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Advancing the Age of Cycling

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Advancing the Age of Cycling

Frank Westerhuis

Dit proefschrift is mede tot stand gekomen met ondersteuning van de Rijksuniversiteit Groningen, Royal HaskoningDHV, de Fietsersbond, het Ministerie van Infrastructuur en Waterstaat, Roessingh Research and Development, Indes, IMDI-SPRINT, en ZonMW.

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Chapter 1

General Introduction

1. General Introduction

1.1. Introduction

For many people in the Netherlands, cycling is a natural mode of transport: people from all age groups use the bicycle (CBS, 2018). Indeed, the country has more bicycles than it has inhabitants and it holds the world's largest percentage of trips travelled by bicycle (Harms & Kansen, 2018). It is therefore not surprising that bicycles are used for many different purposes such as travelling to work, to school, to friends and family, or for shopping (Kennisinstituut voor Mobiliteitsbeleid, 2019). In fact, the bicycle is used most for leisure activities, which highlights that people do not only cycle for functional purposes, but also largely for their enjoyment (Harms & Kansen, 2018).

The fact that cycling is a common mode of transportation in the Netherlands has several reasons. For example, the climate conditions are well suited for cycling and the distances between cities or villages are comparatively short (Heinen, Van Wee, & Maat, 2009). The country is also flat with very few hills and, therefore, cycling requires less physical effort compared to locations where cyclists have to travel further or ascend more frequently (Heinen, Van Wee, & Maat, 2009; Parkin, 2004). The Dutch also have one of the most comprehensive and high-quality cycling networks of which large parts are separated from motorized traffic (Pucher & Buehler, 2008; Wegman, Aarts, & Bax, 2008; Schepers, Twisk, Fishman, & Jensen, 2017). Furthermore, other road users seem to be aware of many cyclists being present and they anticipate them, which leads to more considerate and safer behaviour of other road users towards cyclists (Jacobsen, 2003; Schepers, Twisk, Fishman, & Jensen, 2017).

It is well-known that cycling has positive effects on physical fitness (Van den Brink et al., 2005), but it is also beneficial for independent mobility and quality of life (De Geus, Van Hoof, Aerts, & Meeusen, 2008; Oja et al., 2011). Furthermore, the bicycle may be an important means of personal transportation in any phase during life (Schaap, Harms, Kansen, & Wüst, 2015). For example, small children may ride together with their parents on a separate bicycle seat and children learn to cycle at a young age. Depending on the required travelling distance to school, it is estimated that between 29% and 46% of the primary school children in the Netherlands cycle to school and these numbers increase to 77%-90% for secondary-school children (Van Goeverden & De Boer, 2013; Dessing, De Vries, Graham, & Pierik, 2014). In fact, teenagers between 12 and 18 years of age travel on average twice as much distance on the bicycle compared to all other age groups (CBS, 2015). Also during adulthood, the bicycle is used extensively for commuting and leisure. For example, in 2016, 48% of the commuter trips in the city of Amsterdam were made by bicycle (Harms & Kansen, 2018). When advancing into older age and retirement, commuting may make place for longer or more recreational trips while also shorter trips, for example for shopping, could still be performed by bicycle (Kennisinstituut voor Mobiliteitsbeleid, 2017a). Many Dutch people cycle for nearly their entire life and being urged to give up travelling on a bicycle may be a significant loss.

A group that is currently of particular interest for cycling safety is older cyclists (Rijkswaterstaat, 2016). A reason for this is that, although the overall bicycle-use is increasing in all age groups, the number of older adults who are regularly using the bicycle increases more rapidly than the number of younger or middle-aged cyclists (Kennisinstituut voor Mobiliteitsbeleid, 2017b). A key factor for this increase is that the current generation of older people is healthier than earlier generations because of improved health care and a healthier lifestyle in general (OECD, 2001). Furthermore, the technological developments with regard to bicycle designs, in particular the pedal electric bicycle (pedelec), have turned cycling into an activity that requires less physical effort compared to using a conventional bicycle (Theurel, Theurel, & Lepers, 2012; Popovich et al., 2014). Therefore, longer distances are increasingly being travelled with a pedelec (Kennisinstituut voor Mobiliteitsbeleid, 2015). In fact, 18% of all Dutch bicycle trips in 2017 were made with an electric bicycle and people aged over 65 years were responsible for 47% of the total distance travelled with these electric bicycles (Kennisinstituut voor Mobiliteitsbeleid, 2019). This benefits healthy ageing because cycling contributes to health and quality of life by combining mobility with physical exercise (Van den Brink et al., 2005; Vogel et al., 2009, in De Hartog et al., 2010; Oja et al., 2011; De Geus, Kempenaers, Lataire, & Meeusen, 2013). However, cyclists are also vulnerable road users who run specific risks while participating in traffic, and increasing age has been found to be related to a higher accident risk (Martínez-Ruiz et al., 2013; Martínez-Ruiz et al., 2014), increasing chances of falling from the bicycle (Engbers et al., 2018a), and a more severe crash outcome (Siman-Tov, Jaffe, Peleg, & Israel Trauma Group, 2012).

Because safe and independent mobility is crucial for social participation and quality of life (Metz, 2000; Fagerström & Borglin, 2010), being mobile should be sustained for as long as possible. The available forms of mobility should therefore suit the demands of all people irrespective of their age. However, not only the demands (Van Den Berg, Arentze, & Timmermans, 2011) but also the abilities of people change with age and these changes are relevant for cycling (Mori & Mizohata, 1995). Functional abilities that are particularly prone to decline with age are vision, hearing, motor coordination, reaction speed, attention, and also psychogeriatric conditions such as dementia might occur (OECD, 2001; SWOV, 2015). Furthermore, physical factors such as increased stiffness of the neck, muscles and joints, reduced grip strength, and reduced speed of movements are related to an increased risk for traffic crashes (OECD, 2001; Davidse, 2007; SWOV, 2015). Although there is large variance in types and severities of decline that older people may experience (Hayden et al., 2011), the potential consequences of a bicycle crash may be severe: recovery and rehabilitation could be long-lasting and disability might even be permanent (Olkkonen, Lahdenranta, Slätis, & Honkanen, 1993; Abou-Raya & ElMeguid, 2009). It is therefore meaningful to study the effects of ageing and the factors that make older cyclists vulnerable in order to increase the safety of older cyclists and prevent crashes and injuries, which is also a priority of the Dutch government (Rijkswaterstaat, 2016).

Crash statistics in the Netherlands indicate that after a decline for many years, the number of fatal traffic crashes has increased by 10.6% from 2017 to 2018 (CBS, 2019). This increase also included cyclists and relatively many older cyclists are seriously injured due to a bicycle crash, also outside the Netherlands (OECD/International Transport Forum, 2013). Exact statistics concerning bicycle crashes are limited as bicycle crashes with a relatively minor outcome are not or less often officially reported than crashes with a severe outcome (Juhra et al., 2012; Wegman, Zhang, & Dijkstra, 2012; Schepers, 2013). It is estimated that a large proportion of these crashes are Single-Bicycle Crashes (SBCs): crashes where no other road user is involved (Schepers et al., 2015). In 2016, the majority of SBCs in the Netherlands concerned a loss of balance while cycling (62%) or while getting on or off the bicycle (10%), and 17% collided with an object or a person (VeiligheidNL/Rijkswaterstaat, 2017).

Schepers and Klein Wolt (2012) in their literature review found that the majority of SBCs could be divided in infrastructure-related and cyclist-related crashes. Infrastructure-related crashes occur due to the condition of the road surface or the impact caused by an object. In approximately 50% of the SBCs they investigated, the infrastructure was a significant contributor to the cause of the crash (Schepers, 2008; Schepers & Klein Wolt, 2012). Older cyclists are particularly involved in crashes related to narrow bicycle facilities, entering the verge, or colliding with objects or bollards (Schepers, 2008). The SBC-category of cyclist-related accidents concerns crashes due to the cyclist losing control over the bicycle. This might occur, for example, while mounting or dismounting the bicycle, while cycling at low speeds, or when making mistakes or misjudgements (Schepers & Klein Wolt, 2012).

Although the term SBC basically implies that no other road user was directly involved in the crash, this does not mean that there was no influence of another road user on the occurrence of the crash at all (VeiligheidNL/Rijkswaterstaat, 2017). Indeed, recent studies indicated that SBCs may also be related to the behaviour of another road user or could be preceded by an interaction with another road user (Boele-Vos et al., 2017). It is possible, for example, that an approaching cyclist leaves little room for other cyclists and that someone therefore has to change course to prevent a collision and subsequently falls down due to hitting a kerb or an object. Although strictly defined this would be registered as a SBC, it was the behaviour of another road user that triggered the chain of events that eventually ended with a crash.

Different options should be considered that may contribute to the safety of older cyclists and cyclists in general. Interventions could be aimed at behaviour, infrastructure, and the vehicle or bicycle (Schepers, 2008; Wegman, Aarts, & Bax, 2008). In 1992, the Sustainable Safety vision was developed to provide evidence-based input for generating traffic policies in the Netherlands (Koornstra, Mathijssen, Mulder, Roszbach, & Wegman, 1992). The main goal was to design the traffic environment in such a way that the number of crashes will be as low as possible and that serious outcomes of inevitable crashes will be limited. This vision was updated in 2006 and then based on five basic principles: functionality, homogeneity, predictability, forgivingness, and state awareness (Wegman, Aarts, & Bax, 2008).

Since the infrastructure is a critical factor in SBCs (Schepers, 2008; Schepers & Klein Wolt, 2012), one possibility to increase the safety of older cyclists may be by adjusting the infrastructure. For cyclists specifically, a road or cycle path may be made more forgiving if it supports keeping course and keeping balance (The Forgiving Cycle Path, 2018). For example, smooth and well-maintained surface conditions (Nyberg, Björnstig, & Bygren, 1996; De Geus et al., 2012) as well as noticeable road markings (Schepers & den Brinker, 2011) could therefore be provided. Furthermore, the number of objects that a cyclist could possibly collide with should be kept to a minimum and, if they are absolutely necessary, be made conspicuous and well-visible (Schepers & den Brinker, 2011; De Geus et al., 2012; Fabriek, De Waard, & Schepers, 2012). However, even on the safest roads or paths, there is always the possibility that people make errors and for this reason, there should be sufficient room available to correct for these errors without leading to a crash (Wegman, Aarts, & Bax, 2008; Schepers & den Brinker, 2011).

Another possibility is to design support systems that could be used on bicycles or in a motor-vehicle. Although most support systems that are currently being used in traffic are primarily designed for cars, technologies similar to Advanced Driving Assistance Systems (ADAS) or Intelligent Transport Systems (ITS) may also be used to support cyclists (SWOV, 2010). Such systems could be applied on a bicycle, in a car, or in a setup that communicates with the infrastructure (XCycle, 2016). Examples of (prototype) systems for assisting cyclists are navigation (De Waard et al., 2017), object detection in front or behind the cyclist (Engbers et al., 2018b), or balance improvement by means of adjusted bicycle-geometry (Dubbeldam, Baten, Buurke, & Rietman, 2017).

According to Silla et al. (2017), systems such as Pedestrian and Cyclist Detection systems and Bicycle to Vehicle Communication systems are most likely to improve the safety of cyclists in the future. However, the actual realization of safety-effects is also largely dependent on how many people will actually install and use these systems in their car and/or on their bicycle. It is therefore necessary that these systems meet the needs and wishes of the end-user and that the end-users see the additional value for themselves, preferably as quick as possible after they start using a system (Brookhuis, De Waard, & Janssen, 2001).

Because there are many potential options to implement in the infrastructure or on a bicycle, first more insight in which specific difficulties older cyclists face in their daily cycling routines should be gained. With this information, it is possible to generate and test interventions to alleviate these difficulties and, as a consequence, prevent bicycle crashes by means of a targeted approach.

1.2. Definition of 'older' cyclists

This thesis mainly concerns older cyclists and therefore it is useful to provide a definition of the term 'older'. In the Netherlands, people are generally indicated as 'older' when they exceed the age of retirement. Up until 2013, the retirement age in the Netherlands was 65 years and since then, it gradually increases each year along with the nation's general life-expectancy (Tweede Kamer der Staten-Generaal, 2012). However, it is difficult to base an international scientific norm on this age because the age of retirement differs per country (OECD, 2017). Therefore, it seems more appropriate to form a definition based on the goals and the rationale of the research. In this thesis, the reasons for studying older cyclists are the influence of age-related decline and the risk for SBCs. The first factor introduces another problem, however, because there are large individual differences in the effects of ageing on people and the severity of age-related decline: some people may experience strong decline by the age of 70 years while others may not experience any age-related problems at all (World Health Organisation, 2018). For these reasons, the term 'older' in this thesis is defined by the age of 60, which is the shared 'lower-bound' definition of being 'older' worldwide by the UN and WHO (World Health Organisation, n.d.). However, because the risk on bicycle crashes in the Netherlands seems to increase from age 50 onward (VeiligheidNL/Rijkswaterstaat, 2017), participants from this age and above are also included in studies as older cyclists.

Although the main focus of this thesis is on older cyclists, some studies also include younger participants. Firstly, because traffic participation is obviously not limited to older cyclists, it is valuable to gather information about the perception and behaviour of younger cyclists as well, in particular with regard to traffic interactions and interventions that these may influence. Furthermore, comparing behaviour of older and younger cyclists may provide indications of age-related effects on cycling behaviour because it is assumed that healthy younger people do not experience similar declines.

1.3. Thesis outline

Objective 1 of this thesis is to identify elements in the infrastructure as well as interactions with other road users that may lead to problems and an increased crash risk for older cyclists. For this reason, *Chapter 2* describes a naturalistic cycling study and *Chapter 3* contains a computerised video task. The video material used in *Chapter 3* was collected in real traffic circumstances from the viewing perspective of a cyclist. The *second objective* of this thesis is to assess the effectiveness of interventions to increase the safety of older cyclists. In *Chapter 4* and *5*, interventions were implemented in the infrastructure and in *Chapter 6* on a bicycle, and these interventions' effects on cycling behaviour were investigated. In the majority of the studies, a method was applied that resembled cycling in real life as close as possible. This means that most behaviour was measured while participants were cycling on their own bicycles and in real traffic situations. Prototype interventions were applied at natural locations and on real bicycles. *Chapter 7* concludes this thesis with a discussion of the findings.

Adjustments for the infrastructure were developed in "*The Forgiving Cycle Path*" project, for which studies were performed that aimed to assist older cyclists with keeping course, offering room for correction, and limiting the use of obstacles on a cycle path (The Forgiving Cycle Path, 2018). The main purpose of this project was to gather insight in perceived difficulties of older cyclists in the Dutch infrastructure and to design and test potential interventions to decrease the risk on SBCs (i.e. to make a cycle path more forgiving). The basic principle behind these interventions was to increase safety margins by providing infrastructural features which induce older cyclists to enlarge their distances from situations that are of significant risk for them (Näätänen & Summala, 1976, cited in Kulmala & Rämä, 2013). Studies concerning the improvement of interactions between older cyclists and other road users were part of the CRUISer project (CRUISer, n.d.).

In *Chapter 2*, a naturalistic cycling study is described that aimed to explore which cycling infrastructure could lead to problems for older cyclists. Because many of the available studies that have identified risk factors for older cyclists are based on post-crash questionnaires or expert-assessments, the naturalistic cycling approach is used to assess pre-crash difficulties and scenarios that may lead to crashes (Johnson, Charlton, Oxley, & Newstead, 2010). Additionally, this study investigated the usability of commercially available small GPS-cameras for studying cycling behaviour. A sample of cyclists ≥ 50 years was recruited and followed during their normal cycling routine for approximately one week. During this week, the GPS-cameras were used to capture video material of participants' cycling behaviour and they were also asked to keep a short diary of their trips.

Since SBCs may not only depend on infrastructure, but also on the behaviour of and expectations about other road users (e.g. Davidse et al., 2014), *Chapter 3* describes a study to determine whether it is possible to predict cycling behaviour, in particular to predict the upcoming turn a cyclist is about to take. For this study, short video clips were used that were recorded from the perspective of a cyclist following another cyclist. These videos were presented to participants of all ages by means of an online questionnaire.

Based on the findings of *Chapter 2* and the literature, several infrastructural interventions were developed (The Forgiving Cycle Path, 2018). Before such interventions may be implemented on a large scale, however, the effects of these interventions on cycling behaviour were evaluated to verify whether safety may actually be increased. For this reason, two experiments were conducted in *Chapter 4* that evaluated the feasibility of using optical illusions in the shoulder of a cycle path to stimulate cyclists to keep more distance to the verge. These optical illusions were virtual objects placed in the shoulder of a cycle path, which looked like true three-dimensional boxes that a cyclist would normally try to avoid hitting. The effects of the virtual objects were first assessed in a fixed-camera observational experiment in which five versions of virtual objects differing in colour, structure, and 3D-effect were examined. The first part of this experiment was performed on a crowded cycle path and cycling behaviour of all cyclists that passed by (i.e. no specific age group) was observed to explore general effects of the intervention before implementing it more permanently on a real cycle path. In the second experiment, one version of these objects was studied over a longer trajectory and data of cyclists ≥ 50 years were collected with small GPS-cameras mounted on their own bicycles. Also, subjective opinions about this intervention were assessed during an interview at the end of the experiment.

In *Chapter 5*, the evaluation of infrastructural interventions continues as this chapter studies the effects of edge lines, slanted kerbstones, shoulder strips, and edge strips that were applied on or added to the sides of a cycle path. The effects of these interventions were measured using the same experimental design as in *Chapter 4* with small GPS-cameras, also with cyclists ≥ 50 years. Edge lines were either continuous or intermittent and positioned on different distances from the edge of a cycle path. The shoulder strips were 0.5 m wide and added to both sides of the cycle path and the edge strips were 0.3 m wide and painted onto the edges of the path. The surface types of the shoulder strips differed from the cycle path's surface in order to create a buffer zone between the cycle path and the verge, essentially increasing the total width of the pavement. These strips were made of artificial grass (grey or green coloured) or concrete street-print and caused a warning signal in the form of noticeable vibrations in the bicycle while cycling over them.

Expanding on the findings from *Chapter 3*, the effects of an instrumented bicycle that aimed to assist cyclists with their interactions with other road users were explored in *Chapter 6*. The idea was to improve communication between cyclists and to make turning intentions and riding speed more explicitly visible. This bicycle therefore contained a lighting system that displays riding speed, braking, and turning intentions: a Bicycle Light Communication System (BLCS). To test the BLCS-bicycle, an experiment was carried out in which older (≥ 60 years) and younger (≤ 35 years) cyclists rode their bicycles together with a researcher to observe and experience the BLCS-signals as a fellow road user. They were asked for their opinion and perceived mental effort after cycling behind a BLCS-bicycle. The effectiveness of the BLCS was also measured by comparing the participants' estimations of a researcher's cycling speed, both with and without presenting BLCS-signals. In a small follow-up study, 12 older cyclists were asked to use a BLCS-bicycle for one week to explore their first-hand impressions as BLCS-bicycle user in real traffic. *Chapter 7* concluded this thesis with the implications of the studies and a discussion of the potential use of the interventions.

Chapter 2

Using Commercial GPS Action Cameras for Gathering Naturalistic Cycling Data

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This chapter is based on Westerhuis, F. & De Waard, D. (2016). Using Commercial GPS Action Cameras for Gathering Naturalistic Cycling Data. *Journal of the Society of Instrument and Control Engineers (SICE) of Japan, 55*(5), 422-430. doi:10.11499/sicejl.55.422

For consistency throughout this thesis, the terms ‘accident’ and ‘regular bicycle’ have been changed to ‘crash’ and ‘conventional bicycle’, respectively.

2. Using Commercial GPS Action Cameras for Gathering Naturalistic Cycling Data

Abstract

Naturalistic cycling studies may be performed by making instrumented bicycles available to participants or by having mobile equipment added by the participants themselves to their own bicycles. This paper describes how participants' bicycles can be equipped with a commercially available, small, and unobtrusive action camera to gather naturalistic cycling data. Lateral position, swerving, and speed were analysed using video and GPS to assess cycling behaviour of older cyclists and the influence of different types of cycling infrastructure. The applied method gathered insights in possible interventions in a cost-efficient, inconspicuous, and quick way, compared with instrumented bicycles. Also, several bicycles can be instrumented at the same time with as only limitation the number of cameras available.

2.1. Introduction

2.1.1. Naturalistic data collection

Naturalistic studies are performed in order to capture detailed information about real life behaviour by observing participant behaviour in a setting uncontrolled by a researcher. Naturalistic data collection has increased in popularity and has regularly been carried out using an instrumented vehicle to study driver behaviour. In a car, there is sufficient space to install devices such as video cameras and data loggers as was done in the first large naturalistic driving study, where Dingus et al. (2006) equipped 100 cars with these devices. The focus in analyses was on behaviour preceding (possible) crashes and incidents. Uchida et al. (2010) also made use of instrumented cars for naturalistic data collection to gather behavioural data about (near) crashes. They used the results from this naturalistic study as input for experimental research in which they recreated a right-turn manoeuvring situation at an intersection where oncoming, also right turning cars visually occluded an approaching motorcycle. Davis et al. (2012) compared driving ability ratings between road tests and naturalistic driving data. They found that drivers displayed a larger number of errors in the naturalistic condition as compared to the on-the road test although driving safety was rated to be fairly similar in the two settings. Although features as detailed real-life observation and no restrictions imposed by a researcher make the naturalistic study method a promising research tool, the method also has several limitations. The influence of the mere fact that participants know that they are being observed, the expensive research equipment used, and in particular the large data quantities the equipment delivers, are issues that should be dealt with (Valero-Mora et al., 2013). As the data are continuously being sampled while a participant is driving, quantities increase rapidly while most of the time no safety-relevant incidents occur. These amounts make data analysis very time consuming and resource demanding because relevant situations for research have to be searched manually, often by watching large amounts of video data. Therefore, Dozza et al. (2013) developed a method called chunking. By using this method, one can extract statistically robust data by using thresholds (minimum speed or travelled distance, for example) to search and extract data segments of interest. Subsequently, equal-sized sample-sets are computed and used for further analysis. This way, some degree of standardization can be achieved for statistical analyses.

2.1.2. Naturalistic cycling

Naturalistic cycling studies are less extensive with respect to measures that can be taken compared with naturalistic driving studies. This is mainly due to mounting difficulties, since the space for data logging equipment on bicycles is very limited compared to cars. Also, the absence of a stable power source on non-electrical bicycles restricts the use of electronic measurement devices. However, the current developments in small devices equipped with sensors and efficient batteries create new possibilities for naturalistic data sampling on bicycles.

As an intermediate between a car and a bicycle, Espié et al. (2013) performed a naturalistic study with motorcycles equipped with multiple cameras and sensors. They concluded that near-crash situations could be identified using objective measurements (sensors) and subjective measures (diaries). They argued that subjective reports from participants added valuable insights as certain situations were rated as dangerous while these situations did not trigger movement sensors.

Based on naturalistic driving studies, one of the first naturalistic cycling studies was performed in Australia by Johnson, Charlton, and Oxley (2010) who used helmet cameras to gather cycling data concerning behaviour preceding (near) crashes. They found the method to be very useful although they did experience some practical problems with regard to the large amounts of collected data and poor recording quality under low light circumstances. Gustafsson and Archer (2013) used instrumented bicycles equipped with video cameras and GPS loggers, combined with participant diaries, to assess difficulties and possible dangers that commuter cyclists encounter in the city of Stockholm. They found that the main safety issues were cyclist interactions with cars and right-turns, mainly on shared crossings. Cycling issues concerning the design of the infrastructure were mainly related to crossings, bus stops, traffic lights, low quality road surfaces, sudden endings of bicycle paths, road works, and blockings of cyclist facilities. Dozza and Fernandez (2014) developed a measurement system with multiple sensors applied to instrumented bicycles for naturalistic data collection of bicycle dynamics. Combining the output of these sensors, data concerning bicycle kinematics, impact detection (sudden changes in acceleration), location, and surface detection were successfully acquired. Using these instrumented bicycles, combined with route diaries, Dozza and Werneke (2014) found that cycling near a (visually occluded) intersection was related to an increased risk for a critical event. Poor road surfaces and cyclists or pedestrians crossing a cyclists' trajectory were related to increased risk as well. Using a similar method with added interviews afterwards, Werneke et al. (2015) concluded that critical events were mainly related to traffic interactions and poor road maintenance. In the infrastructure, mainly obstacles and construction works were rated as uncomfortable. Schleinitz et al. (2015) performed a study using participants' own bicycles equipped with a camera and multiple sensors. They found that the majority of safety critical events occurred with non-motorized road users. Moreover, the risk for cyclists to experience a critical event was highest on designated cycling infrastructure.

