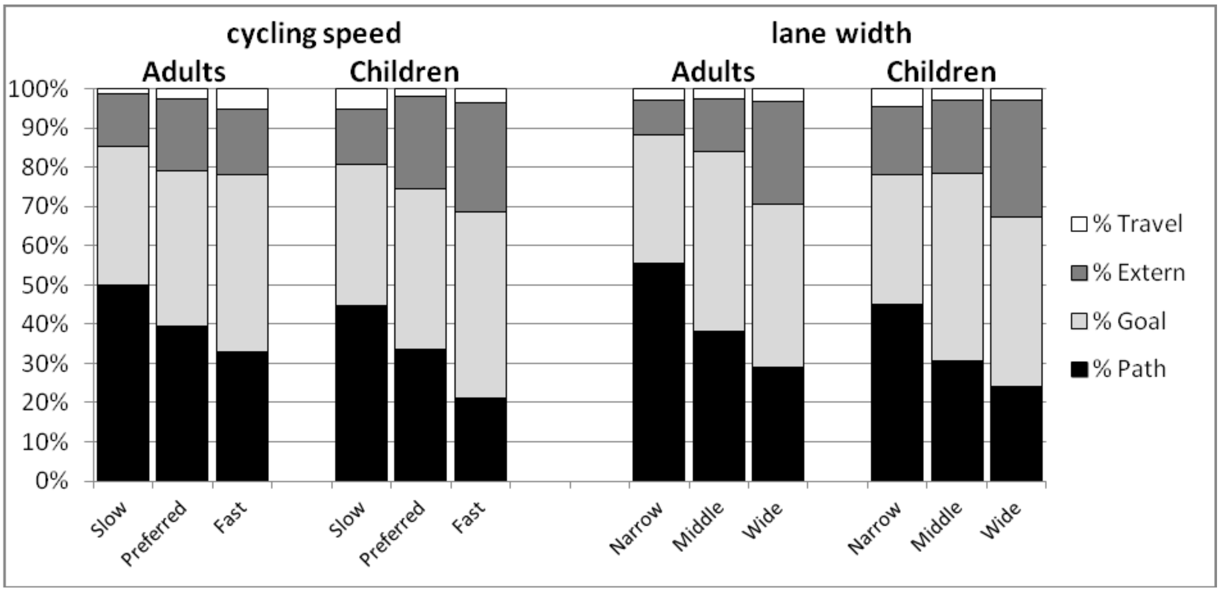

Figure 3 : Effect of cycling speed and lane width on the distribution of the four types of fixations for adults and for children. For Values and significance, see Table 2.

DISCUSSION

In the current study we investigated the gaze and steering behaviour of eight-year old children while cycling through three narrow lanes at three different speeds, and compared these results with the results of adults, described in (Vansteenkiste et al., 2013). In general, children were found to cycle slower than the adults, but no differences in steering precision or gaze behaviour were found. Gaze and steering behaviour of children changed in a similar way to adults.

Surprisingly, the only significant difference between adults and children was their cycling speed. At a low speed adults and children cycled more or less as fast, but at preferred and high speed, the children cycled increasingly slower than the adults. According to the Task Capability Interface model (TCI-model; Fuller, 2005), speed choice is the predominant way to control task difficulty. 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., 2015), they most likely have a lower capability than the adults as well. Therefore, the lower cycling speed could be a compensation for this lower capability. The absence of a difference in cycling speed in the lowest cycling speed condition could be due to the fact that a certain speed has to be maintained to keep a bicycle easily balanced (Schwab et al., 2012). Both children and adults probably chose a low speed based on the lowest speed at which it was still comfortable to ride a bicycle, but chose the preferred and high speed based on their own capabilities. Furthermore, that children's bicycles are smaller than adult bicycles probably also contributed to the lower cycling speed of children.

In general, narrower lane widths increase steering workload and reduce speeds through a speed-steering workload trade-off (Godley et al., 2004). Since children are assumed to have lower capabilities, we expected that the increase of steering workload would affect them more, and therefore children would adapt their cycling speed more to the decreasing lane width than adults. However, children already adopted a lower cycling speed in general, so they already adapted their cycling speed to their capabilities, and therefore the difference in lane width probably did not increase task capability more for children than for adults. It is still likely however, that if the same cycling speeds were imposed for adults and for children, children would adapt their cycling speed more to the lane width than adults. According to the TCI-model, if children do not adapt more to the changing task difficulty but do have a lower capability, they should make more errors than adults as task demand increases. However, the current experiment might have been too short (only 15m) and too easy (straight lane) to evoke a significant difference in errors.

While it was expected that children would spend more time watching external regions and less time watching the goal region, no differences in gaze behaviour were found in the current study. There are three plausible reasons why no differences in gaze behaviour were found. First, as was the case for adults (and in many other experiments using head mounted eye tracking), the number of participants in the current study was rather low and there was a notable between-subject variability in gaze behaviour (characterized by high standard deviations). Therefore, some of the differences (e.g. for path and external) might have failed to reach significance. A second plausible factor that might have contributed to the lack of significant differences in gaze behaviour, is the lower cycling speed of children. Since children adapted their cycling speed, they might not have experienced a higher task demand than adults and therefore, did not have the need to adopt a different gaze behaviour. The gaze behaviour of children might have been different from adults if an imposed 'middle' and 'fast' speed was used instead of a self selected preferred and fast cycling speed. Finally, since cycling through the 15m lanes took only five to six seconds, the trials in current experiment were possibly too short to evoke a significant difference in irrelevant gaze behaviour.

Similar to the differences between novice and experienced car drivers (Mourant and Rockwell, 1972; Underwood 2007) it could also have been expected that learner cyclists would direct their gaze closer to the bicycle than experienced bicyclists. Although the gaze distance was not directly measured in the current experiment, the percentage of goal fixations compared to path fixations gives an indication. With gaze usually stabilized on the goal region once it is within the range of the visual buffer (one to two seconds), larger look-ahead fixations will lead to a higher proportion of goal fixations compared to the path fixations (Vansteenkiste et.al, 2013). However, no significant differences in the percentage of goal or path fixations was found, suggesting that adults and children adopted a similar look-ahead distance/visual buffer. Nevertheless, as was the case for the lack in differences in the percentage of external fixations, the low number of participants, the lower cycling speed of the children, and the experimental set-up might have hampered the emergence of significant differences. Furthermore, some of the differences in gaze behaviour might be caused by the fact that the eye height of adults on adult city bicycles was considerably higher than that of the children on children's bicycles. The lower eye height of the children affects the perception of the scene and possibly also the perception of velocity. Therefore, the smaller bicycles of the children could also have affected their gaze and steering behaviour, However, even if these limitations would have affected the gaze and/or steering behaviour in the current experiment, these differences would also be present during real traffic situations.

Regardless of the limitations of the current experiment, the results indicate that children adopt a cycling speed that fits their capabilities, and that they adapt their visual behaviour to changing constraints in a very similar way like adults do. In other locomotor tasks, such as obstacle avoidance, children have also been found to adopt lower speeds, but this was usually accompanied by a different gaze behaviour as well (Franchak et al., 2011; Pryde et al., 1997; Whitebread and Neilson, 2000). However, in obstacle avoidance and road crossing, multiple regions/objects have to be taken into account. Therefore, the uptake of visual information is more complex and demanding. In the current study on the other hand, the task demand and complexity of visual search was rather low. Therefore children were able to adopt a same visual-motor strategy as adults. When the task would be more demanding and require more steering and planning (e.g. cycling a slalom) children would probably adopt a different visual-motor strategy (Franchak and Adolph, 2010; Pryde et al., 1997).

The current study was one of the first studies to compare the visual behaviour of young learner cyclists with that of adults. Although this investigation provided a valuable contribution to the insights of the visual behaviour of learner cyclists, it only tested gaze behaviour during a simple cycling task in an indoor, distraction-free environment. Therefore, the question remains to what extent the gaze behaviour described in the current study can be generalized to in-traffic gaze behaviour. Future research should focus on the visual motor strategies of children of various ages during more complex and realistic cycling tasks. Insights into the development of the visual motor strategies of children can be helpful to improve cycling skills training and traffic education.

CONCLUSION

Children around the age of 8 cycled slower through narrow lanes than adults, but similarly to adults, shifted their gaze direction towards the goal at higher speeds, towards the near pathway on narrow lanes, and more towards irrelevant areas on wider lanes. This suggest that during a relatively easy task, such as cycling through a narrow lane, children are able to adopt a similar visual-motor strategy as adults, provided that they cycle at their own pace.

ACKNOWLEDGEMENTS

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2.2. Cycling around a curve

Paper4

CYCLING AROUND A CURVE :
THE EFFECT OF CYCLING SPEED ON STEERING AND GAZE BEHAVIOUR

Vansteenkiste P, Van Hamme D, Veelaert P, Philippaerts R, Cardon G, Lenoir M

PLoS ONE 9(7) 2014: e102792

ABSTRACT

Although it is generally accepted that visual information guides steering, it is still unclear whether a curvature matching strategy or a 'look where you are going' strategy is used while steering through a curved road. The current experiment investigated to what extent the existing models for curve driving also apply to cycling around a curve, and tested the influence of cycling speed on steering and gaze behaviour. Twenty-five participants were asked to cycle through a semicircular lane three consecutive times at three different speeds while staying in the centre of the lane. The observed steering behaviour suggests that an anticipatory steering strategy was used at curve entrance and a compensatory strategy was used to steer through the actual bend of the curve. A shift of gaze from the centre to the inside edge of the lane indicates that at low cycling speed, the 'look where you are going' strategy was preferred, while at higher cycling speeds participants seemed to prefer the curvature matching strategy. Authors suggest that visual information from both steering strategies contributes to the steering system and can be used in a flexible way. Based on a familiarization effect, it can be assumed that steering is not only guided by vision but that a short-term learning component should also be taken into account.

INTRODUCTION

The role of eye movements in curve negotiation has been the subject of research for more than 35 years. Although it is generally accepted that visual information guides steering [1–5], there is no consensus on how gaze behaviour contributes to steering through curves.

In their well-known experiment, Land & Horwood [6] showed that at higher speeds (>12 m/s) car drivers look at the road more than 1 s ahead to gain information about its curvature, while position-in-lane information is obtained from the nearer part of the road approximately 0.5 s ahead. Although there has been some discussion about the size and location of these two regions [7,8], it is generally accepted that both road curvature information and position-in-lane information are needed for efficient curve negotiation. Since position-in-lane information can be gathered using ambient vision, fixations are mainly directed to the far region. However, the exact location of drivers' gaze and its influence on steering corrections remains a debated issue.

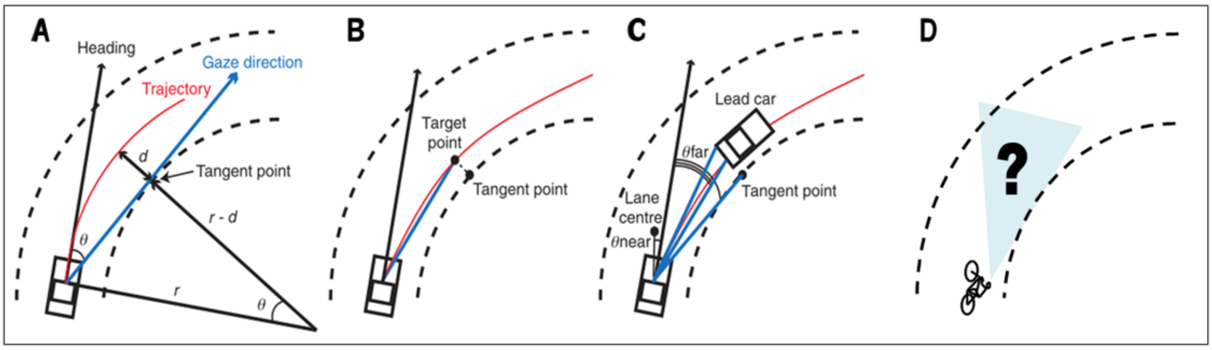

Figure 1 **:** Steering models for car driving (A-C) and cycling (D).
(A) Tangent point strategy according to Land and Lee (1994) (B) 'look where you want to go' strategy (C) Two-point visual control model of Salvucci and Gray (2004) (D) visual behaviour while cycling through curves has never been studied (adapted from Mars 2008).

With respect to curve negotiation, a possible source of road curvature information is the 'tangent point' [2]. This is the innermost point of a curve from the driver's point of view, and its direction relative to the current heading of the vehicle is a good predictor of the road curvature (see Figure 1). Since the gaze angle towards the tangent point and the steering wheel angle are very similar, the tangent point can be used as a pursuit control signal for steering [9]. Pursuit control implies that observed characteristics of a previewed track are transformed directly into steering commands in a continuous fashion. In this case, changes in the visual direction of the tangent point will result in corresponding changes in the steering angle. Therefore, the tangent point has been put forward as an ideal reference point to estimate road curvature and to maintain a trajectory at a fixed distance from the inside edge [10,11]. This strategy of steering through a curve has been referred to as the tangent point strategy. However, Tresilian [9] argued that the use of this particular steering strategy is not absolutely necessary for successful curve negotiation. Other points on the inner edge of a curve could also serve as pursuit control signal and, therefore, guide steering. Furthermore, many studies report the occurrence of gaze near the tangent point, not necessarily at the tangent point itself. Given that this steering strategy uses visual information from the inside edge of the curve to maintain a trajectory at a fixed distance from the inside lane, the current article will refer to the tangent point strategy as the curvature matching strategy from this point onwards.

Several studies have confirmed that the inside edge close to the tangent point is often gazed at during curve negotiation [11–13]. However, Wilkie et al. [5] pointed out a number of problems associated with the use of the curvature matching strategy. A first issue is that this strategy only applies to bends with a continuously visible inside curb or edge line. Therefore, it is questionable whether the curvature matching strategy can be generalized to all types of roads. Furthermore, the studies favouring the curvature matching strategy did not instruct the car drivers about the road position they should maintain. Because of the natural tendency to 'cut the corner' [14], the drivers might just have been watching where they were going. When the drivers were asked to keep their car in the centre or the outside of the lane, it was found that gaze is mainly directed to points on the future path [15]. This observation of Kountouriotis et al. [15] suggests that when steering towards the inside edge of a bend, looking to the inside edge (e.g., the tangent point) could be caused by a 'look where you are going' strategy rather than a curvature matching strategy [5].

According to the 'look where you are going' strategy (which has also been referred to as 'viapoint strategy' and 'future path strategy'), drivers look at a point through which they will actually pass 1–2 seconds ahead of their current position [10]. When negotiating a curve and looking at a point on the desired future path, a combination of information from retinal flow, gaze angle and rate of rotation relative to gaze position provides visual signals about whether the steering angle needs to be remained, increased or decreased [16,17]. This 'look where you are going' strategy is in line with several studies using a wide range of experimental set-ups to confirm that gaze is usually directed in the direction of travelling [18–22]. Due to the large variation of experimental set-ups that have been used to test gaze behaviour during locomotion, there is also a considerable variation in the gaze distribution reported in several studies. Since gaze behaviour is very task and environment dependent [23–24], differences in speed, visibility, curvature type (open vs. closed), curvature radius, imposed task (none or stay central) and location (real road vs. simulator) may have caused this variation in literature. In addition, different measurements of gaze and steering behaviour have been used, which complicates the comparison of study outcomes. Nevertheless, this diversity in experimental set-ups helps to develop a more general theory for gaze behaviour during locomotion. Given that recent studies suggest a flexible / weighted system for gaze distribution [7,8,15,25,26], comparing gaze behaviour changes under various environmental constraints could lead to more generally applicable models for gaze behaviour during locomotion.

Unfortunately, experiments on visual behaviour during curve negotiation mainly investigated car driving situations at a single velocity. Since gaze behaviour changes according to the travelling speed [25] and might be subject to the type of vehicle that is used, the aim of current study was to explore gaze and steering behaviour of cyclists when negotiating a curve at multiple speeds.

Compared to the amount of research conducted in car driving, the transferability of the existing models towards curve cycling is poorly documented. Both vehicles allow faster locomotion than travelling by foot and require steering through a curve to change direction, whereas one can make a point turn when walking and running [27]. However there are many important differences between car driving and cycling that might induce different visual requirements to control locomotion [28]. In a car, the horizontal view is almost unrestricted, but the vertical field of view is restricted by the design of the car (e.g., height of the windshield). As a consequence, the nearest part of the road visible for a car driver is a few meters in front of the driver. A cyclist, on the other hand, has an unrestricted view both in the horizontal as in the vertical plane. This means that the ‘near region’, which provides compensatory closed-loop information, extends to below the cyclist and therefore might provide more feedback from edge lines and visual flow [29]. Furthermore, travelling speed by car is usually much higher than by bike. This will most likely cause cyclists to direct their gaze closer than in car driving experiments [6,25]. Finally, cyclists also have to maintain balance on their bicycle while cars are stable on their own [30]. Since vision contributes to balance control [31,32], a part of the visual attention of cyclists might be used to support this. Due to the differences in field of view [28], travelling speed [25] and balance requirements [30], we expect cyclists to have a slightly different gaze behaviour than car drivers. Nonetheless, we also expect cyclists to use a curvature matching strategy and/or a ‘look where you are going’ strategy to steer through a curve.

METHODS

Participants

A convenience sample of twenty-five participants (aged 21.40 ± 0.58 years; 11 females) were recruited from Ghent University students to participate in the experiment. All participants had normal or corrected-to-normal vision and used their bicycle on regular basis for transportation. To ensure reliable eye-tracking data, only data of participants with a tracking ratio above 90% and good pre-post calibration were retained for analysis. Seventeen participants (aged 21.35 ± 0.49 years; 8 females) met these inclusion criteria.

Apparatus

Gaze was recorded using the Head-mounted Eye-tracking Device (iViewX HED System) and iView X software of SMI (Teltow, GER). The system recorded eye movements of the left eye with a 50 Hz infra-red sensitive camera (using dark pupil position and corneal reflection) and a scene video with a horizontal and vertical field of view of approximately 33° with a 25

Hz camera. Both cameras were mounted on a baseball cap and connected to a notebook (Lenovo 84x201; 1.4 kg) which was worn in a backpack. The system was calibrated using a five-point calibration and has an accuracy of 1° [33].

A 50 Hz HD camera (Panasonic HC-X900) was mounted at the back of the bicycle and pointed backwards to record steering behaviour. A full HD digital camera (25 Hz; Panasonic HDC-HS80) was used as an overview camera to record the experiment.

Experimental setup and procedure

In a gymnasium, a 1.5 m wide cycling track was marked on the floor with 2.5 cm wide white tape. The track consisted of a 15 m run-up and a 3/4 circle with a diameter of 16 m (see Figure 2). Two lines marked the start and the end of a semicircle, the remaining 1/4 of the circle served as a buffer so that 'exit behaviour' only occurred past the semicircle.

On arrival, the participants were briefed about the experiment and were asked to read and sign the informed consent. Both the study and the informed consent were approved by the Ethical Committee of Ghent University Hospital (approval number: OG017). The saddle of an instrumented city bicycle (women's model) was adjusted so that the participants could reach the ground with the tips of their feet while seated. They were then asked to cycle the track at a low (± 8 km/h), medium (± 14 km/h) and high speed (± 19 km/h), corresponding with completing the semicircle in 12.0, 6.7 and 4.9 seconds, respectively. These three speed conditions will be referred to as 'slow', 'medium' and 'fast'. During the familiarization trials, participants' lap time was recorded with a stopwatch and, if necessary, they were instructed to cycle faster or slower. Each speed condition was repeated until the participant managed to cycle the trajectory in the corresponding lap time ±1 second. This usually took only two familiarization trials.

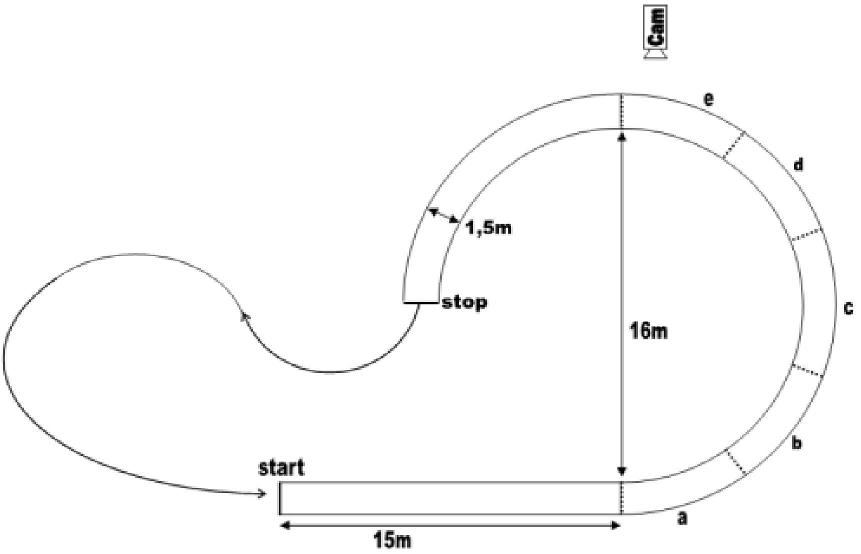

Figure 2 : Experimental set-up.
Length of the semicircle was 26,3m (measured in centre of the lane). Dashed lines were not physically present during the experiment but indicate the five segments of the curve (a-e).

When the participants were familiar with the track and the three speeds, they were asked to put on the eye tracker and secure it with a strap. After calibration the notebook was put in the backpack and the participant was asked to mount the bicycle and line up at the starting line. Participants were asked to ride three consecutive trials through the experimental cycling track at each of the three speeds, which were randomized for each participant. After each speed condition a calibration check was performed.

One of the problems in comparing curvature matching strategies with 'look where you are going' strategies, is that both strategies lead to similar gaze behaviour when drivers cut into the bend (i.e., gaze to the inner edge) [5,34]. To ensure that the two strategies would evoke a distinguishable gaze behaviour, the participants in current experiment were asked to stay in the centre of the track as much as possible. This way, the curvature matching strategy evokes gaze to the inside edge, while using the 'look where you are going' strategy evokes gaze to the centre of the lane.

Data analysis

Steering behaviour.

Based on the video images of the bicycle-mounted camera, the cycled trajectory was reconstructed for all 25 participants using the robust visual odometry method of Van Hamme et al. [35]. This method allows for the reconstruction of relative motion with a typical translational accuracy of 0.10% (i.e., longitudinal accuracy) and rotational accuracy of 0.46°/m over a 10 m segment. Manual lateral measurements at the start, middle and end of the semicircle were used to obtain absolute position and to eliminate rotational drift. This method resulted in 100 XY-coordinates per trial and for each of these coordinates, the lateral distance towards the inner edge was calculated.

To obtain a more detailed view on the steering behaviour throughout the trial, the semicircle was divided into five segments of 36° each (a–e in Figure 2). For each of the five segments of the semicircle, the lateral distances towards the inner edge were used to calculate mean lateral deviation from the inner edge (M Lat Dev) and standard deviation of lateral deviation from inner edge (SD Lat Dev). This standard deviation is a measure of how much variation around the average lateral distance each cyclist showed. However, this does not indicate the number of steering corrections. To this end, the number of times that the lateral deviation from the inner edge changed from increasing to decreasing, or vice versa, was counted and divided by the duration of the trial. Accordingly, the number of steering reversals per second (#SR/s) was calculated for the total semicircle as well as per segment for each participant.

To verify that the participants did not correct their trajectory by varying their velocity along the semicircle, the mean velocity per segment of each participant was extracted by the visual odometry method. To eliminate measurement noise, the obtained velocities were filtered by a type I linear phase lowpass filter with 26 dB amplitude gain at 0.25 Hz.

Gaze behaviour.

Gaze behaviour was analyzed by calculating the dwell time percentage to specific Areas Of Interest (AOIs). This dwell time percentage is the time spent watching a specific AOI (i.e., the sum of all fixations and saccades that hit the AOI [33]), relative to the duration of the trial (time to complete the semicircle). Dwell time % was calculated using the fixation-by-fixation analysis as described in [36]. For this analysis, fixations were determined by the 'SMI fixation detection algorithm' in BeGaze 3.3 (SMI, Teltow GER) and superimposed on the scene video. Using the 'Semantic Gaze Mapping function' of BeGaze, the fixations shown in this gaze-overlay video were analyzed one-by-one and manually assigned to one of the AOIs by the experimenters. Although fixation location and duration is calculated based on screen coordinates, this method has been described to be a valid and time-saving alternative to the classic frame-by-frame analysis to calculate overall dwell time % to AOIs [36][5].

Gaze location was categorized on two levels: 'lateral direction' and 'depth'. On the 'lateral' level, fixations were judged to be either directed towards the 'inside edge', the 'centre' or the 'outside edge'. On the 'depth' level, a distinction was made for fixations that were directed 'near' (up to approximately 4 m in front of the participant), 'middle' or 'far' (looking more than 1/4 of the bend ahead). For the 'far' fixations however, it was difficult to distinguish between fixations to the inside edge, centre or outside edge. Therefore, far fixations were not categorized according to lateral direction. In that way, all fixations to the cycling lane could be categorized to one of the following seven AOIs: 'near inside', 'near centre', 'near outside', 'inside', 'centre', 'outside' and 'far'. A sketch of how the AOIs were spread across the scene video can be found in Figure 5B.

Considering that the participants in the current experiment were instructed to cycle in the centre of the lane, the location of the tangent point was approximately 3.7 m ahead of the cyclists. Therefore, fixations towards the tangent point (the innermost point of the curve from the cyclist's point of view) were labelled under 'near inside'. All fixations that fell outside of one of the previous AOIs were assigned to the category 'other'. The difference between 100% and the sum of the eight AOIs was called 'NoData' and represents saccades between AOIs, blinks and data loss during the experiment.

RESULTS

All variables were analyzed in SPSS22 using repeated measures ANOVA with the Huynh-feldt correction. Post hoc tests were performed using the Bonferroni correction for pairwise comparison. Significance level for all tests was set at $p < 0.05$. A plot of the average cycling trajectory and standard deviation per speed (A) and per trial (B) can be found in Figure 3.

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[5] See paper 1 for an evaluation of this analysis method

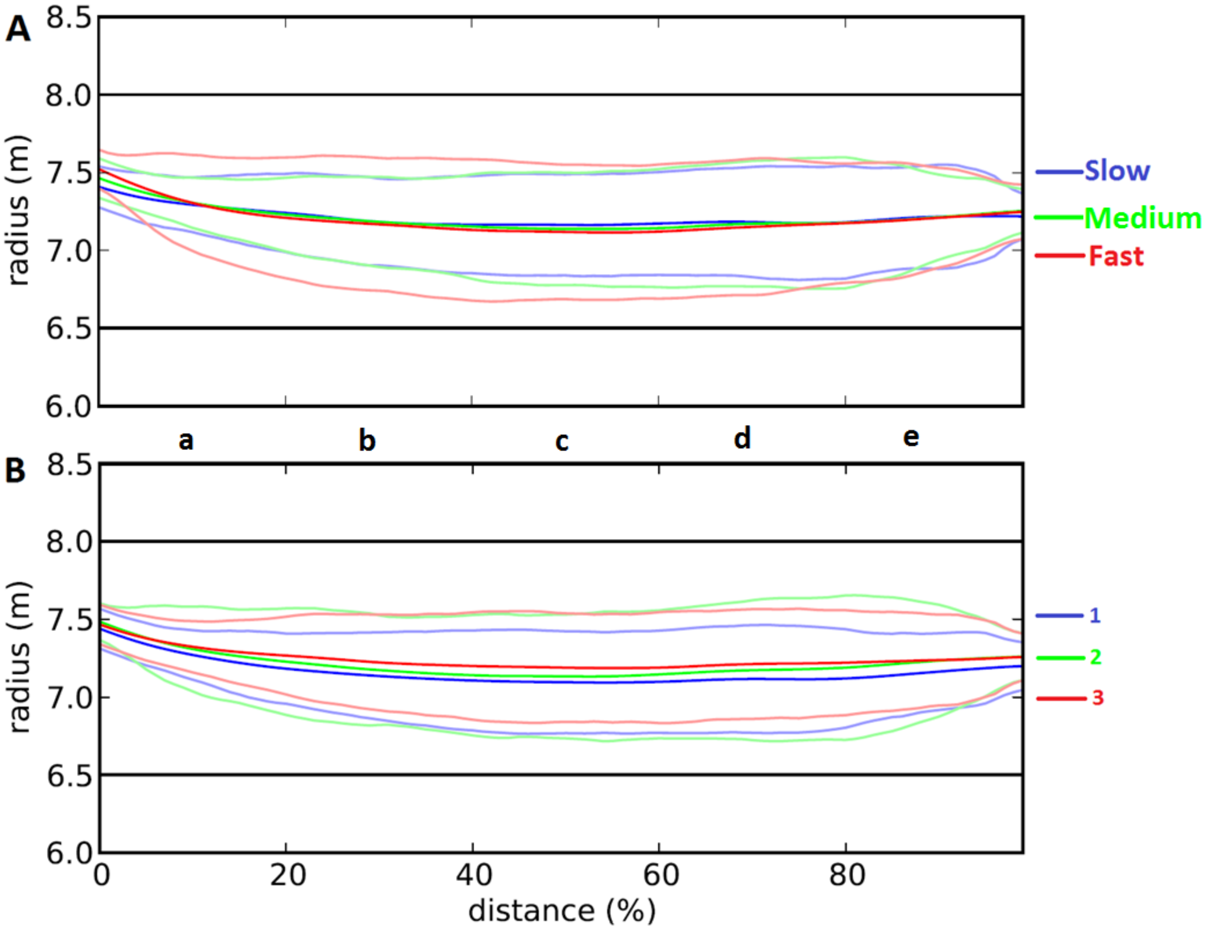


Figure 3 **:** Average cycling trajectory and standard deviation per speed (A) and per trial (B). Straight black lines represent edges of the cycling path. Light colours indicate standard deviation.