Despite the clear advantages of the approach, it may be questioned to what extent research settings in which participants are using instrumented vehicles or bicycles are really naturalistic. Although the environmental and traffic conditions in which the data collection took place are naturalistic indeed, the actual instruments that are operated, and thus used for data collection, were added by the researchers and very often required changes to the bicycle. In particular on bicycles, these can be saliently visible and present and synchronisation of data from different sensors is often difficult but crucial. Sometimes even a complete laptop has to be added to the bicycle (Vlakveld et al., 2015) or people are required to ride another bicycle than their own (Dozza & Fernandez, 2014). In essence, to carry out a 'full' naturalistic study, the participants should not have to operate instruments and should ride their bicycle in their own environment, fitted to their own agendas, and without any action required or researcher around. To that extent, restrictions imposed by a researcher or a device should be minimised and the device should be placed inconspicuously. The advantages and limitations of different naturalistic cycling study approaches, according to the authors, are summarized in table 2.1.

Table 2.1: Advantages and disadvantages of study methods.

Method	Participants' bicycles		Instrumented bicycles
	Helmet cameras	On-bicycle cameras	
Time required to get used to system	-	-	+
Cycling environment limitations	+	+	+
Recording quality	-	+	+
Integration of data	+	+	++
Analysis time	-	-	+
Ease of use	+	+	+

2.1.3. Main goal and background of the study

This paper describes a naturalistic study which was performed as part of a project aimed to improve cycle path infrastructure for older cyclists (Westerhuis & De Waard, 2014a). In the Netherlands, the number of older people who continue to cycle well into old age is rising (Van Boggelen, 2011). Older people nowadays not only remain physically in shape as their age advances, but also since the introduction of the electric bicycle less physically strong older cyclists can continue to cycle into higher age (Kruijer, Den Hartog, Klein Wolt, Panneman, & Sprik, 2012). However, amongst others as a result of declining visual perception, older cyclists have an increased risk to get involved in traffic crashes (Schepers & den Brinker, 2011; SWOV, 2012). Moreover, older bicyclists are more prone to substantial, longer lasting physical damage after crashes have occurred as they do not recover as easily from these injuries as younger people do.

Several aspects of the bicycle infrastructure can be distinguished, which all play a role in the risk of having single-bicycle crashes (Van Boggelen, Kroeze, Schepers, & Van der Voet, 2011). Scheiman et al. (2010) found that crashes involving older cyclists mainly consist of falling while getting on or off a bicycle, falling due to cracks or unlevelled manholes in the road surface, as well as colliding with kerbs. Also, slippery surfaces due to ice, snow, or gravel are mentioned as causes of crashes. For these reasons, a naturalistic cycling study was performed to identify behaviour exhibited by older cyclists, which could potentially lead to crashes.

2.2. Naturalistic Study Method

The current study was performed using a naturalistic cycling method in which only commercially available action cameras with GPS were used for data collection (Westerhuis & De Waard, 2014a). These small cameras were stably mounted on participants' own bicycles. However, for these devices to successfully collect data, it was necessary that the participants were able to operate these devices: to mount them and switch them on and off. Additionally, cyclists were asked for their opinion about current infrastructural elements in order to gather ideas for developing measures to counteract SBCs (Westerhuis & De Waard, 2014a). The main focus of the present paper is however on the naturalistic cycling study that was part of this project, and in particular on the decisions taken with regard to equipment and analyses performed to identify risky situations. The advantages and the limitations of using this system as a research instrument are discussed, as well as the participant user experiences. Lastly, suggestions are made about possible use in other study designs.

2.2.1. Participants

Thirty participants participated and attached an action camera to their bicycle for at least a week. All were older cyclists aged 50 years or above. There were cyclists using a conventional bicycle (European city bike) or an electric bicycle (e-bicycle, pedelec, pedal electric supported bicycle, see table 2.2). The participants were recruited mainly by an informal network and the word of mouth. The study was approved by the Ethical Committee Psychology (ECP) of the University of Groningen and participants received a financial compensation of 15 euros for their time and efforts.

Table 2.2: Participant characteristics.

Group	N	Mean Age	% Male	Average weekly cycling distance
Conventional Bicycle	20	62.7 (SD: 5.2)	60.0	72.4 km
Electric Bicycle	10	66.8 (SD: 6.6)	50.0	52.9 km
Total	30	64.0 (SD: 5.9)	56.7	66.1 km

2.2.2. Research materials

As the participants had to mount and operate the cameras themselves, a user-friendly Contour+2® camera system was used. These cameras are capable of capturing high quality videos and quickly obtaining a GPS signal while at the same time having an acceptable battery life (≥ 2 hours). Cameras were mounted on the participants' own bicycles using a bar mount, preferably attached to the handlebars (see figure 2.1). Ten cameras were available to be used at the same time. Recorded footage was viewed using the 'Contour Storyteller®' software for Windows® in which the GPS track of the ride was also plotted on a map (see figure 2.2). Speed, elevation, and distance driven were also displayed. Additionally, two questionnaires were completed by participants to assess demographic information (such as age, gender, use of medications, perceived physical or mental complaints) and to sample bicycling experiences using a so-called 'route diary'.

2.2.3. Research procedure

A researcher visited each participant at home to mount the camera on their bicycles and to give instructions on how it should be operated. Care was taken to reserve sufficient time to fully instruct the participants as they had to mount and operate the camera themselves during the week. The researcher attached a bar mount on the handlebar of the bicycle. The location as displayed in the left-hand photo in figure 2.1 was preferred, because the camera would then be placed inconspicuously while a maximum amount of the image is functionally used (i.e. recording the environment, not the sky). However, in case a participant had already installed (numerous) devices on their bicycle occupying this space, a different location was used (for example, see figure 2.1, right-hand photo).

Figure 2.1: Mounted cameras.

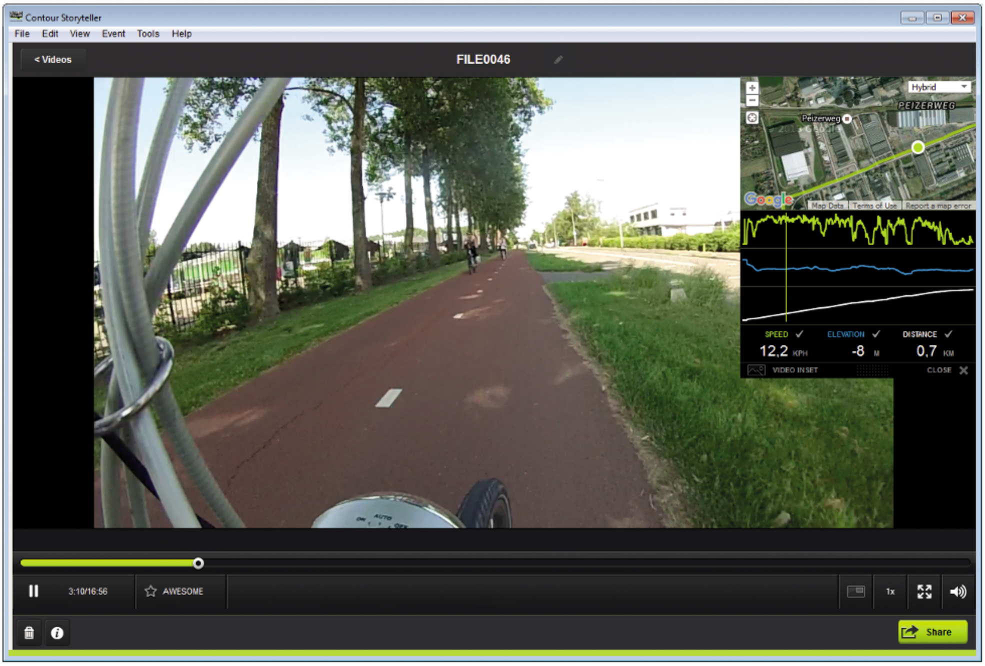

Figure 2.2: Camera footage with GPS location and speed.

Following the attachment process, the researcher checked whether the front wheel was visible on camera to enable lateral distance measurements later, and the mounting procedure was explained to the participant. Lastly, instructions were given on how to charge the batteries using a supplied charger and how to replace them with a spare battery.

2.2.4. Self-reports

Because each participant would be cycling for multiple hours, the total number of collected recordings was rather large. In fact, during this study a grand total of approximately 340 Gigabytes of video material was collected. Keeping logbooks was a very useful tool to quickly find locations or situations marked by participants in these data. In the logbook, participants wrote the time and date of their bicycle journeys as well as the weather conditions, trip goals, and passed locations which they found difficult or dangerous. If safe, participants were also asked to put one hand in front of the camera lens for one or two seconds after an event that they experienced as dangerous or risky, so that the researchers could find these remarks quickly while viewing the videos at an accelerated playback speed.

2.2.5. Lateral position and swerving

Lateral position was assessed using the video data only. Behaviour on different types of road or cycle path layouts were compared by first searching video sections in which participants passed layouts of interest. This process was performed by playing the videos in Contour Storyteller® and using the GPS route on the map. Suitable locations were registered and the corresponding video filenames and timestamps were noted. To perform the measurements, the video files were loaded in VLC Media Player® to keep the window sizes and aspect ratios constant for standardization within and between the videos. Lateral position was determined by measuring the distance of the front wheel to the kerb or shoulder using a transparent digital ruler (JRuler Pro for Windows®). For this reason, it was necessary to have a part of the front wheel clearly visible in the video (see section 2.2.3). Additionally, swerving behaviour (Standard Deviation of the Lateral Position; SDLP) was calculated. Lateral position was first measured in pixels, after which these values were used for estimating real lateral distances.

The Contour+2® camera has a 170° widescreen lens, which is able to capture a broad image of a location but this does distort the video image in the periphery. To estimate lateral position, these distortions needed to be corrected as displayed in figure 2.3. As each strip represents 25 centimetres, the lengths of these strips were measured in pixels. These measurements resulted in conversion factors from pixels to real centimetres per strip. As the lens distortion had its greatest effect at the periphery of the image, the closest 75 centimetres to the front wheel were calculated as one estimated distance factor. The latter 75 centimetres were estimated by calculating separate conversion factors per strip. Furthermore, because the camera was not placed exactly above the front wheel, the centre of this wheel in the filmed image from where the distance to the kerb is measured, was not placed on the exact location where the wheel touches the ground. Therefore, an extra correction in which the distance from the measured tip of the front wheel to an extended line based upon the centre of the front wheel on the ground was measured and subtracted from the distance to the kerb sample measurements.

Figure 2.3: Bicycle and the measurement aiding tool.

2.2.6. GPS position and speed

GPS information was also used to analyse cycled routes and speed over locations and trajectories. The GPS Editor for Windows® application was used to plot GPS tracks of all .gpx output files per participant combined on one map. After importing every single GPS track from a participant, this application was used to merge the tracks and plot all cycled routes on the map. This resulted in a visual image of all cycled routes, distances, and speeds during the study.

2.2.7. Statistical analyses

The participants' noted cycling experiences and difficulties from the route diaries were scored and categorized. Video observations focussed on lateral position: it was scored when the front wheel of a cyclist entered the shoulder or touched a kerbstone. As the data for lateral position and speed were not normally distributed, non-parametric tests were performed to assess the effects of bicycle type (Mann-Whitney U tests) and infrastructure (Wilcoxon Signed Rank tests). For all tests an α-value of 0.05 was used to assess statistical significance.

2.3. Results

2.3.1. Self-reported experiences

During the study, participants were asked to monitor whether they found certain infrastructural elements difficult or (potentially) dangerous. Remarks were counted and clustered in five categories. The reported difficulties were the limited widths of the paths, curves, obstacles, slopes, and road surface issues. A summary is displayed in table 2.3.

Table 2.3: The reported difficulties per category.

Category	Examples	Reports
1. Obstacles	Posts, bollards, traffic islands, fences, cattle guards	15
2. Road surface	Bumps, holes, unpaved paths	8
	Clay, mud or wet paths	3
3. Curves	Strong curves	5
4. Slopes	Steep slopes, ramps, high speed humps	4
5. Path width	Narrow bicycle paths or roads	3

Although not entirely within the scope of this study, also non-infrastructural risks were mentioned by the participants. These were mainly risky behaviours exerted by other cyclists or road users nearby. Mentioned were a minor collision with a cyclist coming from the right (who rode against traffic while being occluded from sight), near collisions with other cyclists, not being noted by other cyclists, busy traffic, being overtaken or cutting in by another road user, being distracted by someone else, vehicles being parked in the way, groups of (racing) cyclists, and the presence of construction works on a cycling route.

2.3.2. Cycling behaviour observations

It was observed that six cyclists entered the verge (one cyclist rode into the verge twice) under different circumstances. The verge was entered following a sharp turn (n = 2), after altering course due to an oncoming (n = 1) or passing (n = 1) cyclist, after passing a group of pedestrians (n = 1), while cycling downhill on a very narrow path (n = 1), and while cycling with a companion (n = 1). Remarkable was that these events only happened when the verge was soft. Cyclists in these circumstances only entered the verge consisting of grass or sand, not a single cyclist hitting the kerb was observed. Also, one cyclist nearly entered the shoulder twice after evading an object.

At times it was also observed that several cyclists evaded all kinds of spots, inconsistencies, or (flat) objects in the surface of a cycle path. This apparent evading behaviour was visible as several participants cycled around manholes or markings on the road's surface. This does not necessarily lead to a risky situation, however, there are certain instances in which this change of course could be potentially harmful. For example, it has been observed once that a cyclist evaded a (level) manhole and subsequently was on a crash course with a bollard on the cycle path (see figure 2.4).

Figure 2.4: A cyclist evading a manhole (bottom-right) and approaching a cycling bollard head-on (circle).

2.3.3. Lateral position

In figure 2.5, the lateral position was assessed for solo and duo cyclists on two types of cycle paths (one-way or two-way). Two groups were compared, namely cyclists using a conventional city bike or an electric bicycle. Lateral position did not differ between cycle paths ($Z = -0.471$, $p = NS$) nor between bicycle types ($Z = 1.165$, $p = NS$). On an overall level, the cyclists' lateral position while cycling on the left-hand side of a duo was far more to the left than the position of solo cyclists ($Z = -2.366$, $p = 0.018$), while the cyclists on the right-hand side position themselves further to the right, compared to solo cyclists ($Z = -2.197$, $p = 0.028$).

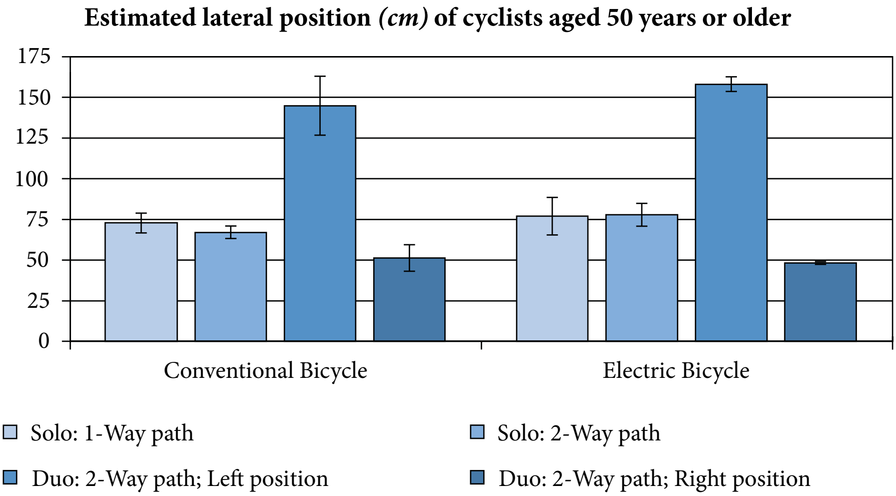

Figure 2.5: Estimated lateral position (cm) of cyclists aged 50 years or older.

2.3.4. Speed

On average, there were no differences in speed between cyclists using a conventional or an electric bicycle (Z = −1.340, p = NS, see figure 2.6). Furthermore, there were no effects of type of cycle path on cyclist speed (Z = −0.534, p = NS). However, on an overall level, cyclists rode significantly slower while cycling with a companion, compared to cycling alone (Z = −2.118, p = 0.034).

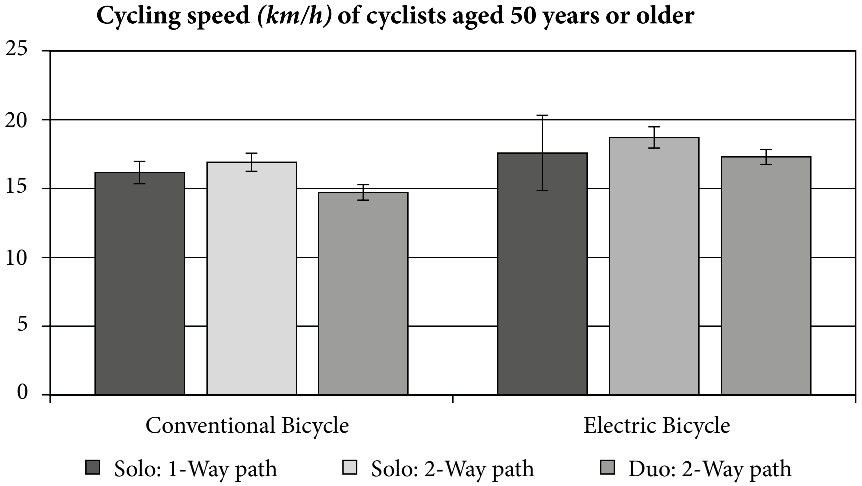

Figure 2.6: Average cycling speed (km/h) of cyclists aged 50 years or older.

2.3.5. User experience

The participant user experiences of the action cameras were assessed by a brief questionnaire at the end of the study. Because some systems can be rather technical, it was assumed that older people, who might not be used to operating such devices, should be equipped with devices which are intuitive and user-friendly to operate. Due to time restrictions while visiting two participants at home to dismount the camera and collect the research materials, 28 participants completed this part of the questionnaire. The presence of the camera on the bicycle was rated mainly as a neutral (43%, n = 12), rather positive (29%, n = 8), or positive (29%, n = 8) experience. A small percentage (11%, n = 3) reported that the presence of the camera had influenced their behaviour (i.e. made them more aware of their own behaviour or holding back). However, 89% (n = 25) reported that this had not been the case. The majority of cyclists (89%, n = 25) did not encounter any camera-related technical problems. However, 11% (n = 3) encountered difficulties to some degree. These participants experienced battery-related problems (no warning at low levels), GPS-related problems (long time to connect), and mounting-related difficulties (too much strength required).

2.4. Discussion

2.4.1. Cycling behaviour

Based on video data, potentially dangerous manoeuvres in the neighbourhood of obstacles were observed as cyclists tend to evade cracks in the roads, or even level manholes, potentially leading to a conflict with an obstacle on or along the cycle path. Furthermore, it was observed that sharp turns, narrow paths, and interactions in which another cyclist approached or overtook an older cyclist can precede a risky situation as this might result in a course change towards an obstacle or into the verge. The latter observation was used as input for an experimental measure to keep cyclists away from the verge (Westerhuis, Jelijs, Fuermaier, & De Waard, 2017). No serious crashes occurred during the study, although one cyclist had a minor collision with a cyclist coming from the right who illegally rode on the pavement and was occluded from sight. Furthermore, cyclists aged 50 years or older mainly considered obstacles, low quality or damaged road surfaces, sharp or unclear curves, slopes, and narrow roads or cycle paths as uncomfortable or potentially dangerous elements in the cycling infrastructure, based on 30 route diaries.

There were no differences found in lateral position between one-way or two-way cycle paths for cyclists riding alone. When riding with a companion, cyclists obviously need more space on the cycle path. However, this made the cyclist on the right ride closer the verge, and the cyclist on the left regularly rides in the opposing lane on a two-way cycle path. This might lead to higher chances of entering the verge or colliding with an oncoming cyclist. However, as said, this did not happen during the study.

The differences in speed between cyclists using a conventional or an electric bicycle were rather small. This finding might be related to the group sample characteristics, as 75% of the participants who used an electric bicycle reported at least one physical complaint, compared to 26% of the conventional bicycle type users. Therefore, it could be that the group using the conventional bicycle was physically more capable of maintaining this speed and the electrical support was used by the other group to reach a similar speed.

2.4.2. Strengths of the study approach

The advantages of the present approach lie in the possibility to collect data during normal everyday cycling. There were no artificial situations or limitations imposed by the researchers and thus with this method one is able to provide a usable basis for exploring behaviour susceptible to interventions. A difference with other naturalistic cycling studies (such as Dozza and Fernandez, 2014) is that the instrumentation was limited to one commercially available action camera. These systems have numerous advantages as they are relatively cheap, inconspicuous, and several bicycles can be instrumented at same time. Furthermore, by letting the participants operate the cameras and the logbooks themselves for at least a week, a lot of data could be gathered in short amounts of time without support on location required. Older participants rated the camera that was used as user-friendly, implying broad use.

2.4.3. Limitations of the study approach

Within the strengths of the research method lie also some limitations. As there are no conditions or limitations imposed by the researchers, this automatically results in a low degree of standardization. This means that significant causal effects cannot be assessed as these can be by using an experimental design and should be considered exploratory. Furthermore, processing the data is very time consuming and to gain reliable distance estimations, video lens corrections have to be applied. A good option to explore for the future is the use or development of new measurement devices or smart video analysis algorithms, which can enhance faster detection of critical behaviour of bicyclists, similar to the algorithm for critical driver behaviour detection in naturalistic driving studies by Dozza and González (2013). Moreover, measurement accuracy can also be increased by using relative comparisons (within subjects or rides) or individual camera calibration during experimental measurements (as used in Westerhuis, Jelijs, Fuermaier, and De Waard, 2017).

2.4.3.1. Relative comparisons (within-subject comparisons)

One of the major limitations for accurate lateral position measurement was that the camera aim and rotation differed between rides as the participants removed the camera in-between trips. However, when properly mounted, its aim and rotation remained stable during the rides. Therefore, relative comparisons within trips can also be performed as the absolute values of lateral position are irrelevant to determine relative differences. Lateral distance to the kerb or shoulder can be measured in pixels, again using the front wheel as a reference point (figure 2.7; upper-left picture). Subsequently, these measurements may be repeated on different locations during the same ride (see figure 2.7; upper-right and lower pictures). Using these repeated measurements, relative differences in lateral position and swerving behaviour between locations can be calculated and analysed.

2.4.4. Future directions of the research field

As studying naturalistic cycling behaviour is a promising approach for identifying experiences and difficulties for healthy (older) cyclists, future research may also focus on exploring cycling behaviour in groups with specific impairments. For example, how do people with cognitive or physical impairments (such as impaired vision) compensate for their impairments and what are typical scenarios they experience? Subsequently, it could be studied whether people with specific impairments can be supported so that they can ride the bicycle more safely. In our institute, such a study is planned to take place in 2016.

Figure 2.7: Repeated measurements within a participant's ride.

2.5. Conclusions

The performed naturalistic cycling study using commercial action cameras proved to be highly useful for gathering global insights in real world cycling behaviour, difficulties, and identifying potential crash risks. The main advantages are that the method is relatively cheap, the devices are user-friendly and can be operated by participants regardless of age or technical skill, multiple bicycles can be instrumented at the same time, and all participants can use their own bicycles during the entire study.

Acknowledgements

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Chapter 3

Reading cyclist intentions

Can a lead cyclist's behaviour be predicted?

This chapter is based on Westerhuis, F. & De Waard, D. (2017). Reading cyclist intentions: Can a lead cyclist's behaviour be predicted? *Accident Analysis and Prevention, 105*, 146-155. doi:10.1016/j.aap.2016.06.026

For consistency throughout this thesis, the terms 'accident', 'cyclist-only accidents' and 'regular bicycle' have been changed to 'crash', 'single-bicycle crash', and 'conventional bicycle', respectively.

3. Reading cyclist intentions: Can a lead cyclist's behaviour be predicted?

Abstract

As a cyclist, it is essential to make inferences about the intentions of other road users in order to anticipate their behaviour. There are official ways for cyclists to communicate their intentions to other road users, such as using their arms to point in the intended direction of travel. However, in everyday traffic cyclists often do not use such active forms of communication. Therefore, other visual cues have to be used to anticipate (critical) encounters or events. During this study, 108 participants completed a video internet survey in which they predicted the intentions of a lead cyclist based on visible behaviour preceding a turning manoeuvre. When the lead cyclist approached the intersection, each video was stopped just before the cyclist initiated turning. Based on visual cues, the participants had to select which direction they thought the cyclist would go. After entering their prediction, they were asked how certain they were about their prediction and on which visible behaviour(s) each prediction was based. The results show that it is very hard to predict the direction of a turning cyclist based on visual cues before the turning manoeuvre is initiated. Exploratory regression analyses revealed that observable behaviours such as head movements and cycling speed were related to prediction accuracy. These results may be used to support cyclists in traffic interactions.