Lateral position at curve entrance

The manual measurement of the lateral deviation from the inside edge at the start (Lat Dev Start) was compared across speed conditions and trials to analyze how participants entered the semicircle. Table 1 shows this lateral deviation at the start of the curve per trial for each speed condition. A repeated measures ANOVA with speed and trial as within-subjects factors revealed that participants entered the curve more towards the middle of the lane in the slow condition than in the medium and fast condition ($F_{2,32} = 8.402$; $p = 0.001$). Although a significant within-subjects effect was found for trial ($F_{2,32} = 4.104$; $p = 0.026$), no significant differences among the trials were found in the pairwise comparisons. However, the analysis also revealed an interaction effect between speed and trial ($F_{4,60} = 2.837$; $p = 0.032$) which shows that in the fast condition, participants entered the curve closer to the outside edge in the second and third trial as compared to their first trial. No differences between trials were found at slow and medium speed.

Table 1 **:** Average and SD of lateral deviation from inner edge at curve entrance. Values are in meters, the middle of the lane is 0.725m. Same letters indicate ($p < 0.05$).

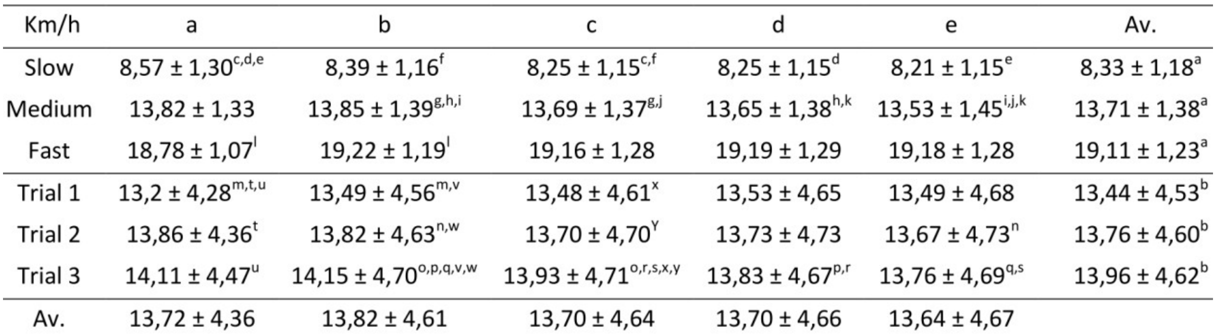
Lat Dev Start	Trial 1	Trial 2	Trial 3	Av.
Slow	0,91 ± 0,15	0,92 ± 0,12^{e,f}	0,91 ± 0,13^{g}	0,91 ± 0,13^{a,b}
Medium	0,94 ± 0,10	1,01 ± 0,14^{e}	0,97 ± 0,10^{h}	0,97 ± 0,12^{a}
Fast	0,93 ± 0,12^{c,d}	1,02 ± 0,10^{c,f}	1,04 ± 0,11^{d,g,h}	1,00 ± 0,12^{b}
Av.	0,93 ± 0,12	0,98 ± 0,13	0,97 ± 0,12	

Cycling speed

A repeated measures ANOVA with speed condition, trial and segment of the semicircle as within-subjects factors was used to analyze cycling speed. Average cycling speeds per speed condition, trial and segment can be found in Table 2.

As instructed, participants cycled slowest in the slow condition and fastest in the fast condition ($F_{2,32} = 636.257$; $p < 0.001$). They were also found to cycle slightly faster as they repeated the trials ($F_{2,32} = 10.559$; $p < 0.002$). Although no general differences across segments were observed ($F_{4,64} = 2.133$; $p = 0.157$), significant interaction effects between speed and segment ($F_{8,128} = 8.319$; $p < 0.001$) and between trial and segment ($F_{8,128} = 14.478$; $p < 0.001$) suggest that in some conditions cycling speed was different between the five segments of the curve. Post hoc results for both interaction effects can also be found in Table 2. These results reveal that there are only minor differences between the three speed conditions in how cycling speed changes over the five segments of the semicircle. The differences in cycling speed between the three consecutive trials are mainly due to differences in the first three segments. In the final two segments of the curve, no significant differences across trials were observed.

Table 2 **:** Average and SD of cycling speed in km/h. All significances are indicates with letters in superscript. Differences in speed were also significant for each segment.



Km/h	a	b	c	d	e	Av.
Slow	8,57 ± 1,30^{c,d,e}	8,39 ± 1,16^{f}	8,25 ± 1,15^{c,f}	8,25 ± 1,15^{d}	8,21 ± 1,15^{e}	8,33 ± 1,18^{a}
Medium	13,82 ± 1,33	13,85 ± 1,39^{g,h,i}	13,69 ± 1,37^{g,j}	13,65 ± 1,38^{h,k}	13,53 ± 1,45^{i,j,k}	13,71 ± 1,38^{a}
Fast	18,78 ± 1,07^{l}	19,22 ± 1,19^{l}	19,16 ± 1,28	19,19 ± 1,29	19,18 ± 1,28	19,11 ± 1,23^{a}
Trial 1	13,2 ± 4,28^{m,t,u}	13,49 ± 4,56^{m,v}	13,48 ± 4,61^{x}	13,53 ± 4,65	13,49 ± 4,68	13,44 ± 4,53^{b}
Trial 2	13,86 ± 4,36^{t}	13,82 ± 4,63^{n,w}	13,70 ± 4,70^{Y}	13,73 ± 4,73	13,67 ± 4,73^{n}	13,76 ± 4,60^{b}
Trial 3	14,11 ± 4,47^{u}	14,15 ± 4,70^{o,p,q,v,w}	13,93 ± 4,71^{o,r,s,x,y}	13,83 ± 4,67^{p,r}	13,76 ± 4,69^{q,s}	13,96 ± 4,62^{b}
Av.	13,72 ± 4,36	13,82 ± 4,61	13,70 ± 4,64	13,70 ± 4,66	13,64 ± 4,67	

Steering

Steering measures were also analyzed using repeated measures ANOVA with speed condition, trial and segment as within-subjects factors. The results per speed condition and trial can be found in Table 3, whereas averages per segment and the result of pairwise comparison can be found in Table 4.

Table 3 **:** Average and SD of steering behaviour measures.
Lat Dev of 0.725m is centre of lane. Same superscript indicates significant difference ($p < 0.05$).

	Slow	Medium	Fast	Trial 1	Trial 2	Trial 3
M Lat Dev (m)	0,70 ± 0,14	0,70 ± 0,14	0,70 ± 0,17	0,64 ± 0,14^{a,b}	0,72 ± 0,15^{a}	0,74 ± 0,15^{b}
#SR/s	0,50 ± 0,49	0,56 ± 0,68	0,64 ± 0,86	0,58 ± 0,71	0,54 ± 0,67	0,59 ± 0,70
SD Lat Dev	0,04 ± 0,02^{c}	0,04 ± 0,03^{d}	0,05 ± 0,04^{c,d}	0,04 ± 0,03	0,04 ± 0,03^{e}	0,04 ± 0,03^{e}

The mean lateral deviation from the inner edge of the semicircle revealed that the mean lateral deviation was significantly lower in the first trial than in the two subsequent trails. Regardless of the speed condition, significant differences between the five segments of the curve ($F_{4,64} = 46.641$; $p < 0.001$) show that participants cycled more towards the outside edge in the first segment (a), and more towards the inside edge in the subsequent segments (b–e).

The analysis of the number of steering reversals per second (#SR/s) revealed significantly less corrections in the first segment as compared to the rest of the curve ($F_{4,64} = 13.022$; $p < 0.001$). No significant effects of speed condition ($F_{2,32} = 1.788$; $p = 0.185$) or trial number ($F_{2,32} = 0.301$; $p = 0.735$) were found.

The analysis of the standard deviation of lateral deviation from inside edge (SD Lat Dev) indicated significant differences between speed conditions ($F_{2,32} = 8.144$; $p = 0.001$), between trials ($F_{2,32} = 4.278$; $p = 0.023$) as well as between segments ($F_{4,64} = 53.168$; $p < 0.001$). Pairwise comparison showed that the SD Lat Dev was higher in the fast condition than in the medium and the slow condition. In addition, SD Lat Dev was lower in the third as compared to the second trial. Results per segment indicate that the largest variations in lateral deviation could be found in the first segment of the curve.

However, the analysis of SD Lat Dev also revealed a significant interaction effect between speed and segment ($F_{8,128} = 4.249$; $p < 0.001$) and between trial and segment ($F_{8,128} = 2.605$; $p = 0.018$). Post hoc results of these interactions can be found in Addendum P4. The most apparent interaction effect is shown in Figure 4 which indicates that the faster the participants cycled, the higher their SD M Lat Dev in the first segment.

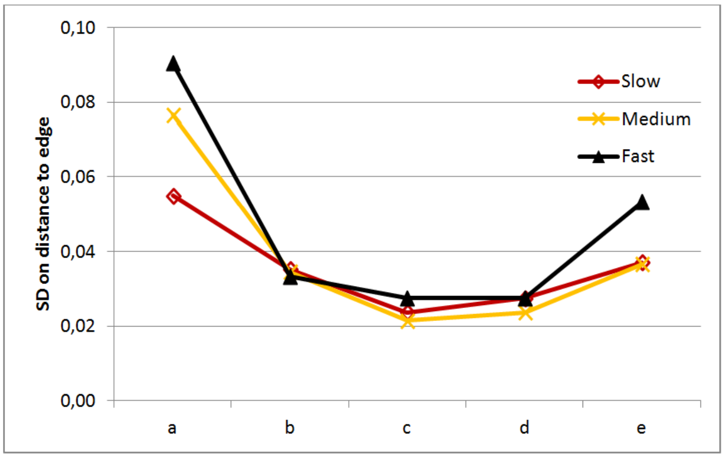


Figure 4 **:** Interaction-effect between speed and Segment on SD of Lateral Deviation. a-e represent the five segments of the curve

Table 4 **:** Average, SD and results of pairwise comparison of steering behaviour measures per segment of the semicircle (a-e).

	a	b	c	d	e
mean lateral deviation (m)	0,82 ± 0,11	0,68 ± 0,13	0,63 ± 0,14	0,66 ± 0,16	0,70 ± 0,15
	a	< 0.001	< 0.001	< 0.001	< 0.001
	b		< 0.001	0.898	1.000
	c			0.109	0.001
	d				< 0.001
#SR/s	0,19 ± 0,44	0,59 ± 0,74	0,70 ± 0,64	0,71 ± 0,72	0,64 ± 0,76
	a	< 0.001	< 0.001	< 0.001	< 0.001
	b		1.000	1.000	1.000
	c			1.000	1.000
	d				1.000
SD of lateral deviation	0,07 ± 0,04	0,03 ± 0,02	0,02 ± 0,02	0,03 ± 0,02	0,04 ± 0,03
	a	< 0.001	< 0.001	< 0.001	0.001
	b		< 0.015	0.173	0.472
	c			1.000	0.001
	d				< 0.001

Gaze: Dwell time %

The effects of cycling speed and trial number on dwell time percentages to each area of interest together with the changes throughout the segments of the curve were also analyzed using repeated measures ANOVA with speed condition, trial and segment as within-subjects factors. The results of the dwell time percentages per speed and segment can be found in Table 5. Figure 5A visualizes how gaze was distributed over the AOIs per speed and trial. In general, these results show that gaze was predominantly directed to the inside edge and the central region of the curve. However, Table 5 also shows high standard deviations for the dwell time percentages. Since the within-subject variability was two to three times smaller than the between-subject variability, this suggests that there were notable individual differences in where participants directed their gaze at during the experiment.

Cycling speed had a significant effect on the time that participants spent watching the areas 'Near centre' ($F_{2,32} = 8.063$; $p = 0.011$), 'Inside' ($F_{2,32} = 14.428$; $p < 0.001$) and 'Centre' ($F_{2,32} = 8.859$; $p = 0.001$). At low cycling speed, gaze was directed more to the near centre of the road and less to the inside edge. At high cycling speed, gaze was directed less to the centre of the road. Dwell time % to the other AOIs was not significantly affected by cycling speed ($p > 0.05$).

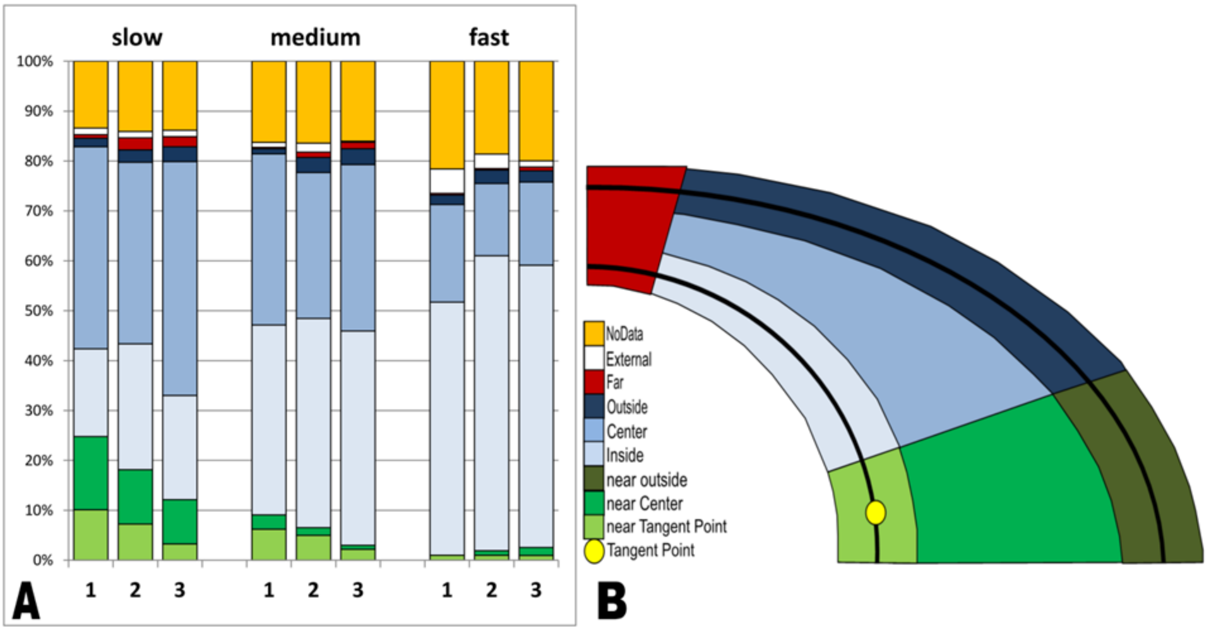


Figure 5 **:** Areas Of Interest and Dwell time percentages

A) Dwell time percentage for each AOI per Trial and Speed B) A sketch of the AOIs as defined on the gaze overlay videos. Black lines represent the Cycling lane. Note that this figure is a sketch of the AOIs, this grid was not scene or road fixed. Each of the fixations was assigned to one of these AOIs as described in the method section.

Between the five segments of the semicircle, significant differences in dwell time % were found for the AOIs 'Inside' ($F_{4,64} = 3.327$; $p = 0.022$) and 'Centre' ($F_{4,64} = 9.162$; $p < 0.001$). Dwell time % to 'Inside' was lower in the last segment (e) as compared to the second last segment (d), and dwell time % to the centre was lower in the last segment than in the rest of the curve.

Dwell time % to all AOIs did not significantly change with increasing trial number and no interaction effects were found ($p > 0.05$).The percentage of NoData changed with increasing speed ($F_{2,32} = 12.161$; $p < 0.001$) and along segments ($F_{4,64} = 42.517$; $p < 0.001$), but not with increasing trial number (F2,32 = 0.269; $p = 0.766$). The percentage of 'NoData' was lower at low cycling speed, and a higher percentage of 'NoData' was found in the last segment than in the rest of the curve.

Table 5 **:** Dwell time percentage in each AOI per speed and per segment.
* indicates significant Univariate results; significance of pairwise comparison is indicated with letters (same letters indicate $p < 0.05$).

Dwell time %	slow	medium	fast	a	b	c	d	e
Near Inside	6,87 ± 14,1	4,45 ± 10	0,97 ± 2,44	5,3 ± 11,02	2,52 ± 5,3	2,93 ± 10,38	4,39 ± 8,18	5,37 ± 9,86
Near Centre*	11,48 ± 14,75^{a,b}	1,74 ± 2,91^{a}	0,83 ± 2,83^{b}	6,16 ± 7,25	4,73 ± 5,92	3,65 ± 5,73	4,23 ± 6,16	4,67 ± 6,21
Near Outside	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Inside*	21,23 ± 21,55^{c,d}	40,99 ± 25,83^{c}	55,48 ± 27,62^{d}	36,23 ± 20,94	39,34 ± 27,47	44,76 ± 25,52	42,28 ± 19,07^{e}	33,56 ± 14,24^{e}
Centre*	41,26 ± 25,53^{f}	32,29 ± 24,8^{g}	16,91 ± 19,87^{f,g}	32,95 ± 20,59^{h}	36,95 ± 23,49^{i}	32,67 ± 24,53^{j}	29,12 ± 18,9^{k}	19,07 ± 14,39^{h,i,j,k}
Outside	2,37 ± 5,79	2,41 ± 6,21	2,29 ± 6,83	2,08 ± 3,99	2,76 ± 5,02	2,03 ± 3,99	1,94 ± 3,61	2,96 ± 7,28
Far	1,72 ± 5,55	0,89 ± 2,82	0,46 ± 1,15	0,7 ± 2,1	0,82 ± 3,4	1,12 ± 4,61	1,27 ± 5,23	1,19 ± 2,27
External	1,3 ± 1,39	1 ± 1,53	3,01 ± 4,88	2,18 ± 4,21	0,68 ± 1,01	1,75 ± 3,81	2,46 ± 3,38	1,79 ± 2,59
NoData*	13,76 ± 4,16^{l,m}	16,24 ± 4,75^{l}	20,05 ± 4,08^{m}	14,4 ± 4,72^{n}	12,19 ± 5,31^{o}	11,1 ± 5,62^{p}	14,32 ± 6,77^{q}	31,39 ± 5,57^{n,o,p,q}

DISCUSSION

The current study explored the visual behaviour while cycling in the middle of a semicircular lane, and investigated the effect of cycling speed on steering and gaze behaviour. Similar to the findings resulting from car driving experiments, cyclists mainly directed their gaze to the inside edge and the centre of the curve. However, current results reveal that at higher cycling speeds, participants direct their gaze further and more towards the inside edge than at lower cycling speeds. Except for cutting more into the bend in the first segment of the curve, no effect of cycling speed on steering behaviour was found. Furthermore, the results show that participants cycled more towards the centre of the bend as they repeated the trajectory.

Steering behaviour

Similar to steering behaviour of car drivers during curve negotiation [37], cyclists in the current experiment entered the curve on the outside of the lane and then cut into the first segment of curve (segment a). This was reflected by a higher mean lateral position, a higher SD of lateral position and a lower frequency of steering corrections in the first segment. After the first segment, steering behaviour was characterized by a stable lateral position and more steering corrections. These findings suggest that a different steering strategy is used at curve entrance (segment a) than during the cornering phase (segments b–e) of the semicircle.

At curve entrance, participants seem to minimize the lateral acceleration by choosing a path with a lower maximum curvature. According to Boer [38] this should lead to i) steering to the left/ right side of the lane before the start of the curve, ii) steering into the curve before the curve's onset, and iii) approaching the inner lane boundary in the middle of the curve. Although participants' steering behaviour of the run-up to the curve was not analyzed, the outside position at curve entrance confirms the first prediction of Boer [38] and the steering results of the first segment confirm that participants steered into the curve (see Figure 5A). Furthermore, the finding that at higher cycling speeds participants enter the curve more towards the outside and cut more into the first segment of the bend is also in line with the suggestion that participants tried to minimize lateral acceleration. With respect to the third prediction of Boer [38], 'cutting the corner', as has been described for bends without cornering phase, was prevented by the length of the semicircle, the relatively narrow lanes and the instructed steering behaviour [14]. Instead, participants stabilized their position in the middle of the lane during the cornering phase of the curve in line with the specific steering instructions. Therefore, the third prediction of Boer, that participants should have steered close to the inner lane boundary of the curve was not confirmed.

Nevertheless, we observed that the lowest lateral deviation from the inner edge was found in the middle segment of the curve, which confirms that participants preferred steering towards the inner edge of the lane. However, if searching for the path with the minimal lateral acceleration were to be the main steering strategy during the cornering phase, participants would favour steering towards the outward side of the curve, since curvature is slightly lower there. Hence, a steering bias towards the inside edge during the cornering phase is in contrast with the idea that participants tried to take the path with minimal lateral acceleration. Instead, this steering behaviour is in line with the suggestion of Wilkie et al. [5], that drivers oversteer to provide a spatial buffer. As follows, possible steering errors or an unexpected increase in curvature would merely lead the vehicle towards the centre of the lane rather than immediately to the outside border. It seems that participants minimized lateral acceleration when entering the curve, but a spatial buffer was preferred during the cornering phase instead of a lower lateral acceleration. An alternative way to deal with lateral acceleration would be to adapt travelling speed [39]. In the current investigation however, participants were asked to cycle at a constant speed and the results did not indicate adjustments to cycling speed to cope with lateral acceleration.

The finding that participants entered the curve more towards the outside edge at higher cycling speeds and cut into the first segment of the curve while making few steering corrections suggests that an anticipatory steering strategy was used when entering the curve. If steering would be purely controlled by compensatory closed-loop behaviour, there would be no need to steer to the outside edge at higher speeds and a similar number of steering corrections would be made over the entire curve. In the subsequent cornering phase, on the other hand, steering corrections and a stable lateral position suggests that a compensatory steering strategy was used to stay on track. This reinforces the suggestion of Godthelp [40] that at curve entrance, steering is based on anticipatory open-loop control, whereas during the cornering phase, steering is primarily based on compensatory closed-loop control. According to Shinar et al. [1] this finding should also be reflected in gaze behaviour since the primary function of the eye movements is to provide preview information during the approach phase and to reinforce the awareness of other cues during the cornering phase. In the current study, however, gaze behaviour was only analyzed in the cornering phase of the curve.

Gaze behaviour

In contrast to some car driving experiments [2,11,13], dwell time percentages in the current study show that cyclist spent very little time watching the AOI ‘near inside’, in which the tangent point was located. However, in the current experiment, the tangent point was located only 3.7 m in front of the participants. This means that the tangent point only fell within the preferred look ahead distance (1–2 s ahead) in the slow cycling condition. As a consequence the tangent point was probably too close to be eligible as a good source for visual information. Instead of looking at the tangent point, gaze was predominantly directed toward the centre and the inside edge of the bend, similar to the results of Kountouriotis et al. [15] and Robertshaw et al. [41]. However, high standard deviations of dwell time percentages show that there were notable individual differences in where participants were looking during the experiment. This is in line with earlier results of gaze behaviour during cycling [25,42] and suggests that individual differences in how vision is used to guide steering exist. Notwithstanding the variation in gaze behaviour among the participants, an increase of cycling speed had a similar effect on the visual behaviour of all participants. As they were instructed to cycle faster, their gaze was less often directed to the near region and shifted from a predominantly central road position towards the inner edge of the lane. Interestingly, this shift of gaze was not accompanied by a steering bias towards the inner edge of the curve.

The anticipatory steering behaviour that was revealed in the first segment of the curve was not accompanied by a different gaze behaviour. Since gaze is proactive, anticipatory gaze behaviour might have taken place in the run-up to the curve, which was not analyzed in current experiment. Gaze behaviour per segment did reveal a decrease of looking towards the inside edge and centre region in the last segment. However, an increase of ‘NoData’ suggests that this decrease of dwell time percentage was caused by more data loss in the last segment. It is possible that the participants started to anticipate the exit of the curve in the last segment, which may have led to a gaze behaviour that was more prone to data loss.

Effect of speed on look-ahead distance.

It has repeatedly been suggested that, when driving through curves, gaze is mainly directed to the road about 1 to 2 seconds ahead [2,10,43]. If a constant gaze-steering span (visual buffer) is used, gaze should be directed further ahead at higher speeds and vice versa. For the current experiment, a gaze-action span of 1 to 2 seconds would mean that gaze would have been directed 2.2–4.5 m ahead in the slow condition, 3.8–7.6 m in the medium, and 5.3–10.6 m in the fast condition. Unfortunately, with the gaze analysis used in the current experiment, it was not possible to calculate the exact look-ahead distance of gaze. Nevertheless, as cycling speed increases, a decreasing percentage of dwell time towards the near region (up to ±3–4 m ahead) was found, reflecting a larger look-ahead distance, which is in line with the idea of a constant temporal size of the gaze-steering span [25].

Alternatively, at lower speeds, gaze could have been directed more to the near region due to the increased need for balance. At lower cycling speeds, bicycles becomes less stable [30] and therefore more steering corrections are necessary to maintain balance. Surprisingly, no effect of speed was found on the number of steering reversals. However, as previously suggested [42], changing visual behaviour can be the first step to cope with higher task demands. In the current experiment, increased visual attention towards the near region could have been enough to cope with the higher demand of balance control. Therefore, steering behaviour was not (yet) affected.

The lack of an increase in dwell time towards the far area was likely due to the fact that it was located further than 10 m from the participant, and thus beyond the area 1–2 seconds ahead. Therefore, the far region in the current experiment could be compared to the 'occlusion point' described by Lehtonen et al. [44] rather than to the far region described by Land & Horwood [6]. Considering its distance from the participant, gaze to the far area would serve as anticipatory open-loop control (guidance level [45]). Given that a familiarized trajectory without obstacles and oncoming traffic was used, there was almost no need for anticipatory glances towards the far area, leading to very few fixations in this area.

It must be taken into account that no exact look-ahead distances were measured in the current experiment. Using a head-mounted eye-tracker without head tracking, it is extremely cumbersome and time-consuming to retrieve actual look-ahead distance. Therefore, the experimenters made an estimate of the look-ahead distance based on reference dimensions in the scenery and categorized the fixations as 'near', 'middle' (blue AOIs in Fig. 3) or 'far'. Although less accurate, this method was found effective to distinguish between the three look-ahead categories and gives an overview of gaze distribution. Nevertheless, further experiments should try to develop a method measuring actual gaze distance in real-life settings to further investigate the effect of driving/cycling speed on exact look-ahead distance.

Effect of speed on gaze to inner edge.

Participants mainly looked at the centre of the road when cycling at lower speeds, while gaze shifted to the inside edge of the curve at higher cycling speeds. This switch of visual attention is compatible with a switch from a 'look where you are going' strategy to a 'curvature matching' strategy. According to Wilkie and Wann [10] ''The 'curvature matching' strategy provides a solution for maintaining a trajectory at a fixed distance from the inside edge, whereas the 'look where you are going' strategy allows any curved path to be chosen''. Although most experiments favour one of both strategies, there is no evidence that these strategies are mutually exclusive [9]. Similar to the weighted way in which near and far road information are used to guide steering [8,15], visual information from the upcoming road and from the inner lane (e.g., tangent point) are possibly also used in a flexible way. Results of the current experiment are in line with the idea that, according to the quality and availability of the visual cues, both strategies contribute to the steering system. Furthermore, using the 'look where you are going' as well as the 'curvature matching' strategy in a flexible way would also explain the high standard deviations of dwell time percentages in the current experiment and the variation of gaze direction in most previous experiments involving curve negotiation.

At higher speeds the ‘curvature matching’ strategy was possibly more advantageous than at lower speeds. As a consequence, gaze shifted from the centre of the road towards the inner lane. However, the question remains whether a different visual input (visual flow) or a higher task demand (higher lateral acceleration) triggered the shift of gaze strategy at higher cycling speeds.

Effect of trial on steering and gaze behaviour

Kandil et al. [11] showed that gaze behaviour while negotiating curves changes with familiarization. However, since in natural steering situations a curve is not repeated several times in succession, we believed that the gaze and steering behaviour in the current experiment would resemble natural behaviour to a greater extent with only a minimum of familiarization trials. Therefore, participants were given no more familiarization trials than necessary to get used to the required speeds.

When checking for an effect of trial, results indeed showed that gaze did not significantly differ across successive trials. Surprisingly, however, participants were found to cycle more towards the centre of the lane as they repeated the trial. Yet, both the curvature matching strategy and the future path strategy rely on visual cues to guide steering. Since these cues did not change across trials, repeating the bend should not result in different gaze or steering behaviour. Changing steering behaviour over successive trials indicates that the participants did not solely rely on visual cues to guide steering but also on previous experiences.

To date, most models of gaze/steering behaviour do not incorporate the influence of road familiarity or other previous experiences except for the steering model of McRuer et al. [46], in which a ‘precognitive control loop’ was active next to a compensatory and a feed forward loop. Although the current results are not in line with an open loop precognitive control mechanism as proposed by McRuer et al. [46], they do reinforce the idea of an additional control level that incorporates a familiarity/learning component that influences the steering, and possibly also the gaze behaviour.

Transferability to real road behaviour

Although this was a non-simulated experiment, it does not necessarily reflect actual in-traffic gaze and steering behaviour. The current experiment was carried out in a distraction-free environment and included only one curve with a constant radius. Therefore, there was a minimal need for anticipatory gaze behaviour. The current investigation also focused on the gaze and steering behaviour only after curve entrance, while many of the previous curve driving experiments included both the approach as well as the cornering phase. Therefore, the suggestion that the ‘curvature matching’ strategy and the ‘look where you are going’ strategy are used together in a flexible way should be tested on curves with different radii. Nevertheless, the findings of the current experiment contribute to the general understanding of how visual information guides steering through curves.

CONCLUSIONS

The current experiment was the first of its kind to test the gaze and steering behaviour of cyclists while steering through a curve. It reinforced the idea that an open-loop anticipatory steering strategy is used at curve entrance, while a closed-loop compensatory strategy is used to steer through the rest of the curve. The gaze behaviour of the cyclists was comparable to gaze behaviour previously described for car driving. By testing the effect of cycling speed, we added new insights to the discussion whether a ‘curvature matching’ strategy or a ‘look where you are going’ strategy is used during curve negotiation. It can be argued that the ‘curvature matching’ strategy and the ‘look where you are going’ strategy are not mutually exclusive and that, dependent on task constraints and the availability and quality of the visual cues, visual information from both strategies likely contribute to the steering system. Finally, the familiarization effect observed in the current experiment is assumed to reinforce the idea that steering models should take a learning component into account.

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SUPPORTING INFORMATION

Addendum P4 **:** Speed*segment, and trial*segment interactions of SD Lat Dev.

	a	b	c	d	e	Av.
Slow	$0,05 \pm 0,03^{a,b,c,p,q}$	$0,04 \pm 0,02^{a,d}$	$0,02 \pm 0,01^{b,d}$	$0,03 \pm 0,02^{c}$	0,04 ± 0,03	$0,04 \pm 0,02^{a}$
Medium	$0,08 \pm 0,03^{e,f,g,h,p}$	$0,03 \pm 0,02^{e}$	$0,02 \pm 0,02^{f,i}$	$0,02 \pm 0,02^{g}$	$0,04 \pm 0,02^{h,i}$	$0,04 \pm 0,03^{b}$
Fast	$0,09 \pm 0,04^{j,k,l,m,q}$	$0,03 \pm 0,02^{j}$	$0,03 \pm 0,02^{k,n}$	$0,03 \pm 0,02^{l,o}$	$0,05 \pm 0,04^{m,n,o}$	$0,05 \pm 0,04^{a,b}$
Trial 1	$0,08 \pm 0,03^{a,b,c,d}$	$0,03 \pm 0,02^{a,e}$	$0,02 \pm 0,02^{b,f}$	$0,03 \pm 0,02^{c,g}$	$0,04 \pm 0,03^{d,e,f,g}$	0,04 ± 0,03
Trial 2	$0,08 \pm 0,04^{h,i,j,k}$	$0,04 \pm 0,02^{h,l,m}$	$0,02 \pm 0,02^{i,l,n}$	$0,03 \pm 0,02^{j,o}$	$0,05 \pm 0,04^{k,m,n,o,v}$	$0,04 \pm 0,03^{c}$
Trial 3	$0,06 \pm 0,04^{p,q,r,s}$	$0,04 \pm 0,02^{p,t,u}$	$0,02 \pm 0,01^{q,t}$	$0,02 \pm 0,02^{r,u}$	$0,03 \pm 0,02^{s,v}$	$0,04 \pm 0,03^{c}$
Av.	$0,07 \pm 0,04^{d,e,f,g}$	$0,03 \pm 0,02^{d,h}$	$0,02 \pm 0,02^{e,h,j}$	$0,03 \pm 0,02^{f,i}$	$0,04 \pm 0,03^{g,i,j}$	

2.3 Cycling a slalom

Paper 5

VISUALLY GUIDED STEERING OF YOUNG AND ADULT BICYCLISTS DURING A SLALOM TASK

Vansteenkiste P, Cardon G, Lenoir M

Submitted to Accident Analysis and Prevention

ABSTRACT

Despite the fact that young cyclists are an accident prone group in traffic situations, their visual-motor strategies are poorly documented. The current study investigated the differences in gaze and steering behaviour of ten learner cyclists (8.00 ± 1.05y) and eleven experienced cyclists (23.73 ± 2.10y) when cycling at a low, preferred and high speed through three slaloms of different widths. Children made more steering errors as the task became more demanding while none of the adults made an error. Analysis of the gaze behaviour revealed that the children seemed to steer around one cone at the time, whereas the adults were found to anticipate to the next steering manoeuvres, suggesting adults plan their trajectory through the slalom. Post-hoc tests showed that some of these differences could also be found between children who made a steering error and those who didn't. These findings suggest that from young, learner bicyclist to experienced adult bicyclist, there is a change from a simple and rigid visual-motor strategy, to a flexible, more holistic strategy to guide steering.

INTRODUCTION

In the past decades, the individual and environmental benefits of choosing a bicycle over a car for transportation have repeatedly been emphasized in multiple studies (de Hartog et al. 2010; Oja et al. 2011; Shephard 2008). Unfortunately, the increasing number of cyclists has also been associated with more bicycle accidents, with children and older (65+ years) cyclists being identified as the most accident prone groups (Carpentier & Nuyttens 2013; Juhra et al. 2012; Maring & van Schagen 1990; DEKRA 2011). Although there have been multiple studies on interventions to reduce risk and severity of bicycle accidents, most of them focus on extrinsic risk factors such as road design (Thomas & DeRobertis 2013; Schepers et al. 2011), and secondary prevention measures such as bicycle helmet usage (de Jong 2012). Only a rather limited amount of research has focussed on the development of intrinsic factors like cycling skills according to age and experience (Wegman et al. 2012). Insights into how cycling skills develop could lead to better understanding of why learner cyclists get involved in more accidents, and could be useful to improve bicycling education and road design.

In general, safe traffic participation can only take place when both cognitive and motor capacities are mature enough (Briem et al. 2004). However, whereas many children have sufficient motor control to ride a bicycle by the age of five or six, research on road crossing behaviour has shown that their cognitive skills are not mature enough yet to safely cope with complex traffic situations (Whitebread & Neilson 2000; Zeedyk et al. 2002).

Since motor and cognitive skills undergo changes until late childhood (Gallahue & Ozmun 2011), children are limited in how they can interact with complex traffic environments (Connelly et al. 1998). To cope with their limited cognitive and motor abilities, children younger than ten years old often use different locomotor strategies when confronted with complex situations (Pryde, Roy, & Patla, 1997). In obstacle avoidance tasks, four to eight year old children not only moved more slowly than adults, they also looked more to the objects that had to be dealt with and often started to plan the avoidance of a second obstacle only when the first one was cleared (Franchak & Adolph 2010; Berard & Vallis 2006). These adaptations in their visual-motor strategies allowed the children to navigate safely through a complex environment.

Similarly, in road crossing studies, children use simpler visual-motor strategies than adults, characterized by waiting longer to cross and making less, but longer fixations to each side of the road (Ampofo-Boateng & Thomson 1991; Whitebread & Neilson 2000). However, these studies also showed that children have difficulties to adjust their actions in function of other moving objects such as cars (Chihak et al. 2010). As a result, for externally paced activities such as road crossing, the simpler visual-motor strategies used by children can lead to risky traffic behavior (Connelly et al. 1998; Underwood et al. 2007). This problem has been emphasized for road crossing, but it has not yet been studied to what extent less developed visual-motor strategies could lead to dangerous cycling behavior.

Therefore, in the current study we investigated the differences in gaze and steering behaviour of learner and experienced cyclists when steering through a set of slaloms. Additionally, participants were asked to cycle at three different speeds to investigate the effect of time constraints on the gaze and steering behavior. Assuming that the findings of earlier studies on the gaze behaviour of children during walking tasks are transferable to cycling, we can expect that children in the current experiment will cycle slower (Pryde et al. 1997; Briem et al. 2004), will look more to the first coming cone (Berard & Vallis 2006; Franchak & Adolph 2010), and will have more difficulties when the task demand increases (Chihak et al. 2010). Furthermore, according to our previous studies (Vansteenkiste et al., 2014b, 2013a) gaze will be directed closer to the participant when task demand is high, and further from the participant at higher cycling speeds.

METHODS

Participants

A convenience sample of seventeen children and nineteen adults participated in the study. The children were recruited by spreading a request for volunteers via elementary schools in the neighbourhood of Ghent University. All children who participated were accompanied by at least one of their parents, and received a toy at the end of the experiment. Adults were recruited from Ghent University students and staff. All of them owned a bicycle and used it on a regular basis for transportation. To ensure reliable eye-tracking data, only data of participants with a Tracking Ratio (TR = percentage of time that direction of gaze could be determined relative to the duration of trial) of at least 90% and a good pre and post calibration were included in the analysis (Vansteenkiste, Van Hamme, et al. 2014). Eye tracking data of seven children and eight adults did not meet these inclusion criteria. The ten remaining children (4♂, 6♀) had an average age of 8.00 ± 1.05y and a TR of 95 ± 3%. The eleven adults (8♂, 3♀) were 23.73 ± 2.10 years of age and had a TR of 96 ± 2%. All participants declared to have normal or corrected-to-normal vision.

Materials

Eye movements were recorded using the Head mounted Eye tracking Device (HED) of SensoMotoric Instruments (SMI; Teltow, GER) which was mounted on a baseball cap. The system recorded the left eye movements with an infrared-sensitive camera at 50Hz using pupil position and corneal reflex and has an accuracy of 1° (SMI, 2012). A scene video with a horizontal and vertical field of view of 33° was recorded at 25Hz by a camera with a 3.6mm lens, placed next to the eye-tracking camera. The two cameras were connected to a recording unit (Lenovo notebook X201; 1,4kg) which was worn in a small backpack. Both scene video and eye tracking recordings were saved using SMI’s software IViewX. Both adults and children reported to experience only minor discomfort of wearing the eye tracking system.

Set up

Three 15m long slaloms with a width of 0 (cones in a line), 0.5 and 1m were constructed in a gymnasium using six cones (see figure 1 for a sketch of the experimental set up). At the first and the last cone, a mechanical gate was placed which gave a visual signal when the cyclist passed through. A start line was drawn at a distance of 15m before the first cone and two overview cameras (A & B in Fig 1; 25Hz, Full HD) were placed at the side and at the end of the slalom to film the participants and the signals of the mechanical gates.

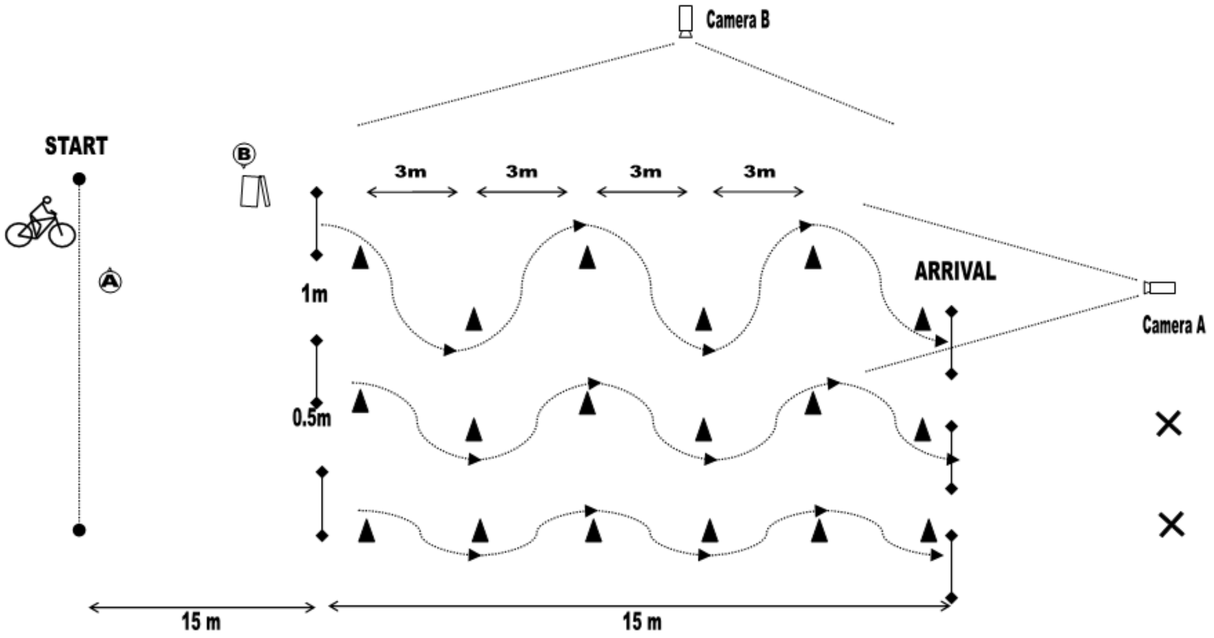

Figure 1 : Experimental set-up. (A) is the experimenter who instructs the participant, (B) is the experimenter with clapperboard who gives the start signal. Camera A is replaced for every slalom, X's indicate the location of the camera for the lower two slaloms.

Procedure

On arrival, the participants or their accompanying parents, were briefed about the experiment and were asked to read and sign the informed consent, which was approved by the Ethical Committee of Ghent University Hospital. Three bicycles were provided: a standard city bicycle, a medium size children's bicycle, and a small children's bicycle. After choosing the most adequate bicycle, the saddle height was adjusted to the participants' length. Participants were asked to cycle around in the gymnasium to get used to the bicycle, and were given one familiarization trial for each slalom. After the familiarization, the participants were asked to put on the eye tracker and secure it with a strap. If necessary, the children were aided by the experimenters. For the calibration of the eye tracker, participants were asked to sit down and look subsequently to five reference points without moving their head. Since children often had troubles holding still, an experimenter helped them by supporting their heads. When the eye-tracker was calibrated and the recording unit was put in the backpack, the participants took place at the start line for the actual experiment.

For each of the three slaloms, the participants were asked to cycle at a preferred speed, a lower than preferred, or a higher than preferred speed. These nine conditions (3 slaloms × 3 speeds) were carried out in a randomized order. A start signal was given to the cyclist by a second experimenter (B on Fig. 1) using a clapperboard. This signal was also used for synchronizing eye tracking data with the video images of the overview camera. When all trials were completed, a calibration check was performed.

Data analysis

Using the video images of camera A and B, the signals from the mechanical gates were detected to calculate the time necessary to cycle from the first to the last cone. This measure was called *Completion Time*. The video files were also used to detect the number of *steering errors*, if any, of the participants per trial.

Using BeGaze 3.2 (SMI), scene video images and eye tracking recordings were combined into a gaze overlay video. The period between the first and the last cone was selected for further analysis for each trial. The 'SMI event detection algorithm' was then applied to determine all *fixations* during each trial. With the analysis tool 'Semantic Gaze Mapping', all fixations were manually assigned to one of the following Areas Of Interest (AOIs): 'C', 'C+1', 'C+2', 'C+3', 'C+4', 'F', 'F+1', 'F+2', 'F+3', 'F+4', Other and 'External'. A fixation was assigned as 'C' when the fixation was directed towards the forthcoming cone and as 'F' when the floor between the cyclist and the forthcoming cone was looked at. A fixation was assigned as 'C+1' when the fixation was directed to the second coming cone, as 'C+2' when third coming come was looked at, etc… The moment when the bottom of the front wheel reached the cone was used to determine when a cone was passed. This moment was determined by using the video footage of the camera B. Note that the assignment of the fixation location is relative to the current position of the participant. The AOI 'Other' was defined as fixations on the travel path, but not identifiable to one of the previous categories. 'External' fixations were fixations that fell outside the travel path. 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, divided by completion time was used to calculate *dwell time %* towards each AOI. This fixation-by-fixation analysis has been described as a valid and time-saving alternative to the classic frame-by-frame analysis (Vansteenkiste, Cardon & Lenoir 2013).

The difference between the sum of the dwell time percentages and 100% was named 'NoData'. This measure represents saccades between AOIs, blinks and data loss during the experiment. Since no fixations were made towards the AOIs F+4 and C+4, these AOIs were excluded from further analysis. When one or more cones were missed during the slalom, the gaze behaviour was analyzed until the participant missed the cone.

Using the gaze overlay videos, the number of 'anticipatory fixations' was manually counted for each trial of each participant. These fixations were defined as fixations to a more distant cone or point on the slalom, immediately followed by a saccade back to the previous fixation location. This 'dual sampling strategy' has been reported previously by Land (Land 1998) for dealing with road hazards, and has been called 'gaze polling' by Wilkie, Wann, &

Allison (2008). In the current article, this fixation sequence will be referred to as '*anticipatory fixations*'.

The gaze overlay videos were also analyzed frame-by-frame to manually measure the time span between the end of the last fixation to the first coming cone and the moment when the cone was actually passed. This time span is similar to the 'look-ahead distance' as described in (Wilkie et al. 2008). However, since a time span is measured and not a distance, this measure will be referred to as the *eye-steering span* in the current article. Given that participants showed different gaze behaviour at the entrance and at the exit of the slalom, only the 4 middle cones were used to calculate the *average eye-steering span* per participant for each trial. To investigate how consistent the size of this eye-steering span was within each trial, the standard deviation of the eye-steering span between the 4 cones was also calculated. This measure represents how large the variability was in the eye-steering span used in each trial for each participant.

Statistical analysis

All variables were analysed for age-related differences using a repeated measures MANOVA with the three speed conditions and the three slalom widths as two within factors, and age group as between factor. For the analysis of dwell time percentage, the eleven AOIs were added as measures. Significant age*speed and/or age*width interactions were further investigated with independent samples t-tests to test for age-related differences per speed and/or width condition. The effects of speed condition and slalom width were investigated separately for the children and the adults using two repeated measures MANOVA tests with speed condition and slalom width as two within factors. Post hoc tests were performed using the Bonferroni correction for pairwise comparison. Significance level was set at 0.05 for all analyses.

Additionally, a post-hoc analysis was done to investigate whether the differences in completion time and gaze behaviour between the adults and the children, could also be found between the four children who made at least one error (C-; 3♀), and the six children who did not make any errors (C+; 3♀). A Shapiro Wilks test of data normality and the Levene test for equality of variances showed significant results. Therefore, the comparison of the C+ and the C- group is done using non-parametric analyses. Mann Whitney U tests were used to investigate differences between the C+ and the C- group, and Friedman tests were used to test the effect of speed and width on both groups. If Friedman tests gave significant results, further analysis was done using Wilcoxon tests. Only a summary of the findings are reported in the text, detailed results can be found in the addendum P5.2 and P5.3.

RESULTS

Table 1 **:** Overview of results per group (A = adults, C = children) and condition. Same superscript letters indicate significant differences ($p < 0.05$).

		Average	Slow	Preferred	Fast	Narrow	Middle	Wide
Completion time (s)	A	7,61 ± 2,65	9,82 ± 2,52^{a}	7,05 ± 1,17^{a,e}	5,97 ± 0,90^{a,f}	6,35 ± 1,43^{b}	7,32 ± 1,40^{b}	9,16 ± 1,60^{b}
	C	8,58 ± 1,83	9,59 ± 1,34^{c}	8,54 ± 1,24^{e}	7,43 ± 1,10^{c,f}	7,37 ± 1,02^{d}	8,50 ± 1,25^{d}	10,49 ± 1,42^{d}
# Anticipatory fixations	A	1.28 ± 1.58	1,91 ± 2,08	1,21 ± 1,29	0,73 ± 0,98	0,79 ± 1,22	1,18 ± 1,4	1,88 ± 1,9
	C	0.71 ± 0.97	0,97 ± 1,07	0,80 ± 1,03	0,39 ± 0,72	0,57 ± 1,01	0,80 ± 0,92	0,77 ± 1,01
Eye-steering span (s)	A	1.16 ± 0.38	1,36 ± 0,45^{a,b}	1,13 ± 0,27^{a}	0,99 ± 0,31^{b}	1,24 ± 0,44	1,11 ± 0,34	1,13 ± 0,35
	C	1.19 ± 0.30	1,20 ± 0,28	1,25 ± 0,34	1,13 ± 0,28	1,28 ± 0,32^{c}	1,07 ± 0,33^{c}	1,24 ± 0,20
Variability Eye-steering span	A	0.26 ± 0.15	0,32 ± 0,14^{a}	0,28 ± 0,17	0,18 ± 0,09^{a}	0,26 ± 0,13	0,26 ± 0,15	0,26 ± 0,16
	C	0.35 ± 0.22	0,42 ± 0,23^{b}	0,37 ± 0,24	0,24 ± 0,15^{b}	0,35 ± 0,22	0,33 ± 0,22	0,36 ± 0,24

Results of the analyses of completion time, number of anticipatory fixation, eye-steering span and the variability of the eye-steering span can be found in Table 1.

Errors

Four of the ten children failed to complete the experiment without missing a cone in at least one of the nine trials. Two children made an error in one condition, one child in two conditions and one child in four conditions (Table 2). None of the eleven adult participants missed a cone during the experiment.

Table 2 : Number or errors made for each condition. All errors were made by four of the ten children.

# Errors	Slow	Pref.	Fast
Narrow	0	0	0
Middle	0	0	3
Wide	1	1	3

Completion time

In spite of the systematic tendency of shorter completion times in adults, no significant differences in completion time between the children and the adult group were found ($F_{1,15} = 2.109$ and $p = 0.167$). No width*age interaction was found ($F_{2,14} = 0.836$; $p = 0.454$). However, a borderline speed*age interaction ($F_{2,14} = 3.341$; $p = 0.065$) showed that adults had a lower completion time than children in the preferred ($t_{19} = -2.847$; $p = 0.010$) and fast condition ($t_{19} = -3.341$; $p = 0.003$), but no significant difference was found for the slow condition ($t_{19} = 0.271$; $p = 0.790$).

Analysis of the effects of speed condition and slalom width on the completion time of adults and children revealed that the completion time of the adult group increased significantly as the slalom was wider ($F_{2,9} = 147.458$; $p < 0.001$) and decreased significantly as the participants were asked to cycle faster ($F_{2,9}$ = 20.605; p < 0.001). Similarly, the completion time of the children also increased significantly as the slalom was wider ($F_{2,4}$ = 92.165; p < 0.001) and tended to decrease with increasing cycling speed ($F_{2,4}$ = 5.741; p = 0.067). However, only the difference between the slow and the fast condition was found to be significant.

Dwell time %

An overview of the dwell time percentages per age group can be found in Table 3 and figure 2 while the effects of cycling speed condition and slalom width are visualized in addendum P5.1. Multivariate results of the repeated measures MANOVA showed that the differences in dwell time percentages between children and adults failed to reach significance in the multivariate analysis ($F_{10,10}$ = 2.621; p = 0.072). However, the between-subjects results showed that adults had a higher dwell time % for the AOI F+1 ($F_{1,19}$ = 5.630 and p = 0.028) and a lower dwell time% for C ($F_{1,19}$ = 4.764 and p = 0.042). A higher % of NoData was found in the adult group than in the children group ($F_{1,19}$ = 3.812 and p = 0.066) but this difference failed to reach significance. No differences in dwell time % between children and adults were found for the other AOIs (F+3: $F_{1,19}$ = 0.018 and p = 0.895; F+2: $F_{1,19}$ = 1.103 and p = 0.307; F: $F_{1,19}$ = 2.540 and p = 0.127; Other: $F_{1,19}$ = 0.025 and p = 0.876; Ext: $F_{1,19}$ = 0.487 and p = 0.494; C+3: $F_{1,19}$ = 0.005 and p = 0.947; C+2: $F_{1,19}$ = 0.005 and p = 0.945; C+1: $F_{1,19}$ = 1.097 and p = 0.308). No significant width*age ($F_{20,58}$ = 1.179 and p = 0.304) or speed*age ($F_{20,58}$ = 0.662 and p = 0.845) interactions were found.

Cycling speed condition did not have a significant effect on the dwell time percentages of the children ($F_{20,16}$ = 1.428; p = 0.237) and the adults ($F_{20,22}$ = 1.361; p = 0.240). Slalom width, however, did have an effect on the dwell time percentages of both children ($F_{20,18}$ = 2.669; p = 0.020) and adults ($F_{20,22}$ = 6.231; p < 0.001). The average dwell time percentage to each AOI per slalom width can be found in Table 3. When cycling through the wider slaloms, both the children and the adults, looked more to the first upcoming cone ($F_{2,18}$ = 9.510; p = 0.002 and $F_{2,20}$ =54.895; p <0.001, respectively) and less to the second one ($F_{2,18}$ = 26.058; p < 0.001 and $F_{2,20}$ = 36.688; p < 0.001, respectively). Dwell time percentage towards 'external' regions was highest on the narrow slalom for both the children and the adults ($F_{2,18}$ = 5.109; p = 0.027and $F_{2,20}$ = 5.548; p = 0.014, respectively). Furthermore, the adult group was found to have a higher dwell time percentage towards F+1 in the wide slalom than in the middle slalom ($F_{2,20}$ = 5.289; p = 0.030).

Anticipatory fixations

Analysis of the 'gaze polling behaviour' showed that adults tended to make more anticipatory fixations than the children ($F_{1,19}$ = 3.695; p = 0.070). No width*age ($F_{2,18}$ = 1.256, p = 0.309) or speed*age ($F_{2,18}$ = 0.571; p = 0.575) interaction was found.

Children did not make significantly more or less anticipatory fixations at higher cycling speed ($F_{2,8}$ = 2.990; p = 0.107) or on wider slaloms ($F_{2,8}$ = 0.230; p = 0.799). Although the adults seemed to make less anticipatory fixations as the cycling speed increased, and more as the slaloms were wider, no significant differences were found ($F_{2,9}$ = 3.164; p = 0.091 and $F_{2,9}$ = 2.736; p = 0.118, respectively).

Eye-steering span

No significant difference in the eye-steering span was found between adults and children ($F_{1,19}$ = 0.132; p = 0.721) and no width*age interaction was found ($F_{3,18}$ = 1.707; p = 0.210). However, a significant speed*age interaction ($F_{2,18}$ = 5.175; p = 0.017) indicates that cycling speed had a different effect on eye-steering span of children compared with that of adults (see Fig. 3). Whereas the eye-steering span of adults decreased significantly as they cycled faster ($F_{2,9}$ = 6.804; p = 0.016), it stayed more or less equal across the three speed conditions for the children ($F_{2,8}$ = 2.851; 0.116). No significant effect of slalom width on the eye-steering span of the adults was found ($F_{2,9}$ = 3.111; p = 0.94). The same analysis for the children however, revealed that the eye-steering span was significantly larger in the narrow slalom than in the medium slalom ($F_{2,8}$ = 5.234; p = 0.035).

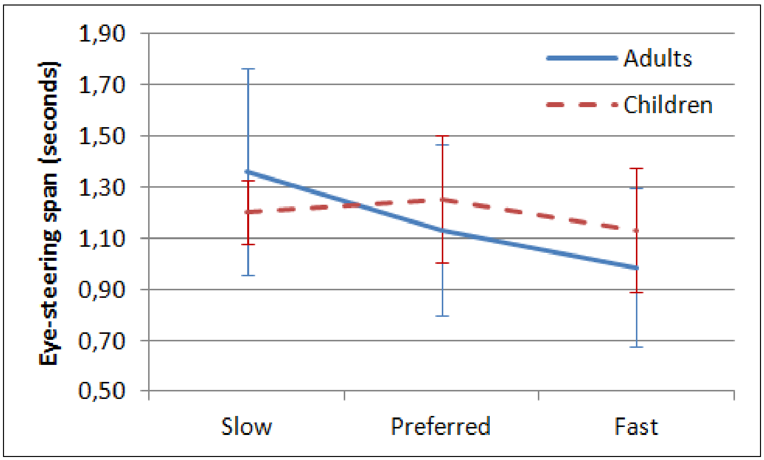

Figure 3 : effect of cycling speed on the eye-steering span of adults and children

In general, children also showed a larger variability in the eye-steering span across the slalom than adults but this difference failed to reach significance ($F_{1,19}$ = 3.994; p = 0.60). Slalom width had no significant effect on the variability of the eye-steering span for both the adults ($F_{2,9}$ = 0.020; p = 0.980) and the children ($F_{2,5}$ = 0.292; p = 0.758). With increasing speed however, the variability of the eye-steering span seemed to decrease in both groups. For both the adults as the children the variability of the slow condition was significantly lower than in the fast condition ($F_{2,9}$ = 9.674; p = 0.006 and $F_{2,5}$ = 6.164; p = 0.045, respectively).

Table 3 : Dwell time percentages per AOI and slalom width for adults and children. *indicates significant difference between adults and children, Significant differences per slalom width are indicated by identical superscript letters

	F	C*	F+1*	C+1	F+2	C+2	F+3	C+3	Other	External	NoData*
Adults	0,25 ± 0,91	20,93 ± 13,36	15,01 ± 11,80	31,52 ± 16,44	1,49 ± 3,00	2,31 ± 5,49	0,02 ± 0,24	0,24 ± 2,36	0,20 ± 1,00	3,96 ± 5,57	24,07 ± 8,55
Narrow	0,19 ± 0,88	11,46 ± 8,72^{a}	11,72 ± 12,94	40,48 ± 14,56^{c}	2,23 ± 3,81	4,26 ± 7,79	0,07 ± 0,42	0,71 ± 4,09	0 ± 0	6,49 ± 7,35^{e}	22,39 ± 9,08
Middle	0,08 ± 0,47	19,39 ± 10,80^{a}	12,92 ± 9,81^{b}	36,76 ± 13,41^{d}	1,36 ± 3,06	1,75 ± 4,65	0 ± 0	0 ± 0	0,25 ± 1,24	3,20 ± 4,42	24,29 ± 7,83
Wide	0,47 ± 1,21	31,93 ± 11,60^{a}	20,39 ± 10,80^{b}	17,33 ± 10,79^{c,d}	0,87 ± 1,66	0,90 ± 1,88	0 ± 0	0 ± 0	0,37 ± 1,19	2,21 ± 3,32^{e}	25,53 ± 8,66
Children	1,37 ± 2,77	27,62 ± 15,45	7,82 ± 8,84	35,79 ± 19,01	0,96 ± 2,55	2,39 ± 4,72	0,02 ± 0,19	0,22 ± 0,95	0,25 ± 1,26	4,92 ± 5,42	18,66 ± 9,91
Narrow	1,03 ± 2,42	16,82 ± 13,08^{f,g}	8,54 ± 10,71	46,92 ± 14,96^{h}	0,52 ± 1,04	4,18 ± 6,67	0 ± 0	0,38 ± 1,26	0 ± 0	7,34 ± 6,4^{j}	14,28 ± 6,1
Middle	1,2 ± 2,59	30,61 ± 15,99^{f}	5,71 ± 6,69	38,17 ± 19,67^{i}	0,65 ± 2,48	1,74 ± 3,45	0 ± 0	0,27 ± 1,06	0,24 ± 1,08	2,91 ± 3,59^{j}	18,5 ± 9,09
Wide	1,87 ± 3,26	35,41 ± 10,63^{g}	9,22 ± 8,56	22,28 ± 13,22^{h,i}	1,71 ± 3,43	1,24 ± 2,61	0,06 ± 0,33	0 ± 0	0,5 ± 1,89	4,51 ± 5,07	23,2 ± 11,86

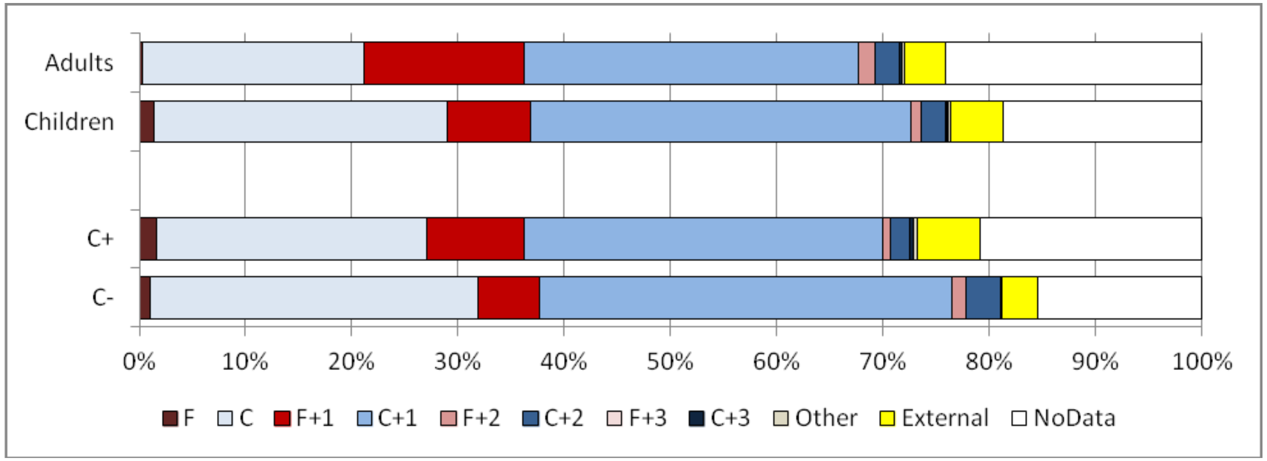

Figure 2 : Overview of gaze distribution of adults and children, and of the children who did not make any error (C+) and the children who made errors (C-; see 5. Post-hoc analysis)

Post-hoc results children+ vs. children-

No differences between the C+ and the C- group were found in age (7,67 ± 0,82y and 8,50 ± 1,29y respectively; t = -1.265 ; p = 0.242), cycling experience (5,00 ± 0,95y and 5,17 ± 1,26y respectively; t = -0.225; p = 0.828) or tracking ratio (0,94 ± 0,03 and 0,96 ± 0,02 respectively; t = -1.323; p = 0.222).