3.1. Introduction

Although the health benefits of cycling (Oja et al., 2011) and its positive effects on the environment are well-known, cyclists are very vulnerable in case of crashes. In the Netherlands, 32% of all fatal traffic crashes concerned cyclists (CBS, 2014). Non-fatal cycling crashes typically lead to injuries to the head, face or neck, traumatic brain injuries, spine and back injuries, damage to the torso, and injuries to the upper- and lower extremities (Siman-Tov, Jaffe, Peleg, & Israel Trauma Group, 2012; Juhra et al., 2012; De Geus et al., 2012). Personal factors associated with crash involvement are age (Bíl, Bílová, & Müller, 2010; Boufous, de Rome, Senserrick, & Ivers, 2012; Schepers, 2012; Siman-Tov, Jaffe, Peleg, & Israel Trauma Group, 2012; Kaplan, Vavatsoulas, & Prato, 2014; Martínez-Ruiz et al., 2014; Martínez-Ruiz et al., 2015), experience (Schepers, 2012; Poulos et al., 2015), and alcohol and drug use (Twisk & Reurings, 2013; Kaplan, Vavatsoulas, & Prato, 2014). Furthermore, environmental factors related to increased risk and injuries include sharing the road with motorised traffic (Kaplan, Vavatsoulas, & Prato, 2014), involvement of other road users (Heesch, Garrard, & Sahlqvist, 2011), high speed limits (Boufous, de Rome, Senserrick, & Ivers, 2012; Kaplan, Vavatsoulas, & Prato, 2014), cycling in the dark (Boufous, de Rome, Senserrick, & Ivers, 2012; Twisk & Reurings, 2013), slippery roads or paths (Kaplan, Vavatsoulas, & Prato, 2014), curves (Boufous, de Rome, Senserrick, & Ivers, 2012), and poorly visible road elements (Schepers & den Brinker, 2011). Cyclists are especially at risk in rural areas (Boufous, de Rome, Senserrick, & Ivers, 2012), near intersections (Dozza & Werneke, 2014), and on designated cycling infrastructure (Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert, 2015).

In the Netherlands, the majority of cycling crashes are Single-Bicycle Crashes (SBCs; Schepers, 2013), although conclusive statistical evidence is lacking due to an underreporting of bicycle crashes (Wegman, Zhang, & Dijkstra, 2012; Schepers, 2013). Frequent types of SBCs are a loss of balance, colliding with an obstacle, or entering the verge (Schepers & Klein Wolt, 2012). However, a considerable number of SBCs are preceded by an interaction with another road user (Davidse et al., 2014). For example, a cyclist misjudging the intentions of another cyclist may lead to a crash (Davidse et al., 2014; Davidse, Van Duijvenvoorde, Boele, Duivenvoorden, & Louwerse, 2014), suggesting a lack of situation awareness (Endsley, 1995). To limit or prevent these crashes, it is important that cyclists are aware of the presence of other road users and able to make accurate inferences about their intentions. The goal of this study is therefore to assess whether cyclists are indeed capable of predicting the intentions of other cyclists, or whether they would benefit from external support such as technical support systems.

3.1.1. Intentions, expectations, and situation awareness

According to the Situation Awareness (SA) theory, one cannot reach its destination through traffic safely by merely perceiving the current state of the environment (Endsley, 1995). In order to prevent crashes, it is crucial to make inferences about oncoming events. SA is achieved in three levels, each describing a different step from perceiving individual elements (level 1), combining these into one holistic representation (level 2), to predicting oncoming events involving these elements (level 3; Endsley, 1995).

Cyclists are supposed to use their arms to communicate their intention as these cues are easily perceived by other road users (Walker, 2005). Informal signals of intention, such as maintaining a certain position on the road, trailing a foot, or seeking eye contact, can be used for SA assessment level 1 as well. Furthermore, car drivers may infer whether a cyclist will behave predictably from the cyclist's physical appearance, and adjust their overtaking accordingly (Walker, 2007). For example, Walker (2007) found that car drivers maintain a greater overtaking distance to cyclists who seem inexperienced, and therefore unpredictable (e.g. children), compared to cyclists who seem experienced. Directing the attention to the cyclist's face first might not always be possible nor be the most efficient strategy to assess their intentions, and it may result in a prolonged processing and reaction time (Walker & Brosnan, 2007). Car drivers respond more quickly and accurately when they expect a car in front to make a turn based on the indicator (Muhrer & Vollrath, 2010). These are merely a few examples of different cues which can be used during SA assessment level 1

(Endsley, 1995). Apart from perceived behaviour by other road users, locational cues are used for predictions in traffic as well. For example, road users' expectations of the category of rural road they are facing are based on how far apart both driving directions physically are (Stelling-Konczak, Aarts, Duivenvoorden, & Goldenbeld, 2011). Martens and Fox (2007) found that the more familiar car drivers were with the location they were passing, the less they looked at relevant traffic signs. However, these experiences can also have negative effects, as drivers tend not to look for signs at locations where they do not expect any, potentially leading to missing critical information (Borowsky, Shinar, & Parmet, 2008).

During the second level of SA, all perceived and (rated as) relevant cues are combined into one holistic comprehension of the current situation (Endsley, 1995). Cognitive processing time is required to form this holistic image. The third level of SA assessment concerns making inferences about the future state of the current situation (Endsley, 1995). In other words: a car driver, cyclist, or pedestrian (or any other) will predict the intentions of other traffic participants in order to make a decision on how to anticipate and possibly evade a potential conflict. Therefore, correct expectations facilitate a quick response, but incorrect expectations are potentially hazardous. For example, an important factor leading to bicycle-car collisions is a cyclist having the incorrect expectation that a car driver will yield (Räsänen & Summala, 1998).

3.1.2. Cyclist intention prediction

In the current study it was assessed whether cyclists are able to predict the direction a preceding cyclist is going to choose, based on perceived informal signals (i.e. absence of the formal arm indication). As SA is not a continuous concept, it is the question whether cyclists are able to predict other cyclists' intentions based on behaviour preceding the actual turning manoeuvre. Hemeren et al. (2014) found that the oncoming direction a cyclist will choose can be predicted by looking at the lateral position, head turns, and speed, for two directions on a T-section (i.e. cyclists going straight or turning left).

It was hypothesized that predictions for any intended direction of travel are more accurate than chance, in accordance with the results by Hemeren et al. (2014). As anticipating the intentions of other cyclists is essential, it was argued that models for driver behaviour might also (partially) explain cyclist behaviour. According to the Task-Capability Interface model, the amount of success for the prediction task depends on the cyclist's capability and the demands of the task (Fuller, 2011; Fuller et al., 2008). The cyclist's capability is determined by physiological characteristics, cycling experience, cycling competence, and human factor variables (Fuller, 2011; Fuller et al., 2008). The current physical environment, behaviour of other road users, properties of the bicycle, and current cycling speed contribute to the overall task demand (Fuller, 2011; Fuller et al., 2008). The second hypothesis was that experienced cyclists are better able to predict the intentions of other cyclists than less experienced cyclists.

3.2. Method

An online survey was created using Qualtrics, in which 24 trials were presented in which participants were asked to predict the oncoming turn of a cyclist, based on a video made in real traffic from the perspective of a cyclist. All questions were asked in Dutch. All participants were offered a financial compensation by using a lottery system: among all submissions, two gift vouchers (€15 value) were randomly allotted. This study has been approved by The Ethical Committee of Psychology, University of Groningen.

3.2.1. Participants

A total of 158 participants started the survey, of which 108 answered all questions (68% completion rate). The mean age of all participants was 39.7 years (SD: 16.0), 63% was female and the majority was living in the Netherlands ($n = 104$). A small number came from Germany ($n = 4$). The participants most frequently used a conventional bicycle ($n = 87$), followed by an electric bicycle ($n = 11$), or a touring bicycle ($n = 6$). A racing bicycle, a mountain bike, a carrier cycle, and a fixed-gear bicycle were used by one participant each.

3.2.2. Design

The study was designed as a within-subjects questionnaire containing 24 trials, in which the independent variable was defined as the correct direction of travel of the lead cyclist (three levels: left, straight, and right directions). The three dependent variables were defined as prediction correctness, prediction certainty, and selected cues on which each prediction was based.

3.2.3. Materials

A total of 24 video stimuli trials were created, plus one practice trial. These video stimuli consisted of video fragments recorded using a Contour+2™ digital action camera with GPS, mounted on the front of a bicycle. The camera was set at 720p quality video settings (170° range of vision). The videos were recorded in real traffic: cyclists were followed until they reached a crossing and either turned left, right, or continued cycling straight on. The filmed cyclists were recorded inconspicuously and were unaware of the fact that they were being recorded, not to influence their cycling behaviour in terms of (over)acting. On four locations in the city of Groningen, footage was selected where cyclists did not use their arms to show their intentions to other road users. Furthermore, care was taken that the filmed cyclists did not have to give right of way to other road users and that no cars were present during the turning manoeuvre. Additional selections based on cue presence were not performed, as these would bias the availability of cues against real life. During filming, an estimated following distance of 4-8 metres was attained between the filming and the filmed cyclist. Three trials were filmed on a cycle path which contained two-choice options (either left or right; location 1), and 21 trials were filmed on roads shared with motorised traffic, which contained three-choice options (left, straight, or right; locations 2, 3 and 4, respectively).

Following the recording and selection phase, the individual trials were created using Adobe Premiere Pro CS6™. Per trial, each video had a total duration of 16 seconds, in which the first four seconds contained a frozen starting image in which a 3-second countdown timer was initiated, in order for the participants to shortly grasp the overall situation. After the countdown, each video was played for 10 seconds after which the image froze again, shortly before the cyclist initiated the turning manoeuvre (see figure 3.1). After freezing, the static image remained visible for two seconds after which it completely disappeared and the overall video screen turned black. This way, each participant had the same amount of visual information available to make a prediction. For practical reasons, the black screen remained in place for 44 seconds: this gave the impression the video had completely stopped, even though the video automatically would restart after these 44 seconds due to an 'auto start' feature of the video in the trials, which could not be disabled. For this reason, the prediction submission time for each trial was recorded and only submission times below 60 seconds were included to ensure that each video had been seen once only, as the participants had no control over the video and they were not able to restart them manually.

Figure 3.1: Two examples of the questionnaire's video trials. First, a frozen image was shown and a 3-second countdown timer was initiated (left picture). Subsequently, a 10-second cycling video clip was played, until it was frozen again on the moment the cyclist starts to steer into a direction (right picture). After two seconds of freezing in front of the crossing, the entire image went black. For cyclists going straight on, similar distances from the crossings as cyclists who did turn into a direction were used to freeze the videos.

3.2.4. Procedure

The participants were mainly recruited via word of mouth through the (informal) network of the researchers. After participants showed an interest, they were given an internet link (URL) to start the survey. Participants were asked not to spread the link to the study on the internet or social media. Upon loading the URL, instructions were given concerning the goal of the study ("are you able to predict the upcoming turn of a lead cyclist?") and participants were informed that they automatically gave their informed consent if they chose to proceed to the actual start of the survey.

3.2.4.1. Personal details

After opening the survey, participants were asked to provide personal details such as age, gender, home country, average weekly cycling distance, and their most frequently used type of bicycle. Mainly cycling experience was used as an indication of cyclist competence (Fuller, 2011; Fuller et al., 2008). The last question enquired about to what extent the participants were familiar with the city of Groningen. This question was asked in order to distinguish between participants who may recognise the traffic situations from real life and those who were not familiar with these particular locations. It was argued that participants who pass these locations regularly might make inferences about other cyclists' intentions, based on normal traffic flow or common destinations nearby. This could influence their perceived chance of cyclists making a certain turn.

3.2.4.2. Trials

After completing the personal details questions, the experimental trials were introduced. The first trial was a practice trial, which contained explanations on how the videos were shown and how the questions could be submitted. The remaining 24 trials were presented after the instructions and practice trial were completed. The first question in each trial involved the expected intended direction of travel, in other words: which direction would the cyclist choose after the video had stopped. After submitting an answer to this question, the participants were asked to provide additional information on their prediction. First, they were asked to report how certain they were about their prediction on a 7-point Likert scale, ranging from "completely uncertain" to "100% certain". Second, they were asked about significant factors or behaviour that contributed to their prediction. These factors were mainly related to 'task demand', according to the Task-Capability Interface model (Fuller, 2011; Fuller et al., 2008). Five factors were already presented for each trial, of which the first four were 'position on the road', 'speed', 'head movements', and 'change in speed', identical to the factors used in the study by Hemeren et al. (2014). However, for the fifth factor presented in this study, the researchers chose to present 'body posture' as a broader term for the factors 'leaning' and 'pedalling' by Hemeren et al. (2014). Lastly, there were three empty text fields available per trial for the participants to fill in other factors, not covered by any of the presented options.

3.2.4.3. End of questionnaire

After completing all trials, the participants were asked how well they knew the locations that were used to film the trials on a seven-point Likert scale. They were also given the opportunity to provide their e-mail address if they wished to be informed about the study results, and/or to sign up for the lottery prize.

3.2.5. Statistical analyses

Basic data processing and explorative statistical analyses were performed using IBM SPSS Statistics 22 for Windows. MLwiN v.2.33 for Windows (Rasbash, Charlton, Browne, Healy, & Cameron, 2015) was used to compute Odds Ratios and Multilevel Models (Rasbash, Steele, Browne, & Goldstein, 2015) in which the observed factors were included. Additionally, post hoc content analyses were performed for all trials.

3.3. Results

The survey was open for participation during six weeks after being launched on January 12th 2015. The majority of the participants rated themselves as being familiar with the city of Groningen ($M = 4.42$, $SD = 2$) on a 7-point Likert scale. However, after exploring the values for each location, the participants were strongly divided into two groups, namely participants who knew the individual locations either hardly, or very well. As expected, the overall best-known location was Location 1, as this was the at the city's main railway station.

3.3.1. Prediction success

To assess whether the participants were able to correctly predict the direction being chosen by the cyclists in the videos, the trials were divided according to their level of chance. As for Location 1, the number of possible directions was limited to turning either left or right (50% chance), this location was analysed separately. Out of all 2592 responses, 41 were rejected as these exceeded the maximum submission time. The remaining mean response time for the trials was 6.5 seconds ($SD = 6$) after the stimuli ended and the screen turned black.

For Location 1, a total of 44% of all trials were predicted correctly, which was not significantly different from 50% chance level ($T\ (df = 2) = -0.760$, $p = NS$). However, out of the three-choice trials for the remaining locations, 49.4% were predicted correctly, which is significantly above 33% chance level ($T\ (df = 20) = 2.932$, $p = 0.008$). For these three-choice trials, the overall results per direction are displayed in table 3.1.

First, it should be noted that on trial level, the predictions for the trials in which cyclists turned left ($T\ (df = 6) = 0.896$, $p = NS$) as well as right ($T\ (df = 7) = 0.686$, $p = NS$) did not differ from chance level, as 42.3% and 38.5% of the trials were correctly predicted. However, 72.5% of the trials containing cyclists going straight were predicted correctly, which is above chance ($T\ (df = 5) = 7.232$, $p = 0.001$). Odds ratios were computed using the true direction as predictor variable for prediction success (see table 3.2).

Table 3.1: Overall results per correct cyclist direction for the three-choice trials. The rows represent the reactions given by the participants (the predictions), the columns represent the true direction the cyclist went. The bold printed counts are correct predictions (hits).

		True direction (trial)			
Response direction (prediction)		Left	Straight	Right	Total
Left	Count	**314**	81	113	508
	Expected Count	169.0	145.5	193.5	508
	% hits (left)/misses (straight, right) within predictions	**61.8%**	15.9%	22.2%	100%
	% hits/misses for true direction	**42.3%**	12.7%	13.3%	22.7%
Straight	Count	284	**465**	410	1159
	Expected Count	385.5	332.0	441.5	1159
	% hits (straight)/misses (left, right) within predictions	24.5%	**40.1%**	35.4%	100%
	% hits/misses for true direction	38.2%	**72.7%**	48.2%	51.9%
Right	Count	145	94	**328**	567
	Expected Count	188.6	162.4	216.0	567
	% hits (right)/misses (left, straight) within predictions	25.6%	16.6%	**57.8%**	100%
	% hits/misses for true direction	19.5%	14.7%	**38.5%**	25.4%

Table 3.2: Overall results per true cyclist direction, for the three-choice trials. The true directions left or right were included as predictors, using 'straight' as reference.

Predictor: True Direction	β	S.E.	$Z=\beta/\text{S.E.}$	e^{β}
Constant	0.977	0.089		1
Left	-1.286	0.116	-11.09	0.28
Right	-1.444	0.113	-12.78	0.24

Considering the percentages and odds ratios presented in table 3.2, it can be concluded that a correct prediction is unlikely when the cyclist is going to make a turn, compared to when the cyclist goes straight on, based on visual cues before an actual turning manoeuvre is initiated. Predicting either direction of a turning cyclist is equally hard, as a Wald Test showed no significant differences between left or right turning cyclists (χ^2 (1) = 2.279, p = NS). However, there are indications for a bias towards selecting the category "straight" as the amount of given predictions for this direction are relatively high (51.9%), compared to the other directions (22.7% for left and 25.4% for right, respectively). Therefore, the resulting values concerning prediction success for 'cyclist going straight' should be interpreted with care, as one could argue that these predictions are an indication of perceived absence of salient cues to infer that a cyclist is going to make a turn. This could effectively result in this category being treated as a forced-choice residual category as well, as one could say that if a cyclist is not going to make a turn, he or she will presumably continue cycling straight on. Of all participants who predicted that the cyclist was going to make a turn, 60% of these predictions were correct (61.9% and 57.9% correct for left and right predictions, respectively). For all predictions that the cyclist was going straight, 40.1% were correct. Odds ratios were computed, although for this equation the responded directions (participants' predictions) were used as predictor variable as a measure of prediction accuracy (see table 3.3). Considering these odds ratios, it is more likely that a prediction is correct if the performed prediction is a turn, as opposed to continuing straight on. A Wald Test yielded no significant differences between response directions left or right (χ^2 (1) = 1.748, p = NS). However, it should be kept in mind that the overall prediction success for making a turn was not above chance level.

Table 3.3: Overall results per responded prediction, for the three-choice trials. The responded predictions left or right were included as predictors, using 'straight' as reference.

Predictor: True Direction	β	S.E.	$Z=\beta/S.E.$	e^{β}
Constant	-0.400	0.060		1
Left	0.882	0.109	8.09	2.42
Right	0.717	0.104	6.89	2.05

3.3.2. Predictive factors

As all participants were free to choose any factor they felt of importance for their predictions, there was no limit in selecting factors. As a consequence, several participants selected all of the five presented factors they could choose, which resulted in high inter-correlations between subjective predictive behaviour(s). In essence, selecting all factors also meant that the participants took all possible factors into account for all possible trials and manoeuvres, and did therefore not make any specific choice during the study. This could have been due to not having understood the instructions properly, however, the exact reason cannot be assessed in hindsight. Therefore, to limit multicollinearity and to create more reliable estimations, a conservative approach was used in order to prevent statistical inflation of factor relevance. For this reason, the nine participants who selected all five factors on all 21 trials were rejected from this analysis.

3.3.2.1. True direction 1: cyclist turning left

In figure 3.2, the proportions of all selected factors per trial in which the cyclist would turn left (true direction) are displayed. For all trials in which the cyclist turned left, 52% of all correct predictions were justified by taking head movements into account, which was significantly different from all incorrect predictions, as 16% of the participants who gave incorrect predictions took 'head movements' into account (T (671) = 10.8, p < 0.001). Therefore, it seems that taking head movements into account increases the chance of making a right prediction, when a cyclist is going to turn left. This also seems to be the case for the factor 'change in speed', as the group that made correct predictions based their decision significantly more often on this factor compared to the group that made incorrect predictions (T (671) = 4.04, p < 0.001). However, relatively more incorrect predictions were made when the factor 'speed' was taken into account, compared to the group that made correct predictions (T (671) = -7.4, p < 0.001).

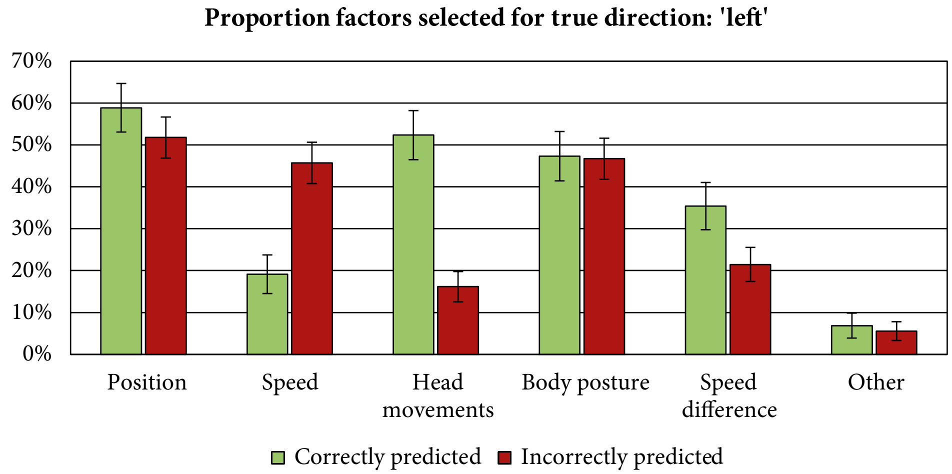

Figure 3.2: The proportion of factors selected by the participants for all trials in which the cyclist would turn left (true direction). The error bars represent the standard error of the mean.

3.3.2.2. True direction 2: cyclist going straight on

The proportions of all selected factors per trial in which the cyclist would go straight (true direction) are displayed in figure 3.3. As opposed to turning left, taking the speed of a cyclist into account seems to be the only factor positively related to prediction success for a cyclist going straight on, as more correct predictions were based on speed compared to incorrect predictions (T (579) = 10.14, p < 0.001). Remaining factors such as head movements (T (579) = -3.36, p = 0.001), body posture (T (579) = -2.47, p = 0.014), and a change in speed (T (579) = -4.75, p < 0.001) were selected more often in incorrect predictions, compared to correct predictions. No differences in prediction success were found for the factor position on the road.

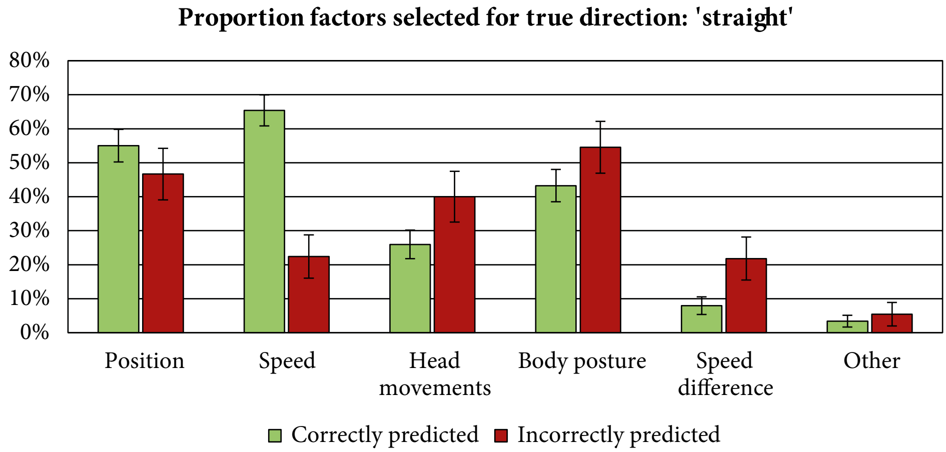

Figure 3.3: The proportion of factors selected by the participants for all trials in which the cyclist would go straight on (true direction). The error bars represent the standard error of the mean.

3.3.2.3. True direction 3: cyclist turning right

Lastly, the proportions of all selected factors per trial in which the cyclist would turn right (true direction) are displayed in figure 3.4. For this direction, speed seems negatively related to prediction success (T (769) = -5.795, p < 0.001) when a cyclist is turning right. Changes in speed seem positively related to prediction success, however (T (769) = 5.19, p < 0.001).