No overall differences between C+ and C- were found in completion time, number of anticipatory fixations or eye-steering span. All averages and standard deviations per condition for both C+ and C- can be found in table 4. For complete results of these analyses, see addendum P5.2.

See Figure 2 for an overview of the dwell time percentages of C+ and C- group. Similar to the difference between adults and children, the C- group tended to spend more time watching the first coming cone than the C+ group (Z = -1.706; p = 0.088). The difference in dwell time % to F+1, however, was not found significant (Z = -0.748; p = 0.454). Furthermore, the C+ group looked significantly more to external objects than C- (Z = -2.345; p = 0.019) and tended to spend less time watching F+2 (Z = -1.711; p = 0.087). See addendum P5.3 for more detailed results.

Table 4 **:** Overview of results per group (C+ and C-), and per condition.
Same superscript letters indicate significant differences.

		Average	Slow	Preferred	Fast	Narrow	Middle	Wide
Completion time (s)	C+	8.58 ± 1.01	9,42 ± 1,93^{g,h}	8,45 ± 1,52^{g}	7,89 ± 1,76^{h}	7,17 ± 1,26^{i}	8,36 ± 1,47^{i}	10,22 ± 1,28^{i}
	C-	8.78 ± 1.45	9,92 ± 2,31	8,72 ± 1,58	6,79 ± 1,83	7,67 ± 1,61	8,49 ± 1,49	11,05 ± 2,42
# Anticipatory fixations	C+	0.81 ± 1.01	0,83 ± 0,99	1,06 ± 1,16^{a}	0,56 ± 0,86	0,50 ± 0,86	1,11 ± 0,96	0,83 ± 1,15
	C-	0.56 ± 0.91	1,17 ± 1,19	0,42 ± 0,67^{a}	0,10 ± 0,29	0,67 ± 1,23	0,33 ± 0,65	0,67 ± 0,78
Eye-steering span (s)	C+	1.17 ± 0.26	1,19 ± 0,28	1,18 ± 0,32	1,13 ± 0,17	1,19 ± 0,27	1,08 ± 0,34	1,23 ± 0,13
	C-	1.24 ± 0.35	1,22 ± 0,28	1,36 ± 0,36	1,13 ± 0,40	1,41 ± 0,37	1,05 ± 0,33	1,25 ± 0,29
Variability Eye-steering span	C+	0.32 ± 0.22	0,43 ± 0,21^{c}	0,31 ± 0,25	0,21 ± 0,15^{c}	0,29 ± 0,18	0,32 ± 0,26	0,34 ± 0,23
	C-	0.39 ± 0.22	0,41 ± 0,27	0,46 ± 0,22	0,29 ± 0,14	0,43 ± 0,25	0,34 ± 0,16	0,39 ± 0,25

DISCUSSION

In the current experiment, the visual behaviour of children and adults, who cycled slaloms of three different widths at three different speeds, was analyzed. Children completed the slaloms slightly slower than the adults and made more steering errors as the task became more demanding. In general, both children and adults directed their gaze mainly to the first and the second coming cone. However, children spent more time looking to the first coming cone, whereas adults focused more on the functional space between the cones and tended to make more anticipatory fixations. Although there was no difference in the average size of the eye-steering span, adults adapted it according to the imposed cycling speed condition, while children seemed to switch their gaze at a rather random moment.

Steering behaviour

According to the Task-capability interface model, the task demand should stay within the borders of the driver's capability to stay in control of a vehicle (Fuller 2005). When the task demand exceeds the capability, the risk of losing control increases. Since the young participants in the current experiment were about eight years old, we can presume that their perceptual-motor and cycling skills were not fully developed yet (Assaiante 2011; Chihak et al. 2010; Zeuwts et al. 2015; Ducheyne, De Bourdeaudhuij, Lenoir & Cardon 2013). Therefore they were expected to have a lower capability than the adult group. In order to cope with this lower capability, children lowered the task demand by adapting their travelling speed in the preferred and the high speed conditions, a behaviour that has been documented in earlier experiments (Pryde et al. 1997; Berard & Vallis 2006; Briem et al. 2004). The lower cycling speed buys them more time to process the visual information and to prepare the appropriate motor action. For the low cycling speed condition however, no difference was found in completion time of adults and children. At low cycling speed, children may not have needed to adapt their cycling speed to cope with the task demand. Overall, it should also be taken into account that the smaller size of the bicycles used by children most likely also affected their cycling speed.

Given that increasing slalom width and cycling speed increases the task demand, we also expected that the difference in completion time between the adults and the children would increase. The current results show that children did not adapt their cycling speed more than adults, but they did make more steering errors as the task demand increased. These errors are most likely caused by an overestimation of their own capabilities and/or the underestimation of the task demand. In general, children seemed to cycle slower than adults to cope with their lower cycling capabilities, but when the task constraints changed, they failed to adapt their cycling speed in such a way as to keep the level of task difficulty within the boundaries of their own capabilities.

Gaze behaviour

Franchak and Adolph (2010) showed that from infancy to adulthood, obstacle navigation shifts from foveal to peripheral control. The observation that adults in current experiment spent more time watching the functional space between the cones than the children, seems to be in line with this idea. However, gaze of the adults was still directed more than three times as much to the cones than to the functional space between them. Although it is hard to estimate to what extent participants made use of central and peripheral vision based on only eye-tracking measures, current results suggest that both groups relied primarily on foveal vision to steer through the slalom. Nevertheless, it is still likely that, similar to the experiment of Franchak and Adolph, the adults made more use of peripheral vision than the children (Franchak & Adolph 2010; Assaiante & Amblard 1992). Adults in the current study probably did not make as much use of peripheral vision as in the study of Franchak and Adolph because of the different task constraints. In the current study, completing the slalom was the primary task. Therefore, looking to the cones was essential for an optimal guidance/navigation through the slalom. In the study of Franchak and Adolph however, the primary task was a scavenger hunt in which gaze was primarily used to search for the hidden stars, rather than for controlling locomotion. In addition, the different gaze constraints between cycling and walking probably also induced a different gaze behaviour (Schepers & den Brinker 2011; Vansteenkiste, Cardon, D'Hondt, et al. 2013).

Furthermore, that adults made more fixations to the space between two cones does not necessarily mean that this was done in function to perceive both cones peripherally. Similar to the 'look where you are going' strategy for driving through curves, the participants might have been looking at a spot through which they wanted to pass 1-2 seconds ahead of their current position (Mars 2008; Vansteenkiste, Van Hamme, et al. 2014; Wilkie et al. 2010; Wilkie & Wann 2003b). Therefore, the higher percentage of looking at 'F+1' might indicate that instead of focussing only on the cones, adults also focus on points between the cones to which they have to steer to maintain an optimal trajectory. This gaze strategy implies that adults plan a track through the slalom rather than steering from one cone to another. The finding that adults tended to make more use of anticipatory fixations than children is in line with this idea. The use of this dual sampling strategy (gaze polling) provided the adults with information about the future trajectory and helped to plan a smooth trajectory through the slalom (Wilkie et al. 2008). Children on the other hand, made less use of anticipatory fixations and seemed to be steering around one cone at the time, in line with the findings of Berard & Vallis (2006). They focused on the first coming cone until it was approximately 1.2 seconds ahead, and then switched their focus to the next cone. Possibly, children cannot process visual information fast enough to efficiently make use of the dual sampling strategy. Therefore, children adopt a simpler and less demanding steering strategy which focuses on one action at the time.

Surprisingly, and in contrast with the results of Franchak and Adolph (2010), the eye-steering span of children was not smaller than that of the adults. Furthermore, the eye-steering span of adults decreased as the cycling speed increased, whereas it stayed constant with the children. This seems to imply that adults switched their gaze at a certain distance from the cone whereas children rather switched their gaze away from the next cone each time more or less at the same time from the cone. These suggestions are in line with earlier findings that adults tend to rely primarily on distance for gap estimation (Parsonson et al. 1996). However, in road crossing studies, both children and adults were found to use a strategy based both on distance and velocity (te Velde et al. 2005). Furthermore, the slightly higher variability in the eye-steering span of the children suggests that children might have switched their gaze to the next cone at a rather random moment, while adults did this in a more systematic way. Therefore, further research should be carried out to find out in which cases adults and children rely on distance and/or velocity.

Children spent more time watching the next cone than adults. However, in contrast with what might have been expected, children did not switch their gaze away from the next cone later than adult. This indicates that the lower percentage of looking at the first coming cone of adults is not due to an earlier switch to the next cone. Instead, the lower percentage of dwell time to the next cone of the adults was most likely due to the more intensive use of the dual-sampling strategy.

In general, it seems that from young learner bicyclist to experienced adult bicyclist, there is a change from a simple and rigid visual-motor strategy, to a flexible, more holistic strategy to guide steering. These findings are in line with the idea that with increasing age and/or experience, visual search behaviour becomes more rapid, more systematic, more exhaustive and more strategically-focused on relevant features (Ampofo-Boateng & Thomson 1991; Berard & Vallis 2006; Geoffrey Underwood 2007; Day 1975).

Post-hoc tests

The comparison of the completion times of the C+ and the C- group revealed no general differences in completion time between the two groups. However, in the fast condition, in which 6 of the 8 errors were made, the C- group tended to cycle faster than the C+ group. This suggests that the errors in the C- group were caused by failing to adopt an appropriate cycling speed for the imposed condition. This is in line with the earlier suggestion that children have difficulties in estimating their own capabilities and/or the task demand.

Similar to the experiment of Whitebread and Neilson (2000), the differences in gaze behaviour reported in the adult-children analysis were also found between the children who made at least one steering error during the experiment and those who did not make any errors. The C- group focussed more on the first coming cone than the C+ group, and tended to make less anticipatory fixations. This supports the idea that error-prone participants did not plan a trajectory through the slalom, but rather cycled from cone to cone. However, not all differences in gaze behaviour were the same. Whereas the eye-steering span decreased with cycling speed in adults and that of children didn’t, the visual span of both the C+ and C- group was not affected by cycling speed. Instead, the variability of the eye-steering span in the C- group did not decrease with cycling speed as it did for adults and the C+ group. This suggests that the C- group adapted their visual behaviour less to the changing constraints than the C+ group and the adults.

Surprisingly, no differences in age or cycling experience were found between the C+ and C- group. The first possible explanation for this is that the number of participants was too low to detect differences between the age and/or cycling experience of the C+ and C- children. However, a more likely reason is a difference in processing speed. Many of the differences in perceptual and cognitive abilities between adults and children have been attributed to the underdeveloped processing speed of children (Fry & Hale 2000; Kail & Salthouse 1994). As a consequence, the development of processing speed could also be related to the development of more mature visual-motor strategies and therefore to the capability to perform more complex motor skills. This relation between the development of processing speed and visual strategies has been suggested for pedestrian skills (Whitebread & Neilson 2000), and is in line with the results of the current study.

Limitations

Some important limitations have to be taken into account when discussing the results of the current experiment. First, the number of participants included in the analyses was rather low, especially with respect to the differences between the C+ and the C- group. However, the sample size of eleven adults and ten children is still rather large compared to other studies that use mobile eye-tracking data (Berard & Vallis 2006; Franchak & Adolph 2010; Vansteenkiste, Zeuwts, et al. 2014; Pelz & Rothkopf 2007; Patla & Vickers 1997; Marigold et al. 2007). Nevertheless, with improving eye-tracking equipment and data processing tools, the analysis of mobile eye-tracking data is becoming less strenuous and time consuming, and is therefore becoming more suited for experiments with larger number of participants (Vansteenkiste, Cardon & Lenoir 2013; Müller-feldmeth et al. 2014).

Second, some of the differences in gaze behaviour might be caused by a different size of bicycle. The eye height of adults on adult city bicycles was considerably higher than that of the children on children’s bicycles. Therefore their view on the slalom was slightly different as well. From a higher point of view, adults might have had a more clear overview on the entire slalom than the children. The smaller bicycle of the children could also have affected the steering behaviour, as smaller bicycles are usually more agile than large bicycles. Furthermore, it is plausible that adults inspected the slalom better before the start of the experiment, and therefore were able to plan their steering better than the children. However, even if these limitations have affected the gaze and/or steering behaviour in the current experiment, these are differences that are also present during real traffic situations.

Finally, it should be noted that in the current experiment participants were asked to cycle faster than their ‘preferred’ pace. This task probably pushed the children out of their ‘comfort area’, and was a direct cause for the increase of steering errors. In traffic situations however, children have often been found to behave more cautious than adults (te Velde et al. 2005). Therefore, in a real traffic situation, it is likely that instead of making errors, some children would slow down or would not move at all when they are confronted with a demanding situation (Berard & Vallis 2006).

Practical implications

Regarding traffic education, it might be better to teach alternative visual-motor strategies to children as long as they are not able to imply adult-like visual-motor strategies efficiently. Knowing that young children often plan only one action at the time and are easily distracted (Dunbar et al. 2001; Whitebread & Neilson 2000), traffic education, but also road infrastructure in the school environment, should to be adapted to their perceptual-motor capabilities. Especially in situations where time constraints are higher, children will be more prone to take risky decisions.

General conclusion

The gaze and steering behaviour of adults and children during the current slalom study showed that eight year old children do not yet use the same visual-motor strategies as adults. Whereas adults seemed to plan the whole trajectory and visually anticipated to the next steering manoeuvres, children's gaze and steering strategy seemed to be based on cycling around one cone at the time. Post-hoc analysis showed that some of these differences also exist between the error-prone children and the children who did not make any steering errors.

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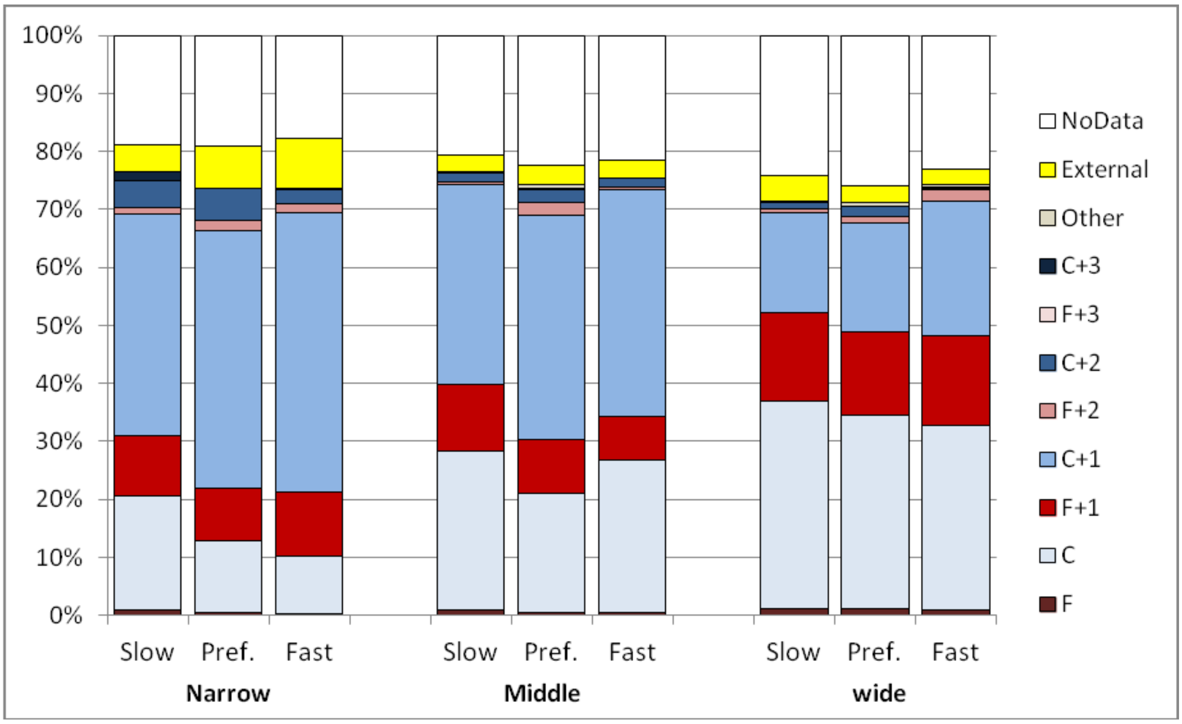
Addendum P5.1. : Effect of cycling speed condition and slalom width on gaze distribution



Addendum P5.2. : results of C+ vs. C- comparison

Completion time

Similar to the adult-children comparison, no overall difference in completion time was found between the C+ and C- group (Z = -0.107; p = 0.915). However, whereas adults completed the slalom significantly faster in the preferred and the fast condition, these differences were not found between the C+ and the C- group. In contrast, the C- group tended to complete the slaloms faster in the fast condition than the C+ group (Z = -1.706; p = 0.88). In general, both groups' completion time increased as slalom width increased, and decreased as cycling speed increased. However, these differences did not always reach significance (See Table 4).

Anticipatory fixations

On average, no difference in number of anticipatory fixations was found between the C+ and the C- group (Z = -0.758; p = 0.449). However, the comparison per condition revealed that C+ made significantly more use of gaze polling in the preferred speed condition (Z = -2.047; p = 0.041) and tended to make more anticipatory fixations in the fast speed condition (Z = -1.768; p = 0.077). No significant differences were found in the other speed and width conditions. No effects of slalom width or cycling speed were found on the number of anticipatory fixations of both the C+ and the C- group.

Eye-steering span

No overall differences in eye-steering span was found between C+ and C- (Z = -0.426 and p = 0.670) and no effects of speed or slalom width condition were found for both the C+ and the C- group. The variability of the eye-steering span in the C- group was not significantly higher than in the C+ group (Z = -0.962 and p = 0.336). Similar to the adult group, the variability of the eye-steering span decreased as cycling speed increased for the C+ group (X^2 = 8.333; p = 0.016). However, the variability in eye-steering span did not change significantly with increasing cycling speed for the C- group (X^2 =4.133; p = 0.127). No effect of width was found for the C+ (X^2 = 1.333; p = 0.513) and the C- group (X^2 = 0.000; 1.000).

Addendum P5.3.

For both the C+ and the C- group, dwell time percentages towards the AOIs did not change significantly with changing cycling speed. Similar to earlier findings, increasing slalom width also seemed to lead to a higher percentage of dwell time towards the first upcoming cone and a lower percentage towards the second for both the C+ and the C- group. However, not all differences reached significance.

Dwell time percentages per AOI and slalom width for children who did not make any error (C+) and children who made errors (C-). **indicates significant difference between two groups, * indicates trend of significance between groups (0.05 <p < 0.1). Significant differences per slalom width are indicated by identical superscript letters.

	F	C*	F+1	C+1	F+2*	C+2	F+3	C+3	Other	External**	NoData
C+	1,59 ± 3,12	25,46 ± 12,96	9,19 ± 9,99	33,77 ± 18,63	0,67 ± 2,04	1,82 ± 3,94	0,03 ± 0,24	0,32 ± 1,18	0,39 ± 1,61	5,94 ± 5,85	20,82 ± 11,10
Narrow	1,45 ± 2,88	16,22 ± 13,69^{a,b}	11,39 ± 12,74	43,76 ± 15,01^{c}	0,43 ± 0,99	2,39 ± 5,18	0 ± 0	0,51 ± 1,54	0 ± 0	8,59 ± 7,22	15,25 ± 5,73^{e,f}
Middle	1,22 ± 2,85	25,66 ± 10,31^{a}	6,54 ± 7,10	38,02 ± 19,97^{d}	1,09 ± 3,16	1,59 ± 3,43	0 ± 0	0,46 ± 1,35	0,40 ± 1,39	3,83 ± 4,01	21,19 ± 10,39^{e}
Wide	2,09 ± 3,69	34,51 ± 7,29^{b}	9,62 ± 9,25	19,54 ± 10,89^{c,d}	0,49 ± 1,34	1,48 ± 3,02	0,10 ± 0,42	0 ± 0	0,76 ± 2,41	5,38 ± 5,08	26,02 ± 13,48^{f}
C-	1,03 ± 2,14	30,84 ± 18,29	5,78 ± 6,36	38,81 ± 19,43	1,39 ± 3,13	3,24 ± 5,65	0 ± 0	0,06 ± 0,38	0,04 ± 0,25	3,39 ± 4,34	15,41 ± 6,72
Narrow	0,39 ± 1,36	17,73 ± 12,65	4,26 ± 4,26	51,65 ± 14,19	0,65 ± 1,14	6,86 ± 7,91	0 ± 0	0,19 ± 0,66	0 ± 0	5,46 ± 4,57	12,82 ± 6,58
Middle	1,16 ± 2,27	38,04 ± 20,24	4,47 ± 6,10	38,40 ± 20,10	0 ± 0	1,97 ± 3,60	0 ± 0	0 ± 0	0 ± 0	1,52 ± 2,37	14,45 ± 4,59
Wide	1,55 ± 2,62	36,76 ± 14,58	8,62 ± 7,75	26,38 ± 15,73	3,53 ± 4,72	0,88 ± 1,93	0 ± 0	0 ± 0	0,13 ± 0,43	3,20 ± 4,99	18,97 ± 7,57

Chapter 3
Visual-motor behaviour in an actual traffic environment

<u>In this chapter :</u>

The gaze behaviour of experienced adult and young learner bicyclists was investigated in an actual traffic environment. To investigate to what extent bicycle path quality affects the visual behaviour of bicyclists, visual behaviour was measured on both a high quality bicycle path and a low quality bicycle path.

Paper 6

THE IMPLICATIONS OF LOW QUALITY BICYCLE PATHS ON GAZE BEHAVIOR OF CYCLISTS
A FIELD TEST

Vansteenkiste P, Zeuwts L, Cardon G, Philippaerts R, Lenoir M

Transportation Research Part F 23 (2014) 81–87

ABSTRACT

Unlike for car driving and walking, the visual behaviour during cycling is poorly documented. The aim of this experiment was to explore the visual behaviour of adult bicycle users 'in situ' and to investigate to what extent the surface quality affects this behaviour. Therefore cycling speed, gaze distribution and gaze location of five participants were analyzed on a high and a low quality bicycle track. Although there was no difference in cycling speed between the low and the high quality cycling path, there was an apparent shift of attention from distant environmental regions to more proximate road properties on the low quality track. These findings suggest that low quality bicycle tracks may affect the alertness and responsiveness of cyclists to environmental hazards.

INTRODUCTION

Human locomotion is primarily guided and controlled by visual information (Patla, 1997). The visual channel provides input for planning one's trajectory, for on-line control, and for anticipation to specific events. Especially in traffic, not noticing possible hazards can have disastrous consequences. Therefore the determinants of visual search and hazard perception are often the subject of traffic research (Chapman, Underwood, & Roberts, 2002; Crundall et al., 2012; Mourant & Rockwell, 1970; Recarte & Nunes, 2003). The effects of age, alcohol, traffic density, billboards, etc. on visual attention in traffic all have been described during past years (Borowsky, Oron-Gilad, & Parmet, 2009; Deery & Love, 1996; Edquist, Rudin-Brown, & Lenné, 2012; Horswill, Helman, Ardiles, & Wann, 2005; Shinoda, Hayhoe, & Shrivastava, 2001; The Effects of Commercial Electronic Variable Message Signs (CEVMS) on Driver Attention, 2009; Young & Regan, 2007). The majority of these studies, however, focused on car driving. The visual attention of cyclists on the other hand, is poorly documented, even though the number of bicycle users is increasing and, unfortunately, the number of bicycle accidents has increased as well (de Hartog et al., 2010; Juhra et al., 2012). Therefore, more insight in the visual behaviour of cyclists could be beneficial for traffic education and infrastructural planning.

For car driving, the two-level model of steering (Donges, 1978; Land & Horwood, 1995; Schieber & Schlorholtz, 2009) is a well documented and generally accepted model for gaze behaviour. According to this model, car drivers watch distant road features foveally for guidance and anticipation while the close regions are attended peripherally for lane keeping. This theory has been proven to be useful in various car driving situations (Salvucci & Gray, 2004) but could only partly explain the visual behaviour of cyclists as it does not take environmental conditions into account (Vansteenkiste, Cardon, D'Hondt, Philippaerts, & Lenoir, 2013). However, the assumption that both the near and the far region are necessary for efficient steering still seemed valid. These regions provide visual information for compensatory closed-loop and anticipatory open-loop steering control. Although foveal gaze towards the far region and peripheral perception of the near region has repeatedly been put forward as a safe gaze strategy for car driving, some researchers suggest that the compensatory and anticipatory steering mechanisms can be used in a more flexible way. Therefore a weighted use of these mechanisms has been suggested (Frissen & Mars, 2013; Kountouriotis, Floyd, Gardner, Merat, & Wilkie, 2012; Vansteenkiste, Cardon, D'Hondt, Philippaerts, & Lenoir, 2013).

There are several important differences between car driving and cycling that induce different visual requirements (Schepers & den Brinker, 2011). Unlike car drivers, cyclists have an almost unrestricted visual field, travel at lower speeds and are more subject to environmental conditions as weather and road quality. In addition, cyclists have to maintain their balance while cars are stable on their own. From this point of view cyclists' visual behaviour might resemble more to that of pedestrians, although pedestrians travel at even lower speeds and are not limited by the capabilities of a vehicle.

Pedestrians only spend a limited amount of their visual attention to the pathway and a large part of their attention is spent watching the scenery (Foulsham, Walker, & Kingstone, 2011; Pelz & Rothkopf, 2007). When walking on an irregular surface however, gaze is directed significantly more to the travel path itself (Marigold & Patla, 2007; Pelz & Rothkopf, 2007). Although gaze is necessary for on-line visual control of human locomotion (Hollands, Marple-Horvat, Henkes, & Rowan, 1995; Patla & Greig, 2006; Turano, Geruschat, Baker, Stahl, & Shapiro, 2001) it seems that it is rarely directed to the ground on a flat, obstacle-free path. The two-level model as applied for car driving, however, does not predict gaze behaviour when attentional demand is low and does not reckon with changing environmental constraints. Therefore, the model is not suitable for the visual behaviour during walking and cycling.

The aim of current experiment is to investigate the gaze behaviour of cyclists 'in situ' on high quality and low quality cycling tracks. It is expected that the higher task complexity on a low quality cycling track will lead to a higher percentage of gaze in the functional approach space (the space immediately surrounding one's body; Laurent & Thomson, 1991) of the cyclist and to less irrelevant fixations (Vansteenkiste, Cardon, D'Hondt, Philippaerts, & Lenoir, 2013).

METHODS

Participants

Ten participants (22–24 years of age) took part in the study and signed the informed consent. All participants were students of the department movement and sports sciences from Ghent University. Four participants were left out since their Eye-Tracking Ratio (% of time eye movements was actually measured) was less than 80% and one participant was left out because of the busy traffic situation during the test. The five remaining participants (1♂, 4♀) had a good pre and post calibration, and were tested during a similar traffic situation. All participants used their bicycle at daily basis for transportation and had normal or corrected-to normal vision.

Apparatus

Eye movements and gaze location were recorded using the IviewX Head mounted Eye tracking Device (SMI, Teltow GER). The system with a 1° accuracy was mounted on a baseball cap and recorded the left eye movements with an infrared-sensitive camera at 50 Hz using pupil position and corneal reflex. Scene video was recorded at 25 Hz by a camera with 3.6 mm lens, placed next to the eye-tracking camera. Scene video had a horizontal and vertical field of view of approximately 33°. The two cameras were connected to a notebook (Lenovo X201; 1.4 kg) which was worn in a backpack and both scene video and eye tracking recordings were saved using SMI's software IViewX (see Fig. 1).

Figure 1 **:** Participant wearing on bicycle wearing the Head-mounted Eye-tracking Device (SMI). Insert: frontal view of eye tracker.

Protocol

After giving informed consent, participants were asked to put on the eye tracker and secure it with a strap. A five-point calibration was performed indoors and the participant was then asked to follow the test leader to the bicycle rack. The saddle of the city bike, rented from the university bicycle service, was adjusted to the participants height and the participant was asked to follow the test leader for a familiarization trial. For the actual test, participants were asked to cycle the same route as the familiarization trial at preferred speed until the test leaders, who cycled behind, instructed them to stop. A calibration check was performed before both high and low quality cycling path by instructing the participant to watch certain objects in the environment. After the test, a final indoor calibration check was done and the data were saved. Since sunlight disturbed the infrared-signal of the eye tracking system, all tests were performed in overcast weather.

Cycling route

Cycling route consisted of a 4 km tour in the city of Ghent which included a similar low quality (LQ) and a high quality (HQ) cycling track on the sides of a river. Both tracks were straight and were neighboured by a bush and a river on the one side and by trees and a car road at the other side (see Fig. 2). The HQ track was a recently renewed cycling path of 2 m in width and had a brick surface. The LQ track was 1 m 30 wide and consisted of large tiles that had moved or were lacking at some places (see video 1). On a scale of zero to five (with 0 being ‘very bad’ and 5 ‘very good’), participants rated the overall driving comfort of LQ at 1.71 and HQ at 4.57. Based on landmarks, a trajectory of 120 and 136 m (approximately 25 s) was selected from the route for analysis of HQ and LQ respectively. Participants were unaware that only this part would be used for analysis. During the selected trajectory an average of 3.4 cyclists and 0.8 cars passed by on HQ and 0.6 cyclists and 2.4 cars on LQ.

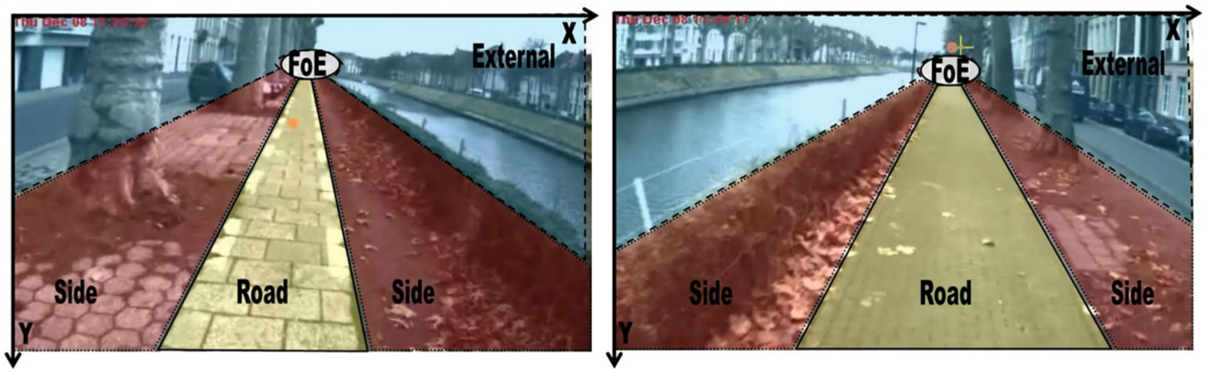


Figure 2 **:** Low quality (left) and high Quality (right) cycling track with AOI overlay and X and Y axis. See also addendum P 6. (http://www.youtube.com/watch?v= -1NQTCXQC6w).

Data analysis and statistics

Cycling speed was calculated as the length of the trajectory divided by the time (in m/s). 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 widely spread gaze behaviour results in higher standard deviations.

Videos with gaze cursor were coded frame by frame to assign gaze location to one of following areas of interest (AOI): road, side, external, focus of expansion and cyclist. When no data was available the frame was coded as NoData. Percentages of gaze to each AOI was calculated in Excel. This direct inspection method has been reported to be ‘’rather tedious but surprisingly effective’’ (Duchowski, 2007, p.138). Differences between HQ and LQ for all measurements were statistically tested using Wilcoxon tests in SPSS19. Significance level was set at $P \leq 0.05$.

RESULTS

Cycling speed and eye movement distribution

No difference in cycling speed was found between HQ and LQ ($Z = 0.135$ $p = 0.893$). Standard Deviation of X-coordinates was higher on HQ than on LQ ($Z = 2{,}023$; $p = 0.043$). No difference was found in Y-coordinates ($Z = 4.405$; $p = 0.686$; see Table 1)

Table 1 **:** Cycling speed and standard deviation of X and Y coordinates (in pixels) of five subjects on high and low quality cycling track. ** =p < 0.05.

	Cycling speed		X-coordinates		Y-coordinates	
	HQ	LQ	HQ	LQ	HQ	LQ
CM	17,85	16,32	185,19	97,03	72,89	58,35
GM	20,04	21,74	196,90	170,56	130,42	112,24
IL	17,76	17,05	150,29	131,32	56,12	65,30
IV	19,82	20,33	164,88	117,64	92,86	98,37
LM	18,29	18,57	101,66	84,00	71,54	81,21
			**	**		
Mean ± SD	18,75 ± 1,09	18,80 ± 2,25	159,79 ± 37,14	120,11 ± 33,59	84,77 ± 28,66	83,09 ± 22,45

Gaze location

All five participants looked more at the Road on LQ when compared to HQ (Z = 2.023; p = 0.043). Although participants also seemed to look less to the Sides and External regions on LQ, no significant differences were found for these AOIs (resp. Z = 1.512; p = 0.131 and Z = 1.753; p = 0.080). Percentage of gaze towards Focus of Expansion stayed constant across the two conditions (Z = 0.542; p = 0.588). No significant difference was found between the two cycling paths in percentage of NoData (Z = 1.841; p = 0.066). Finally, participants looked more to other cyclists on HQ than on LQ (Z = 2.032 p = 0.042; see Table 2 and Fig. 3).

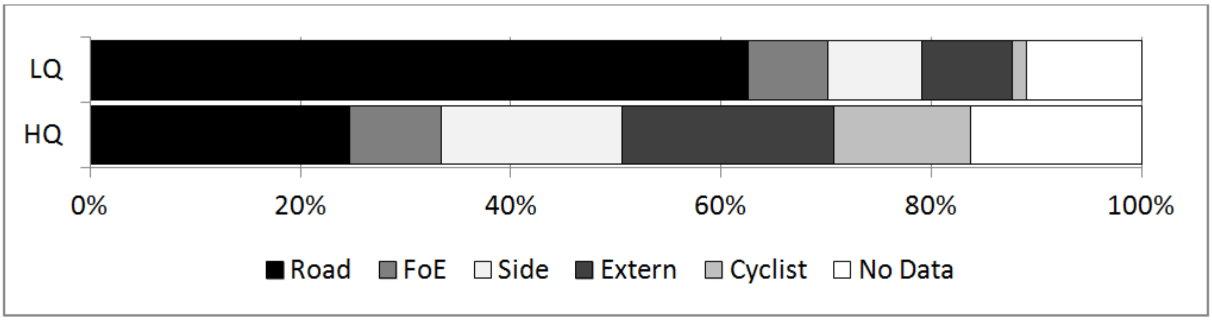


Figure 3 : Sum of percentages of gaze towards road, Focus of Expansion, side and external and the percentage of gaze that was missing or unclear for low quality and high quality bicycle track.

Table 2 : Ratios of gaze towards each area of interest for each of the five participants.
$* = p < 0.1$ $** = p < 0.05$

	High Quality						Low Quality					
	Road	FoE	Side	Extern	Cyclist	No Data	Road	FoE	Side	Extern	Cyclist	No Data
CM	0,21	0,00	0,19	0,16	0,25	0,19	0,90	0,01	0,02	0,00	0,00	0,07
GM	0,10	0,07	0,22	0,24	0,12	0,25	0,40	0,00	0,32	0,07	0,00	0,21
I L	0,03	0,26	0,21	0,26	0,06	0,17	0,35	0,24	0,04	0,27	0,00	0,11
IV	0,28	0,06	0,21	0,30	0,06	0,10	0,76	0,00	0,04	0,09	0,00	0,10
LM	0,62	0,05	0,03	0,05	0,16	0,10	0,73	0,12	0,03	0,00	0,07	0,06
	**			*	**	*	**			*	**	*
Mean	0,25	0,09	0,17	0,20	0,13	0,16	0,63	0,08	0,09	0,09	0,01	0,11
±	±	±	±	±	±	±	±	±	±	±	±	±
SD	0,23	0,10	0,08	0,10	0,08	0,06	0,24	0,10	0,13	0,11	0,03	0,06

DISCUSSION

The general aim of this study was to describe cyclists' visual behaviour in situ and to investigate to what extent it is dependent of the road quality. On the high quality road, gaze was more or less evenly distributed over the different areas of interest. However, high standard deviations in dwell time% reflect large differences among the participants. This suggests that no specific visual strategy is needed to safely bicycle on a cycling lane. That participants only watched the road intermittently also confirms earlier findings that continuous visually monitoring of the road is not necessary and that visual attention can be 'shared' over multiple areas of interest (Land, 1998; Senders, Kristofferson, Levison, Dietrich, & Ward, 1967; Thomson, 1983; Wilkie, Wann, & Allison, 2008). Notwithstanding this seemingly unconstrained visual behaviour, an apparent shift of attention towards the road region was made by all participants when cycling on the low quality cycling path.

As was the case in the indoor test of Vansteenkiste, Cardon, D'Hondt, Philippaerts, and Lenoir (2013), current results are not fully suitable with the two-level model as applied for car driving since it does not take into account the influence of environmental factors on the gaze behaviour. The duality concept of steering, with a guidance and a stabilization level (Donges,1978), still seems valid. Results were in line with gaze behaviour reported for pedestrians (Foulsham et al., 2011; Pelz & Rothkopf, 2007) and support the idea of a flexible combination of compensatory closed-loop and anticipatory open-loop steering control (Frissen & Mars, 2013; Kountouriotis et al., 2012; Vansteenkiste et al., 2013).

The shift of visual attention towards the cycling path when cycling on the low quality path could be due to two different causes. First, the shift of gaze could be due to the differences of the visual environment between the two tracks. Since the surface on the low quality cycling path was more rugged and irregular, it might have been more salient as well. The low quality path was also narrower than the high quality path, which, according to Godley, Triggs, and Fildes (2004), increases the steering workload. Therefore, the visual characteristics of the low quality track could have caused the shift of gaze towards the travel path. In addition, the more rugged structure of the low quality surface might also have lead to an increase of visual information coming from optic flow. This might have provided more information about speed and direction of locomotion on the road region on the low quality road than on the high quality road (Gibson, 1950; Kountouriotis et al. 2012; Lappe, Bremmer, & van den Berg, 1999). Second, according to Patla (1997), vision is essential for the regulation of the dynamic stability during locomotion. On a lower quality road, cyclists need to make more steering adjustments to maintain this dynamic stability. This increased need for compensatory closed loop control leads to an increase of the task demand/cognitive load (Vansteenkiste et al., 2013) and consequently to gaze concentration towards the road centre (Engström, Johansson, & Östlund, 2005). Although peripheral vision can be sufficient for small gait adaptations (Marigold, Weerdesteyn, Patla, & Duysens, 2007), the shift of visual attention towards the road on the low quality cycling path seemed essential to safely cope with the road properties within the functional approach space (Laurent & Thomson, 1991).

It should be mentioned that some of the differences in gaze behaviour could be due to other factors than the road quality. Firstly, the larger percentage of looking to other cyclists is simply due to the fact that more cyclists were encountered on the high quality cycling path. The traffic density during the experiment was one of the inclusion criteria for the participants, but since the experiment was executed on public roads in a city known for the many bicycle users, the experimenters could not ensure identical traffic situations for all participants and on both cycling tracks. Secondly, the higher percentage of NoData might be a consequence of the more widely spread gaze behaviour on the high quality road. A more active gaze behaviour is more demanding for the eye tracking system during the experiment and gaze is more likely to be assigned as indistinct during analysis. Therefore the high quality road indirectly lead to a higher loss of data.

Unlike for the gaze behaviour, no differences were found in cycling speed between the two roads. According to the Task Capability Interface Model (TCI) (Fuller, 2005) steering behaviour is related to the balance between task demand and the capability of the driver. When task demand increases and approaches the drivers' capability, the driver will attempt to lower the task demand, often by slowing down. Consequently, in the current study it was expected that participants would lower their cycling speed when cycling on the low quality road. However, Fuller also referred to the state of arousal as a determinant of capability. In demanding situations, drivers can ''step on the accelerator of mental effort'' to increase capability. In current study it is likely that the gaze concentration towards the road caused an increase of the cyclists' capability and therefore it was not yet necessary to adjust the cycling speed. When the road quality would be even lower, a maximum capability would be reached and cycling speed would probably go down anyway to lower task demand. In other words, changing the visual behaviour was the first step to cope with higher task demands caused by a low quality cycling path.

It could be questioned however, if increasing the mental effort and the subsequent shift of attention while cycling on a low quality road is sufficient to keep the same level of safety. One could argue that cycling on a lower quality road increases the cyclists' arousal, which adds to his attentiveness to task-relevant stimuli (less 'external' fixations) and therefore to his safety. Although, the shift of attention towards the functional approach space may be supportive for the bicycle stability, it is at the expense of the visual search for more distant hazards. Furthermore, an increase of workload leads to a smaller functional field of view (De Waard, 1996; May, Kennedy, Williams, Dunlap, & Brannan, 1990; Young & Hulleman, 2013). Therefore, low quality cycling lanes might affect the alertness and responsiveness of cyclists to environmental hazards. Poor road conditions have been identified as an important cause of injuries in children in villages (Kiss, Pótó, Pintér, & Sárközy, 2010) and as the direct cause in 29% of the single bicycle accidents in the Netherlands (Blokpoel, 2000). Current results suggest that road quality is probably also an indirect cause for cycling accidents and confirm the importance of qualitative cycling infrastructure to decrease the number of accidents (de Geus et al., 2012).

An important limitation of current study, is the low number of participants. This limitation had two main causes. First, data loss due to sunlight is inevitable in outdoor eye tracking research. Therefore, as was mentioned in the protocol, all tests had to be done in overcast weather. This dependence of weather conditions strongly impeded the planning of the experiment. Second, strict inclusion criteria (tracking ratio >80% and calm traffic conditions) lead to the fact that half of the participants had to be left out of the analysis. When looking at the individual data however, it is obvious that the effects of bicycle track quality were apparent in all five participants.

A second limitation of current study is the lack of the actual gazing distance. Since a head-mounted eye-tracker without head tracking was used in a natural environment, no reference distances were available and therefore it was impossible to measure how far ahead the cyclists actually looked. Nevertheless, most fixations towards the road seemed to be about 1–2 s ahead (see also video). This would be in line with previous findings of (Land & Hayhoe, 2001; Wilkie & Wann, 2003) and would underpin the idea that gaze was used for compensatory closed loop control. Further experiments should try to find a method to measure actual gazing distance in real-life settings to confirm these suggestions. Still, even without actual gazing distances, results suggest that the shift of gaze from 'side' and 'external' towards 'road' represented a shift of attention from environmental regions to the functional approach space.

CONCLUSION

Although there were remarkable differences in the viewing strategies among the participants, they all made an apparent shift of attention from distant environmental regions to more proximate road properties when cycling on a low quality bicycle track. Therefore low quality bicycle tracks may affect the alertness and responsiveness of cyclists to environmental hazards. Surprisingly, no difference was found in cycling speed. Apparently the change of the visual behaviour was sufficient to cope with higher attentional demands. These results confirm the importance of qualitative cycling infrastructure.

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Addendum P6. SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found, in the online version, at https://youtu.be/-1NQTCXQC6w

Paper 7

THE IMPLICATIONS OF LOW QUALITY BICYCLE PATHS ON THE GAZE BEHAVIOUR OF LEARNER CYCLISTS

Vansteenkiste P, Zeuwts L, van Maarseveen M, Cardon G, Savelsbergh G, Lenoir M

Manuscript in preparation

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 adapted cycling speed. The current experiment 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.

INTRODUCTION

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. 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 (Oja et al. 2011; Pucher & Buehler 2012; Hamer & Chida 2008). Therefore, many countries have recognized the importance of promoting cycling as a mode of transportation. Unfortunately, with increasing numbers of bicyclists, the number of bicycle accidents also increase. Even though the benefits of cycling outweigh the risks by far, 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 under 15 and elder people over 65 are at risk (DEKRA 2011; Carpentier & Nuyttens 2013).

Since human locomotion is primarily guided and controlled by visual information (Shinar et al. 1977; Wilkie et al. 2010; Patla 1997), identifying the differences in gaze behaviour between ‘high risk groups’ and less accident prone bicyclists could shed light on the reason 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 heavily affect the visual attention of bicyclists. 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 than on 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 & Thomson 1991). Compared to adults, they rely less on peripheral vision (Franchak & Adolph 2010), look more to irrelevant areas (Whitebread & Neilson 2000), anticipate less on future actions (Berard & Vallis 2006), and have more difficulties to synchronize their actions to other moving objects (Chihak et al. 2010; Connelly et al. 1998). However, children seem to compensate for this lack of mature skills by adopting 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, we also expect that the difference in cycling speed between adults and children will be larger on the low quality cycling track than on the high quality cycling track.

METHODS

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. 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.

Apparatus

Gaze behaviour was recorded using the Eye Tracking Glasses 2.0 (ETG) of SensoMotoric Instruments (SMI; Teltow, GER). 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, GER), used in our previous experiment (Vansteenkiste et al., 2014), the ETG was capable of performing eye tracking in broad daylight.

Figure 1 **:** Child participant with eye tracker

Protocol and cycling route

At 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. After this, the gaze data was saved, and the eye tracking device was removed from the participant.

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 (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, GER). 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 about 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 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 of these AOIs 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, Cardon & Lenoir 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, and data loss during the experiment. Participants were only included for further analysis when the share of NoData was less than 50%[6]. Gaze data of three adults and three children did not meet this inclusion criteria. Therefore further analysis is based on the remaining 15 adults (aged 25.93 ± 2.71 years; 8 females) and 13 children (aged 9.08 ± 1.98 years; 7 females).

Statistics

The effect of age and road quality on cycling speed and on the dwell time % towards the 6 AOIs was analyzed using repeated measures ANOVA tests with HQ and LQ as within subjects factor, and the age group as between factor. The Huynh-feldt correction was applied and significance level was set at $p \leq 0.05$.

RESULTS

Cycling speed

Average completion times per road type and age group can be found in table 1. Adults cycled significantly faster than the children ($F_{1,16} = 26.644$; $p < 0.001$), but no significant effect of road quality was found on the cycling speed ($F_{1,26} = 1.238$; $p = 0.276$). No speed*age interaction was found either ($F_{1,26} = 0.425$; $p = 0.520$).

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[6] 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 addendum P7 for dwell time percentages with different inclusion criteria.

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	121,85 ± 14,43	126,58 ± 19,04	124,22 ± 16,73^{b}
Average	111,42 ± 15,09^{a}	114,28 ± 18,15^{a}	

Gaze location

For an overview of the dwell time percentages per age group, road type, and AOI, see Table 2 and Figure 3. Adults were found to spend significantly more time watching the road ($F_{1,26}$ = 14.077; p = 0.001) whereas children looked more to the side of the road ($F_{1,26}$ = 17.075; p < 0.001) and the surrounding environment ($F_{1,26}$ = 5.220; p = 0.031). No significant difference in dwell time % was found for the AOIs FoE ($F_{1,26}$ = 0.146; p = 0.705), cyclists & pedestrians ($F_{1,26}$ = 0.298; p = 0.590), and NoData ($F_{1,26}$ = 2.500; p = 0.126).

On the low quality road, participants looked significantly more to the road itself ($F_{1,26}$ = 99.045; p < 0.001) and the side of the road ($F_{1,26}$ = 6.693; p = 0.016), and less to surroundings ($F_{1,26}$ = 48.639; p < 0.001), FoE ($F_{1,26}$ = 24.070; p < 0.001), and cyclists & pedestrians ($F_{1,26}$ = 29.373; p < 0.001). Furthermore, the size of NoData was lower on the low quality road compared to the high quality road ($F_{1,26}$ = 12.480; p = 0.002), and no Age*Road quality interactions were found (p < 0.05 for all AOIs).

Table 2 **:** Dwell time percentages per AOI, Age, and road quality. Same superscript letters indicate significant differences

AOI	Group	Road		Average
		High Quality	Low Quality	
road	A	26,33 ± 22,45	71,33 ± 16,69	48,83 ± 30,02^{a}
	C	11,57 ± 6,67	46,63 ± 19,12	29,1 ± 22,73^{a}
	average	19,48 ± 18,37^{d}	59,86 ± 21,55^{d}	
Side	A	1,99 ± 1,86	4,08 ± 4,04	3,03 ± 3,27^{b}
	C	7,18 ± 5,32	13,59 ± 11,21	10,39 ± 9,2^{b}
	average	4,4 ± 4,62^{e}	8,5 ± 9,36^{e}	
surroundings	A	23,39 ± 18,14	3,47 ± 3,43	13,43 ± 16,35^{c}
	C	33,97 ± 15,27	9,48 ± 8,64	21,73 ± 17,42^{c}
	average	28,3 ± 17,41^{f}	6,26 ± 6,97^{f}	
FoE	A	11,45 ± 12,3	3,2 ± 4,78	7,33 ± 10,08
	C	9,19 ± 6,82	3,51 ± 2,84	6,35 ± 5,88
	average	10,4 ± 10,02^{g}	3,34 ± 3,93^{g}	
Cycl-Ped	A	7,87 ± 6,63	0,85 ± 1,4	4,36 ± 5,91
	C	8,92 ± 7,46	1,28 ± 1,14	5,1 ± 6,52
	average	8,35 ± 6,92^{h}	1,05 ± 1,28^{h}	
NoData	A	28,97 ± 7,49	17,07 ± 9,39	23,02 ± 10,31
	C	29,17 ± 9,2	25,5 ± 10,89	27,33 ± 10,05
	average	29,06 ± 8,17^{i}	20,98 ± 10,81^{i}	

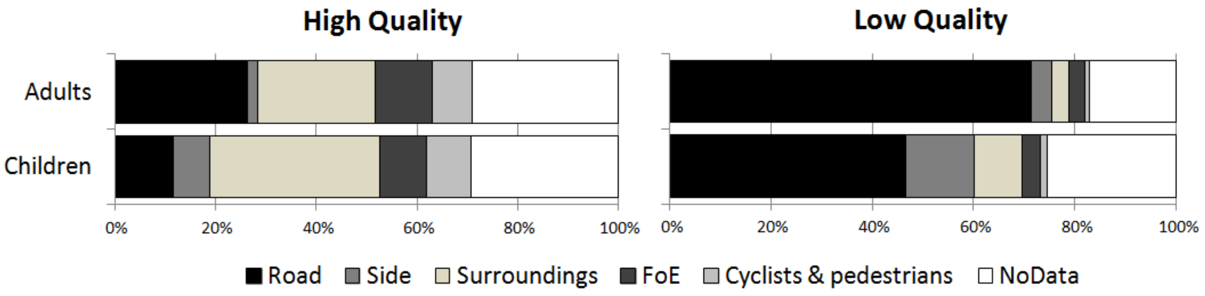

Figure 3 : Dwell time percentages towards the 6 AOIs per age group and per road type

DISCUSSION

In general, children were found to cycle slower than adults, and looked more to 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 an effect on the cycling speed of both adults and children but 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 cycling speed or the gaze behaviour of children than it had on the adults.

Cycling speed

In car driving, it has been shown that drivers adjust their speed to deal more easily with hazards and/or potential difficulty (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 reduction of cycling speed was found on the low quality bicycle track for both adults and the children. However, drivers respond to variations in task difficulty both in terms of autonomic arousal and adjustments in speed (Fuller 2005; Taylor 1964; Vansteenkiste, Zeuwts, 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, cfr. Task-Capability Interface model (TCI model; Fuller, 2005). As a result, there was no need to adapt cycling speed.

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; Zeuwts et al. 2015; Hatzitaki et al. 2002; Plumert et al. 2011), it was assumed that they would have lower capabilities, and therefore would be affected more easily 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 task demand on the low quality road might have been too low for both adults and children to adapt their normal cycling pace. In this case, the difference in cycling speed might be due simply to the fact that children's bicycles are smaller than adult bicycles.

Gaze

As was the case for cycling speed, the difference in gaze behaviour between adults and children was not larger on the low quality track than on the high quality track. On both tracks children spent more time looking at the side of the road and the surroundings, whereas adults spent more time looking at the road. Gaze behaviour of the adults is consistent with the results of the previous experiment (Vansteenkiste, Zeuwts, et al. 2014).

It has been suggested that children make less use of their peripheral vision to guide actions than adults (Franchak & Adolph 2010). Considering the higher percentage of dwell time towards the AOI 'side' in current experiment, children might have fixated the edges of the track sometimes for lane keeping, whereas adults control this task using primarily peripheral vision (Franchak et al. 2011). The more 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 task demands that they should (Whitebread & Neilson 2000; Foot et al. 1999).

It should be noted that there are also other possible causes for the different gaze behaviour between children and adults. Firstly, as was mentioned earlier, children cycled slower than adults. Due to this lower cycling speed the children might have had more time to look at the surroundings. However, this difference might be undone by the longer fixations of children (Whitebread & Neilson 2000). Second, some of the differences in gaze behaviour might be caused by a lower point of view of children compared to adults.

Perceptual motor strategy

Overall, it seems that children had a different visual-motor strategy than adults, characterized by lower movement times and a different visual behaviour. The steering behaviour is in line with earlier suggestions that children adopt a more cautious strategy (Berard & 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). However, when dealing with high task demands, it has been suggested that visual behaviour is adapted before steering behaviour is adapted (Vansteenkiste, et al. 2014). It seems therefore somewhat contradictory that children adopt a cautious steering strategy, but tend to have a incautious visual behaviour. 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, that 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.

Limitations and future research

In the current study, the children ranged from 6 to 12 year old. However, 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 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.

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Addendum P7.

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.

			High Quality							Low Quality						
Inclusion criterion (% of data loss)		#	Road	Side	Surr.	FoE	Cycl. & ped.	other	NoData	Road	Side	Surr.	FoE	Cycl. & ped.	other	NoData
No criterion	Adults	18	26,02	2,27	21,59	9,72	6,64	0,08	33,68	66,74	4,77	3,59	2,68	0,72	0,00	21,50
	Children	16	11,71	6,04	30,18	7,56	7,31	0,41	36,79	40,88	15,72	8,17	3,04	1,06	0,19	30,93
Less than 50 %	Adults	15	26,33	1,99	23,31	11,45	7,87	0,08	28,97	71,33	4,08	3,47	3,20	0,85	0,00	17,07
	Children	13	11,57	7,18	33,47	9,19	8,92	0,50	29,17	46,63	13,59	9,25	3,51	1,28	0,24	25,50
Less than 40%	Adults	15	26,33	1,99	23,31	11,45	7,87	0,08	28,97	71,33	4,08	3,47	3,20	0,85	0,00	17,07
	Children	10	11,65	7,95	35,04	10,52	8,57	0,44	25,83	48,09	13,88	9,64	3,51	1,52	0,22	23,14
Less than 35%	Adults	11	27,42	1,87	25,78	12,70	6,73	0,08	25,42	72,93	3,68	3,40	3,53	0,88	0,00	15,58
	Children	8	13,01	8,16	30,79	11,85	10,28	0,41	25,50	48,89	13,01	11,11	4,23	1,74	0,28	20,75
Less than 30 %	Adults	7	25,29	2,08	28,20	13,23	6,38	0,11	24,73	76,38	4,49	3,28	2,55	0,51	0,00	12,80
	Children	5	12,54	8,90	28,44	15,14	10,80	0,26	23,92	54,58	9,74	13,12	4,64	1,66	0,06	16,20
Less than 25%	Adults	5	18,88	1,40	30,94	18,74	6,84	0,18	23,02	73,96	3,58	3,96	4,02	0,50	0,00	13,98
	Children	2	13,70	7,55	33,95	17,00	9,95	0,60	17,25	52,90	12,45	12,40	5,15	2,40	0,05	14,65

Part 3

GENERAL DISCUSSION

The current thesis focussed on the role of visual information gathering in the steering behaviour of young and adult bicyclists. Since there are no standard procedures for the collection of head-mounted eye tracking data, and the analysis of these data, the **first section** of the general discussion addresses eye tracking methodology. In the **second section**, the visual behaviour of adult bicyclists is discussed. We focus on how the different constraints affected gaze and steering behaviour, and if this is in line with literature about pedestrians and car drivers. In a **third section**, the two-level model of driver steering behaviour is reviewed and redefined based on the findings of current thesis. In **Section four** we discuss the findings concerning the gaze and steering behaviour of children. Again we focus on how the different constraints affected gaze and steering behaviour, and we discuss how these findings fit to the current models. In **section five** some limitations about the current thesis are considered, and we suggest how these could be addressed in future research. Finally, in **section six** we look at the practical implications of the current work for traffic safety.

1. Eye tracking methodology

In the current thesis, multiple eye tracking methods have been adopted to obtain dwell time percentages to predefined Areas Of Interest (AOIs). Unfortunately, since all methods seemed to have advantages and disadvantages, it is still unclear which method is best suited for head mounted eye tracking analysis. In this section we briefly review the methods used in the current thesis, and discuss some recurrent limitations to head mounted eye tracking research.

1.1. Methods used

With the **frame-by-frame fixation detection method** (used in paper 2 and 3), the researcher determines when a fixation starts and ends by replaying the gaze overlay video (and preferably also the eye image). This way, all data is manually analyzed and errors and/or irregularities in the raw data are easily notice. Furthermore, in contrast to most methods using algorithms to detect fixations, it is possible with this method to detect smooth pursuit. This is a quite straightforward method since it only requires a skilled researcher and video software capable of replaying the video frame-by-frame. However, as was mentioned in paper 1, this method has the large disadvantage of being very time consuming. Furthermore, the start and the end of a fixation is not always clear, and fixation duration is therefore prone to subjective judgments of the researcher (Holmqvist et al. 2011; p175). Nevertheless, this method still seems the best option to obtain detailed information about the use of fixations during natural behaviour.

As detailed information about individual fixations was not always essential for the current experiments, the **frame-by-frame gaze location method** was used in paper 6. In this analysis, the researcher does not determine fixations, but only assigns the gaze location of each frame to a certain area of interest. Since no judgement of beginning and/or start of a fixation has to be made, this method is faster, and less subjective. However, no information about number of fixations and fixation duration is obtained using this method and it still requires the researcher to go through the whole gaze overlay video frame by frame.