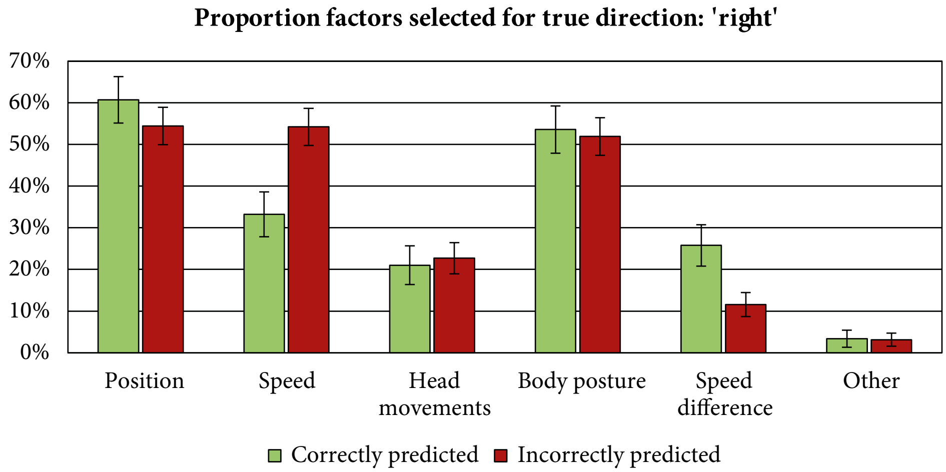

Figure 3.4: The proportion of factors selected by the participants for all trials in which the cyclist would turn right (true direction). The error bars represent the standard error of the mean.

3.3.3. Multilevel Logistic Regression Model

As during the exploring phase, it was found that for each direction different predictors seemed either positively or negatively related to prediction success, three different multilevel models were designed using MLWiN (Rasbash, Charlton, Browne, Healy, & Cameron, 2015). Goal was to explore the role of all different variables assessed during the survey, for each direction. The trials were treated as a level 1 variable, which were technically nested within the participants group (level 2), as all participants answered all items (Rasbash, Charlton, Browne, Healy, & Cameron, 2015). These models and their corresponding predictors are presented in table 3.4. For each predictor Wald Tests were performed to assess significance.

For all three trial directions, certainty is a significant predictor for response success (see table 3.4). However, the most predictive impact is gained by the selection of speed and head movements. Remarkable, however, is that detecting a certain speed only has a positive influence on predictive accuracy when the cyclist continues cycling forward ($\beta = 1.687$, $p < 0.001$). If the cyclist makes a turn (in either direction), the β values for speed as a predictor for turning left ($\beta = -1.244$, $p < 0.001$) or right ($\beta = -0.816$, $p < 0.001$) are both negative, decreasing the probabilities for making correct predictions. The opposite is found for the factor head movements, as the detection of head movements is only a significant positive predictor when the cyclist makes a left turn ($\beta = 1.551$, $p < 0.001$), and is negatively related to prediction accuracy for lead cyclists going straight on ($\beta = -0.593$, $p = 0.009$). Head movements did not have any predictive value for cyclists turning to the right in the corresponding model. The detection of a change in speed is a significant predictor that the lead cyclist will make a turn to the right ($\beta = 0.838$, $p < 0.001$), however. Lastly, the factor 'body posture' was only a negative predictor for the lead cyclist going straight on ($\beta = -0.495$, $p = 0.028$). The remaining factors such as participant age, gender, cycling experience, observed position on the road, and other factors did not have any predictive value for any direction in the models.

3.3.4. Post hoc trial content analyses

As no prior selection was performed on cue availability, post hoc content analyses were performed concerning the availability of the preselected factors (position, speed, head movements, body posture, and changes in speed). Lateral position was measured in Kinovea™ for Windows™. For each measurement, a perspective grid was placed over the road or path which divided it in 16 equally sized sections. Two samples were scored, one at the start and one at the end of the video. A shift in position was calculated by subtracting the beginning position from the ending position. Average speeds were calculated by measuring the distance between start and ending points in Google™ Earth, and dividing this by the total duration of the moving video. Speed change, head movements, and body posture adjustments were scored visually. The results of the analyses are depicted in table 3.5, 3.6, and 3.7.

Table 3.4: An overview of all predictors included in separate logistic regression models for each direction of travel. All significant predictors (Beta-values) are printed in bold.

True Direction	Left			Straight			Right		
Predictor	β	S.E.	p	β	S.E.	p	β	S.E.	p
Constant (i)	**-1.781**	**0.499**	**<0.001**	0.427	0.521	NS	-0.556	0.393	NS
Constant (j)	0.166	0.138	NS	0.000	0.000	NS	0.004	0.084	NS
Certainty	**0.257**	**0.059**	**<0.001**	**0.258**	**0.069**	**<0.001**	**0.114**	**0.051**	**0.024**
Familiarity	0.061	0.042	NS	-0.073	0.045	NS	0.003	0.033	NS
Age	0.000	0.007	NS	-0.012	0.007	NS	-0.006	0.005	NS
Gender	-0.272	0.224	NS	-0.092	0.235	NS	0.014	0.174	NS
Experience	0.002	0.002	NS	-0.000	0.002	NS	-0.001	0.001	NS
Position	0.189	0.191	NS	0.209	0.211	NS	0.169	0.161	NS
Speed	**-1.244**	**0.216**	**<0.001**	**1.687**	**0.225**	**<0.001**	**-0.816**	**0.164**	**<0.001**
Head	**1.551**	**0.205**	**<0.001**	**-0.593**	**0.228**	**0.009**	-0.188	0.193	NS
Body Posture	-0.203	0.199	NS	**-0.495**	**0.225**	**0.028**	-0.018	0.164	NS
Speed Diff.	0.326	0.209	NS	-0.511	0.295	NS	**0.838**	**0.209**	**<0.001**
Other	0.469	0.388	NS	-0.508	0.498	NS	0.033	0.436	NS
		N=666			N=575			N=764	

Table 3.5: Content analyses for all trials in which true direction = left. Lower lateral position value = to the right. Values for speed change are as follows: -1 = decelerating, 0 = constant speed, +1 = accelerating.

Trial	Lateral position			Speed		Head movements		Body posture	
	Start	End	Shift	Mean	Change	Left	Right	Freq.	*Movement*
3	4	3	-1	15	-1	1	0	1	*BR, SP*
9	2	4	+2	19	0	2	1	1	*RH*
10	2	2	0	17	0	1	0	2	*LF, BL*
11	4	2	-2	21	-1	1	1	1	*SP*
15	5	4	-1	13	-1	1	0	0	
16	5	8	+3	14	0	1	1	1	*LH*
22	8	4	-4	20	0	0	0	0	
M	4.3	3.9	-0.4	16.8	-0.43	1	0.43	0.86	

BR = Brakes
SP = Stops pedalling
RH = Right hand off handlebar
LF = Leans Forward
BL = Balance loss (shortly)
LH = Left hand off handlebar

Table 3.6: Content analyses for all trials in which true direction = straight. Lower lateral position value = to the right. Values for speed change are as follows: -1 = decelerating, 0 = constant speed, +1 = accelerating.

Trial	Lateral position			Speed		Head movements		Body posture	
	Start	End	Shift	Mean	Change	Left	Right	Freq.	*Movement*
4	4	2	-2	19	0	0	0	1	*SP*
7	6	4	-2	16	0	0	0	0	
12	1	2	+1	15	0	0	0	2	*LH, RH*
13	2	3	+1	19	0	0	0	1	*RH*
17	3	3	0	13	-1	0	0	0	
23	3	3	0	13	0	2	2	0	
M	3.2	2.8	-0.3	15.9	-0.17	0.33	0.33	0.67	

SP = Stops pedalling
LH = Left hand off handlebar
RH = Right hand off handlebar

Table 3.7: Content analyses for all trials in which true direction = right. Lower lateral position value = to the right. Values for speed change are as follows: -1 = decelerating, 0 = constant speed, +1 = accelerating.

Trial	Lateral position			Speed		Head movements		Body posture	
	Start	End	Shift	Mean	Change	Left	Right	Freq.	*Movement*
5	3	4	+1	15	0	0	0	0	
6	5	2	-3	16	0	0	1	0	
8	3	3	0	17	0	1	0	0	
14	7	4	-3	19	-1	0	0	2	*SP, RH*
18	5	5	0	14	0	0	0	0	
19	5	1	-4	16	0	0	1	0	
20	4	3	-1	15	0	0	0	0	
24	2	2	0	18	0	1	0	0	
M	4.3	3.0	-1.3	16.5	-0.13	0.25	0.25	0.25	

SP = Stops pedalling

RH = Right hand off handlebar

There were no large differences between cyclists turning left or right on mean lateral position, however, cyclists going straight seem to be positioned slightly more to the right compared to turning cyclists. Furthermore, an overall slight trajectory shift towards the right was observed for cyclists who were about to make a right turn. The average speed for cyclists were observably different between clips. Overall, the cyclists most frequently showed head movements when they were about to turn left, and these were more often head movements to the left than to the right. Cyclists also performed most body posture adjustments when they were about to turn left, compared to the other conditions.

3.4. Discussion

3.4.1. Prediction success

In a real traffic situation, cyclists have to make inferences about the expected future behaviour of other cyclists in order to prevent conflicts. To form these predictions and act accordingly, cyclists first have to perceive all relevant cues and create one holistic image of the current situation, according to the first two levels of the situation awareness theory (Endsley, 1995). During this study, participants predicted the potential manoeuvres of a lead cyclist approaching an intersection, based on video clips.

The intended directions of lead cyclists were predicted more accurately than on chance level when the cyclist was going straight on (i.e. not making a turn). In case the cyclist would make either a left or right turn, the average prediction scores were not significantly above chance level. Therefore, it is concluded that cyclists cannot predict that a cyclist ahead is going to make a turn *before a cyclist actually starts a turning manoeuvre*, and are therefore most likely to predict that a cyclist is continuing to cycle straight on and is not going to alter its course. Nevertheless, the high percentage of correct predictions for those cases in which cyclists went straight do reveal that the expectation that a cyclist will go straight are more often correct than on chance level.

However, after perceiving certain cues, cyclists do seem able to predict the direction a lead cyclist is going to choose more accurately. Within the given predictions, it was found that 60% of all predictions that a cyclist would make a turn, were correct. There were no differences found between prediction accuracy for all left or right responses. Furthermore, 40% of the predictions that a cyclist would go straight were correct, which is above chance.

To assess whether certain observable behaviours contribute to making a correct prediction of which direction the leading cyclist will take, three multilevel models were created in which several predictors were analysed. For each direction, trial certainty was related to prediction success. For a cyclist turning left, cyclist speed and head movements were predictors for prediction success, although taking speed into account negatively influenced a correct prediction. For a cyclist going straight, cycling speed was a significant factor which positively contributed to prediction success, as opposed to head movements and body posture, which negatively contributed to the prediction being correct. For a cyclist turning right, the results were ambiguous, as the speed negatively contributed to a correct prediction and a change in speed contributed positively. In summary: if a high cyclist speed is detected, it is more likely that the cyclist will continue straight and less likely that he or she will make a turn. If head movements are detected, it is more likely that the lead cyclist will make a left turn and less likely to continue cycling forward. Overall, it can be concluded that mainly perceived speed and head movements may potentially contribute to all three levels of situation awareness sufficiently, in order to make inferences about a future turn of a lead cyclists (SA level three) (Endsley, 1995). However, these findings are indicative, as the resulting Beta values are related to prediction success, no causal relationship between these variables can be inferred. Participant characteristics, including age, gender, and cycling experience, did not add predictive value to any of the models.

3.4.2. Strengths and weaknesses of the research

3.4.2.1. Computer-based survey

As with every study, there are several strengths and limitations worthy of mentioning. The first issue concerns the use of an open access internet survey protocol, as anyone with internet access could have participated and influenced the results. However, as the participants were mainly recruited by word of mouth, they were asked not to spread the link on the internet or social media. Furthermore, additional information to classify cyclists (Dill & McNeil, 2013) was not assessed, which limits the insights in the cyclist sample characteristics. Lastly, as the survey was performed online in its entirety, it was not possible to fully standardize the environment. Although it was recommended to perform the survey on a computer and not on a smartphone or tablet, different devices, screen sizes or even viewing distances from the screen could have influenced perception, and thus the results. Also, participants had more time to give their prediction compared to real traffic, as the mean response time was 6.5 seconds. This may influence the generalizability to real world situations.

3.4.2.2. Trial content

There were some limitations resulting from the selection and design of the trials. The first limitation concerns the locations of the recordings. As the main scope of the study was to assess whether cyclists are able to predict the intentions of another cyclist in real traffic, trials were randomly recorded in real traffic in the city of Groningen. Therefore, all cyclists and locations filmed for the trials were sampled within the specific cycling infrastructure and culture of the Netherlands, potentially limiting generalizability to other countries. However, as the three locations used in the analyses were roads shared with motorised traffic, the influence of specific cycle path lay-outs was limited. Furthermore, no motorised traffic was present at the moments the cyclists were about to make their turns. Another limitation originates from the contents of the trial videos. As all trials were taken from real traffic, no a priori selection was performed to assess whether certain cues were available or visible, as any prior selection based on cue availability would undermine the naturalistic basis of the study and would not represent real traffic. Post hoc content analyses revealed that there were indeed differences in cue availability between trials, and this may have influenced the results overall to a limited extent.

For every video clip the moment of freezing was carefully selected by watching each one using a very slow playback speed. However, it cannot be ruled out that the selection of these moments was influential on the perceived predictability for each trial. This approach was used, however, as one could reason that a prediction by definition has to take place before the *actual* manoeuvre is initiated, as it would otherwise have been a test of observing movements. Additionally, during the recording of the trials, the researchers carefully tried to maintain a consistent constant following distance to the filmed cyclist ahead. However, the following distances were still variable and therefore these distances were not standardized to a high degree. This could have made certain cues such as body movements more or less visible as well.

3.4.2.3. Naturalistic content

Many of the mentioned study limitations are due to the fact that all trials were recorded in real traffic, partly resulting in a lack of standardization and limited influence on the content of the trials. At the same time this is a major strength of the study as the ecological validity of the real-world situations from the cyclist's perspective, and the random presentation of 24 trials to a 100+ sample of participants, resulted in a highly suitable combination of ecological valid trials and digital measurement accuracy. Moreover, as the content analyses revealed that there were differences between stimuli, any selection of clips based on cue appearance would have influenced the naturalistic content and was therefore not performed.

3.4.3. Contribution to the knowledge and to the theory in the field

The findings of the current study contradict previous findings by Hemeren et al. (2014), who indicated that observers were relatively good at predicting that cyclists would either turn left (78%) or go straight (75%). The difference between the study by Hemeren et al. (2014) and the current study is the recording perspective, as the video stimuli used by Hemeren et al. (2014) were recorded from a fixed perspective 6 meters high and 20 metres away from the crossing. Therefore, it could be that participants are more accurate at predicting the intentions of a cyclist when they observe them from a "helicopter view", compared to the perspective of a cyclist in real traffic. This has clear implications for the relevance of studying intention prediction in ecologically valid settings, as the perspective of a cyclist is the actual perspective in which the predictions have to take place.

3.4.4. Practical implications of the results

As in this study it is concluded that making inferences concerning future turns of lead cyclists are difficult, it remains important to explicitly communicate intentions while cycling in traffic. Therefore, it is essential to use cues which are easy to interpret, for example by pointing in the intended direction of movement by using the arms (Walker, 2005) and to do this sufficiently early, i.e. before a turn is initiated. As the cues related to prediction success have to be considered exploratory, more research has to be performed to find out which cues are actually performed in real life cycling traffic, and whether these cues are sufficiently visible to be perceived and used by other cyclists (or road users) for assessing intentions.

3.4.5. Future research

The results concerning the ability to predict the intentions of cyclists from this study and work by Walker and Brosnan (2007) and Hemeren et al. (2014) are mixed, it therefore remains difficult to draw definite conclusions about the ability of observers to predict intentions in real traffic. Future research could include eye movement measurements and should be aimed at further identifying which cues are potentially critical for predicting cyclists' behaviour, and whether technical devices may be able to read intentions, as opposed to human observers, based on sophisticated measurement devices. In this area of research, Schmidt and Färber (2009) found that multiple sources of pedestrian information (i.e. head and leg movements; "body language") and traffic parameters (i.e. speed and density) can be used to predict whether pedestrians are going to cross the road. For car drivers' intentions, Ohn-Bar et al. (2015) found that observations from multiple visual perspectives and modalities can be used to make inferences about the intentions of a car driver. Also, Bi et al. (2015) found that the intention of car drivers to change lanes in a driving simulator can be predicted by monitoring the drivers' steering angle sequences. Although these current techniques are not yet suitable to be used safely in real traffic, these results may contribute to the development of predictive driver assistance systems. These systems might be capable of providing critical information, assistance, or even intervene, once critical driver intentions or potential conflicts are detected. Future studies should aim at using comparable techniques for cyclists.

3.5. Conclusions

One hundred and eight participants predicted the direction of travel of 24 cyclists that approached a crossroad up to the moment a movement in the direction of travel was initiated. The cyclists would either turn left, turn right, or continue cycling straight on. On an overall level, the participants were not able to predict the direction a cyclist would take more accurately than on chance level. However, certain factors such as head movements and the speed of the cyclist ahead increased reliability of predictions for cyclist turning either left or straight.

Acknowledgements

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Chapter 4

Using optical illusions in the shoulder of a cycle path to affect lateral position

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This chapter is based on Westerhuis, F., Jelijs, L.H., Fuermaier, A.B.M., & De Waard, D. (2017). Using optical illusions in the shoulder of a cycle path to affect lateral position. *Transportation Research Part F, 48*, 38-51. doi:10.1016/j.trf.2017.04.014

For consistency throughout this thesis, the terms 'single-sided', 'accident', 'European city bicycle', and 'treatment' have been changed to 'single-bicycle', 'crash', 'conventional bicycle', and 'intervention', respectively.

4. Using optical illusions in the shoulder of a cycle path to affect lateral position

Abstract

An important factor in single-bicycle crashes of older cyclists is that they ride off the cycle path onto the verge. Two experiments were performed to assess the feasibility of using virtual 3D objects in the verge to affect the lateral position of bicyclists. In the first experiment, different virtual objects were placed in the shoulder and 1150 passing bicyclists were observed using a fixed camera. The (standard deviation of the) lateral position and speed in four conditions with virtual objects differing in colour, structure, or 3D effect were compared with a control condition in which no virtual objects were applied. In a second experiment, the behaviour of 32 bicyclists aged 50 years or older was measured by mounting two digital action cameras with GPS on the participants' bicycles. The participants cycled a route of approximately 12 km in which several locations were passed, one of these contained 15 virtual objects similar to the ones used in the first experiment placed in the shoulder of the cycle path. Cyclist behaviour was compared with behaviour at a control location consisting of a solitary two-way cycle path with a grass shoulder. Results indicate that the virtual objects in the tested format had little overall effect on cyclists' behaviour. However, bicyclists were positioned closer to the virtual objects and the shoulder when they looked at the objects or when they reported that they saw them while cycling. This suggests that the overall visibility of the object design may have been too conservative.

4.1. Introduction

4.1.1. Cycling in the Netherlands

In the Netherlands, cycling is a very popular mode of transportation. Estimations are that 26% of all journeys in the Netherlands are made by bicycle (Ministry of Transport, Public Works, and Water Management, 2008). Cycling can be an effective mode of transportation and an important contributor to physical health and fitness (Oja et al., 2011) although cycling in traffic is not without risks. In 2012, 59% of all first-aid interventions after traffic crashes in the Netherlands involved cyclists (Schepers, 2013).

Several factors influence cycling safety, such as adverse weather conditions, state of the pavement, other road users, defects of bicycles, alcohol or drug use, gender, helmet use, and bicycle use by two occupants (Juhra et al., 2012; Martínez-Ruiz et al., 2013; Martínez-Ruiz et al., 2014). Common types of crashes are falls while getting on or off the bicycle and falls due to potholes or pavement irregularities, kerbstones, or similar (Scheiman, Moghaddas, Björnstig, Bylund, & Saveman, 2010).

4.1.2. Older cyclists

As our society is ageing, bicycle use by older people is also increasing (Wegman, Zhang, & Dijkstra, 2012). This is a positive development as it contributes to independent mobility, which is an important factor for healthy ageing and quality of life (Fagerström & Borglin, 2010; Törnvall, Marcusson, & Wressle, 2016). However, increasing age is also related to a greater risk for being involved in a serious bicycle crash (Martínez-Ruiz et al., 2014) and for sustaining severe injuries with poor outcome after a crash (Kaplan, Vavatsoulas, & Prato, 2014; Siman-Tov, Jaffe, Peleg, & Israel Trauma Group, 2012). In the Netherlands, 67% of all bicyclist fatalities were among cyclists aged 60 years or older. This is more than twice as much as fatally affected car drivers within the same age group (CBS, 2014).

The increased crash risk for older cyclists can be explained by both cognitive and physical decline (OECD, 2001). Cognitive factors such as a decrease in attention, working memory, and reaction capability can make many traffic situations a more mentally demanding task. Physical factors such as decreased balance, increased muscle stiffness, and bone fragility lead to more severe injuries after a collision or fall. These factors show the need to increase safety for older cyclists, which is currently one of the priorities within the Dutch cycling safety policy (Rijkswaterstaat, 2016).

4.1.3. Single-bicycle crashes

Older cyclists in the Netherlands are particularly at risk for single-bicycle crashes, which are crashes not involving other traffic participants (Schepers & Klein Wolt, 2012). Although minor bicycle crashes in the Netherlands are underreported (Schepers & Klein Wolt, 2012; Wegman, Zhang, & Dijkstra, 2012), estimations are that in more than 60% of all cyclist crashes leading to injuries, no other traffic participants are involved (Schepers, 2013). In 50% of all single-bicycle crashes, infrastructural factors are of influence (Schepers & Klein Wolt, 2012; Schepers & den Brinker, 2011; Fabriek, De Waard, & Schepers, 2012) and 33% of these crashes happen on a cycle path (Schepers, 2008).

Westerhuis and De Waard (2016) studied the behaviour of older cyclists in a naturalistic cycling setting and identified behaviour potentially leading to a crash. They found that 20% of the cyclists accidently entered the verge once or more during a week of cycling. Although these events did not lead to any crashes in the observed cases, it is known that in 21% of all single-bicycle crashes in the Netherlands, cyclists end up riding off the road either hitting a kerbstone or entering the verge (Schepers, 2013). Interacting with a cycling companion (45%), alcohol use (19%), not looking ahead (17%), moving out of the way for another road user or performing an overtaking manoeuvre (13%), or physical problems (12%) are important factors preceding these types of accidents (Schepers, 2008).

4.1.4. Safety measures

Current Dutch traffic policies are based on the evidence-based “Sustainable Safety” vision, in which several principles are applied to prevent crashes and limit injuries (Wegman, Aarts, & Bax, 2008). The current study is based on the principle of physical forgivingness, meaning that the infrastructure should be designed to prevent crashes or constrain negative outcome (Houtenbos, 2009). Examples of such safety measures are implementing a passable shoulder or reducing the number of objects on a cycle path. As a different form of physical forgivingness, the current study explores the use of optical illusions to influence the position of cyclists preventing them from riding off the road. As, currently, physical objects are mostly used to fence-off roads or cycle paths (i.e. posts or bollards), these are objects cyclists can collide with potentially leading to a single-bicycle crash.

4.1.5. Optical illusions

As optical illusions are visual deceptions they are, in principle, undesirable in any traffic situation as they tend to misinform traffic participants (CREST, 2013). Remarkably, there are indications that they can be used to enhance traffic safety. For example, several studies have shown that the application of transverse delineation on roads can reduce driving speeds in motorised vehicles (Godley, Triggs, & Fildes, 2000; CREST, 2013; Wu, Hu, & Li, 2013). Furthermore, Wu, Hu, and Li (2013) concluded that speed-reducing optical illusions also evoke a tendency in motorcyclists to maintain a more central lateral position, an effect they did not find in car drivers.

A more specific use of optical illusions in the traffic infrastructure is anamorphosis (CREST, 2013; Plankermann, 2013), which is purposefully distorting an image so that it can be seen from different perspectives, at greater distances, or at higher speeds. This paper describes a study in which anamorphic images placed in the cycle path shoulder might be used to affect the behaviour of cyclists. It was observed during a naturalistic cycling study that cyclists have a tendency to regularly move around objects, such as manhole covers, which may be a threat to balance (Westerhuis & De Waard, 2016). Therefore, it was hypothesised that creating virtual objects in the shoulder of a cycle path influences the lateral position of cyclists by provoking a natural reaction to avoid colliding with this object. As the object can be perceived either consciously or unconsciously through foveal vision or peripheral vision, respectively, lateral distance to these objects (and therefore the shoulder) should be increased. Furthermore, it was hypothesised that cyclists would lower their speed as an anticipatory reaction as they pass the objects.

The virtual objects were placed along the right-hand side of the cycle path so that they would be perceived in the peripheral visual field of passing cyclists and function as a subtle warning signal that the edge of a cycle path needs to be avoided. Furthermore, because the illusions would only simulate height, these measures would automatically be 'forgiving' because cyclists simply cannot collide with them as they are flat drawings and not physical objects. Eventually the idea evaluated is that virtual objects could increase distance to potentially dangerous shoulders using two different experimental approaches.