To further reduce the workload of data-analysis, a **fixation-by-fixation method** was tested (paper 1) and used for the papers 4, 5, and 7. This method is less time consuming and therefore allows to analyze much longer recordings. However, it also has some important limitations. Whereas in the aforementioned methods the fixations' start and end are judged by the researcher, this method relies on fixation detection algorithms. Although this has the advantage that it is less subjective and therefore more easily to be applied by multiple researchers, there has been discussion about the validity and reliability of the fixation detection algorithms for head mounted eye tracking (see paper 1 and (Duchowski 2007; Holmqvist et al. 2011)). For example, most of the fixation detection algorithms will detect as multiple fixations where one long smooth pursuit fixation is made. Furthermore, due to the fact that partially processed data is analyzed instead of raw data, it is harder for the researcher to notice errors and irregularities in the gaze data. Finally, it is questionable if this method is still reliable with high speed stimuli, shorter experiments and/or small AOIs.

In general, it seems that the analysis method should be carefully reconsidered for each experiment. If the number and duration of individual fixations are of interest for the research, then the frame-by-frame fixation detection method still seems the best choice. At the moment, it is the most reliable method to obtain this kind of detailed gaze behaviour, provided that the data is analyzed by a skilled researcher. However, when a general overview of the distribution of visual attention is the main focus of an experiment, the fixation-by-fixation method might be more appropriate, provided that the AOIs are large regions and an extended timeframe is analyzed. This method can be described as a quick-and-dirty way to obtain an overview of the distribution of visual attention. Nevertheless, when applying a fixation-by-fixation analysis, it is advisable to check some random samples of raw data to verify if there are no systematic errors.

A **combination of multiple gaze measures** might also give a better insight in the gaze behaviour throughout the experiment. In paper 5 for example, the fixation-by-fixation method was applied to obtain dwell time percentages to the different cones, but additionally, some extra measures were manually analyzed by replaying parts of the gaze overlay video frame-by-frame. Depending on the focus of the experiment, the time frame between looking at an object and dealing with it, the scan pattern (sequence of AOIs looked at), and many other possible measures, could possibly contribute to a better overview on the gaze behaviour of the participants. For an overview of possible eye tracking measures, see Holmqvist et al. (2011).

1.2. Recurring issues with head mounted eye tracking equipment

- **Calibration issues**

Whereas remote eye tracking devices are able to perform a validation test of the **eye tracking precision** in the X and the Y axis for each subject, this is less common for head mounted eye trackers. In many papers, only the accuracy of the eye tracker given by the manufacturer is provided. However, these accuracies are usually measured during ideal conditions and with an artificial eye instead of with real subjects. Furthermore, many factors can influence this eye tracking accuracy (Holmqvist et al. 2012). Therefore, self measured accuracy is usually lower than the marketed accuracy. Although the experiments in current thesis also made use of simple dots for calibration, it might be more interesting to use concentric circles as calibration points. This way, when the distance from the participant to the calibration grid, and the distance between the concentric circles are known, the deviation from the bull's-eye, and thus the accuracy of the calibration, can be calculated easily.

Furthermore, by measuring the eye tracker's accuracy at different distances from the calibration grid, an estimation of the **parallax effect** can be given. This parallax effect causes the accuracy of the eye tracker to decrease as the target is further or closer than the distance used for calibration. This is caused by the scene camera not being on the same line as the eye camera (see Fig. 1). For this reason, the calibration grid should be presented to the participant at a similar distance as that at which the stimuli are expected during the experiment. However, this could be problematic in natural environments where the distance to various stimuli can differ considerably. In the latest generation of mobile eye trackers however, the eye tracking system is usually mounted in middle of a pair of glasses. Therefore, the parallax effect is rather limited. Nevertheless, since in natural environments objects of interest can usually be found both far away and close by, reporting the accuracy at different distances might shed light on this possible confounding factor.

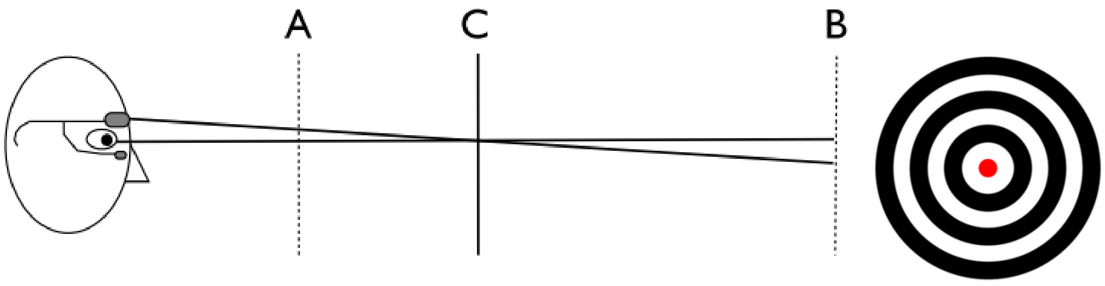

Figure 1 : Illustration of parallax effect (Left; Figure from Evans et al. 2012), and an example of a calibration target that could be used to measure accuracy (Right).

- **Infrared signal disturbance**

An important constraint for most of the current studies was that the eye tracking device could not be used in full sunlight. The Head-mounted Eye-tracking Device (HED, SensoMotoric Insturments, Teltow, GER) uses **infrared signals** to detect the motions of the eye. Unfortunately, in broad daylight this signal was too disturbed by sunlight to perform outdoor experiments. Due to this technical constraint, outdoor testing in this current thesis was limited. In study 7 however, the Eye Tracking Glasses (ETG, SMI, Teltow, GER) were used. Since with this eye tracker the infrared sensors are built in the framework of a pair of glasses, there was less disturbance of sunlight and outdoor testing was possible (see Fig. 2).

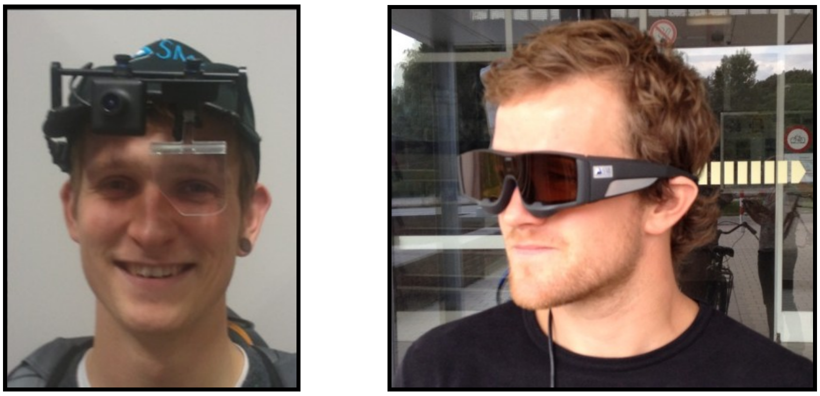

Figure 2 **:** Head-mounted Eye-tracking Device (HED, left) and Eye Tracking Glasses (ETG, right)

- **Participant drop-out and Share of 'missing data'**

Even when there was few disturbance of the infrared signal, head mounted eye tracking devices sometimes suffer from data loss due to multiple disturbing factors. Some of the known disturbing factors, such as mascara, hard lenses, and glasses (Holmqvist et al. 2011) were avoided during the current experiments, but some participants' eye movements still seemed to be harder for the equipment to measure. In these cases, calibration was difficult and/or the tracking ratio was very low. These eye tracking problems led to a considerable **participant drop-out.** Out of the 141 participants tested in the current thesis, only 90 were actually used for further analysis. A drop-out of 27.17%. However, the inclusion criteria were often different, with minimum tracking ratio of 80% to 90%. Choosing the minimum **tracking ratio** for the inclusion of participants is a balance between having more subjects with more missing data, or having a smaller group with less missing data. It is possible that a certain type or direction of gaze was more susceptible for data loss. Therefore, results obtained with a lower tracking ratio could possibly be biased. 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.

Tracking ratio indicates how much of the time the eye tracker could record the position of the eye. However, not all raw gaze data (X & Y coordinates) can be processed into meaningful measures of gaze behaviour. When the position of the eye is not stable for at least 80ms (or another minimum fixation duration threshold), or fell outside of the range of the scene video, these eye movements were not labelled as a fixation, and were therefore often not included in measures of gaze behaviour such as dwell time percentage. As a result, even with a high tracking ratio, the share of **missing data** can still be considerably large. If the data loss occurs systematically during a certain gaze behaviour (e.g. looking very close by or using a lot of smooth pursuit eye movements), this could potentially lead to distorted results. The share of missing data should therefore be as low as possible, and if possible controlled for systematic errors.

EYE MOVEMENTS → Eye tracking → **RAW DATA** → Analysis → **MEASURES OF GAZE BEHAVIOUR**

Figure 3 : Process of recording and analyzing gaze behaviour. Both in the 'eye tracking', and in the 'analysis' part data can be lost or considered erroneous.

1.3. Conclusion

Head mounted eye tracking experiments in outdoor environments are still challenging and the eye tracking method and analysis are usually chosen in function of the experimental setting and goal. It is important to constantly monitor the eye tracking methodology used, and question its validity. Standardized procedures to control the eye tracking quality could be of great interest for eye tracking experiments. However, creating these procedures is difficult since eye tracking equipment and the software to analyze the data is evolving quickly. Nevertheless, the improvements in eye tracking technology have made it more convenient to test visual behaviour more thoroughly and in more realistic settings. The current developments in computerized object recognition, virtual reality (e.g. oculus rift), and the integration of GPS, EEG, and other devices in eye tracking systems, are promising and will hopefully open many more possibilities in studying gaze behaviour.

2. Gaze behaviour of adult bicyclists

In the current thesis we investigated the perceptual-motor behaviour of bicyclists during isolated steering tasks and in an actual traffic environment. In this section we focus on the visual behaviour of adult bicyclists, how gaze behaviour changed with changing constraints, and how this relates to the visual behaviour of pedestrians and car drivers.

2.1. Constraints approach for gaze behaviour

In general, motor coordination and motor control is dependent of many constraints. Constraints can be defined as physical or non-physical boundaries and features that limit motor behaviour or make it happen. According to the constraints theory of Newell (1986), three types of constraints determine motor behaviour: individual, task and environmental constraints (see also Fig. 5). This constraints approach can be applied for visual behaviour in traffic situations.

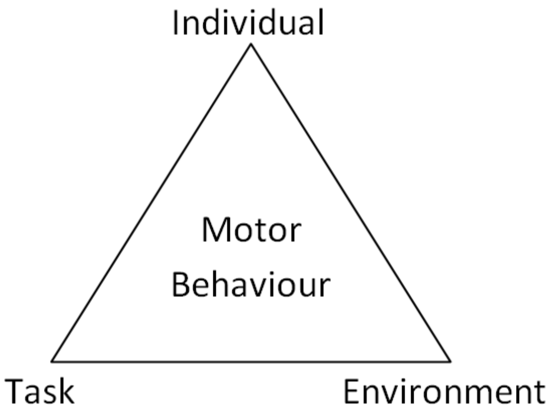

Figure 4. Constraints model of Newell (1986).

Individual constraints on gaze behaviour were most apparent when the comparison was made between the visual behaviour of adults and children. These differences will be elaborated on in section 4. Next to differences between adults and children, large standard deviation in dwell time percentages suggested that there were also considerable individual differences in gaze behaviour among the adult participants. Possibly, these differences were the result of a different preferred source of visual information to judge heading (egocentric strategy vs. optic flow, see also next section). In paper 2 these two strategies of visual information led to a different scan pattern for some participants, which is shown in figure 3 of that paper.

Regardless of the individual differences, gaze behaviour of the bicyclists in current thesis was also affected by the **environmental constraints.** This was most obvious in study 6, where low quality cycling lane was found to cause an apparent shift of visual attention from distant environmental regions to more proximate road properties. Since bicyclists are also more subject to the weather than car drivers, the effect of different weather conditions on the visual behaviour of bicyclists might also be worth investigating.

Finally, **task constraints** also had a large influence on gaze behaviour. On a straight lane, gaze was either directed to the path itself, or to the end of the lane. However, when the lane was wide enough not to require precise steering, 20 to 30 percent of the gaze was directed to task-irrelevant regions. Steering through a curved lane on the other hand, evoked a specific gaze pattern, characterized by a high proportion of gaze directed to the inner edge and the centre of the lane. Although this lane was 1.5m wide, few task-irrelevant fixations were made. Finally, during a more complex task such as cycling through a slalom, gaze behaviour was characterized by frequent anticipatory fixations. That bicyclists adapt their visual behaviour to the task is in line with the vast amount of literature confirming that gaze behaviour is strongly task dependent (Yarbus 1967; Vaeyens et al. 2007; Higuchi et al. 2009; Dicks et al. 2010).

2.2. Recurring results

Although gaze behaviour was different for each participant and was adapted to the steering task and environment, some characteristics of steering behaviour were similar throughout all constraints.

- **Large standard deviations in dwell time percentage**

As was mentioned in the previous section, large standard deviations in the dwell time percentages towards the different AOIs were found in all of the current studies. This was a reflection of considerable individual differences in gaze behaviour between the participants, and suggests that steering behaviour could be guided by multiple visual strategies. Since information about heading direction can be derived from both perceived visual direction (egocentric strategy; Rushton et al. 1998) and optic flow patterns (Beall, Andrew & Loomis, Jack 1996; Loomis, Jack & Beall, Andrew 1998; Warren et al. 2001) the differences in gaze behaviour between the participants might have been the result of a different preferred **source of visual information to judge heading**. It has often been suggested that a weighted combination of these (and other) sources of information are used to control steering (Wilkie & Wann 2002; Wilkie & Wann 2003a; Wilkie & Wann 2005). Different individuals might therefore 'weigh' these sources of visual information differently to obtain heading information, with considerable differences in gaze behaviour as result.

The combined use of perceived visual direction and optic flow patterns to determine heading also might explain why participants shifted from a 'look where you are going' strategy to a curvature matching strategy when steering through a curve at higher speeds. The 'look where you are going' strategy for steering shows similarities with the egocentric strategy of controlling heading (using perceived visual direction). In both cases, the steering strategy can be described as follows: i) direct gaze towards the ‘target’ (i.e. point-attractor Fajen & Warren 2003), ii) rotate the body/vehicle in a direction that should reduce the angle between the gaze and the midline, iii) evaluate the difference between the angle of the gaze and the orientation of the body iii) reiterate the loop (Rushton et al. 1998; Wilkie & Wann 2003a). During the curvature matching strategy and the optic flow strategy however, gaze is directed a point (TP or FoE) that should stay at the same angular direction from the heading direction. As cycling speed increases, the optic flow rate also increases (Warren et al. 2001). As a result, it could be expected that the visual information from optic flow also becomes more apparent, and therefore bicyclists/car drivers might rely more on optic flow. As a result, at higher speeds it might have been more advantageous and/or preferable to direct gaze to a location which enables a maximal use of optic flow (i.e. curvature matching strategy for curve negotiation and optic flow strategy for heading detection).

- **The use of a “visual buffer”**

It has often been shown that gaze is proactive, and directed one to two seconds ahead during locomotion (Wilkie & Wann 2003b; Marigold & Patla 2007; Land 2006). This time span between vision and action has been referred to as the “visual buffer”[7]. Although this time span was not directly measured in most of the current experiments, **gaze was often directed to the travel path about one to two seconds ahead**. The use of such visual buffer was most obvious in during the slalom task, where gaze was switched to the next cone about 1.2 seconds before reaching the nearest cone. This indicates that the final 1.2 seconds of this steering action was completed without actively looking at the cone. However, by manipulating the presence of peripheral information during a slalom, Wilkie et al. (2008) showed that peripheral vision on road obstacles closer than the direction of gaze can still provide important cues for steering. Therefore, it seems that the last part of the steering action is not completed by using only a buffered representation of the close environment, but also by using peripheral vision.

- **OKN, and the lack of travel fixations**

When gaze was directed to the travel path close to the bicycle, OptoKinetic Nystagmus (OKN) was observed. This is a reflexive eye movement consisting of a succession of tracking eye movements in the direction of visual motion, (slow phase) and fast resetting saccades in the opposite direction (Authié & Mestre 2012). In both the indoor as the outdoor tests, a slow eye movement was made to keep the direction of gaze on a certain spot on the travel path while moving forward. After about 200-300ms, a forward saccadic eye movement was made to redirect gaze to a new spot on the travel path at about the same distance as the previous fixation was started. This gaze behaviour is apparent in the saw tooth-like graph, obtained when plotting Y-coordinates of gaze direction over time (see figure 3 of study 2).

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[7] Also referred to as “memory buffer” (Land & Furneaux 1997),” temporal buffer” (Wilkie et al. 2008), “information buffer” (Land 2006), and “look-ahead distance” (Wilkie & Wann 2003b)

This gaze behaviour was previously reported in laboratory settings (Howard & Ohmi 1984; Lappe et al. 1998; Niemann et al. 1999), and only very recently in car driving (Authié & Mestre 2011; Lappi & Lehtonen 2013). In walking experiments on the other hand, Patla and Vickers (2003) described the use of 'travel fixations'. During this type of fixation, the observer's direction of gaze should be directed to the floor at a fixed distance in front of the observer and travels at the same rate as the observer. However, the existence of these kind of fixations has been seriously doubted (Pelz et al. 2009), and it was suggested that the observation of these travel fixations might have been due to temporal averaging of small saccades, and/or an **artefact of the experimental set-up**. The identification of OKN in the current thesis adds up to the doubts about the prevalence of travel fixations since the use of travel fixations would mean that this reflexive eye movement is suppressed.

- **Indoor versus outdoor experiments**

Furthermore, it is promising that the visual behaviour during indoor and outdoor tests also **showed many similarities**. When the task demand is low (i.e. on wide lane and good surface), gaze was directed to task-irrelevant regions for 20 to 30% of the time. With increasing task demand however (i.e narrower lane and poor surface quality), gaze is directed less to task-irrelevant areas and more to the path itself. The gaze to the road region also seemed to be about one to two seconds ahead and was subject to OKN eye movement pattern. Although the outdoor tests did not include cycling a curve or a slalom, the similar results of cycling a straight lane suggests that the visual control of steering that was described in the indoor tests is transferable to outdoor situations. Nevertheless it should be taken into account that next to steering, bicyclists will have to deal with extra tasks in actual traffic environments. The steering task was deliberately isolated during the indoor experiments, but outdoor cycling will also involve hazard perception, traffic sign detection, synchronizing with other traffic participants, etcetera.

- **Summary**

In summary, bicyclists seem to use a weighted combination of information from the perceived visual direction and optic flow to judge heading. Although the existence of travel fixations is doubted in the current thesis, gaze indeed seems to travel forward at the speed of locomotion at about one to two seconds ahead. However, this does not occur in a smooth way as described by Patla and Vickers (2003), but rather by applying OKN-like eye movements. The similarities in gaze behaviour in the indoor, and the outdoor tests suggest that the findings of how visual information contributes to steering behaviour described for isolated steering tasks are transferable to more realistic traffic situations.

2.3. Visual behaviour of bicycling compared to walking

The **visual behaviour of bicyclists is in many ways similar to that of pedestrians**. During both walking and bicycling, gaze is often directed to the scenery when the task demand is low (Foulsham et al. 2011; Pelz & Rothkopf 2007). When visual information about the travel path is required however, gaze is used in a feed-forward manner, fixating the path or objects approximately one to two seconds (or two steps) in advance (Patla 1997). In a complex environment, both pedestrians and cyclists also seem to use a visual sampling strategy to anticipate to the upcoming path (Mohagheghi et al. 2004; Patla & Greig 2006). Finally, when the task demands a high degree of spatiotemporal precision, motor behaviour is continuously regulated based on visual information to ensure accurate movements (Matthis et al. 2013). In walking tasks this is characterized by adapting gait parameters such as stride length, in cycling tasks this is usually reflected in lower cycling speed.

The role of **peripheral vision** in bicycle steering control was not directly tested in the current thesis. Nevertheless, since the gaze behaviour of bicyclists and pedestrians show many similarities, and peripheral vision plays an important role in the control of locomotion in pedestrians (Marigold 2008; Marigold et al. 2007; Franchak & Adolph 2010), it could be expected that peripheral vision is also important for bicycle steering. Although this experiment is not included in the current thesis, a variation of study 4 has been carried out in which the use of peripheral vision while cycling a curved path was investigated[8]. In line with earlier suggestions, the results of this study confirm that peripherally perceiving the road ahead can contribute to the steering behaviour of bicyclists.

In contrast to pedestrians, bicyclists were not found to use so called ‘travel fixations’. However, as was argued before, the travel fixations described while walking might have been an artefact of the experiment set-up and/or analysis. Another difference between pedestrians and bicyclists is how they can **change direction**. Whereas pedestrians are able to make a point-turn, bicyclists have to take a curved path to change direction. Nevertheless, the gaze behaviour accompanying a point-turn shows similarities with steering through a curve. In both cases, vision is used in a feed forward manner by directing gaze towards the future path (Hollands et al. 2002). When pedestrians are required to take a curved path, gaze is directed to the future direction of the curved trajectory about 1 second in advance (Grasso et al. 1998; Imai et al. 2001). This gaze behaviour is even more similar to that of cyclists and car drivers, and is in line with the egocentric strategy of controlling heading. For bicyclists however, the higher travelling speed probably induced a more pronounced optic flow. Since people increasingly rely on optic flow as it is more present (Warren et al. 2001), bicyclists and car drivers are probably more likely to use a visual strategy that relies on optic flow rather than on perceived visual direction. The curvature matching strategy might therefore be adopted instead of a ‘look where you are going’ strategy.

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[8] An abstract of this study has been accepted for a special issue of Journal of vision : “*Scene Perception from Central to Peripheral Vision*”; See appendix B

2.4. Comparing to car drivers

As was repeatedly emphasized in the studies of the current thesis, cyclists have to cope with different constraints than car drivers, which in turn induce different visual requirements to control locomotion. In contrast to car drivers, bicyclists have an almost unrestricted view on the environment, have a much lower travelling speed, are more subject to environmental conditions, and have to maintain balance whereas cars are stable on their own (Schwab et al. 2012). Nevertheless, **in general, the gaze behaviour of bicyclists was comparable to that of car drivers**. As was also the case for pedestrians, gaze behaviour of car drivers is characterized by a focus on the road about one to two seconds ahead, occasional anticipatory fixations to the future road and an important role for peripheral vision (Lehtonen et al. 2014; Summala et al. 1996; Crundall et al. 2002; Wilkie & Wann 2003b). Furthermore, as was emphasized for bicyclists in current thesis, the gaze behaviour of car drivers is also dependent of individual (Mourant & Rockwell 1972; Chapman et al. 2002; Vlakveld 2011), environmental (Borowsky et al. 2012), and task constraints (Land & Lee 1994; Kandil et al. 2010).

In contrast to bicycle behaviour, many models for car steering behaviour have been proposed. The effects of various constraints on the visual and steering behaviour of bicyclists is in line with the **Task Capability Interface model** of Fuller (2005). In agreement with this model, the behaviour of bicyclists seems to be affected by the balance between task demand and the individual’s capability. However, current studies showed that an increase in task demand does not immediately lead to a change in bicycling behaviour. The first step is to increase arousal by paying more attention to the task-specific sources of information. Only when task demand was still high after this step, bicycling behaviour was adapted (usually by lowering cycling speed).

When comparing the visual and steering behaviour of bicyclists to the **two-level model** of driver steering behaviour however, it was not completely in line with the model. Although the subdivision of the steering task in a compensatory closed-loop mechanism and a anticipatory open-loop mechanism seemed adequate for bicyclists, the model does not explain the changes in visual behaviour due to the various constraints. In the next section, the two level model for driver steering behaviour is reviewed and redefined in function of changing constraints.

3. A framework for perceptual-motor behaviour in traffic

An adaption of this section will be submitted as a commentary paper

The two-level model of driver steering behaviour (Donges 1978), which divides the steering task into a stabilizing and a guidance level, is one of the most influential models for the visual control of steering[9]. Ever since the paper of Land and Horwood (1995) "Which parts of the road guide steering?", the guidance level has been associated with visual information from a 'far' region, and the stabilization level with visual information form a 'near' region. However, this model did not seem to be fully applicable to cycling behaviour. Furthermore, the research conducted in the current thesis raised some questions about the interpretation of this model. Therefore, in this section we review the use of the two level model and redefine it.

3.1. The two-level model of driver steering behaviour

The central idea in the two-level model is that steering behaviour can be divided in two levels of steering control that are used in parallel. In the **guidance level**, information from the instantaneous and future course of the road is used to construct a desired path. This desired path is referred to by Donges as 'the forcing function' and depicts the future course to be taken. Since visual information is used to construct schemes of the road and plan a desired path, the guidance level is referred to as an anticipatory open-loop control mode. In the **stabilization level** on the other hand, the driver estimates the instantaneous position and the course of the vehicle as related to the desired path, and makes steering corrections accordingly. Steering corrections in the stabilization level are based on the perception of two error signals: *lateral deviation error*, and *heading angle error*. This error-corrective feedback mode of control has been referred to by Donges as compensatory closed-loop control.

In the case of rectilinear motion, the lateral deviation error and the heading angle error can easily be derived from the visual field. On curved roads however, "*the perception of heading angle error is complicated by the fact that the instantaneous direction of the desired path is no longer directly visible but must be extrapolated from the perspective pattern of the curved road. The simplest way of stabilizing vehicle motions with respect to roads of constant curvature might be keeping the perspective road patterns within the visual field in constant shape and position.*" (Donges 1978). Donges therefore suggested a third error signal for steering corrections in the stabilization level : *path curvature error (see also Fig. 5)*. This error signal can be detected by extrapolating the curvature of the vehicle's actual path from the changes in the visual field (dynamic flow), and comparing it with the directly visible curvature of the desired path.

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[9] cited over 290 times

In short, the two-level model of driver steering behaviour can be summarized as a steering system that works at two levels: a guidance level that depicts a desired path in an anticipatory open-loop control mode, and a stabilization level whereby deviations from the desired position (lateral deviation) and the desired course (heading angle and path curvature) are detected and compensated for in a closed-loop control mode.

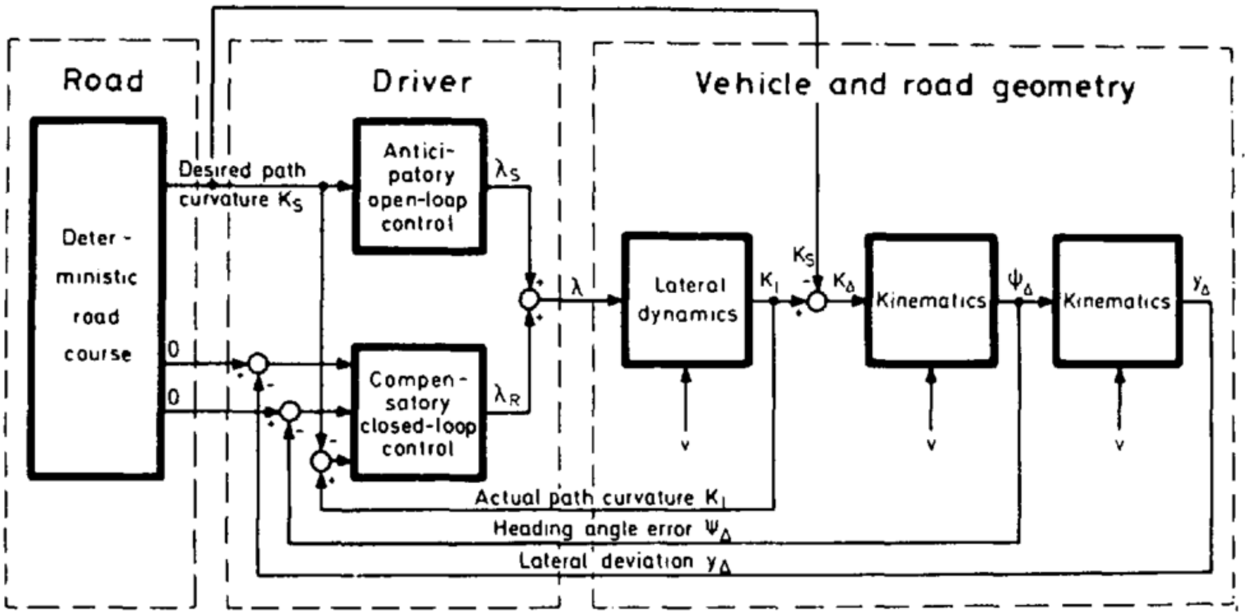

Figure 5 : A structural scheme of human steering behaviour according to the two-level model of driver steering behaviour. The guidance level is represented by anticipatory open-loop control and depicts the desired path. The stabilization level is represented by compensatory closed-loop control and formulates steering corrections based on the three feedback signals. From Donges 1978.

- **Which parts of the road guide steering?**

Although both levels in the two-level model are based on visual information, Donges (1978) only suggests that visual information is derived from ‘the forward view of the road’. The question therefore remained which parts of the road ahead supply the visual information for the stabilization and the guidance level. It was this question that led to the paper of Land & Horwood (1995) “Which parts of the road guide steering?”

In this paper, Land and Horwood used a driving simulator that showed only a 1° high segment of the road. By altering the position of this segment between 1° and 10° below the horizon, they investigated how steering behaviour changed when only parts of the road were visible. They found that when only the **far region** of the road was visible, the curvature was smoothly matched, but position-in-lane was not well maintained. With only the **near region** being visible, steering was difficult and jerky, but the position in the lane was maintained quite well. When both a near and a far segment was visible, the steering accuracy was similar as when the whole road was visible. Land and Horwood concluded that distant parts of the road provide information about the road curvature whereas nearer parts of the road provide position-in-lane info, and that these results strongly support the two-level model of Donges (1978). Although the exact size and location of the regions has been debated (Cloete & Wallis 2011; Frissen & Mars 2013; Chatziastros et al. 1999), ever since the paper of Land and Horwood, the guidance and the stabilization level of the two-level model have been associated with visual information from a far and a near region, respectively (Vansteenkiste, Cardon, D'Hondt, et al. 2013; Mars 2008; Robertshaw & Wilkie 2008; Lappi & Pekkanen 2013; Cloete & Wallis 2011).

However, testing the two-level model by occluding large parts of the visual field has an important limitation that has not been taken into account. It is presumed that when far road information is occluded, the 'jerky' steering behaviour is the consequence of the lack of guidance information. However, since the locomotor system is able to use a weighted combination of various information sources (kountouriotis et al. 2012; Vansteenkiste, Van Hamme, et al. 2014), occluding the far region may also have affected the perception of some sources of stabilization information. Therefore, the different steering behaviour could be the result of a decreased availability of stabilization information rather than the absence of guidance information.

- **Two sublevels in the stabilization level**

According to Donges (1978), two types of deviations from the desired path can lead to compensatory steering actions in the stabilization level: deviations from the desired instantaneous position, and deviations from the desired course. It has been suggested that deviations from the desired **instantaneous position** are detected by monitoring the lateral deviation from the centre, or the edges, of the road (kountouriotis et al. 2012; Coutton-jean et al. 2009). This feedback information can be acquired by perceiving the road near the vehicle with peripheral vision. Therefore, occluding the far region should not have an effect on this source of stabilization information

Compensating for deviations from the **desired course** however, involves the perception of more distant parts of the road. Donges suggested that the path curvature error is extrapolated from the dynamic changes in the visual field of the driver (cf. Optic flow; Authié & Mestre, 2012; Loomis, Jack & Beall, Andrew, 1998) and that this error provides lead information for the driver to make steering corrections. This type of control mechanism, in which characteristics of the road ahead are transformed directly into steering commands in a continuous fashion, is called the ***pursuit control mode*** (Tresilian, 2012; p. 561). Instead of optic flow information, specific visual cues could also be used as feed-forward signals for pursuit control (cf. egocentric strategy of controlling heading). For car driving, multiple visual cues have been identified as potential cues for pursuit control (e.g. focus of expansion, tangent point, future path, lead car; Kandil, Rotter, & Lappe, 2009; Land, 1998; Lappi, 2014; Salvucci & Gray, 2004). However, regardless of whether visual information for pursuit control comes from optic flow or from specific cues, the availability of this information is severely reduced when the far region is occluded.

Summarized, the two 'sublevels' of steering control within the stabilization level make use of different visual cues. In a first sublevel, feedback information from a region close to the vehicle is used to make steering corrections for deviations from the desired instantaneous position. In a second sublevel, feed forward information is used to make steering corrections for deviations from the desired course, in a pursuit control mode.

This duality in the compensatory control of steering was also used by the **two-point visual control model of steering** (Salvucci & Gray 2004; see Fig. 6). This on-line control model, in which current visual information is translated into the immediate steering response (Lehtonen et al. 2014), relies solely on the perceived visual direction of two points (cf. Stabilization level). A near point on the centre of the road to monitor lateral position and stability, and a far point to monitor lateral stability and maintain a predictive steering angle that compensates for the upcoming road profile. Salvucci and Gray suggested three possible points that could be used as 'far' point: the vanishing point (focus of expansion), the tangent point, or a lead car. Unfortunately, the name of this model, and the use of a 'far' and a 'near' point confusingly suggested that this model was based on the stabilization and the guidance level of the two-level model of steering. However, at the end of their paper, Salvucci and Gray literally state that "*the two-point model is NOT, at present, able to capture open-loop steering during visual occlusions. However, we could imagine an open-loop component added to the model that predicts movement of the near and far point given the current (and future) steering trajectories and generates predictive steering using this information*".

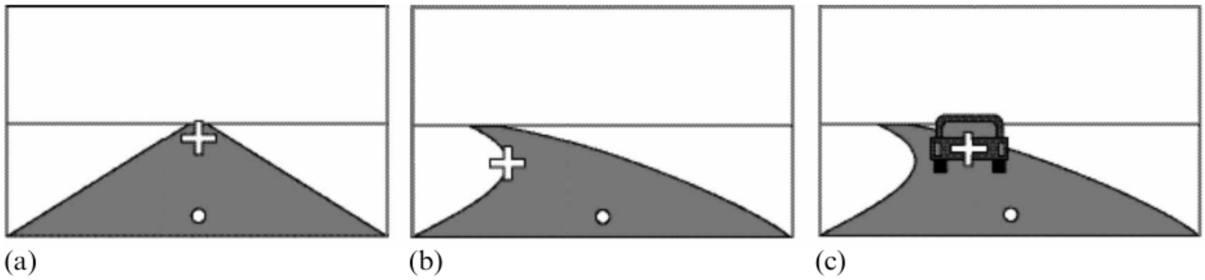

Figure 6 : near (circle) and far (cross) points for three driving scenarios according to the two-point visual control model of steering. (a) straight road with vanishing point, (b) curved road, and (c) presence of a lead car. Adapted from Salvucci & Gray, 2004

- **Anticipatory open-loop information**

The two sublevels of compensatory steering control, and the two-point visual control model of steering of (Salvucci & Gray 2004) suggest that the two steering tasks that were distinguished in the experiment of Land and Horwood ('keep a proper distance from the edge' and 'match the road curvature'; 1995), can be executed using solely compensatory closed-loop control from feedback and feed forward information. This underpins the idea that in the experiment of Land & Horwood (1995; and those of Cloete & Wallis, 2011 and Frissen & Mars, 2013), not only the guidance level is affected by occluding a 'far' region, but also the stabilization level. As a result, the current evidence for the association of a far and a near region to the guidance and the stabilization level of the two-level model, respectively, can be questioned.

The use of two sublevels of control within the stabilization level leads to a new question : if both the near and the far region of the visual field can provide compensatory closed-loop information, then which parts of the road provide anticipatory open-loop information? First, it must be emphasized that fixating a certain region in function of pursuit control does not exclude the possibility that anticipatory information can be derived from the same visual region. It has been previously shown that visual information of multiple sources can contribute to the steering system at the same time (Wilkie & Wann 2002; Loomis, Jack & Beall, Andrew 1998; Warren et al. 2001). In the same way, one visual region could possibly support both the stabilization and the guidance level of the two-level model (Lehtonen et al. 2014).

Second, we believe that the forward field of view should not be divided into only a near and a far region. The typical ‘preview time’ that has been described during steering actions (and more generally also most visually guided actions), rarely exceeds two seconds. This preview time, or as it has been referred to ‘visual buffer’ (Wilkie et al. 2008; Vansteenkiste, Cardon, D’Hondt, et al. 2013), indicates a time-span wherein visual information can still be used for on-line control. Visual cues for pursuit control therefore should always fall within the visual buffer. Fixations directed further than two seconds ahead however, are usually described as anticipatory look-ahead fixations (Lehtonen et al. 2013; Lehtonen et al. 2014; Mars & Navarro 2012) and do not immediately serve an ongoing action. They rather provide information that serves the planning of the future trajectory, hazard detection, or irrelevant tasks to car driving such as billboard watching.

Hence, it seems more appropriate to divide the forward field of view in three, rather than only two regions. 1) A **near region**, which encloses the space immediately in front of the person/vehicle, 2) a **pursuit region** in which visual information up to approximately two seconds ahead is likely to be used in a pursuit control mode, and 3) an **anticipation region** in which information from further than two seconds ahead is most likely to provide anticipatory open-loop information (Lehtonen et al. 2013). That the pursuit region is associated with the visual buffer implies that the size of the pursuit region is dependant of the travelling speed (see table 1). This could possibly explain why in the experiment of Land and Horwood (1995) the near road mechanism was adequate on its own at lower speeds. At low speed, the pursuit region stretches less far and therefore might be difficult to distinguish from the near region (Vansteenkiste, Van Hamme, et al. 2014).

Table 1 : size of the visual buffer at different speeds

	Km/h	m/s	Visual buffer of 2 seconds provides forward view of …(m)
Walking speed	5	1,39	2,78
Cycling speed	15	4,17	8,33
Speed limit in dense urban region	30	8,33	16,67
Speed limit in suburban region	70	19,44	38,89
Speed limit on highway	120	33,33	66,67

- **Redefining the two-level model for steering behaviour**

It is confusing that within the two-level model, the stabilization level can also be split up in two ‘sub-levels’ of compensatory steering behaviour. In addition, the term ‘guidance level’ is somewhat confusing to refer to an anticipatory open-loop control mode since ‘guidance’ is rather associated with a closed-loop process than with a open-loop process. In naturalistic tasks, ‘guiding fixations’ have been described as fixations that lead the action by one to two seconds (Lehtonen et al. 2013). Similarly, in car driving, the tangent point and points on the future path have been identified with these ‘guiding fixations’. However, these visual cues match a pursuit control mode (stabilization level) rather than the guidance level of the two-level model.

Therefore, we propose a redefined two-level model of steering behaviour wherein the terms ‘stabilization’ and ‘guidance’ are avoided, but ‘**compensatory closed-loop control**’ and ‘**anticipatory open-loop control**’ are used instead. Compensatory closed-loop control is represented by two sublevels: instantaneous control and pursuit control (see Table 2). These three levels of steering could be associated with ‘checking what you did’ (position-in-lane feedback), ‘controlling what you’re doing’ (pursuit control), and ‘planning/preparing for future steering actions’ (anticipation). This way of representing the two-level model of driver steering behaviour maintains the original function of the two levels of steering control of Donges (1978), but clarifies that visual information from more than just a ‘near’ and a ‘far’ region can contribute to the control of steering. The three regions that are currently proposed instead of the near and the far region, can be associated with instantaneous control, pursuit control, and anticipatory open loop control (see also Table 2). These regions have also been referred to as the ‘near extrapersonal space’, the ‘far extrapersonal space’ and ‘ambient extrapersonal space and visual background’ (Lappi 2013).

Nevertheless, we want to emphasize that **multiple steering mechanisms/strategies can contribute the steering control in each level**. For example, pursuit control during curvature negotiation can be based on a curvature matching strategy (Land & Lee 1994; Tresilian 2012; Kandil et al. 2009) and/or a ‘look where you are going’ strategy (Wilkie & Wann 2003b; kountouriotis et al. 2012). However, the other way around, visual information from **multiple**

regions can also contribute to the same level of steering control. Whereas gaze is directed to a region approximately two seconds ahead in both curve steering strategies (see also study 4), the curvature matching strategy relies largely on optic flow (Authié & Mestre 2012). This optic flow information can be derived from peripheral vision rather than foveal vision. Therefore, the heading direction is not necessarily derived from the fixated region.

Table 2 : Redefining the two-level model for steering behaviour.

Two levels of steering control	Compensatory closed-loop control		Anticipatory open-loop control
Function	Instantaneous control	pursuit control	Anticipatory open-loop control
Location of visual information	Near region	Pursuit region	Anticipation region
Type of information	Feed Back	Feed Forward	Anticipatory / Look-ahead

3.2. The two-level model as a constraints model

In study 2, we stated that the visual behaviour of bicyclists could only partially be explained by the two-level model as described for car driving. While the two-level model provides a good framework to describe how visual information leads to steering behaviour, it does not predict how gaze and steering behaviour change under different constraints. Although the research paradigm used in this study was not optimal to test the two-level model (Schepers et al. 2013), it did emphasize that gaze and steering behaviour are susceptible for task and environmental factors. The extent to which visual information is used for compensatory closed-loop control and for anticipatory open-loop control seems to be dependent on individual, task, and environmental factors (Cf. Constraints approach of Newell 1986). To account for these findings, the two-level model was presented as a '**gaze constraints model**'. This adaption of the two-level model also relies on the assumption that lane keeping is controlled by both compensatory closed-loop processes and anticipatory open-loop processes. However, depending on the individual, task, and environmental factors, the need for anticipatory open-loop and compensatory closed-loop control will be higher or lower. For example, as the bike lane becomes more narrow, the need for more precise steering increases, and the subject will rely more on compensatory closed-loop processes. As a result the bicyclist directs his/her gaze more towards the regions associated with these closed-loop processes.

According to this gaze constraints model, the combined need for anticipatory and compensatory control will determine the attentional demand necessary to control the steering task. As the need for anticipatory open-loop control and/or compensatory closed-loop control increases, the attentional demand also increases. However, if the limited capacity of human information processing is taken into account, this implies that there will be less 'spare attentional capacity' for task-irrelevant gaze. Similar to the dynamic interaction between task demand and drivers' capability in the TCI model (Fuller 2005), there could be a dynamic interaction between the attentional demand and the attentional capacity in the gaze constraints model. In this case, as long as the attentional capacity is higher than the attentional demand, all visual stimuli would be efficiently processed. When the attentional demand exceeds the attentional capacity however, there would be an impending overload of information which could lead to uncertain and/or hazardous motor actions. Figure 7 shows how these suggestions would fit in the gaze constraints model.

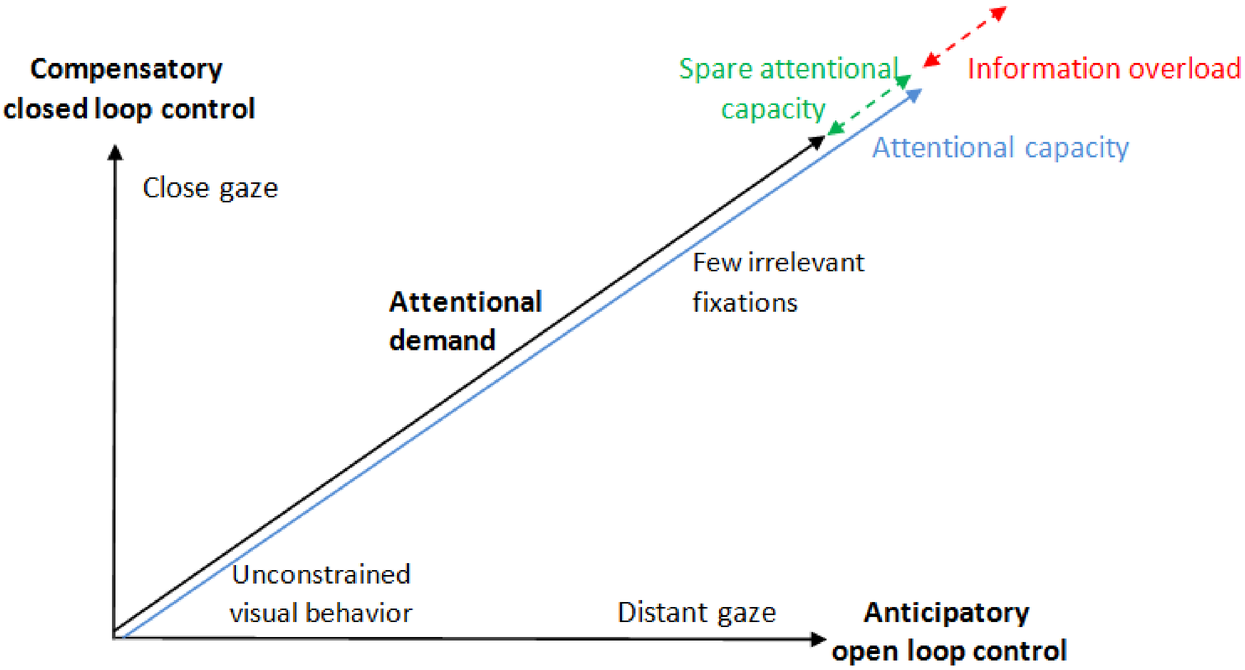

Figure 7 : Gaze constraints model for steering

3.3. The constraints model and the current studies

Although the studies in the current thesis did not explicitly test the gaze constraints model, the results of these (and other) studies are in line with it. As **straight cycling lanes** become more narrow and/or have a crooked surface, steering needs to be more precise (Cf. Studies 2, 3, 6 and 7). According to the gaze constraints model, this implies that there is a larger need for compensatory steering behaviour, characterized by more visual attention to the proximate road regions. This shift of visual attention is exactly what was described in the current studies. Unfortunately, in none of the current experiments, the need for anticipatory information was experimentally manipulated. Furthermore, in each of the experiments, the participants were familiarized with the cycling course, which possibly even lowered their need for anticipatory gaze behaviour.

Nevertheless, steering behaviour during **curve negotiation** (study 4) was in line the suggestions that an open-loop anticipatory steering strategy is used at curve entrance, while a closed-loop compensatory strategy is used to steer through the rest of the curve (Shinar et al. 1977; Lehtonen et al. 2013). Interestingly, Lehtonen et al. (2013) tested the effects of an additional cognitive task on the visual behaviour during and preceding curve negotiation. According to the gaze constraints model, an additional cognitive task will lower the availability of attentional resources of the driver and leave less attentional resources to distribute between anticipatory and compensatory steering control. Since the straight road preceding a curve makes more use of the open-loop anticipatory steering strategy, it is in this segment that the visual system will be most under stress due to the additional task. In line with these predictions, Lehtonen et al. (2013) found that higher cognitive loads led to shorter look-ahead lead distances and shorter look-ahead fixations, especially in the straight segment preceding a curve.

With regard to **steering through a slalom**, study 5 also showed that increasing the steering demand evokes a shift of gaze towards the first cone to be steered around. Interestingly, although the dwell time percentage towards the upcoming cones decreased with increasing steering demand, the number of anticipatory fixations (a quick glance to the upcoming track) did not decrease. This suggests that the participants planned their steering behaviour ahead rather than deal with one cone at the time. In other words, participants' steering strategy did not solely rely on compensatory steering mechanisms to steer through the slalom, but also involved an anticipatory open-loop mechanism. This visual behaviour has also been referred to as 'gaze polling' (Wilkie et al. 2008) and 'dual-sampling strategy' (Land 1998).

The **differences between adults and children** reported in the current studies also can be related to the gaze constraints model. Children process information more slowly (Fry & Hale 2000; Kail & Salthouse 1994), and have a lower visual working memory capacity (Riggs et al. 2006). Therefore, children most likely have more limited attentional resources and will reach the limits of their attentional resources more easily. Furthermore, children also have difficulties to distinguish between what is relevant and irrelevant on the road (Whitebread & Neilson 2000; Foot et al. 1999). As a consequence, children might not only have to deal with an information overload due to their limited attentional resources, but also due to a failure of giving adequate priority to relevant features (Whitebread & Neilson 2000; Foot et al. 1999).

To test this model more thoroughly **future research** should manipulate both the need for compensatory closed loop control and the need for anticipatory open loop control. In addition, the subdivision of the compensatory closed-loop control into instantaneous and pursuit control should be further investigated. One way to investigate these suggestions is to occlude the regions where the information for these mechanisms is believed to be found. Another way however, is to investigate whether the different control mechanisms evoke neural activity in different regions in the brain (Billington et al. 2013; Billington et al. 2010).

3.4. The gaze constraints model and general traffic behaviour

The constraints model of steering behaviour approaches visual behaviour from a lane keeping perspective. Obviously however, traffic behaviour is much more than only lane keeping, and gaze is used for many different purposes in traffic situations. Of all the tasks required for safely steering a vehicle, **hazard perception** is probably the most extensively studied (Rosenbloom et al. 2011; Wetton et al. 2011; Underwood et al. 2011). Studies have argued that there is an important dissociation between the driving tasks of hazard perception and lane keeping (Horrey et al. 2006; Summala et al. 1998), and therefore, vehicle guidance in a traffic situation involves constantly multitasking between lane keeping and hazard perception (Lehtonen et al. 2012; Salvucci & Taatgen 2008). However, hazard perception is the ability to detect and interpret hazardous situations unfolding on the road ahead, which enable early anticipation (Wetton et al. 2011). Perceiving a possible hazard can therefore be seen as an anticipatory cue that will lead to a change of the desired path. This process of using information of the forward scene to plan a desired path is exactly what was defined as the anticipatory open-loop control of steering by Donges (1978). Regarding the gaze constraints model, hazard perception could therefore be considered as anticipatory open- loop control.

Other tasks that are carried out simultaneously with steering a vehicle, such as talking, listening to music, configuring a GPS, etc., all occupy a part of the attentional resources. From the perspective of traffic safety, these tasks can be classified as **task-irrelevant**. Therefore, these tasks should be the first to be discontinued when task demand threatens to exceed the individual’s capacity. Unfortunately, a failure to recognize or anticipate an impending increase of the task demand is often the cause of accidents (Mcknight 2003).

With regard of the **SEEV-model,** the top-down factors that determine the direction of gaze (Expectancy & Value) could be regarded as constraints that either benefit or inhibit gaze for compensatory or anticipatory steering control. The two bottom-up factors (Saliency and Effort) then determine the exact location of gaze. In a broader view on traffic behaviour however, the top-down factors do not only determine if compensatory or anticipatory information is looked for, they also determine to which task attention is directed. **Situation awareness** could then be seen as having a holistic view on all current traffic, and non-traffic related tasks.

4. Gaze behaviour of cycling children

A second important part of this thesis was to focus on the differences in visual and steering behaviour between experienced adult bicyclists and young learner bicyclists. All tests were carried out with both adults, and six to twelve year old children, except for the curvature steering test. In general, **cycling speed** of the children was lower than that of the adults. However, this is most likely largely due to the smaller bicycles that children used. Nevertheless, it is also possible that children adopted lower cycling speeds to compensate for their lower capabilities.

When cycling on **narrow lanes** (paper 3), children were not found to make more steering errors, and no general difference in visual behaviour was found either. Furthermore, with increasing lane width and cycling speed, children made the same shifts of visual gaze direction as the adults. For this simple precision steering task, children seemed to be able to adopt a similar visual-motor strategy as adults. When cycling in an **actual traffic environment** (paper 7) however, children spent more time looking at the surrounding environment and less to the path itself. Although children also made a shift of visual attention from the surrounding elements to the path region when cycling on a low quality path, they still paid more attention to the scenery, and less to the cycling path than the adults. This is in line with the findings of road crossing studies, that children fail to distinguish between relevant and irrelevant features, and fail to give priority to relevant features even when the task demands it (Foot et al. 1999; Whitebread & Neilson 2000).

During the **slalom** test, few distracting elements were present, and no difference in 'task-irrelevant' gaze was found between the adults and the children. Instead, the task demand was manipulated by making the slalom more difficult. Children made more errors as the slalom was more demanding, whereas none of the adults made any steering error. Since smaller bicycles are usually also more agile than large bicycles, the difference in number of steering errors is not likely to be due to the difference in bicycle size. Children were found to adopt a different visual behaviour, characterized by a focus on the upcoming cone, whereas adults looked at the functional space between the upcoming and the next cone. Furthermore, adults also tended to make more use of anticipatory fixations than children. These differences in visual behaviour suggested that children steered from one cone to another, while adults planned the their steering action ahead. From child to adult bicyclist, there seemed to be a gradual change from a simple and rigid visual-motor strategy, to a flexible, more holistic strategy to guide steering.

4.1. Constraints approach

The **individual constraints** were apparent when the visual behaviour of young and adult bicyclists were compared. Since the executive functions of 6 to 12 year old children are not mature yet (Schiebener et al. 2014; Best & Miller 2010), children have to adapt their perceptual-motor behaviour to their capabilities. The differences in visual behaviour between adults and children described in the current thesis, are most likely a reflection of these cognitive constraints. Next to cognitive constraints however, children also have to deal with different physical constraints. Since children are smaller than adults, they use smaller bikes and have a lower eye level than adults.

In an actual traffic setting with many distracting stimuli, children seemed to be more distracted by task-irrelevant stimuli than adults. This suggests that children might be more susceptible for **environmental constraints** than adults. Surprisingly, the low quality road had a similar effect on both the visual behaviour of adults and children. However, the presence of distracting elements does not immediately affect the cycling task whereas the different road surface does. Correspondingly, manipulating the **task constraints** led to similar changes in gaze and steering behaviour in both adults and children.

In general, it seems that children's visual behaviour changes in a similar way to changing task constraints as the visual behaviour of adults. Due to the cognitive and physical constraints however, children have less attentional resources and apply it less efficiently.

4.2. The use of peripheral vision and gaze polling

Although there are no age differences in the detection of stimuli using peripheral vision (Cohen & Haith 1977), it has often been suggested that children make less use of their peripheral vision to guide their actions than adults (Franchak & Adolph 2010). In both paper 5 and 7 of the current thesis, it was suggested that children also might make less use of their peripheral vision than adults to guide steering. To compensate for a lack of peripheral information, making more and shorter fixations would be a logical solution. Unfortunately, since children have lower processing speeds, they are usually not yet able to efficiently make 'quick checking fixations' (Whitebread & Neilson 2000).

Peripheral vision and 'gaze polling[10]' have often been indicated as two important visual mechanisms for efficient steering (Wilkie et al. 2008; Crundall et al. 2002; Summala et al. 1996). If these two visual mechanisms indeed are lacking in children, this would be an important limitation in their visual information processing system regarding traffic behaviour. Unfortunately the use of peripheral vision to guide bicycle steering was not tested in the current thesis. Nevertheless, findings of paper 5 are in line with the suggestions that children make less use of short anticipatory fixation.

4.3. Visual behaviour of children and the current models for steering behaviour

The visual-motor behaviour of children is in line with in the **constraints model** proposed in the current thesis. It can be assumed that children's information processing capacities[11] are not mature yet (Chihak et al. 2010). Therefore, the total attentional resources[12] of young

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[10] Also referred to as anticipatory fixations

[11] The rate at which information can be efficiently processed

[12] The amount of attention that can be distributed over the multiple stimuli and/or tasks

bicyclists is lower than that of adults. When task demand is low, such as in paper 3, this will hardly have any effects on the gaze and steering behaviour of children. In a more demanding task such as steering through a slalom however, the attentional resources of children are under pressure. Therefore, the children will not have the attentional resources to direct their attention to both compensatory (the first cone to be dealt with), and anticipatory information sources (the next cones). As a result, children will mainly focus on one task at the time, and disregard anticipatory information. Adults on the other hand, can divide their attention between compensatory and anticipatory cues more easily. In the slalom test this was achieved by using more anticipatory fixations, and probably also by using peripheral vision more efficiently. In line with the model, changes in the task demand had a similar effect on the need for anticipatory and compensatory information for both adults and children.

Since children fail to distinguish between relevant and irrelevant features, and fail to give priority to relevant features (Foot et al. 1999), the presence of distracting stimuli could be an additional problem for children. Whereas adults will look at task-irrelevant stimuli using spare attentional resources, children might look at task-irrelevant stimuli at the expense of compensatory and/or anticipatory information. Regarding the **SEEV-model**, children's gaze behaviour might be guided more by bottom-up factors (Saliency and Effort), than by top-down factors (Expectancy and Value), compared to the adults. Due to these limitations in information acquisition and processing, valuable information might be missed, leading to a poor **situation awareness**. In turn, this could be the cause for the inappropriate gaze behaviour of young learner bicyclists.

4.4. Summary

The current experiments were the first to describe the visual control of bicycle steering in young learner bicyclists. The findings suggest that due their limited information processing capacities and attentional resources, children adopt a different visual behaviour while bicycling in a complex environment. Children were more easily distracted by task-irrelevant stimuli, and were less able to anticipate on future steering actions. However, similar to adults, children also adapted their visual behaviour to changing environmental and task constraints.

These findings suggest that in a more complex situation, the steering task is more demanding for children than for adults, and that children will cope with this by adopting a different gaze behaviour at the expense of anticipatory gaze behaviour. However, this might be at the expense of their situation awareness. In the current studies missing anticipatory information and having a poor situation awareness could only lead to steering next to a cone, at worst. If anticipatory clues would be missed in an actual traffic situation however, this could have far worse consequences.

5. Limitations

5.1. Eye movement methodology

Eye movements were used as the main measure in the current thesis, and in a first section of the general discussion we already discussed some of the advantages and disadvantages of head mounted eye tracking methodology. However, studying gaze behaviour might not always be the best way to study visual information processing. The differences in visual behaviour between adults and children in current thesis are believed to be mainly the result of developing cognitive functions. It would therefore be interesting to test these functions together with perceptual and motor behaviour. Other experimental methods such as occlusion and distorted vision could also shed more light on how visual information is processed and used for steering control. The constraints model implies that different sources of information can serve different control mechanisms (compensatory vs. anticipatory). Recent tests that measured brain activity during simulated steering tasks confirmed these suggestions (Billington et al. 2013). Combining eye movement research with brain activity can shed further light on how visual information is processed into steering commands.

Furthermore, the use of eye movements as a measure always leaves some important questions unanswered. Since only foveal vision is measured, it is difficult to estimate to what extent participants made use of peripheral information. Studies have shown that peripheral vision is of great importance for locomotion, therefore the use of peripheral information in young and adult bicyclists should be further tested.

5.2. Isolated steering tasks

In the current thesis, the different steering tasks were isolated on purpose to limit the presence of distracting elements. Although the outdoor tests suggest that the visual behaviour described in the indoor tests is transferable to actual traffic situations, this was only tested for cycling on a straight cycling track, separated from other traffic. It would be interesting to test steering behaviour on a more complex route including winding roads, different surfaces, different environmental settings, etcetera.

Furthermore, as was mentioned before, the current thesis only focussed on the steering task. In actual traffic settings, this is only one of the many tasks that have to be dealt with. Nevertheless, the findings of current studies provide valuable insight in how visual behaviour in function of the steering task is constrained. Future research should combine this steering task with other tasks such as hazard perception, synchronizing with other traffic participants, in-vehicle technology tasks, etcetera.

5.3. Development of visual behaviour

The young participants in current studies ranged from 6 to 12 years old. Since the cognitive functions are still developing during this period, there might have been considerable differences among the children. The subdivision within the children made in paper 5, supports the idea that some children already showed more adult-like perceptual-motor behaviour than others. Unfortunately, the sample sizes were too small to divide them into smaller age groups. Furthermore, as was shown in the introduction, elder bicyclists are also overrepresented in accident statistics. Since information processing capacity declines after adulthood (Kail & Salthouse 1994) elder bicyclists might have similar problems with complex traffic situations as children. However, in contrast to children, elder bicyclists have a lot of traffic experience to rely upon. It seems therefore advisable for future research to focus on larger groups ranging from young learner cyclists to older experienced cyclists, and investigate the link between the development of the cognitive functions and perceptual-motor behaviour in traffic.