4.2. Method – Experiment 1

4.2.1. Virtual Objects

Based on anamorphic optical illusions, an image was created which represented a three-dimensional box when viewed from the correct position. As this was a first study, a simple box was chosen and not a threatening image to restrict the chance on potentially intense reactions. To determine the appropriate size and location for the object, a 'real' prototype box (12.5 x 12.5 x 28.5 cm) was created first. Subsequently, a virtual version was made by first locating the edges of the real model and drawing them on a two-dimensional surface on the exact locations from which a human spectator saw these. A longitudinal perspective of 3.6 m was used, for functional as well as practical reasons (see figure 4.1). It was hypothesised that the illusion would have its strongest effects on cyclists who were cycling relatively close to the edge of the cycle path. Therefore, a lateral distance of 50 cm was used for the perspective of the illusion. The virtual object was completed by connecting the edge-points using Adobe Photoshop™. The resulting images and dimensions are displayed in figures 4.2, 4.3, and 4.4. The same virtual objects were used for both experiments, which were approved by the Ethical Committee of the Department of Psychology of the University of Groningen.

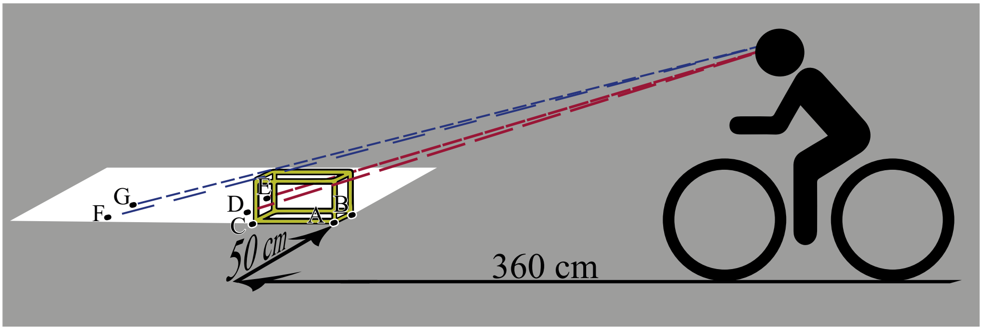

Figure 4.1: An illustration of the way the virtual image was constructed from the perspective of a human spectator.

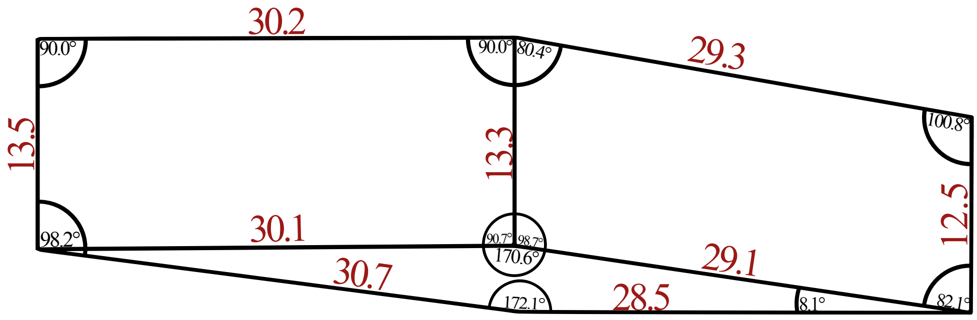

Figure 4.2: Top view of the resulting lay-out of the virtual image. The dimensions are in centimetres.

4.2.2. Experiment 1: Fixed perspective

Cyclists were observed on a crowded bicycle path on a location close to the main public transport station in the city of Groningen. On this location, the behaviour of passing cyclists was observed from a fixed perspective using a video camera and different versions of the virtual objects were placed on the right-hand side of the two-way cycle path (figure 4.3). The virtual objects were printed and glued to a thin piece of wood so that they could be placed and removed quickly. The objects were placed 0.2 m in the verge; therefore, the illusion would have its strongest effects when a cyclist would cycle 0.3 m from the edge of the cycle path. Only cyclists who passed the illusions on their right were included.

Figure 4.3: A bicyclist's view of the experimental location in the city of Groningen.

4.2.3. Experimental conditions

In the first condition, a grey 3D illusion was placed next to the cycle path. In the second condition, the grey 3D illusion had a stone structure print added to it. The third condition had a red coloured virtual 3D object with white horizontal striping similar to commonly used cycling bollards in the Netherlands. The fourth condition consisted of a two-dimensional object, which had the same total surface area as the 3D versions, yet entirely printed in black. The fifth and last condition was a control condition in which no objects were placed along the cycle path. An overview of the different (virtual) objects is presented in figure 4.4. During each condition, three identical objects were placed with 3.6 m of space between them. During five days all conditions were presented to passing bicyclists for 30 minutes in a randomized order, resulting in a total observation time of 150 minutes per condition.

4.2.4. Material

Cyclist's behaviour was recorded using a JVC Everio® digital camcorder fixed to a lamppost close to the cycle path. A total of 12½ h of video footage was collected between the 3rd and 12th of June 2014, all in dry weather conditions.

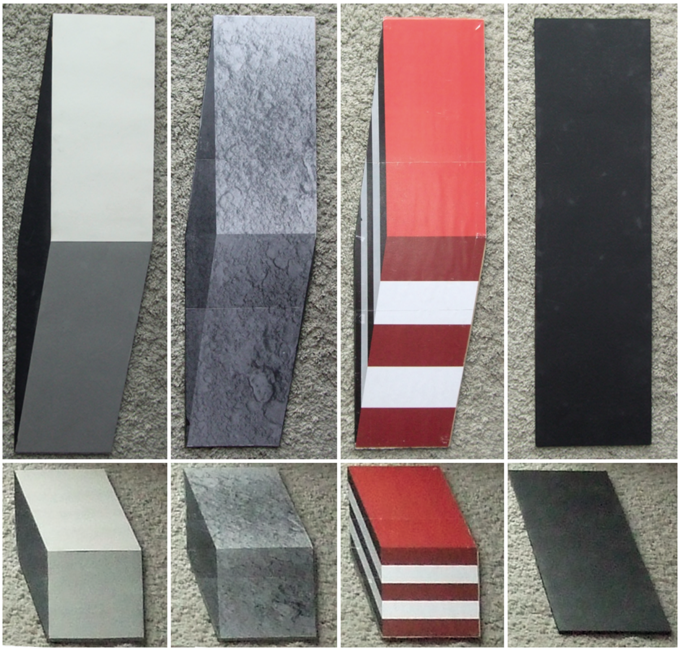

Figure 4.4: An overview of the different types of optical illusions used during Experiment 1. From left to right: grey virtual 3D object, grey virtual 3D object with structure, red coloured virtual 3D object with white striping, 2D black object. During the control condition no virtual objects were placed along the cycle path.

4.2.5. Video analysis

The video data were analysed using the software programme Kinovea™ for Windows™ (Charmant, 2016). A perspective grid was placed over the cycle path using pre-recorded positions marked by the researchers (see figure 4.5). The dimensions of the grid were adjusted to represent the real size of the measurement area (7.2 x 3.0 m). Subsequently, the position of the cyclist's front wheel along the grid was semi-automatically tracked using the 'track path' tool. The tracking was initiated when the cyclist's front wheel entered the grid and was ended as soon as the front wheel left the grid. Bicyclists who were accompanied or bicyclists who followed another bicyclist at approximately 7 m or less (the length of the grid) were excluded from the analysis.

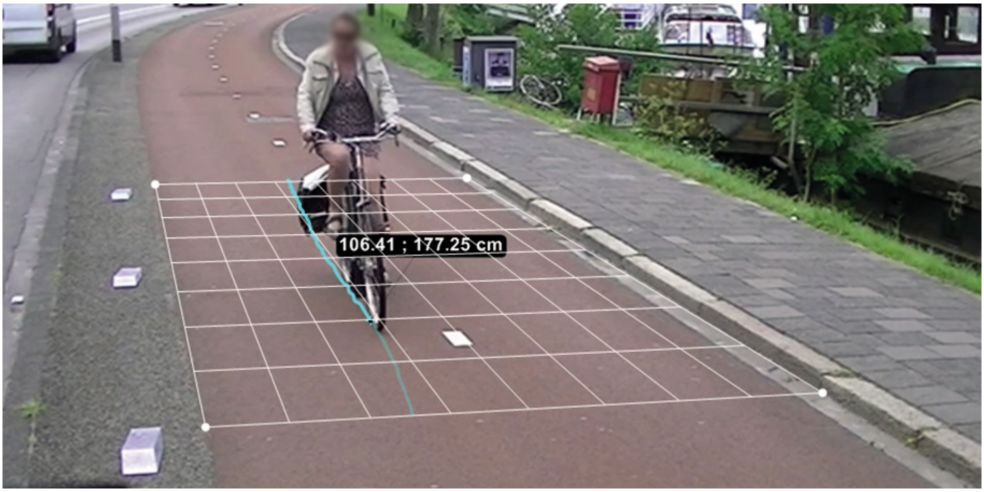

Figure 4.5: An illustration of the cyclist position measurement process. Using Kinovea™, a perspective grid was placed at the experimental location and calibrated reflecting the length and width of the cycle path measurement area (7.2 x 3.0 m). Along the grid, the position of the front wheel was semi-automatically tracked and lateral position (horizontal position) and speed were sampled.

4.2.6. Statistical analysis

Effects of the virtual object conditions on cyclist lateral position, swerving behaviour (SD of the Lateral Position, SDLP), and speed were analysed using a multivariate analysis of variance (MANOVA) as the data were normally distributed and based on large sample sizes. SDLP data were logarithmically distributed, therefore its values were first transformed to a normal distribution before performing the analysis. Statistical analyses were performed using IBM SPSS Statistics™ 22 for Windows™ and an α-value of 0.05 was applied to assess statistical significance. When applying multiple comparisons, the p-value was Bonferroni corrected. Lastly, eta squared (η^2) values were computed to determine effect sizes of multivariate comparisons, of which values of $\eta^2 = 0.0099$ were interpreted as small effect sizes, $\eta^2 = 0.0588$ as medium effect sizes and $\eta^2 = 1.379$ as large effect sizes (Cohen, 1988). For pairwise comparisons, Cohen's d was calculated as the measure of effect sizes, of which $d < 0.20$ corresponds to negligible effects, $d = 0.20$ represents a small effect, $d = 0.50$ a medium effect and $d = 0.80$ corresponds to a large effect (Cohen, 1988).

4.3. Results – Experiment 1

4.3.1. Experiment 1

During Experiment 1, a total of 744 min of video data recorded from the fixed camera perspective were analysed, and a total of 1150 cyclists were scored. Fifty-five percent of the cyclists were men and at least 205 cyclists were scored per condition. For an overview of all scored participant characteristics, see table 4.1.

During data processing it was observed that, by judging upon their head movements, several bicyclists were looking at the objects, an indication that they had noticed these while cycling (table 4.1). Furthermore, as the experiment was performed along a bidirectional cycle path, it was also noted that 21% of all participants passed the experimental conditions while one or more oncoming cyclists were present on the opposing lane. For these reasons, it was also analysed whether these factors exerted any effects on the lateral position, SDLP, or speed of the participants by including these variables in the analysis.

Table 4.1: Scored participant data per condition.

Condition	N	Male (%)	Without oncoming bicyclist (%)	Looking at one object at least (%)	Total video time analysed
Control	228	57.0	78.5	n/a	153min
2-Dimensional	271	54.2	78.6	18.5	155min
3D: No Structure	205	55.6	79.5	36.6	140 min
3D: Structure	224	55.8	80.8	43.3	148 min
3D: Red Coloured	222	54.1	79.3	44.1	148 min
Total	1150	55.3	79.3	27.8	744 min

The results for the MANOVA are depicted in table 4.2. Small significant effects were found for the virtual object conditions and very small effect sizes were found for looking at the objects, although these effects were marginally significant. Medium and significant effects of oncoming cyclists were also found. All remaining interaction effects were non-significant and resulted in negligible effect sizes (table 4.2).

Table 4.2: Multivariate test results for the effects of illusion conditions, looking and oncoming cyclists on speed, lateral position, or SDLP.

Effect	Value	F	df	p	η^2
Condition	0.03	2.49	12, 3396	0.003*	0.009
Looking	0.01	2.58	3, 1130	0.052	0.007
Oncoming	0.08	31.63	3, 1130	<0.001*	0.077
Condition x Looking	0.01	0.99	9, 3396	0.45	0.003
Condition x Oncoming	0.01	1.10	12, 3396	0.36	0.004
Looking x Oncoming	<0.001	0.07	3, 1130	0.98	<0.001
Condition x Looking x Oncoming	0.01	1.28	9, 3396	0.24	0.003

* = Significant at $p < 0.05$

4.3.2. Illusion conditions

To explore the effects of the different forms of 3D objects, the mean lateral position per condition is depicted in figure 4.6. The analyses showed negligible non-significant effects of the conditions on lateral position ($F(4, 1132) = 1.69$, $p = 0.15$, $\eta^2 = 0.006$) and SDLP ($F(4, 1132) < 1$, $p = 0.86$, $\eta^2 = 0.001$). However, a small significant effect of condition on cyclist speed was found ($F(4, 1132) = 5.33$, $p < 0.001$, $\eta^2 = 0.018$, figure 4.7). Additional Bonferroni corrected pairwise comparisons were performed to determine the effects of each individual condition on cycling speed, revealing negligible and non-significant results for the *3D: No Structure* and *2-Dimensional* conditions (see table 4.3). However, small effects were found for the *3D: Structure* and *3D: Red Coloured* conditions, of which only the latter reached significance (table 4.3). This finding indicates that cyclists rode at a higher speed during the red coloured condition.

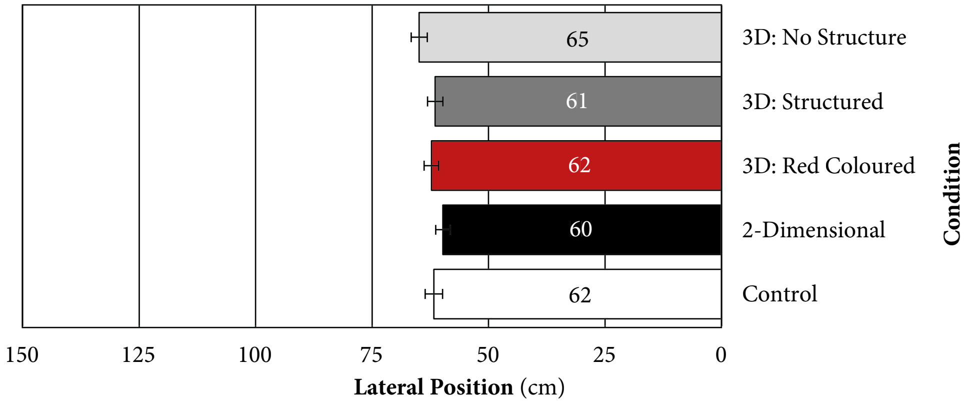

Figure 4.6: The mean lateral position (in centimetres) of bicyclists passing the experimental and control conditions. The error bars represent the Standard Error of the Mean (SE).

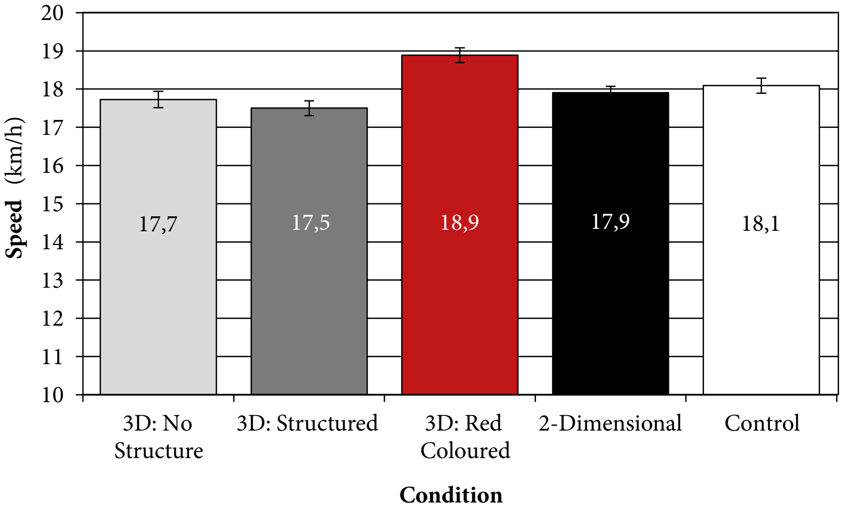

Figure 4.7: The mean cycling speed (in kilometres per hour) of bicyclists passing the experimental and control conditions. The error bars represent the Standard Error of the Mean (SE).

Table 4.3: Bonferroni corrected post hoc tests for the effects of condition on cycling speed.

Condition (I)	Condition (J)	Mean Difference (I-J)	SE	p*	d
3D: No Structure	Control	-0.36	0.28	1.00	0.121
3D: Structure	Control	-0.59	0.27	0.30	0.202
3D: Red Coloured	Control	0.80	0.27	0.04**	0.272
2-Dimensional	Control	-0.19	0.26	1.00	0.066

* = Bonferroni adjusted p-value for multiple comparisons

** = Significant at $p < 0.05$

4.3.3. Looking at the objects

As displayed in figure 4.8, additional analyses on looking behaviour showed very small significant effects on lateral position as cyclists looking at an object were positioned closer to the edge of the cycle path compared to cyclists who were not looking at an object ($F(1, 1132) = 7.65$, $p = 0.006$, $\eta^2 = 0.007$). Further comparisons per condition resulted in negligible and non-significant effects for the *3D: Structure* and *3D: Red Coloured* conditions. Small effects for cyclists looking at the *3D: No Structure* and *2-Dimensional* conditions were found, however, only the effect for the *2-Dimensional* object condition was significant, indicating that the cyclists who were looking at the 2-Dimensional objects rode closer to the edge of the cycle path than cyclists who were not looking at these objects (see table 4.4).

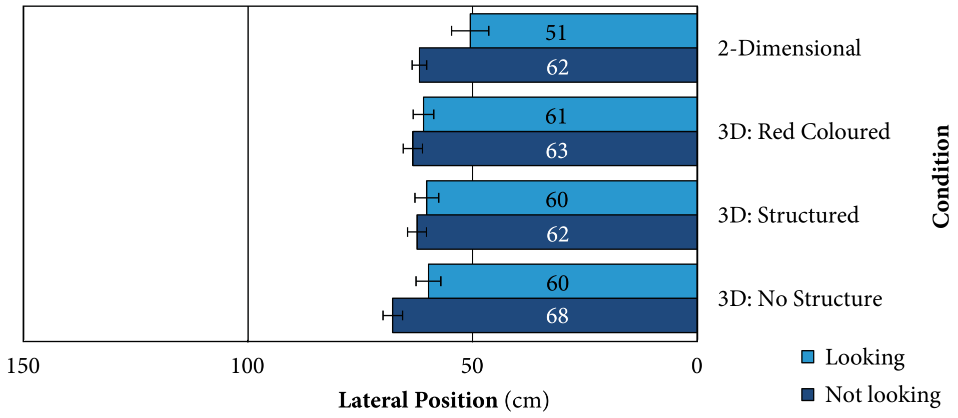

Figure 4.8: The mean lateral position (in centimetres) of bicyclists either looking or not looking at the virtual objects while passing the experimental conditions. The error bars represent the Standard Error of the Mean (SE).

Table 4.4: Bonferroni corrected test results for the effects of cyclists who looked at the objects versus cyclists who did not look at the objects on lateral position.

Condition	Mean Square	df	F	p*	η^2
3D: No Structure	3027.4	1, 203	4.997	0.104	0.024
3D: Structure	268.3	1, 222	0.438	1.00	0.002
3D: Red Coloured	304.9	1, 220	0.553	1.00	0.003
2-Dimensional	5234.6	1, 269	8.180	0.02**	0.030

* = Bonferroni adjusted p-value for multiple comparisons

** = Significant at $p < 0.05$

4.3.4. Presence of oncoming cyclists

Overall, a medium and significant effect for the presence of oncoming cyclists on lateral position was found, as cyclists who were cycling without any oncoming cyclists maintained a greater distance to the shoulder (M = 66 cm, SD = 25 cm) compared to cyclists who met oncoming cyclists (M = 46 cm, SD = 19 cm), F (1, 1132) = 92.22, $p < 0.001$, $\eta^2 = 0.075$ (see figure 4.9). However, the interaction term *Condition x Oncoming* was not significant and resulted in negligible effect sizes (see table 4.2).

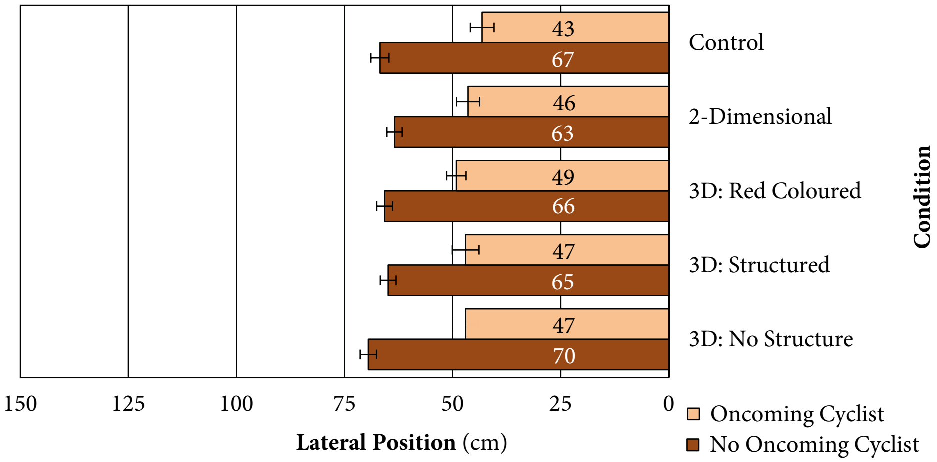

Figure 4.9: The mean lateral position (in centimetres) of bicyclists either being in the presence or absence of one or more oncoming cyclists while passing the experimental and control conditions. The error bars represent the Standard Error of the Mean (SE).

4.4. Method – Experiment 2

The second study was an experimental study with participants and was performed on a cycle path located near a small village in the Netherlands. This experiment was performed as part of the 'forgiving cycle path' project (Westerhuis & De Waard, 2014c) in which the effects of several measures in the shoulder of a cycle path were assessed. During this experiment, participants aged 50 years and above were asked to cycle a route of 12 km and their behaviour was observed using mobile cameras mounted on their bicycles. On the experimental location, 15 virtual objects were painted on pavement tiles and placed along the right-hand side of a cycle path. Objective as well as subjective data were gathered from bicyclists using either a conventional (European city) bicycle or an electric bicycle (pedelec). In this paper, the effects of the virtual objects will be presented only. The participants received 15 euros for their participation in this study.

4.4.1. Participants

A total of 32 participants aged 50 years and above participated in the second study, of which 18 were male. A conventional bicycle was used by 17 participants and 15 participants used an electric bicycle. Participants were recruited locally by placing ads on a local TV station and in local supermarkets, as well as via word of mouth. The mean age of the participants was 68.3 years (SD: 9 years). Bicyclists using an electric bicycle were slightly older (M = 70.2 years, SD = 9.8 years) than bicyclists using a conventional bicycle (M = 66.5 years, SD = 8.0 years). On average, the participants made six bicycle trips per week, corresponding to a total weekly cycling distance of

46 km. On an overall level, all participants were healthy although 47% experienced physical and 28% reported mental complaints to some degree (e.g. overall stiffness of joints, painful knees, feeling uncomfortable in busy or unclear traffic situations, reduced reaction speed). Nearly all participants used their own bicycles, one made use of the possibility to borrow a bicycle.

4.4.2. Location

Approximately one kilometre after the start of the cycling route, 15 virtual objects were placed in the right-hand cycle path shoulder (see figure 4.10, right-hand photo). These virtual objects were identical to the grey objects used in Experiment 1. On this location, the objects were painted on pavement tiles of 0.4 x 0.6 m, as displayed in figure 4.11. Every pavement tile containing an illusion was followed by five non-painted pavement tiles, resulting in a repeating pattern of one virtual object per 3.6 m. In accordance with the first study, the objects had been positioned 0.2 m to the right of the cycle path edge, again so that the illusion would have its strongest effects when a bicyclist was positioned 0.3 m from the edge of the cycle path. The objects were placed along a cycle path section of 50 m that was 2.3 m wide. Participants also passed a control location shortly after they left the village. This control location was also a solitary two-way cycle path of 2.3 m wide although this path was paved in asphalt and had a grass shoulder (figure 4.10, left photo).

Figure 4.10: The control condition (left photo) and the experimental condition (right photo).

4.4.3. Questionnaire and interview

The participants were asked to fill in a questionnaire which contained sixteen items concerning general, demographic, and cycling information, such as the type(s) of bicycle(s) used and whether the participants used medication or not. This questionnaire was sent to the participants in a letter beforehand as part of a package. This package also contained instructions for the study and the starting location.

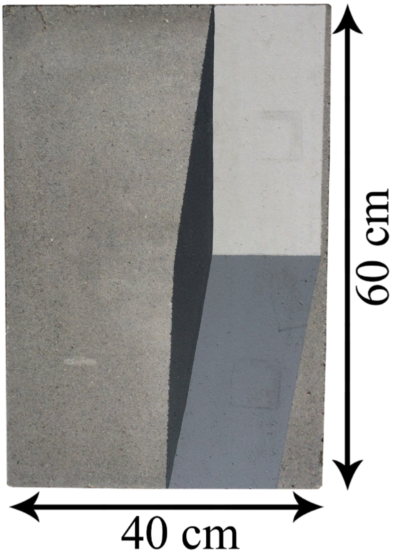

Figure 4.11: A top-down view of the pavement tile containing the virtual object.

Immediately after each participant's bicycle ride was completed, an interview was conducted. During this interview, subjective data concerning the virtual object visibility and the bicyclist's experiences were collected by asking participants thirty questions about what they had seen during the route, how they interpreted what they had seen, and what their opinion was concerning bicyclist safety, distraction, and potential risk. Also, the participants were asked what their thoughts were while they were cycling along the virtual objects. Most questions were open-ended questions (17) to collect unbiased and spontaneous answers and the questionnaire also contained 13 closed-ended questions. Nine questions were about the virtual objects. Furthermore, participants could report their experiences using the video recording of their own journey which was presented on a 15" laptop screen during the interview. These videos were displayed after the participants had answered the open questions concerning what they remembered about their bicycle trip, again to make sure that the first answers collected were unbiased and spontaneous, and also as a measure of object visibility.

4.4.4. Video recordings

Cycling behaviour was collected using video recordings made with two Contour+2™ digital action cameras with GPS mounted on the front of the participants' bicycles. One camera was directed forward to the cycle path ahead for a situational overview and the other was directed downward for increased accuracy in lateral position measurements. The videos were recorded using a resolution of 1280x720 pixels at a frame rate of 30 frames per second.

4.4.4.1. Observable behavioural measures

Cycling behaviour was assessed by measuring speed (km/h), the lateral position (in centimetres), and by calculating SD of the Lateral Position (SDLP). A total of 30 lateral position samples per condition were scored by measuring the distance of the front wheel to the edge of the cycle path using a digital ruler (JRuler Pro™ 3.1 for Windows™). Because the cameras were equipped with 170° widescreen lenses, a measurement aiding tool was filmed before each bicycle trip to allow for correct measurement of lateral position.

4.4.4.2. Statistical analysis

Effects for the virtual objects on cycling speed, lateral position, and SDLP were analysed by comparing the virtual objects condition with the control condition. As all dependant variables were not normally distributed, non-parametric Wilcoxon Signed Rank Tests were performed while applying an α-value of 0.05 to determine statistical significance. Effects of bicycle type were analysed using Bonferroni corrected multiple Mann-Whitney U Tests to control for the problems of multiple testing. Effect sizes were calculated for non-parametric data using the r statistic: an r value of 0.5 corresponds to a large effect, a value of 0.3 represents a medium effect and 0.1 represents a small effect size (Fritz, Morris, & Richler, 2012). All statistical analyses were performed using IBM SPSS Statistics 22™ for Windows™.

4.5. Results – Experiment 2

4.5.1. Behavioural measurements

Because the virtual objects could only be placed on one side of the cycle path they were only passed once, on the way to the turning point. Behaviour on this location is compared with a control location during the same phase of the trip. To determine the effects of the virtual objects on lateral position, SDLP, and speed of bicyclists, non-parametric Wilcoxon Signed Ranks tests were performed in which condition was used as within-subjects factor. As displayed in figure 4.12 and table 4.5, the virtual objects revealed negligible and non-significant effects on lateral position and SDLP. However, there was a small effect found of condition on cycling speed which did not reach significance. Lastly, small non-significant effects were found of bicycle type.

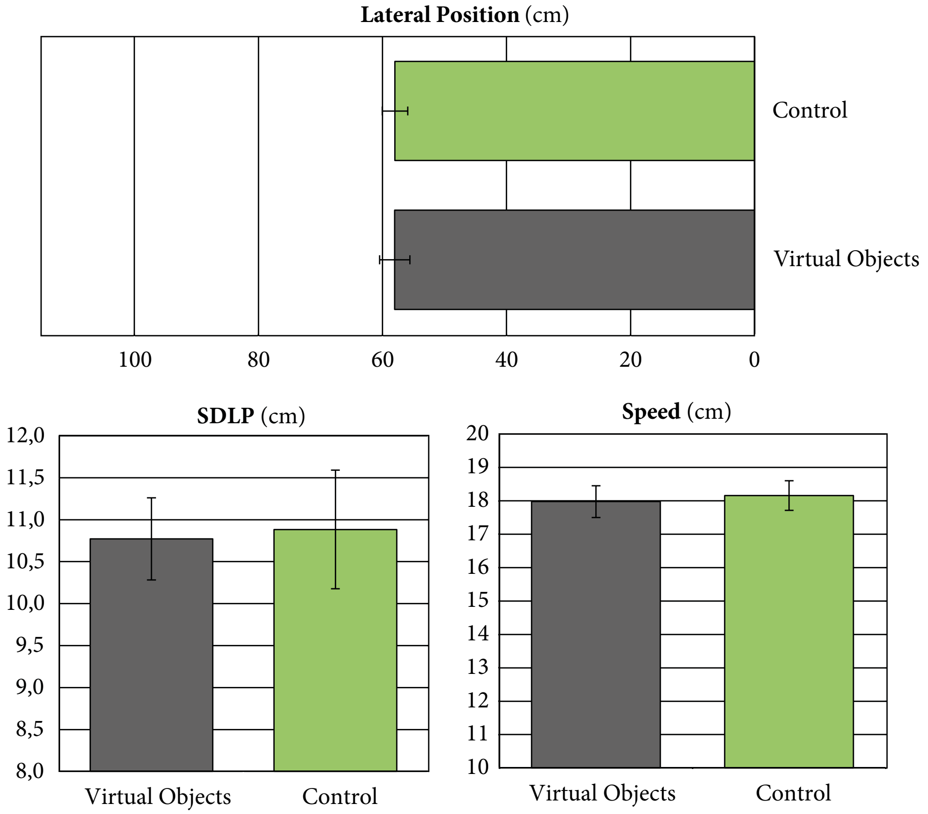

Figure 4.12: An overview of the measurements on the experimental and the control location: lateral position (top graph), SDLP (lower left graph), and speed (lower right graph). The error bars represent the Standard Error of the Mean (SE).

Table 4.5: Multivariate test results for the effects of the virtual objects condition versus the control condition on cyclist lateral position, speed, and SDLP.

Variable	Rank	N	Mean Rank	Sum of Ranks	Z	p	*r*
Lateral position	Negative Ranks	17	16.18	275.0	-0.206	0.84	0.04
	Positive Ranks	15	16.87	253.0			
Speed	Negative Ranks	12	15.79	189.5	-1.393	0.16	0.25
	Positive Ranks	20	16.93	338.5			
SDLP	Negative Ranks	17	15.06	256.0	-0.150	0.88	0.03
	Positive Ranks	15	18.13	272.0			

4.5.2. Visibility

After each trip, the participants were first asked about their experiences during their bicycle ride along the route. Without actually mentioning the virtual objects, the participants were asked whether they had noticed any 'adjustments' along the route. The experimental location was described as "*the part of the route in an urban area in which the cycle path surface was made of pavement tiles. There was also a fence to the right of this cycle path*." Based on these instructions, it was assessed whether the participants mentioned the objects spontaneously and if so, how they described these. After these instructions, 9% of the participants mentioned the virtual objects instantly. For the remaining participants whom could not remember anything, a picture of the location and the objects was shown after which an additional 13% said they did remember the objects. This resulted in an overall percentage of 22% ($n = 7$) of participants who had seen the virtual objects. Using these data, non-parametric Mann-Whitney U tests were performed to assess differences on the behavioural measures between these groups. Although based on different group sizes ($n = 7$ vs. $n = 25$), analyses indicated medium and significant effects of looking on lateral position and SDLP, as bicyclists who had seen the virtual objects rode 12.5 cm closer to the shoulder of the cycle path (U (30) = 41.0, Z = -2.120, p = 0.034, $r = 0.37$) and also swerved more (U (30) = 34.0, Z = -2.439, p = 0.015, $r = 0.43$) compared to bicyclists who had not seen the objects. A small effect on speed was also found although this was not significant (U (30) = 61.0, Z = -1.208, p = 0.23, $r = 0.21$). On the control location, only small and non-significant differences were found on all three measures.

4.5.3. Subjective measures

During the interview, bicyclists were asked about their opinion concerning the virtual objects in the shoulder of the cycle path. First, when mentioning the location but not explicitly the objects, the answers given were fairly diverse, ranging from "*the illusions were not conspicuous*", "*I saw them and thought they were real*", and "*it suggests that you cannot cycle there*" to "*it looked like a concrete stumbling block*". Moreover, several non-relevant answers were given, such as: "*I saw a former colleague*" and "*I saw white delineation*". After showing the participants a photo of the location with the objects and their own recorded bicycle trip, they were asked what they thought about the measure in general. Of the most commonly given reactions, the majority was mainly neutral or slightly negative as many mentioned that they did not see any benefit for bicyclists (33%). They thought the virtual objects were inconspicuous (22%), dangerous or scary (19%), they thought bicyclists could fall over them (11%), or 15% gave a neutral reaction or had no opinion about the measure.

4.6. Discussion

In this study the effects of anamorphic optical illusions on the lateral position and course of cyclists were assessed by performing two observational studies. In the first study, data were collected from a fixed camera perspective and in the second study, data were obtained from the bicyclist's perspective. During the first study 1150 passing bicyclists were observed, scored, and analysed on a crowded two-way cycle path on which several versions of anamorphic '3D boxes' were placed near the right edge. During the second study, the behaviour of 32 participants aged 50 years and above was observed while cycling a trajectory of 12 km. In both studies lateral position, SDLP (from video data), and cycling speed (from video or GPS) were measured and in the second study subjective experiences were also gathered by conducting structured interviews after the trips.

4.6.1. Behavioural measures

It was hypothesised that cyclists would consciously or unconsciously perceive the virtual objects and would respond to their presence by keeping more distance to them and lower their speed. Firstly, negligible and non-significant effects of the virtual objects near the edge of the cycle paths on bicyclist lateral position or SDLP were found. However, a small exploratory effect on cycling speed was found as the average speed was higher when red-coloured objects were placed along the cycle path. As this variant of the objects was the only exception and the effect size was small, it remains unclear where this effect could originate from. It could be that the red colour and the white stripes made this particular object more visible than the others, which were mainly grey or black coloured. Perhaps the colour itself could have been of influence as red is often associated with danger (Pravossoudovitch, Cury, Young, & Elliot, 2014). Overall, it can be concluded that the virtual objects, in their current format, are not an effective measure to affect the course or speed of cyclists.

4.6.2. Looking behaviour

During both studies it was scored whether participants (clearly) looked at the virtual objects, or whether they remembered them in a structured interview after their bicycle trip in experiment 1 or 2, respectively. Data analyses revealed that cyclists who had seen the virtual objects cycled closer to the edge of the cycle path compared to the group of cyclists who had not seen the objects. In Experiment 1, this effect was very small and only marginally significant for the 2-dimensional condition only, making it unlikely that visibility was linked to 3D properties. In Experiment 2, a medium and significant decrease of lateral position as well as a medium and significant increase in SDLP were found for cyclists who had explicitly mentioned that they have seen the virtual objects. As the direction of the effect on lateral position is contrary to the a priory hypothesis, it remains unclear what the causal direction of the effects are: did bicyclists observe the objects because they were cycling closer to them, or were they cycling closer to the objects because they noticed them?

4.6.3. Oncoming cyclists

Although not directly related to any of the virtual objects, it was observed in the first study that many cyclists passed the experimental location while an oncoming cyclist was present. By adding this factor into the analysis, it was found that cyclists are positioned significantly closer to the edge of the cycle path when an oncoming cyclist is present compared to when no oncoming cyclist is present. This effect is also found in car driving, as drivers tend to move away from oncoming traffic, increasing their distance from the centre of the road (Triggs, 1997) even when cyclists are present in the same lane (Dozza, Schindler, Bianchi-Piccinini, & Karlsson, 2016). The medium effects in this study were found within all conditions.

4.6.4. Study limitations

In Experiment 2, all participants were aged 50 years or older. Therefore, these results cannot easily be generalized to other age groups. However, interventions aimed at preventing cyclists from entering the shoulder are mainly helpful for older cyclists as they are overly represented in cycling crash statistics (CBS, 2014).

Due to practical limitations, it was not possible to randomly assign the experimental conditions to the participants in Experiment 2. As a within-subjects design with a fixed starting point was used, it cannot be ruled out that the order of conditions exerted some effects on any of the measures. However, the fact that the virtual objects were not detected by a large proportion is an indication that order effect may not be so important.

Overall, the type of illusions used during both studies were designed rather conservative, as a 3D image of a cube along a cycle path could be considered as a non-threatening object for cyclists. This may have affected the effectiveness of the objects and their visibility. As only 22% reported that they had seen the object during Experiment 2, it could be that the design of the objects was too conservative to be influential on an overall level. Even though many participants did not see the objects, all participants were included in the analyses because the virtual objects in the periphery could affect behaviour either consciously through direct perception or unconsciously via peripheral vision. However, consciously noticing an element in the layout of a road is not an absolute requisite for it to influence behaviour as road elements can also influence behaviour without the road user having explicit knowledge (for example, see Lewis-Evans & Charlton, 2006, and Lewis-Evans, De Waard, Brookhuis, & Jolij, 2012). For this reason, discarding all participants who reported not having seeing any of the virtual objects would make it impossible to assess any unconscious or implicit effects.

Additionally, as it was observed that bicyclists regularly manoeuvre around manholes (Westerhuis & De Waard, 2016), perhaps virtual versions of these manholes could also be tested as a means of influencing the behaviour of bicyclists. Lastly, the application of these types of drawings could be limited, as it requires extra space along the cycle path which could not be used as a surface for the cycle path itself.

4.6.5. Implications for future research

As the optical illusions did not have an effect on cycling behaviour, perhaps other measures may be developed to fulfil this purpose. As to date there is not many research focussing on specific infrastructural modifications to influence the lateral position of cyclists, maybe existing concepts to influence car driving can be used to generate other ideas for cyclists. For example, applying different forms of delineation (e.g. Steyvers & De Waard, 2000; Godley, Triggs, & Fildes, 2000), optically narrowing the road (e.g. Wu, Hu, & Li, 2013), or providing haptic feedback upon approaching a road's edge can be used to influence the lateral position and speed of car drivers (e.g. De Waard, Jessurun, Steyvers, Raggatt, & Brookhuis, 1995). Perhaps comparable measures are also suitable to be used for cyclists as well.

4.7. Conclusion

No effects of optical illusions on lateral position choice and lateral position control were found. However, a small exploratory effect was found of the objects on cyclist speed, as the average cycling speed was higher when red-coloured objects were placed along the cycle path. This effect was not found for the other conditions, however. As such, in its tested format, the visual illusions were not effective. However, it was found that cyclists who were looking at the objects or reported that they have seen them were positioned more closely to the shoulder. Therefore, it might be that other types of illusions, and perhaps other dimensions of illusions with increased visibility, might be noticed better and may be effective.

Acknowledgements

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Chapter 5

Cycling on the edge

The effects of edge lines, slanted kerbstones, shoulder, and edge strips on cycling behaviour of cyclists older than 50 years

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This chapter is based on Westerhuis, F., Fuermaier, A.B.M., Brookhuis, K.A., & De Waard, D. (2020). Cycling on the edge: the effects of edge lines, slanted kerbstones, shoulder, and edge strips on cycling behaviour of cyclists older than 50 years. *Ergonomics, 63*(6), 769-786. doi:10.1080/00140139.2020.1755058

For consistency throughout this thesis, the term ‘treatment’ has been changed to ‘intervention’.

5. Cycling on the edge: the effects of edge lines, slanted kerbstones, shoulder, and edge strips on cycling behaviour of cyclists older than 50 years

Abstract

To prevent single-bicycle crashes, this study is the first to evaluate effects of slanted kerbstones, edge lines, shoulder strips, and edge strips on cycling behaviour of cyclists ≥ 50 years. In Experiment 1, 32 participants cycled on a control path and paths with edge lines, slanted kerbstones, and three types of 0.5m wide shoulder strips (with grey artificial grass, green artificial grass, or concrete street-print). In Experiment 2, 30 participants cycled a different route including a control path and paths with edge lines or 0.3m white edge strips. Cyclists rode closer to the main cycle path's edge in the shoulder strips conditions, although the presence of these strips resulted in a larger total distance to the verge compared to the control condition. Furthermore, cyclists cycled further from the verge in the edge strip condition than the control condition. Safety implications of the shoulder and edge strips are considered to be positive.

5.1. Introduction

5.1.1. Crashes of older cyclists

In the Netherlands, the bicycle is widely used as a daily means of transport and increasing amounts of older people (65+) use a bicycle (Schepers, Stipdonk, Methorst, & Olivier, 2017). Cycling contributes to healthy, independent mobility (Oja et al., 2011) and a safe infrastructure can help to prevent crashes (Reynolds, Harris, Teschke, Cripton, & Winters, 2009). Although the cycling infrastructure in the Netherlands is traditionally considered world leading in terms of safety (Schepers, Twisk, Fishman, & Jensen, 2017), increasing amounts of (older) cyclists and the developments with regard to electric bicycles demand authorities to ensure that the infrastructure is also suitable for these contemporary demands (Wegman, Zhang, & Dijkstra, 2012).

Single-bicycle crashes are common in the Netherlands and older cyclists are particularly at risk for sustaining serious injury in these crashes (Schepers, 2013). Therefore, current policies in the Netherlands emphasize that the safety of older cyclists should be improved (Rijkswaterstaat, 2016). It is estimated that 21% of all cyclist crashes, including younger and middle-aged cyclists, are caused by accidently leaving a road and cycling into the verge (Schepers & Klein Wolt, 2012). Potential causes are cycling too close to the edge, swerving, being distracted, misjudging the course of the infrastructure, or being hit by another road user (Schepers & Klein Wolt, 2012; Davidse et al., 2014). Westerhuis and De Waard (2016) found that this situation also occurs on cycle paths: 20% of their cyclists-sample ≥ 50 years accidentally entered the verge at least once during one week of everyday cycling trips. Fortunately, these occurrences did not result in falls or crashes. However, with level differences, near objects, or a marshy verge, this may lead to injuries. According to Davidse et al. (2014) in 15-27% of crashes they investigated cyclists hit a kerb or entered the verge unintentionally.

Electric bicycles have gained popularity because these allow people to cycle with less physical effort compared to conventional bicycles (Theurel, Theurel, & Lepers, 2012; Berntsen, Malnes, Langåker, & Bere, 2017). Longer distances and ascending trajectories become easier to cycle and this makes it also useful for older cyclists or people with physical complaints (Dill & Rose, 2012). There are indications, however, that e-cyclists have an increased risk for a crash that requires treatment at an emergency department (Schepers, Fishman, Den Hertog, Klein Wolt, & Schwab, 2014) and that the injuries after a crash with an electric bicycle are more severe compared to conventional bicycles, in particular for older cyclists (Poos et al., 2017). A reason could be that e-cyclists ride with higher speeds or accelerate faster compared to conventional cyclists (e.g.Vlakveld et al., 2015; Dozza et al., 2016; Kovácsová et al., 2016; Schleinitz et al., 2017) although similar speeds and behaviour are also found (e.g. Langford, Chen & Cherry, 2015; Westerhuis & De Waard, 2016).

Since crashes due to entering the verge can lead to serious injuries, particularly for older cyclists, the current study assesses infrastructure interventions that aim to prevent cyclists from leaving a cycle path and entering the verge. The goal of these interventions is to provide extra guidance or offer more space to correct course deviations while cycling.

5.1.2. Infrastructure interventions for run-off crashes

Although the current knowledge of infrastructure interventions effects on cycling behaviour is limited, important conclusions can be learned from car driving research (Zegeer & Council, 1995). Numerous studies use on-road observations or crash data that are collected with interventions in the real world (see e.g. Hatfield et al., 2009). Although this could be considered a preferred method because of ecological validity (Hoc, 2001), these studies can be prone to confounding of interventions due to other unique properties of locations (Fridstrøm et al., 1995, cited in Hatfield et al., 2009; Wegman, Zhang, & Dijkstra, 2012). Therefore, simulators can be an alternative, although this method seems to limit ecological validity compared with measuring on-road behaviour (see e.g. Branzi, Domenichini, & La Torre, 2017; O'Hern, Oxley, & Stevenson, 2017).

5.1.3. Line marking

Cyclists can be guided by delineation or line marking. Line marking can be applied on the edge or in the centre of a road or path to influence the position of cyclists (i.e. edge lines or centrelines, respectively). For example, Van Houten and Seiderman

(2005) found that cyclists keep more distance from parked cars when edge lines are applied, compared to locations without markings. On these locations, cyclists were positioned in-between the car travel lane and parked cars. Effects were found both when there was only an edge line between the car travel lane and the cyclists, and when there was a full cycling lane between the car travel lane and the parked cars (i.e. edge lines to the left and the right of the cyclists). Based on detailed crash information, Schepers and Den Brinker (2011) argue that edge lines and centrelines should be present on cycle paths to reduce single-bicycle crashes.

For car driving, McKnight, McKnight, and Tippets (1998) found that only very low contrast delineation conditions were related to reduced lane keeping performance compared to normal or higher contrast conditions. Steyvers and De Waard (2000) compared driving behaviour on edge-lined roads with control conditions either containing no delineation or centre-axis delineation only. After comparing with roads without edge lines, they found that car drivers keep a greater distance from the road's edge when edge lines are applied. Additional results showed no differences in perceived mental effort, driving performance, and subjective ratings, suggesting that edge lines are a basic and efficient way to keep drivers away from the verge. Speed comparisons indicated that drivers drove faster on edge-lined roads compared to non-delineated roads, but there was no difference with speed on roads with dashed centre markings (Steyvers & De Waard, 2000).

Few studies have been performed on centrelines on shared paths for cyclists and pedestrians. In a blind curve on a path that contained a yellow centreline and a directional arrow, relatively more cyclists were found to remain cycling in the proper lane, compared to a pre-measurement at the same location (Jordan & Leso, 2000). Hatfield and Prabhakharan (2016) found comparable effects: more cyclists tended to cycle in their own lane on a shared path with a centreline than on a path without a centreline. The behavioural effects of centrelines on cycling behaviour therefore seem similar to car driving, because in a driving simulator study De Waard, Steyvers, and Brookhuis (2004) found that applying centrelines on a two-way road caused drivers' lateral position to move closer to the edge, and therefore more into their own lane, than on roads with no delineation.

The effects of shared path centrelines on cycling speed are mixed: observations of Hatfield and Prabhakharan (2016) revealed that a centreline was related to a lower cycling speed, while Boufous, Hatfield and Grzebieta (2018) concluded that cyclists were more likely to cycle at higher speeds when a centreline was present. They argue that this difference could potentially be explained by the idea that cyclists can interpret a centreline as being part of a road for cars, and therefore might increase their speed. The strongest predictor of an increased cycling speed was for visually segregated paths: higher speeds were more likely to occur when the areas for cyclists and pedestrians differed in surface type or colour (Boufous, Hatfield, & Grzebieta, 2018).

5.1.4. Haptic feedback

Road users may also be warned that they are about to drive off the road by haptic feedback. Haptic feedback is often applied as an addition to lane marking by means of rumble strips, Audio Tactile Lane Marking, or Profile Lane Marking (PLM). These are milled-in or raised markings that cause vibrations in the vehicle to warn drivers that they are deviating from their lane. Hatfield, Murphy, and Soames Job (2008) interviewed 775 Australian drivers on PLM and reported that 75% believed it was an effective intervention to remain on the road. In particular, the increased visibility of the road edges and the urge to avoid the marking because of unpleasant sound and vibration seem to increase road safety. The most frequent application of edge rumble strips is on alerting sleepy drivers (e.g. Anund, Kecklund, Vadeby, Hjälmdal, & Åkerstedt, 2008).