5.4. Personal factors affecting visual-motor behaviour

The current studies were the first to explore the role of visual behaviour in the steering control of bicyclists and might serve as reference values for future experiments involving learner and adult bicyclists. However, the results might have been confounded by some other factors than the imposed conditions and the differences in age.

The **smaller bicycles** used by the children not only led to lower cycling speeds, but also to a lower eye level for children. This evokes a slightly different view on the environment and could have contributed to the differences in visual behaviour. Among adults, a different saddle height could also have led to a different head inclination, and therefore to a different visual behaviour. To make the visual-motor experience the same for all participants, the experimental setting and bicycle size should be scaled to the participant’s height. Alternatively, experiments could be carried out in a bicycle simulator which could provide identical stimuli for both adults and children.

Zeuwts et al. (2014) showed that there is a correlation between the cycling skills and the **general motor competence** of 9-year-old children, and suggested that **BMI** might be negatively associated with the development of cycling skills in children. Moreover, **environmental and psychosocial factors** have often been shown to determine the likelihood of choosing the bicycle for transportation (de Geus et al. 2008; Ducheyne et al. 2014). It seems likely that these personal characteristics not only affect cycling experience and cycling skills, but in turn also the visual-motor behaviour during cycling.

Since both the adult and the young participants were convenience samples recruited from colleagues, friends, family and neighbouring schools, the subject sample was rather homogenic. Adults were recruited from the department of health and movement sciences. Their **level of physical activity** was therefore most likely higher than the average in Belgium.

Regarding the children, most of them were recruited from friends and family of employees at the university. It is therefore likely that this sample of participants was biased towards higher levels of **socioeconomic status**. These samples of participants might have had more cycling experience and/or better access to bicycle facilities than the average population, which in turn could have affected their visual-motor behaviour while cycling. Therefore, the selection bias of adults and children who participated in the current experiments might have biased the results. It is advisable to take these and other personal characteristics into account in future research.

6. Practical implications

Although the current work focussed on only one element in traffic behaviour (lane keeping), the findings also have practical implications for traffic safety in general. In this section we discuss how the current findings can add to the three E's of injury prevention (i.e. Enforcement, Engineering and Education), and elaborate on how current findings can be of use for future research.

- **Enforcement**

Current findings suggest that learner bicyclists lack the cognitive skills necessary to focus on the appropriate information, and to process it efficiently into adequate steering responses. Unfortunately, based on the current results it is difficult to say to what extent cognitive functions such as attention and processing speed should be developed in order to behave safely in traffic. If the development of these functions could be linked to the development of cycling skills and traffic behaviour, these might serve as a **guideline** for when parents could let their children cycle independently. Likewise, investigating the decline of these cognitive functions in elder bicyclists might also provide insights into why this group is accident prone.

Furthermore, the findings emphasize that it is indeed necessary to adapt traffic rules to children. Especially in regions such as schools and playgrounds, **traffic rules** should take the limited capabilities of children into account. Slowing down other traffic, separate the car traffic from pedestrians and cyclists with (natural) barriers, and easy to understand traffic rules are advisable in these areas.

- **Engineering**

The visual behaviour of both adults and children was strongly dependent of task, and environmental factors. At complex intersections, it is therefore important to keep the task and environmental constraints as low as possible. This way the task demand of lane keeping is kept to a minimum, and attention can be devoted to scanning the environment for hazards and/or other important information (such as traffic signs). In practice, this implies that on complex intersections, road quality should be high, cycling speed reduced, and light conditions optimal. Tram tracks at bicycle crossroads, for example, could possibly distract the bicyclists from upcoming traffic, and hinder the perception of anticipatory cues.

That bicyclists were also found to direct most of their attention to the inner edge or middle of the road while cycling a bend suggests that they have few spare attention to direct to the environment. Detecting traffic lights and signs in, or immediately after, a sharp turn might therefore be problematic. These constraints on visual behaviour should therefore be taken into account when designing new **road infrastructure**.

- **Education**

When confronted with challenging steering tasks, children adopt a different visual-motor strategy. Since this is probably due their **limited capabilities**, it is important that traffic education acknowledges these limitations. It might be better to teach alternative visual-motor strategies to children as long as they are not able to imply adult-like visual-motor strategies efficiently. Children should therefore be encouraged to adopt simpler and safer visual-motor strategies, characterized by simple step-by-step actions.

However, it is still likely that children also make hazardous decisions because of a **lack of experience** in traffic situation. The current work only investigated visual behaviour in function of lane keeping. Regarding hazard perception, children might be able to detect cues as fast as adults, but might lack the experience to do so, and to interpret the information adequately. Hazard perception tests for bicyclists (such as in appendix A), could provide valuable insights into the situation awareness of children. These tests might lead to innovative traffic education tools such as hazard perception games.

- **General implications and future research**

As was mentioned before, the **methodological** study done in the current thesis can be of use for other researchers. The fixation-by-fixation analysis method was proposed as a quick-and-dirty method to obtain general distribution of visual attention. Faster analysis methods allow researchers to analyze more data, and therefore contribute to the insights into visual behaviour during various tasks. Nevertheless, to guarantee the control of external variables, many experiments are still conducted using video stimuli and remote eye trackers instead of head-mounted eye trackers. The validity of these video-based experiments should be further tested in similar ways as was done by Foulsham et al. (2011) and Dicks et al. (2010). Furthermore, with improving eye-tracking technology it should be possible to **measure actual gaze distance**. This could provide a more accurate measurement of look-ahead distance.

There is still few knowledge about the visual behaviour during **other traffic tasks** such as hazard perception. However, future research should not only focus on investigating single traffic tasks, but also the integration of multiple tasks. In traffic situations, lane-keeping, hazard perception, navigation, etcetera, are often carried out simultaneously. Therefore, being able to efficiently multitask is an essential aspect of safe traffic behaviour. Nevertheless, the current findings already provide insights into how gaze is distributed during different bicycle steering tasks, and how it changes with different constraints. Future research should investigate how these lane keeping tasks interact with other traffic tasks.

Whereas the current work focussed on visual information, this is not the only source of information in traffic. Auditory signals can also provide important anticipatory cues, but can also be a source of distraction. Unfortunately, the **integration of multiple sensory stimuli** in traffic environments is poorly documented. A focus on the integration of visual and auditory stimuli could shed more light on the issue whether listening to music reduces the alertness to other important cues.

In general, bringing together the visual behaviour during walking, biking and car driving added to the general understanding of the visual control of locomotion. We suggested that the strategy that is used to **detect heading direction** (egocentric or optic flow strategy) might determine the preferred direction of gaze. More insights into how heading direction is determined during various traffic tasks might clarify the visual behaviour of car drivers and bicyclists when steering through a curve.

Finally, the **constraints model** that was proposed could be used to predict how various factors will affect the visual behaviour of traffic participants. Nevertheless, further testing is necessary to assess the validity and usability of this model.

7. General conclusion

In general, the current thesis provides insights into how visual attention of young and adult bicyclists is distributed during different steering tasks, and how this is affected by individual, task, and environmental constraints. Based on the current results, a gaze constraints model for steering was proposed. Furthermore, it seems that children adapt their visual behaviour to their limited capabilities, but that children’s visual behaviour changes in a similar way to changing task constraints as the visual behaviour of adults. These findings suggest that traffic rules, road infrastructure and traffic education should take the limited capabilities of children into account. However, it should be noted that this work only focussed on the lane-keeping task. Future research should therefore study the integration of these findings in the visual control of other traffic tasks such as hazard perception. A better understanding of the development of information processing of young learner bicyclists could potentially lead to better traffic education and more appropriate road infrastructure.

Additionally, a new fixation-by-fixation analysis method to analyze head-mounted eye tracking data was tested in this thesis. This method was found to be a good alternative to the time-consuming frame-by-frame method, provided that the areas of interest were large, and the analysis is done over an extended period of time.

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Link to scientific profiles :

Google scholar : http://scholar.google.be/citations?user=jwIWNIsAAAAJ&hl
On 06-05-15: 18 publications, 27 citations, h-index = 2, i10-index = 1

Research Gate : https://www.researchgate.net/profile/Pieter_Vansteenkiste
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Appendix A

A first step towards a hazard perception test for bicyclists

A HAZARD-PERCEPTION TEST FOR CYCLING CHILDREN : AN EXPLORATORY STUDY

Vansteenkiste P, Zeuwts L, Cardon G, Lenoir M

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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, a first hazard perception test for bicyclists has been developed and tested on 27 adults and 21 children of ± eight year old. The test consisted of three sections in which visual behaviour, environmental awareness, and risk perception and reaction time were measured. Children were found to perceive, interpret, and anticipate to, hazardous traffic situations differently than adults. The lack of mature perceptual-cognitive skills might contribute to the overrepresentation of children in accident statistics. Unfortunately, the development of these skills in function of safe traffic participation is still poorly documented. We discuss how the use of hazard perception tests for bicyclists could contribute to this domain.

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 as 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 some 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, 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 adapt simpler strategies when confronted with complex situations (Day 1975; Berard & Vallis 2006; Ampofo-Boateng & Thomson 1991; Pryde et al. 1997). Although these perception-action strategies might contribute to the higher accident proneness of children, they have not yet been described for cycling.

In car driving, learner and newly qualified car drivers have also been identified as a higher risk group for traffic accidents (Pollatsek et al. 2009; Fisher et al. 2006). In contrast with 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 the hazard perception tests showed that experienced drivers detected hazardous situations faster and show shorter reaction times to these hazards (Huestegge et al. 2010; Chapman & Underwood 1998; Underwood et al. 2011). 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 which describes how individuals create understanding of what is going on around them (Endsley 1995; Salmon & Stanton 2013; Vlakveld 2011). According to Endsley (1995), there are three levels within situation awareness which are interrelated. Level 1 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 2 is the comprehension of the current situation. The cyclist relies on long-term memory knowledge to interpret the stimuli in the environment. In the long-term memory, knowledge is stored in schemata or mental models. Schemata offer a more coherent and organized framework for information processing which develop from experience. In addition, mental models are more complex schemata to model the behaviour of systems. The last level describes the ability to predict the future actions of the elements in the current situation. Level 3 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 1 SA, 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 accident 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 differently 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 into 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 designed infrastructure.

In the current study, we explore how a hazard perception test can contribute to the knowledge of the development of perceptual-cognitive skills of learner cyclists such as visual attention and judgement of traffic situations. A hazard perception test for cyclists was developed in which multiple aspects of traffic related cognitive skills were investigated. The exploratory results are discussed, and the usability of the hazard perception test was evaluated.

METHODS

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, and based on video quality and the type of traffic situation that was filmed, 34 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 videos were corrected for vibrations using the video stabilizing 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. 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 a question about the video fragment after each clip. This question could be traffic related (e.g. what traffic sign did you see?) or non-traffic related (e.g. which animal did you see?). 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. Although anticipation is beyond the concept of situation awareness, the second and 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).

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 Ghent University ethical committee, and completed the test in the Ghent University campus of Physical Education. The children were recruited via an elementary school nearby Ghent 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.

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 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

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 cycle 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.

	Age (y)	min.	max.	Accuracy X (°)	Accuracy Y (°)	TR (%)
Adults	21,65 ± 1,93	18	25	0,44 ± 0,11	0,41 ± 0,10	92,87 ± 3,72
Children	8,36 ± 0,50	8	9	0,34 ± 0,08	0,39 ± 0,09	89,61 ± 4,46

Table 1 : Age, horizontal and vertical eye tracking accuracy, and tracking ratio (TR) of the adults and children

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 Fig. 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.

Procedure

At arrival, participants were informed about 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 had live feedback on the position of the participant relative to the eye tracking device 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. Participants could ask for a break at any moment, but none of them did. The whole experimental procedure took 30 to 40 minutes per participant.

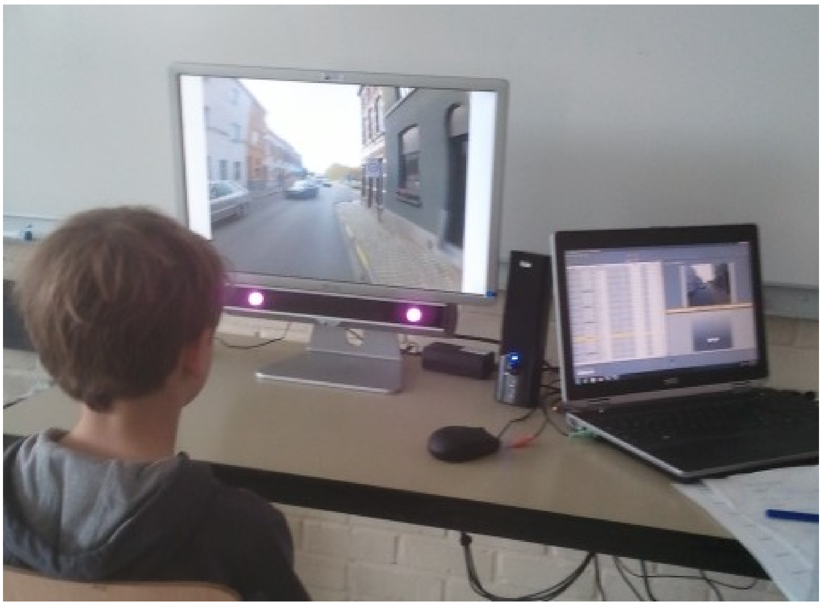

Figure 2 Experimental set up. Red dots on the eye-tracker are infra-red lights, and cannot be seen by the participant

ANALYSIS

The number of fixations made by children and adults was calculated for each of the 34 clips, and for the average of the whole test using the 'SMI Event Detection' algorithm. For each video clip, potential sources of important visual information were determined. These were then appointed as Areas Of Interest (AOIs) using the dynamic AOI editor of the gaze analysis software BeGaze 3.4 (SenoMotoric Instruments, Teltow, GER). 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.

For each clip the number of fixations in each AOI, and the dwell time percentage towards the AOIs, were compared between children and adults. To compare the gaze behaviour to the different AOIs between children and adults across the whole test, the AOIs that frequently recurred were averaged over the whole test. These AOIs were 'road', 'other cyclists', 'pedestrians', 'cars', 'traffic signs' and 'traffic lights'. These AOIs were appointed as areas of interest in respectively 20, 17, 12, 19, 12 and 5 clips out of the 34 clips.

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', and can be compared to the first level of situation awareness, (Ensley 1995). The percentage of correct answers was also calculated for traffic related (4/9), and non-traffic related (5/9) clips separately.

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 a 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.

Finally, the results of the reaction time relative to the start of the clip were exported to Excell and analyzed per clip and on average. Since participants did not always respond to each hazard, a response rate was calculated per participant (#reactions/#hazards). After Reaction time data of three adult participants were lost during the analysis. All comparisons between adults and children were done using independent samples T-tests. Significance level was set at $p \leq 0.05$.

RESULTS

Gaze behaviour

There were two clips in which children made significantly more fixations than adults, and two clips in which children made significantly less fixations than adults. No significant difference was found in the total number of fixations made throughout the hazard perception test ($t = 0.406$; $p = 0.688$).

The results of the analysis per AOI can be found in Table 2, an overview of the gaze distribution across the AOIs for children and adults can be found in Figure 5. In general, independent samples T-tests showed that children tended to make more fixations to traffic signs (t = -1.905; p = 0.081) than adults, and spend more time watching them (t = -1.986; p = 0.071). However, these differences did not reach significance in any of the 12 clips where the traffic signs were appointed as an AOI. On average, adults were found to make more fixations to the cars (t = 2.155; p = 0.041), but the difference in dwell time percentage did not reach significance (t = 1.887; p = 0.070). No significant difference in number of fixations or dwell time % was found for the AOIs 'road', 'pedestrians', 'cyclists' and 'traffic lights'.

A significant difference in number of fixations and/or dwell time percentage was found for some AOIs which only appeared in one clip as well. Adults had a higher number of fixations and dwell time percentage towards some billboards in one of the clips in the second part of the test. Also in the second part of the test, children had higher dwell time percentage to the fair in one clip and to a horse in another clip. However, this was not accompanied by a significantly higher number of fixations. Finally, also in the second part of the test, adults had a higher number of fixations to the pedestrian crossings.

Table 2 number of fixations and dwell time percentage per AOI

AOI	Signs	Road	Pedestrians	Cyclists	Cars	Lights	Total
# clips with AOI	12	20	12	7	19	5	34
Average # fixations	**				**		
Adults	1,00 ± 0,38	9,69 ± 4,01	5,95 ± 1,19	3,92 ± 1,10	6,6 ± 1,72	2,54 ± 1,62	18,01 ± 3,01
Children	1,59 ± 0,99	9,81 ± 3,87	5,54 ± 1,30	3,74 ± 1,09	5,36 ± 1,02	2,75 ± 1,28	17,58 ± 2,28
# sign. clips	0/12	2/20	0/12	1/7	5/19	0/5	4/34
Average dwell time %	**				*		
Adults	2,06 ± 0,74	19,79 ± 6,07	13,91 ± 2,87	7,47 ± 2,17	11,92 ± 2,94	8,85 ± 1,66	/
Children	3,40 ± 2,16	19,15 ± 7,39	13,98 ± 2,27	7,83 ± 1,71	9,83 ± 2,77	9,27 ± 1,39	/
# sign. clips	0/12	1/20	2/12	1/7	4/19	0/5	/

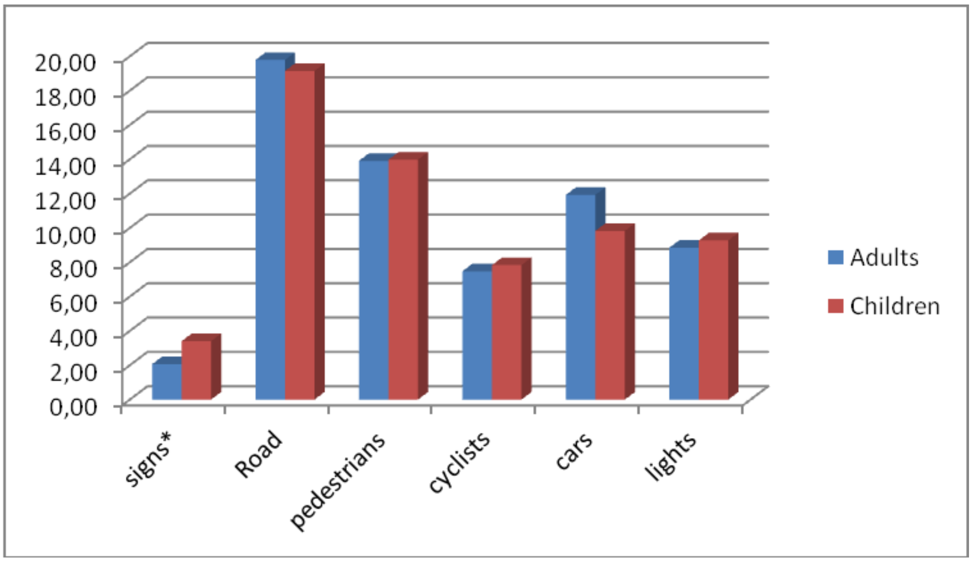

Figure 3 : Dwell time percentage of children and adults per AOI

Environmental awareness

Overall, adults answered 59 ± 14% of the questions correctly, compared to 52 ± 15% for the children, but this difference was not significant (t = 0.805; p = 0.218). However, adults tended to answer the non traffic related questions better than the children (65 ± 26% and 45 ± 24%, respectively; t = 1.975; p = 0.059).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 = -0.693; p = 0.494).

Risk Perception and reaction time

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 = -2.031; p = 0.053). This difference was most pronounced in the four least ‘hazardous’ situations (1.43 ± 1.13 vs. 0.68 ± 0.72, respectively; and t = -4.028; p < 0.001) than in the ten others (2.16 ± 1.32 vs. 1.95 ± 1.14, respectively; and t = -1.084; p = 0.288).

Children reacted on as many hazardous situations as the adults (70 ± 16% and 71 ± 16%, respectively; t = 0.161; p = 0.874). 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 0.927 seconds earlier in the adult group than in the children group (t = -3.883; p = 0.001).

DISCUSSION

In the current exploratory study, the visual behaviour, environmental awareness, risk perception, and reaction time to hazards, of young inexperienced bicyclists and adult experienced bicyclists were investigated using a hazard perception test. 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.

Gaze behaviour

There were no differences in the total number of fixations made by children and adults, but children tended to direct their attention to different regions than adults. Children seemed to spent more 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. 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 more time watching the traffic signs that adults. Alternatively, the longer dwell time percentage to the AOI ‘traffic signs’ could also indicate that the children needed more time to process the relevant information.

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 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. 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 reflects in less well 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 accidents (LandTransport, 2005, in:(Bao & Boyle 2009). The finding that children’s gaze tends to be biased towards traffic signs instead of to other road users is in line with the suggestion of Zeedyk et al. (2002), that the visual search of children tends to be inadequate.

That few other differences in gaze behaviour between the young and adult bicyclists were found 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. 2012; 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 scan the environment more 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.

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.

In 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. 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. Nevertheless, information about the visual behaviour of children and adults could shed light on underlying cognitive processes. 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 for cyclists 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. Furthermore, 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.

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 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)(REF slalom). 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.

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 insecurity 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 differ in the first level of situation awareness, but also in the second : 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 (Vlakveld 2011; Crundall et al. 2012). Therefore, future tests in risk perception (or more generally situation awareness) in children, should make a distinction between different types of hazards (Vlakveld 2011).

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 reacted on as many hazards as 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.

Whereas adults did not react more often to hazards than children, they did react systematically earlier. 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 SA does not include anticipation, it precedes decision-making and action guidance (Endsley 1995). As children reacted slower for hazardous situations this might be explained by less developed schemata. Therefore children only reacted when cues became more salient. In addition, schemata are tied to scripts which is are type of schemata. Scripts support decision-making and provide sequences of actions which improves with experience. Experience tightens the ties between scripts and schemata resulting in more automated reactions (Endsley 1995; Salmon et al. 2014). However, additionally to a lack of experience, children also do not have matured perceptual-cognitive skills yet. 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 to reporting only differences in reaction time, a hazard perception score for each video clip can also be calculated based on the reaction time within a response window. 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. and when young and adult cyclists are tested, a general test score can be provided for each age group. However, since the perceptual-motor skills of children are not fully mature yet at the age of eight, a simple reaction time test should be added to the experiment to control for individual and physiological differences in reaction time (Vlakveld 2011). 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.

Conclusion

To our knowledge, this is the first study to explore the differences between experienced adult bicyclists and inexperienced young bicyclists using a hazard perception test. The results of current exploratory study suggest that children lack perceptual and cognitive skills in all three levels of situation awareness which resulted in longer reaction times for dangerous situations (Endsley 1995). Children look at different regions and seem to be less aware of the elements in the environment (perception), they interpret traffic scenarios differently (comprehension), and they fail to predict how situations develop (projection). Therefore children only react when dangerous events become unavoidable and miss the chance to anticipate which might result in an accident. The slower reaction times also reflect 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, 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 into 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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Appendix B

Cycling a curve with manipulated look-ahead distance

Abstract for special edition of Journal of Vision

Abstract for special edition of Journal of Vision

Scene Perception from Central to Peripheral Vision

Vansteenkiste Pieter, Van Hamme David, Veelaerts Peter, Cardon Greet, Lenoir Matthieu

Corresponding author:
pieter.vansteenkiste@ugent.be
Department of Movement and Sports Sciences,
Ghent University,
Watersportlaan 2,
9000 Ghent, Belgium
Tel: +32 (0) 9.264.86.83

Cycling a curve with manipulated look-ahead distance

INTRO. In car driving, it is believed that a near region provides position in lane information, and that a far region provides anticipatory information. Therefore, when only the far region of the road is visible, steering is smoothly matched, but the vehicle's lateral position is not well maintained. When only a near region is visible on the other hand, position in lane is maintained quite well, but steering is described as 'jerky' (Land & Horwood 1995; Cloete & Wallis 2011; Frissen & Mars 2013). However, these assumptions have only been tested using occlusion paradigms. Since locomotion often makes use of peripheral vision, it is unclear to what extent a manipulated gaze to the near region will affect steering behaviour. In the current study we tested to what extent steering was affected when gaze was restricted to the near region without occluding the far region.

METHODS. Eighteen bicyclists cycled a semicircular lane at a speed of about 14km/h, under four gaze conditions. Once with unrestricted gaze behaviour, and once with gaze restricted to a laser point projected 1.5, 3.5, and 5m ahead. These fixed gaze points provided a visual buffer of ±0.40, 0.90 and 1.30 seconds, respectively. Task load (NASA-TLX) and steering behaviour (cycling speed, mean lateral deviation, SD on lateral deviation, and number of steering wheel reversals) were measured and compared for each gaze condition.

RESULTS. Task load was highest in the near gaze condition and lowest in the free gaze condition. Similar to the steering behaviour described when the far region is occluded, the participants in the current study steered more towards the outside edge of the lane when gaze was directed closer to them. However, in contrast to previous studies, the steering behaviour was not found to be more 'jerky' when gaze was directed close to the participants.

CONCLUSIONS. The results of the current study suggest that peripherally perceiving the road ahead can contribute to the steering system.

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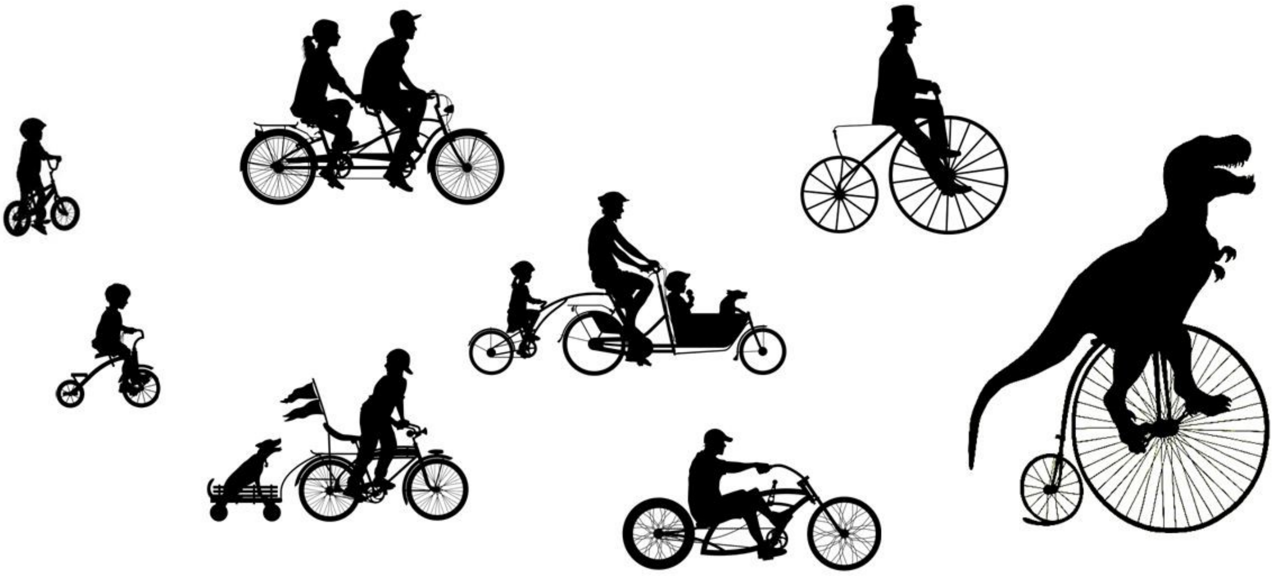
Dankwoord



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Een toen vrij onbewuste, maar heel belangrijke beslissing in mijn leven was om te beginnen volleyballen. Nu, ongeveer 20 jaar en enkele kampioenenvieringen later, speel ik nog steeds met volle goesting volleybal bij Marke-WeBis. Ik heb reeds heel veel plezier gehad en onvergetelijke momenten beleefd zowel tijdens als na de trainingen en wedstrijden. Maar aangezien er te veel namen zijn om op te noemen, iedereen bij Marke-WeBis: bedankt voor alle fantastische jaren!

Volleybal heeft me ook niet alleen naar Marke-WeBis geleid, maar ook naar volleybalkampen en stages, waar ik ook stuk voor stuk goede herinneringen aan overhoud. Via deze stages leerde ik ook Karel kennen, die al snel een van mijn beste vrienden werd. Hij overtuigde mij om samen met een zekere Luca op reis te gaan. Het werd een tiendaagse reis in Noord-Frankrijk, waarbij we toch minstens 6 dagen na elkaar mossels met frieten gegeten hebben en waarbij we ons vooral dik geamuseerd hebben. Mossels hebben we sindsien niet meer gegeten (wordt wel eens tijd), maar het amusement is zeker gebleven. Dus ook voor Karel en Luca: merci e.

Ondertussen was ik zogezegd ‘volwassen’ geworden en was ik rijp om nog een stap verder uit het familienest te zetten. Ik koos voor hetzelfde pad als dat van mijn broer en ging LO gaan studeren in Gent. Een keuze die ik mij zeker niet beklaagd heb. Ik heb prachtige herinneringen aan de weekends, (ski)reizen, natuurgebonden stage, sportlessen, feestjes en zelfs aan creatieve danslessen, die ik heb meegemaakt gedurende deze vier jaar. Helaas zien we elkaar de laatste jaren wat minder, maar ik hoop dat er binnenkort weer wat meer BBQ’s, housewarmings en trouwpartijen zullen zijn. Zo kunnen we snel weer goede herinneringen ophalen, en plannen maken om weer meer af te spreken. Aan alle LO’ers, bedankt voor een prachtige 4 jaar !

Na mijn studies had ik het geluk om de kans te krijgen om nog eens 4 jaar op het HILO te blijven. Ook als doctoraatsstudent bleek het HILO een heel aangename plaats te zijn. De lange uren achter een PC werden veel dragelijker door koffiepauzes en sporadische middagsporten met meer dan aangename collega’s. De HILO-weekends, en het voorbereidend weekend hierop, bewezen telkens dat er toch nog een stukje student in ons schuilde. Ook aan alle collega’s een welgemeende merci voor de afgelopen jaren!

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“Menigeen die het ver gebracht heeft, dankt dit meer aan zijn kennissen dan aan zijn kennis”
(Cees Buddingh)