Haptic feedback may also be applied to centreline markings in order to reduce head-on crashes on two-lane rural roads (Persaud, Retting, & Lyon, 2004). Hatfield, Murphy, Soames Job, and Du (2009) suggest based on crash data that profile markings both in the centre and near the edge of the road are most effective in reducing crash risk. Furthermore, haptic feedback is not necessarily restricted to rumble strips. For example, De Waard, Jessurun, Steyvers, Raggatt, and Brookhuis (1995) investigated whether haptic feedback could decrease comfort for speeding drivers and prevent crashes due to swerving out of lane. They found that combining visual narrowing of the lanes and applying rippled surfaces on road edges reduced driving speed compared to a control location with edge and centreline marking, due to increased mental workload and discomfort while driving at higher speed. Overall, Khan, Abdel-Rahim and Williams (2015) concluded that rumble strips lead to fewer crashes in car drivers. However, Wu, Donnel and Aguero-Valverde (2014) did not find effects on injury severity.

5.1.5. Road widening

Zegeer, Reinfurt, Hummer, Herf, and Hunter (1988) defined four factors to reduce crashes on two-lane roads: lane width, shoulder width, shoulder type, and roadside characteristics. Observations on cyclist and pedestrian shared paths indicate that a wider path is related to higher cycling speeds (Boufous, Hatfield, & Grzebieta, 2018). However, the safety effects of widening a road on car driving are mixed as Manuel, El-Basyouny, and Islam (2014) found a negative association between the number of collisions and the width of the road, for example. Some drivers might take more risk on wider roads and drive at higher speeds than on roads that are narrower (Lewis-Evans & Charlton, 2006). Widening a road is also an expensive intervention and might therefore not be possible in many occasions.

5.1.6. Shoulders and shoulder characteristics

So-called 'forgiving roadsides' can be applied to allow road users who are drifting off the road to safely return back onto that road without risking a crash (Wegman, Aarts, & Bax, 2008). Safety effects can be achieved by paving the shoulders (Ogden, 1997) or by increasing the width of the shoulder (Gross & Donnel, 2011).

Objects near a road or cycle path are also potentially dangerous for causing a crash while cycling (Fabriek, De Waard, & Schepers, 2012). For car drivers, collisions with objects (e.g. trees or poles) are related to a higher risk for severe or fatal injuries compared to crashes with guardrails or concrete barriers (Holdridge, Shankar, & Ulfarsson, 2005). Limiting or removing roadside objects increases the forgivingness of a road because obviously a road user cannot collide with these anymore but they can often also return to the road safely (Wegman, Aarts, & Bax, 2008). Since it is not always possible to remove such objects, their visibility can also be increased by changing colour, increasing contrast, or adding delineation (Schepers & den Brinker, 2011; Fabriek, De Waard, & Schepers, 2012).

5.1.7. Infrastructure interventions for forgiving cycle paths

The current study evaluates infrastructure interventions designed to increase cycling safety by changing the edge of a cycle path. For this, the influence of different types of edge lines, shoulder strips, and edge strips on cyclists' lateral position, swerving (SDLP), speed, and subjective opinion was measured to explore their potential use for providing safety and comfort for older cyclists. An increase in lateral position and a decrease in the amount of swerving are considered safer, because the chance of (accidentally) leaving the path are smaller and there is more space available to correct a potential mistake. Effects on speed were also explored because bicycle infrastructure interventions are also known to influence cycling speed differently (e.g. Hatfield & Prabhakharan, 2016; Boufous, Hatfield, & Grzebieta 2018). Therefore, no concrete hypotheses with regard to speed were defined.

5.2. Methodology

5.2.1. Design

Two separate within-subjects experiments were performed on two locations where different variants of cycle path interventions were applied. The experimental interventions were specifically designed for this research and constructed in cooperation with the provincial authorities of Fryslân and Overijssel in the Netherlands. Because the provided locations were 70km apart and the accompanying interventions were produced at different time periods, two separate experiments were performed: Experiment 1 and Experiment 2.

In Experiment 1, two variants of edge markings and three types of 0.5 m wide paved shoulder strips were added next to a cycle path. These were compared with two control conditions that contained a similar sized cycle path without intervention. In Experiment 2, three types of edge lines and one condition with a 0.3 m wide white edge strip of light-coloured chippings was placed on the edge of the cycle path. These interventions were compared with one control condition. The participants only participated in one of the experiments and were asked to cycle a short predefined route on their own bicycle that we equipped with research instrumentation. During the experiment, the participants passed the infrastructural interventions while lateral position, swerving, speed, and subjective opinion were measured. Ethical consent was provided by the Ethical Committee Psychology (ECP) of the University of Groningen (PPO-013-253 & PPO-015-007).

5.2.2. Participants

Thirty-two and thirty cyclists participated in Experiment 1 and Experiment 2, respectively (see table 5.1). The minimum age for participation was 50 years and all participants had to be capable of riding their own bicycle safely and independently through everyday traffic. One participant in Experiment 2 was excluded due to not having cycled for many years. Two groups were included in each experiment: cyclists with a conventional bicycle and cyclists with an electric bicycle. No specific selection strategy was applied, however. The participants were asked to preferably use their own bicycle although a loan bicycle was also available.

Recruitment took place by means of advertisements in local news media, posters in local supermarkets, invitations sent to local cycling clubs and unions, and via word of mouth. The participants were told that the study was about “the experience of a cycle path” and that cyclists older than 50 years were invited to bring their own bicycle to cycle a fixed route of 12 or 6 km on a cycle path near their village. No further details were provided other than that their bicycle would be equipped with small cameras, that they would be asked several questions about their experience, and that a financial compensation of €15 was offered.

Table 5.1: Participants’ demographic characteristics.

Experiment	Bicycle	N	% Male	Age (in years)	Weekly cycled km
Exp. 1	Conventional	17	70.6	M = 66.5, SD = 8.0	M = 34.4, SD = 26.5
	Electric	15	40.0	M = 70.2, SD = 9.8	M = 61.1, SD = 59.8
	Total	32	56.3	M = 68.3, SD = 9.0	M = 46.5, SD = 45.9
Exp. 2	Conventional	20	50.0	M = 61.6, SD = 5.1	M = 78.4, SD = 70.9
	Electric	10	60.0	M = 65.5, SD = 7.2	M = 79.5, SD = 54.7
	Total	30	53.3	M = 62.9, SD = 6.1	M = 78.7, SD = 65.0

5.2.3. Locations and experimental designs

In Experiment 1, the participants cycled a 6 km cycle path in a rural area and passed five experimental and two control sections. The experimental conditions contained infrastructural interventions such as white Edge Lines Continuous (ELC), white Slanted Kerbstones (SK), and three types of shoulder strip conditions: Grey and Green Artificial Grass Strips (AGS) and Concrete Street-print Strips (CSS, see figure 5.1A-E). These shoulder strips were different from the cycle path's main surface and caused clear and uncomfortable vibrations in the bicycle to warn the cyclists that they had left the cycle path. Although the surfaces were sufficiently firm to safely return to the cycle path, they were not designed to cycle continuously over and acted as a buffer zone in-between the cycle path and the verge.

As the route consisted of one straight cycle path, the participants turned around halfway and rode the same path back to the starting point. The lengths of the intervention areas differed between 50 m and 225 m and the order of the conditions was fixed (see table 5.2). Two Control Locations (CL1 and CL2; figure 5.1F & G) that matched the width of the cycle paths with interventions were also measured. Because the SK intervention was applied on an asymmetrical cycle path that was wider than any cycle path in the near area, this intervention was also compared with CL1.

In Experiment 2, the participants cycled a 2.5 km long two-way cycle path in a rural area and passed four experimental conditions and one control condition in a fixed order. This route was also a 'there and back' trip, meaning that the participants covered a total distance of 5 km. The experimental interventions either had intermittent edge lines located 5 cm or 15 cm from the path's edge (ELI 5 and ELI 15, respectively), a continuous edge line located 15 cm from the path's edge (ELC 15), or White Chippings Edge Strips (WCES) each 30 cm wide on both sides of the path (see figure 5.2). The design of the edge strip was different from the shoulder strips in Experiment 1, because the edge strip was placed on the edge of the main cycle path and therefore a part of the cycle path's main surface. The lengths of the intervention areas varied between 135 and 950 m and there was little to no distance in-between interventions (see table 5.2). The Control Location (CL3) was equally wide as the pavement of the experimental locations and did not contain edge lines or strips (see figure 5.2E).

Table 5.2: Experimental conditions properties.

Condition	Order		Distance in-between (m)		Intervention length (m)		Sampling stretch (m)		Path width (m)		Strip width (cm)
Outbound / Return	O	R	O	R	O	R	O	R	O	R	
SK	-	7	-	-	-	90	-	85	-	2.5	-
ELC	1	6	525	0	90	50	85	50	2.5	2.3	-
CL 1	2	5	1650	450	1600	1600	85	85	2.3	2.3	-
Grey AGS	3	4	0	1650	225	225	85	85	3.0	3.0	50
Green AGS	4	3	0	0	75	75	75	75	3.0	3.0	50
CSS	5	2	0	0	150	150	85	85	3.0	3.0	50
CL 2	6	1	0	0	575	575	85	85	3.0	3.0	-
ELI 5 cm	2	4	45	0	450	450	102	102	3.5	3.5	-
ELI 15 cm	3	3	0	45	950	590	102	102	3.5	3.5	-
ELC 15 cm	4	2	0	0	135	510	102	102	3.5	3.5	-
WCES	5	1	0	0	340	340	102	102	3.5	3.5	30
CL 3	1	5	0	-	100	100	91	91	3.5	3.5	-

Abbreviations: AGS = Artificial Grass Strip; CL = Control Location; CSS = Concrete Street-print Strip; ELC = Edge Line Continuous; ELI = Edge Line Intermittent; SK = Slanted Kerbstones; WCES = White Chippings Edge Strip

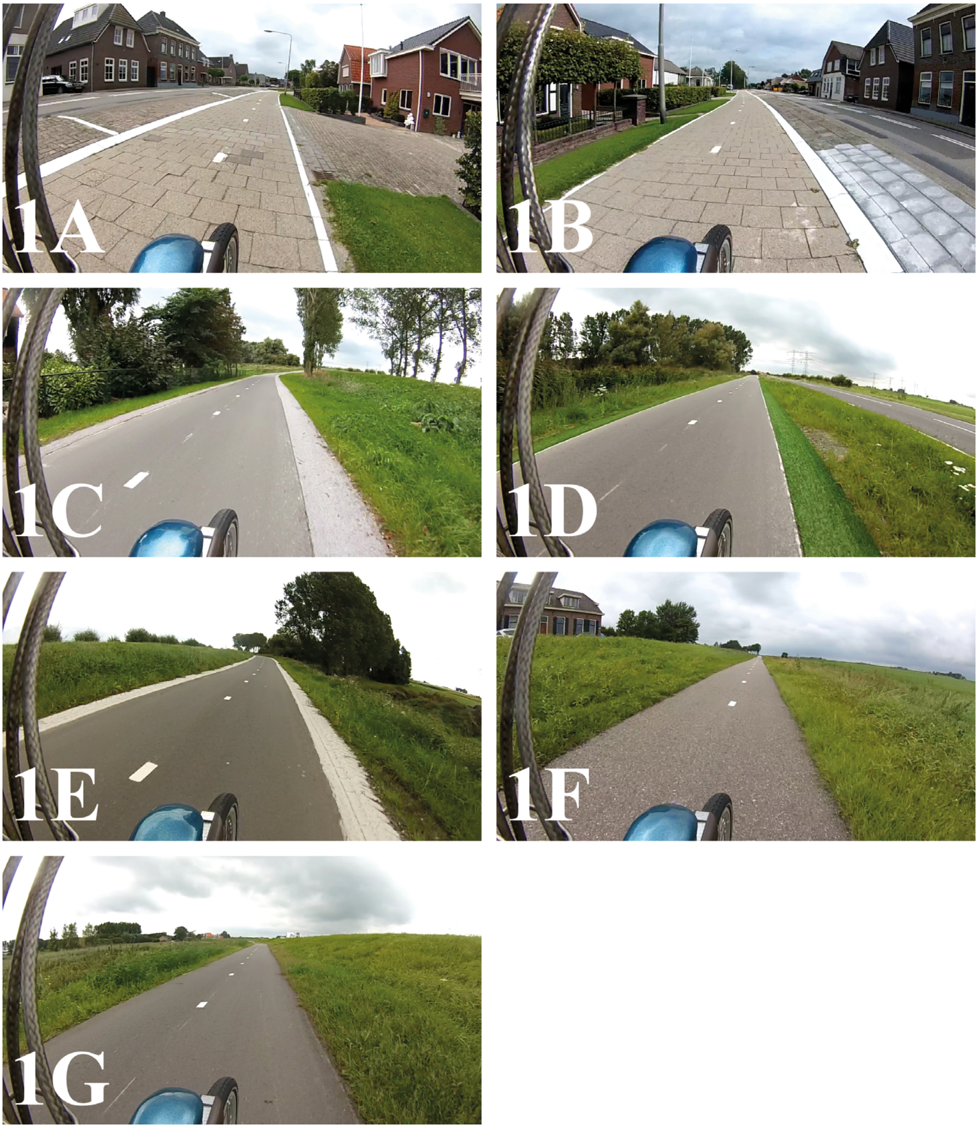

Figure 5.1: All conditions from Experiment 1. 1A: Edge Lines, 1B: White Slanted Kerbstones, 1C: Grey Artificial Grass Strips, 1D: Green Artificial Grass Strips, 1E: Concrete Street-print Strips, 1F: Control Location 1, 1G: Control Location 2.

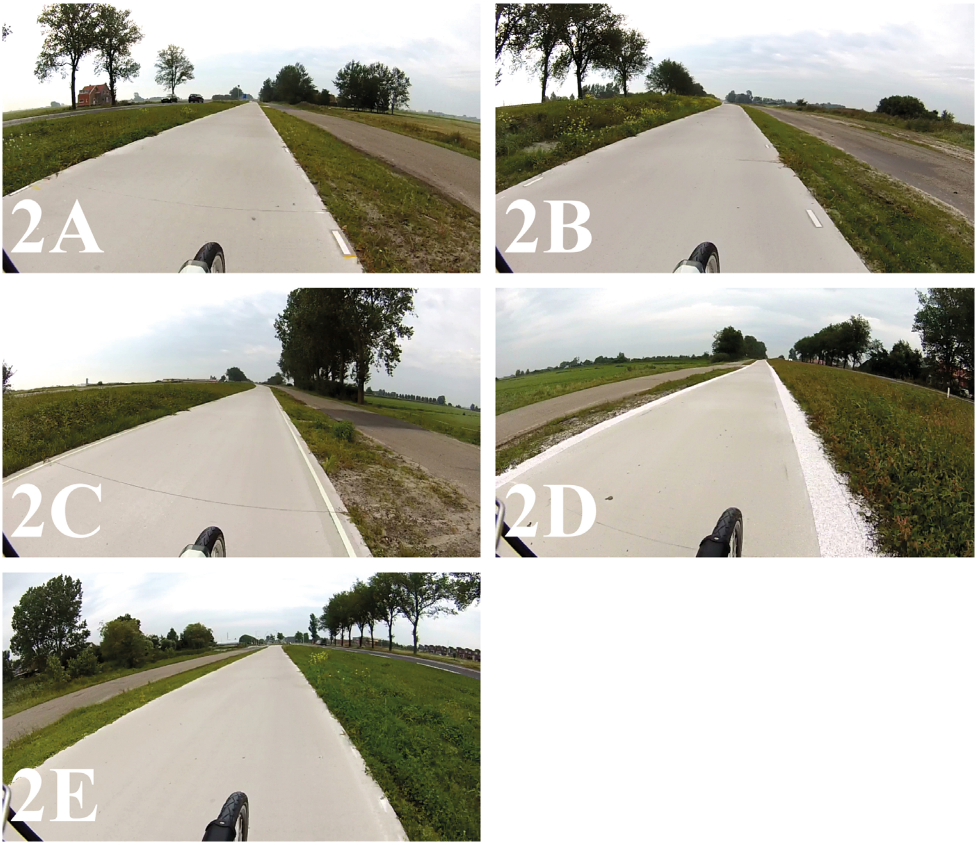

Figure 5.2: All conditions from Experiment 2. 2A: Intermittent Edge Lines 5 cm, 2B: Intermittent Edge Lines 15 cm, 2C: Continuous Edge Lines 15 cm, 2D: 30 cm White Chippings Edge Strip, 2E: Control Location 3.

5.2.4. Materials and equipment

The bicycle rides were recorded with two Contour+2™ digital action cameras with GPS that were mounted on the participants' bicycles. The cameras recorded videos with a resolution of 1280x720 (170 degrees field of view) at 30 frames per second. A measurement tool was used before each bicycle ride to capture the real-world distances in the video (Westerhuis, Jelijs, Fuermaier, & De Waard, 2017). A public-transport (loan) bicycle was also provided in case participants could not bring their own bicycle.

5.2.5. Questionnaires and interviews

The participants gave written informed consent and completed a questionnaire and a semi-structured interview. The questionnaire concerned demographics and cycling habits and the interview after the bicycle ride was about the participants' subjective experiences of the experimental interventions. During this interview, participants were asked whether they remembered the interventions and what their opinion was about the effectiveness and safety of these. Pictures of the conditions were used if participants could not remember a location. Based on the experiences of Experiment 1, the questions for Experiment 2 were made more succinct to increase the efficiency of the interviews. An overview of the questions in the interviews is listed in Appendix A.

5.2.6. Procedure

Participants who were interested contacted the researchers by email or telephone. Before the experiment, they received a package with general information about the experiment, directions to the study location, and the questionnaire concerning demographics and cycling habits. Participants were invited to bring their own bicycle and were awaited by two researchers. One researcher provided them with additional information about the purpose and the rationale of the experiment, the camera instrumentation, and the route, while the other researcher installed and calibrated the two cameras on the bicycle. The cameras were mounted on the handlebars as described in Westerhuis, Jelijs, Fuermaier, and De Waard (2017). One camera was aimed forward to record the cyclist's view and the other was aimed downward to measure lateral position (see figures 5.1 - 5.3). GPS data concerning position and speed were also recorded. A measurement tool was used to determine real world distances (figure 5.3).

Although the routes differed between Experiment 1 and Experiment 2, the procedures were the same. All participants were asked to cycle alone to prevent the influence of a companion (De Waard, Schepers, Ormel, & Brookhuis, 2010). The instructions were to cycle normally and they were given a phone number to call the researcher if necessary. No hints or instructions concerning any of the interventions were provided. The participants could enter the cycle path and cycle in the indicated direction until they noticed a "Turn Around" sign. At this point, they turned and cycled the same route back to the starting location.

After the ride, the participants were asked by means of open-ended and Likert- scale questions whether they recognised each condition and what their opinion was about the interventions. The questions concerned general opinion, perceived usefulness, and estimated effects on safety. In Experiment 1, open conversations concerning the shoulder strip and control conditions were initiated by the experimenters. In Experiment 2, the participants were asked about all conditions, although the questions in this experiment were more specific and structured to save time based on the experience of Experiment 1. Questions concerning the edge lines that were 5 and 15 cm from the path's edge were combined because it was difficult to see the difference while cycling. To explore whether participants remembered the locations in Experiment 1, they were first asked what they have seen without mentioning anything specific about the conditions. If they were unable to recall a location, a photo was shown after which the remaining questions were asked. The participants also watched video recordings of their own bicycle ride on a laptop screen in Experiment 1. In Experiment 2, participants were explicitly asked whether they could remember an intervention (yes or no) after they were shown a photo and to what extent they believed that a condition would help to keep cyclists on the cycle path (on a 5-point Likert scale ranging from 'not' to 'very much').

5.2.7. Data Processing and Statistical Analysis

Video and speed data were analysed with the Contour Storyteller™ for Windows™, VLC Media Player™, and a digital ruler (JRuler Pro™). The videos were viewed in Contour Storyteller™ to determine when participants passed each condition in the video. The GPS data of these timeframes were exported to a comma-separated values file (.csv) and average speed data were calculated in Microsoft™ Excel™. All locations were selected to have minimal gradient differences, although the Grey Artificial Grass intervention in Experiment 1 contained some level differences within the lateral position sampling area. For this reason, a larger speed sampling window for this intervention was measured.

Lateral position was measured by inserting the recording of a measurement tool as a video overlay in VLC Media Player™ (see figure 5.3). As each stripe of the tool represented 25 centimetres, the lateral position was measured by adding up all stripes plus the measured value of the last stripe that hit the shoulder. JRuler Pro™ was calibrated to reflect the size of the last stripe and its value was measured.

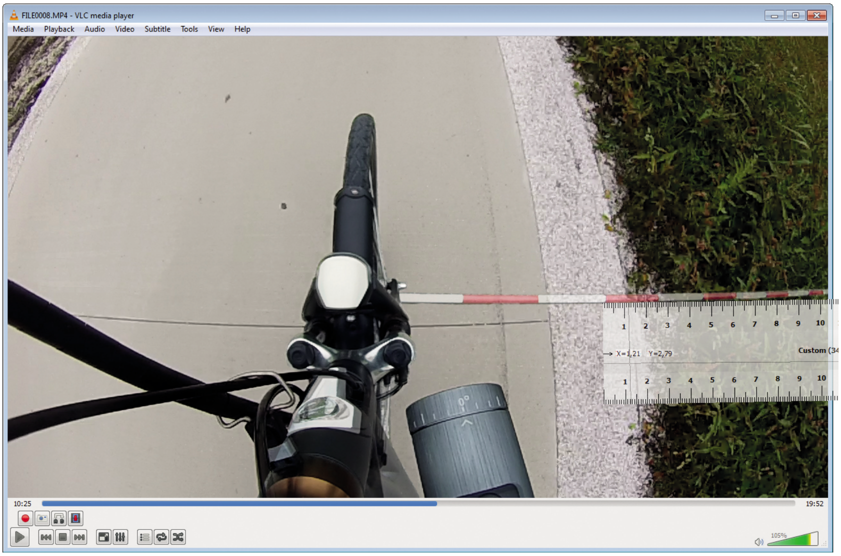

Figure 5.3: The lateral position measurement process with VLC Media Player™ and JRuler Pro™. In this example, the lateral position is measured and calculated as 75cm + 12cm = 87cm.

For each condition and participant, lateral position samples over a fixed measurement area were scored and mean Lateral Position (LP) and Standard Deviation of the Lateral Position (SDLP) were calculated as the primary dependent variables. The size of the measurement areas ranged between 50 m and 102 m per condition (see table 5.2 in paragraph 5.2.3). Lateral position was sampled on fixed visible parts of the path, in Experiment 1 these were the dashed centrelines, in Experiment 2 these were the transition points of the cycle path's surface blocks. Because the participants turned around halfway the route, all conditions were passed and measured twice except for the Slanted Kerbstones condition that was only applied to one side of the cycle path (see table 5.2). Lateral position was measured as the distance between the bicycle's front wheel and the edge of the main cycle path's pavement to keep the measurements the same between conditions (figure 5.4).

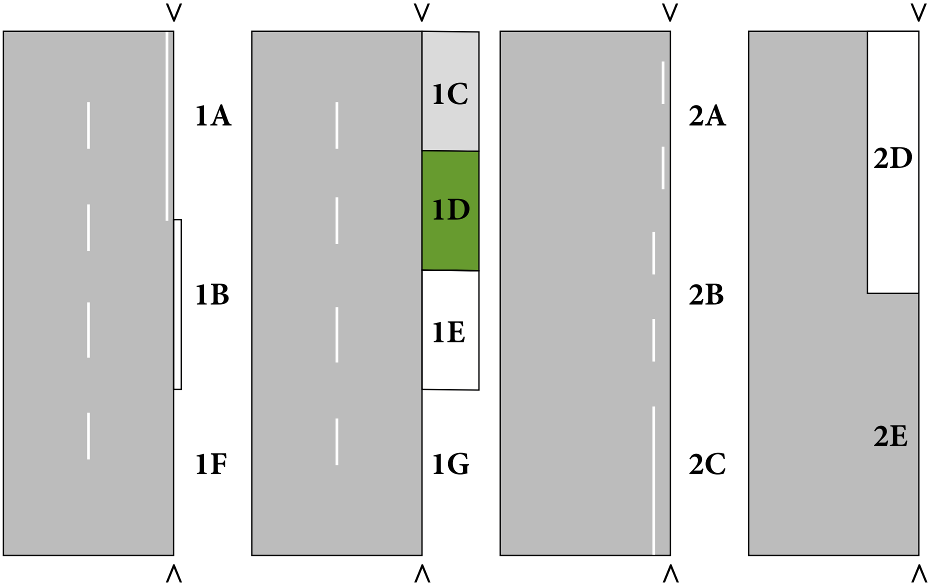

Figure 5.4: A schematic representation of the conditions for Experiment 1 (left: 1A = Edge Line, 1B = Slanted Kerbstones, 1C = Grey Artificial Grass, 1D = Green Artificial Grass, 1E = Street-print, 1F = Control Location 1, 1G = Control Location 2) and Experiment 2 (right: 2A = Intermittent Edge Lines 5 cm, 2B = Intermittent Edge Lines 15 cm, 2C = Continuous Edge Lines 15 cm, 2D = White Chippings Edge Strip, 2E = Control Location 3). The notch represents the edge of the path that was used to measure the lateral position.

The first analyses concerned potential differences between users of conventional and electric bicycles. Mann Whitney U Tests were performed to compare lateral position, swerving, and speed measurements between the groups collapsed over all conditions. Omnibus tests and pairwise comparisons were performed by means of the Friedman Test and Wilcoxon Signed Ranks Test, respectively. Intervention and control locations that best matched the width of the treated sections were compared. In Experiment

1, the Edge Lines and Slanted Kerbstones interventions were compared with Control Location 1 and the shoulder strips conditions were compared with Control Location 2. In Experiment 2, all intervention conditions were compared with Control Location 3 (see table 5.2). Because non-parametric analyses do not allow testing for interaction effects, ipsative scores of each intervention were calculated and compared per bicycle type by means of Mann Whitney U Tests. For all pairwise comparisons, Bonferroni correction was applied to control for alpha inflation error in multiple testing (i.e. $\alpha = .0055$). Effect sizes for non-parametric data were calculated and interpreted using the r statistic (Fritz, Morris, & Richler, 2012). An effect size of $r > .1$ is considered a small effect, $r > .3$ a medium effect, and $r > .5$ resembled a large effect.

During the study, 10 participants were either initiating or performing an overtaking manoeuvre. This manoeuvre increased their lateral position and swerving values compared to when they were not overtaking a cyclist. The overtaking manoeuvres for these participants were therefore discarded from the analyses by removing all samples in-between a continuously increasing sequence of lateral position values followed by a continuously decreasing sequence of lateral position values. A similar procedure was performed when participants entered one of the shoulder strips to try these out. In total, 14 overtaking manoeuvres and 11 manoeuvres in which participants intentionally entered the shoulder strips were removed from the dataset (see Appendix B for more details).

The average cycling speed for each condition was derived from the camera's GPS data and analysed as the third dependent variable. The same overtaking and try-out manoeuvres that were discarded during the lateral position sampling process were also removed in the speed sampling procedure. One condition of one participant was additionally removed as he or she encountered a small group of cyclists who could not be overtaken before the condition ended. This event slowed the participant down.

The answers in the post-ride interviews about the experimental interventions of Experiment 1 were clustered and assigned to one of three categories (i.e. positive, neutral, and negative) by two researchers independently. Inter-rater reliability was calculated by means of the linear weighed kappa statistic (Hallgren, 2012). Hereafter, the researchers reached a joint agreement on the items that were rated differently and the resulting percentages of the coded answers were calculated. In Experiment 2, the participants' answers were recoded into 'very helpful' (categories 'much' and 'very much'), 'rather helpful' (categories 'a little' and 'to some extent') and 'not helpful' (category 'not'). For this reason, the categories differ per experiment.

5.3. Results

5.3.1. Bicycle Type

No significant effects of bicycle type on any of the infrastructure interventions were found in Experiment 1. In Experiment 2, only the overall mean lateral position of cyclists with an electric bicycle was higher compared to cyclists using a conventional bicycle (see table 5.3). No effects on swerving or speed were found in Experiment 2. For this reason, only lateral position was analysed per bicycle type to explore potential effects of the experimental conditions.

Table 5.3: Descriptive statistics and non-parametric test results for the differences between users of conventional and electric bicycles, collapsed over all conditions.

Experiment	Variable	Mean (± SD) Conventional	Mean (± SD) Electric	U	Z	p	*r*
Exp. 1	Lateral Position	67.88 ± 15.57	68.81 ± 14.59	127	-0.02	.99	0.00
	SDLP	16.48 ± 3.73	14.39 ± 4.09	81	-1.76	.08	0.31
	Speed	18.05 ± 2.99	17.76 ± 2.08	106	-0.52	.61	0.09
Exp. 2	Lateral Position	76.54 ± 15.70	87.58 ± 10.31	54	-2.02	.04	0.37
	SDLP	15.01 ± 3.90	15.89 ± 1.86	78	-0.97	.33	0.18
	Speed	17.59 ± 2.59	18.63 ± 2.55	75	-1.10	.27	0.20

5.3.2. Lateral Position

In figure 5.5, the mean lateral position values per condition and bicycle type are shown. The first analysis revealed a significant main effect of the conditions on lateral position in Experiment 1 (χ^2 (7) = 136.39, $p < .001$). Pairwise comparisons with the control conditions showed that the mean lateral position at the Edge Line and Slanted Kerbstones locations was significantly higher than in the Control Condition. Furthermore, in all the Shoulder Strip conditions cyclists rode significantly closer to the edge of the main path than in the Control Condition. There were large effect sizes (see table 5.4). The analyses of Experiment 2 also revealed a significant main effect on lateral position (χ^2 (4) = 34.19, $p < .001$). Pairwise comparisons revealed that only the mean lateral position on the White Chippings Edge Strip location was higher compared to the Control Condition (table 5.4).

Because in the overall analyses of bicycle type only effects were found on lateral position in Experiment 2, additional analyses were performed for each intervention condition in this experiment. As displayed in table 5.5, the analyses revealed that cyclists with an electric bicycle maintained a larger distance from the edge than cyclists with a conventional bicycle in all conditions. However, due to the Bonferroni correction for multiple comparisons, these effects did not reach significance. Also none of the ipsative scores comparisons revealed significant effects of bicycle type.

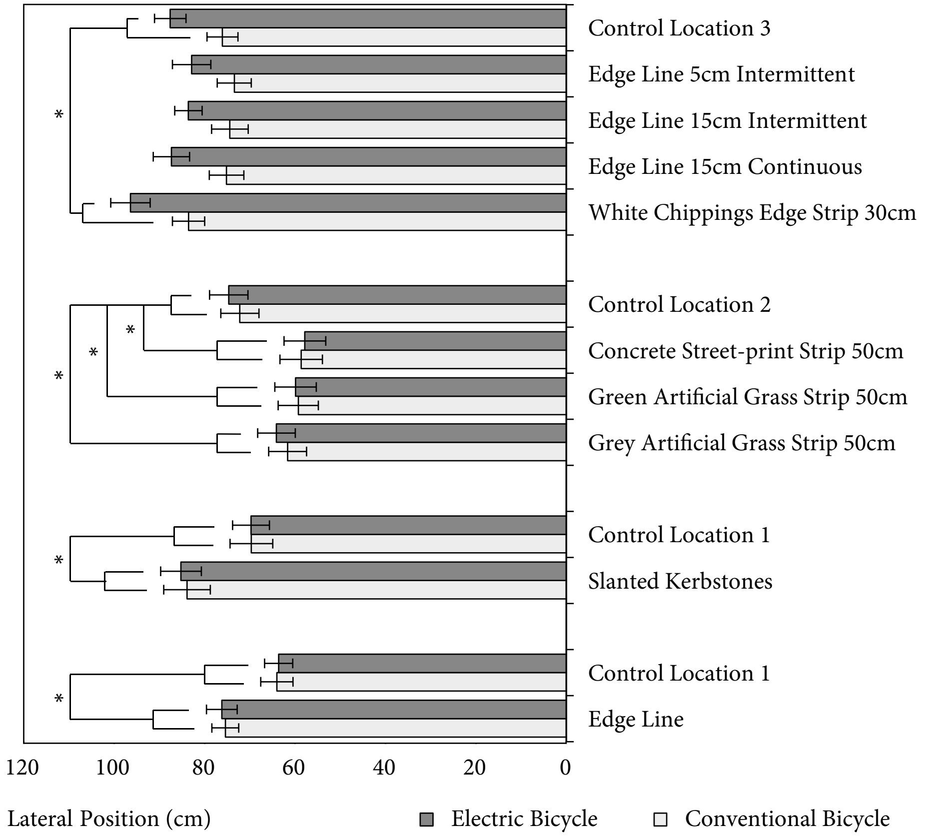

Figure 5.5: The average lateral position (in cm) per condition: 0 = right hand cycle path edge as indicated in figure 5.4. The error bars represent the Standard Error of the Mean (S.E.).

Table 5.4: The results for the pairwise effects on lateral position for the conditions in Experiment 1 and 2. All effects are comparisons with the control conditions.

Condition	Z	df	p	*r*
Edge Lines - White	-4.94	1	< .001	0.87
Slanted Kerbstones - White	-4.56	1	< .001	0.81
Artificial Grass Strip - Grey	-4.45	1	< .001	0.79
Artificial Grass Strip - Green	-4.49	1	< .001	0.79
Concrete Street-print Strip	-4.77	1	< .001	0.84
Edge Line 5cm Intermittent	-2.40	1	.017	0.44
Edge Line 15cm Intermittent	-1.16	1	.245	0.21
Edge Line 15cm Continuous	-0.11	1	.910	0.02
White Chippings Edge Strip	-3.57	1	< .001	0.65

Bonferroni corrected α = .0055

Table 5.5: Lateral Position effects of Bicycle Type for each condition in Experiment 2.

Location	Mean (± SD) Conventional	Mean (± SD) Electric	U	W	Z	p	*r*
White Chippings Edge Strip 30cm	83.56 ± 15.96	96.42 ± 13.82	53	263	-2.07	.039	0.38
Edge Line 15cm Continuous	75.16 ± 17.14	87.35 ± 12.69	47	257	-2.33	.020	0.43
Edge Line 15cm Intermittent	74.44 ± 18.09	83.61 ± 9.61	61	271	-1.72	.086	0.31
Edge Line 5cm Intermittent	73.44 ± 16.87	82.89 ± 13.45	64	274	-1.58	.113	0.29
Control Location 3	76.07 ± 15.40	87.62 ± 11.08	53	263	-2.07	.039	0.38

Bonferroni corrected α = .01

5.3.3. Swerving (SDLP)

As displayed in figure 5.6, all SDLP values were similar to the Control Condition with the exception of the Edge Line and Slanted Kerbstones in Experiment 1. The Non-Parametric Friedman Test resulted in a significant main effect of location on swerving in Experiment 1 (χ^2 (7) = 47.67, p < .001) and, as displayed in table 5.6, these effects were only significant in the Edge Line and Slanted Kerbstones conditions compared to the control condition. The analyses of Experiment 2 did not reveal a main effect of SDLP (χ^2 (4) = 3.65, p = .46). Furthermore, analyses in which the interventions' ipsative scores of SDLP were compared per bicycle type, only showed a medium effect on the Edge Line Intermittent 15 location. At this intervention, it seems as if cyclists with an electric bicycle swerve less than cyclists with a conventional bicycle ($M_{\text{Conventional}}$ = 1.87 (±6.47) and M_{Electric} = -4.46 (±2.70). However, this effect did not reach Bonferroni-corrected significance (U = 39; Z = -2.68, p = .007, r = 0.47).

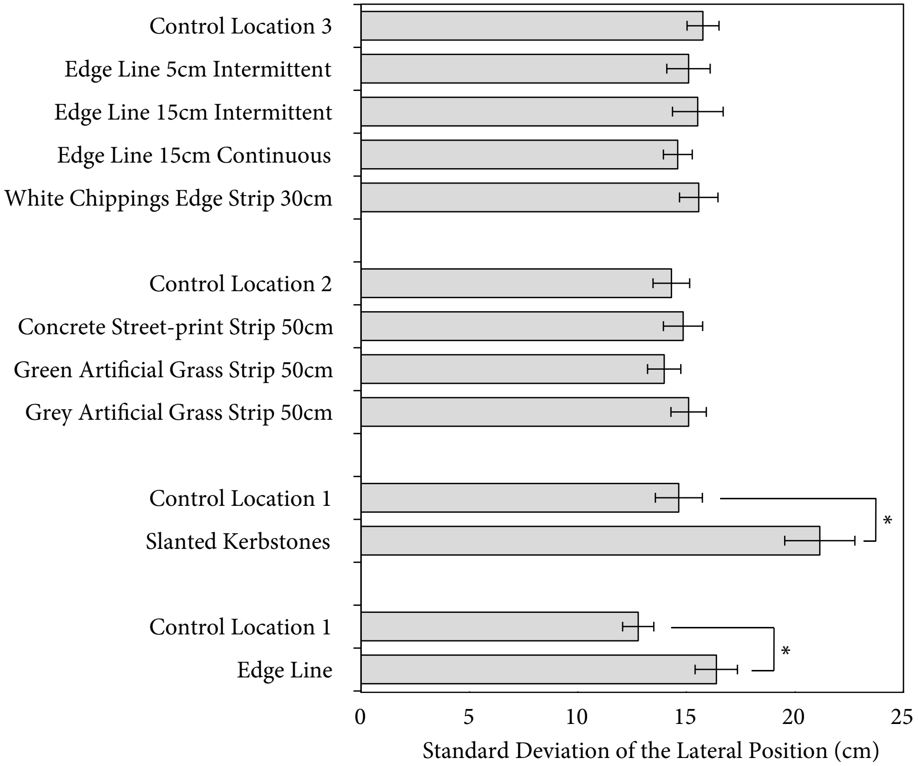

Figure 5.6: The average SDLP (in cm) per condition. The error bars represent the Standard Error of the Mean (S.E.).

Table 5.6: The results for the pairwise effects on swerving (SDLP) for the conditions in Experiment 1 and 2. All effects are comparisons with the control conditions.

Condition	Z	df	p	*r*
Edge Lines - White	-3.39	1	.001	0.60
Slanted Kerbstones - White	-3.52	1	< .001	0.62
Artificial Grass Strip - Grey	-0.72	1	.472	0.13
Artificial Grass Strip - Green	-0.44	1	.660	0.08
Concrete Street-print Strip	-0.11	1	.911	0.02
Edge Line 5cm Intermittent	-1.00	1	.318	0.18
Edge Line 15cm Intermittent	-0.60	1	.551	0.11
Edge Line 15cm Continuous	-1.31	1	.192	0.24
White Chippings Edge Strip	-0.36	1	.721	0.07
Bonferroni corrected α = .0055				

5.3.4. Speed

In figure 5.7, the average speeds per condition are listed. A non-parametric Friedman Test revealed a significant main effect in Experiment 1 (χ^2 (7) = 142.43, p < .001). Further comparisons resulted in large significant differences between the control condition and each of the intervention conditions (see table 5.7), meaning that participants cycled at a higher speed in the control conditions than in the experimental conditions. The analyses also revealed a significant main effect in Experiment 2 (χ^2 (4) = 27.93, p < .001) and, based on the pairwise comparisons, this effect was only significant in the 5cm Edge Line condition (see table 5.7).

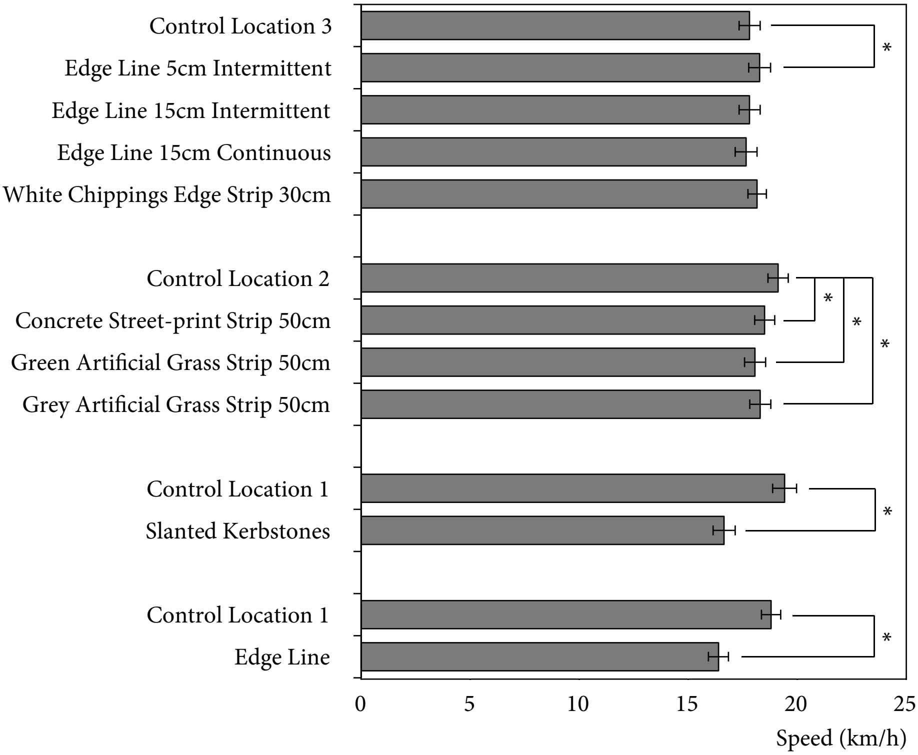

Figure 5.7: The average cycling speed (km/h) per condition. The error bars represent the Standard Error of the Mean (S.E.).

Table 5.7: The results for the pairwise effects on speed for the conditions in Experiment 1 and 2. All effects are comparisons with the control conditions.

Condition	Z	df	p	*r*
Edge Lines - White	-4.86	1	< .001	0.87
Slanted Kerbstones - White	-4.86	1	< .001	0.87
Artificial Grass Strip - Grey	-4.31	1	< .001	0.76
Artificial Grass Strip - Green	-4.66	1	< .001	0.82
Concrete Street-print Strip	-3.95	1	< .001	0.70
Edge Line 5cm Intermittent	-4.20	1	< .001	0.77
Edge Line 15cm Intermittent	-0.14	1	.885	0.03
Edge Line 15cm Continuous	-0.66	1	.510	0.12
White Chippings Edge Strip	-1.87	1	.061	0.34
Bonferroni corrected α = .0055				

For the Green Artificial Grass and Concrete Street-print interventions, large significant effects of bicycle type on the ipsative scores of speed were found. Cyclists with an electric bicycle decreased their speed less than cyclists with a conventional bicycle on these intervention areas (see table 5.8).

Table 5.8: Mann-Whitney U significant test results (α ≤ .0055) for the effects of bicycle type on the Ipsative Scores of Speed per Intervention. The Ipsative Scores are the difference scores per Intervention (i.e. Intervention – Control Condition).

Intervention	M (±SD) Conventional	M (±SD) Electric	U	Z	p	*r*
Green AGS	-1.53 (± 1.10)	-0.52 (± 0.46)	45.0	-3.12	.002	-0.51
Street-print	-0.98 (± 0.72)	-0.21 (± 0.46)	32.5	-3.59	< .001	-0.54
Bonferroni corrected α = .0055						

5.3.5. Subjective opinion

According to the guidelines of Landis and Koch (1977, cited in Hallgren, 2012), the researchers reached moderate, substantial, and almost perfect inter-rater reliability for the Green Artificial Grass Strip, the Concrete Street-print Strip, and the Grey Artificial Grass Strips, respectively, in Experiment 1 (see table 5.9). The average percentages of the researchers' joint agreements are also displayed in table 5.9. A majority of participants remembered the interventions except for the Grey Artificial Grass strip condition in Experiment 1. Furthermore, there were no distinct differences between the subjective evaluations of the shoulder strip conditions in Experiment 1 and no clear preference could therefore be derived. In Experiment 2, however, the 15 cm Continuous Edge Line and the 30 cm White Chippings Edge Strip were the most positively evaluated interventions (see table 5.10). Examples of specific comments for the 30 cm White Chippings Edge Strip ranged from "*clear*" and "*smart, you will feel it instantly*" to "*keep away from that strip!*" and "*it makes me insecure*".

Table 5.9: Subjective opinions in percentages for the interventions in Experiment 1.

Intervention	Remembered after presentation	Positive	Neutral	Negative	Weighed κ
Grey Artificial Grass Strip	50.0	36.7	30.0	33.3	0.89
Green Artificial Grass Strip	84.4	38.7	29.0	32.3	0.55
Concrete Street-print Strip	56.3	38.7	25.8	35.5	0.72

The evaluations include all participants and not only who remembered the intervention.

Table 5.10: Subjective opinions in percentages for the interventions in Experiment 2.

Intervention	Remembered after presentation	Very helpful	Rather helpful	Not helpful
No Line (Control Condition)	90.0	33.3	33.3	33.3
Edge Line 5-15 cm Intermittent	90.0	44.4	48.1	7.4
Edge Line 15 cm Continuous	80.0	91.7	8.3	0.0
White Chippings Edge Strip 30 cm	100.0	86.7	10.0	3.3

The evaluations include all participants and not only who remembered the intervention.

5.4. Discussion

5.4.1. Main findings

In this study, the effects of nine interventions on or near the edge of a cycle path on lateral position, swerving, and speed were examined with cyclists aged 50 years and older. Two experiments were performed of which the first contained a cycle path with either edge lines, slanted kerbstones, or three types of shoulder strips with surfaces made of grey and green artificial grass, and street-print. In the second experiment, three types of edge lines or a white edge strip made of chippings were added onto the surface of the cycle path. The participants cycled a route in one of the experiments and they passed the intervention locations and control locations, for which the latter only contained a similar sized cycle path with no additional interventions.

Participants with either a conventional or a pedal electric bicycle were recruited for the experiments. The first analyses concerned potential behavioural differences between the users of the two bicycle types. Only differences on the overall lateral position measurements are found in Experiment 2, where cyclists with an electric bicycle cycle further away from the edge of the path than cyclists with a conventional bicycle. Because this effect was only found on lateral position in Experiment 2 and not in Experiment 1, it is unclear whether these effects are generalizable to other locations. Perhaps the larger width of the path or the absence of centrelines influenced the lateral position, although this did not lead to differences in swerving behaviour or speed between the two groups.

The effects of the edge line interventions on cycling behaviour are inconsistent between experiments and conditions. In Experiment 1, cyclists were found to keep more distance from the edge of the cycle path, to swerve more, and to cycle slower in the edge line condition compared to the control condition. In Experiment 2, however, it was found that only in the 5 cm intermittent edge line condition, cyclists tend to cycle faster and closer to the edge of the cycle path than in the control condition. These were large and medium effects, respectively, of which only the first reached significance. The analyses of the remaining conditions did not reveal any effects.

Because the effects are opposite and the absolute differences between the means in Experiment 2 are very small, it is difficult to fully attribute the effects to the edge line interventions. Because the edge line location of Experiment 1 was within a village, contained a slight curve in the first (outbound) part, and a bus stop platform in the second (return) part of the cycle path, it is possible that these elements also affected cycling behaviour. The outbound and return journeys of the edge line and control conditions in Experiment 2 were all in a very similar (rural) environment and this could explain the absence of differences between the edge line conditions in Experiment 2. A limitation of Experiment 2 is that there was no centreline marking and that the contrast between the road surface and the edge line conditions was lower compared to Experiment 1. It seems unlikely, however, that the contrast was too low to have an effect (McKnight, McKnight, & Tippetts, 1998) because the vast majority of participants could remember these interventions.

The effects of the white slanted kerbstones are similar to the effects of the edge line condition of Experiment 1. Cyclists at this location cycle further away from the edge of the cycle path, swerve more, and have a lower speed compared to the control condition. Perhaps a similar limitation as with the edge line condition of Experiment 1 applies here as well: because the cycling lane of this intervention was 20 cm wider than the control condition, it is difficult to fully ascribe the found effects to the intervention. Also, during the data scoring process the researchers noticed that many participants cut the (slight) curve on this location and it could be that this affected lateral position and SDLP. For this reason, it is recommended to further investigate these effects with a pre-post-test study design that enables measurements of both conditions in the same environment or very similar locations.

Large and significant effects were consistently found on lateral position and speed for all the shoulder strip interventions in Experiment 1. At these locations, the cyclists are positioned between 11 and 15 cm closer to the edge of the cycle path (i.e. the edge of the asphalt) and cycled up to 1 km/h slower on average compared to the control condition. This finding is similar to the behaviour of car drivers, as multiple studies such as Bella (2013) and Mecheri, Rosey, and Lobjois (2017) found that increasing the size of the shoulder is related to a lateral position shift towards the edge of a road. A possible explanation for the decreased lateral distance could be that the cyclists experience the shoulder strips as clear zones, similar to the effect of car drivers who are positioned closer to the edge of a road when there is less vegetation or when there are less trees or other objects near a road's edge (Fitzpatrick, Samuel, & Knodler Jr., 2016).

With regard to run-off crashes, an intervention is considered to increase safety if the position of cyclists is further away from the verge compared to the control condition. For this reason, the effects of the shoulder strips on lateral position seem to decrease rather than increase safety. However, the distances that cyclists shift to the right (i.e. between 11 and 15 cm) were smaller than the space that was added by the shoulder strips in-between the cycle path and the verge (i.e. 50 cm). Because the shoulder strips are only designed to create a buffer zone for cyclists to return to the cycle path, the net distance between the cyclists and the soft verge actually increased with 35-39 cm. An implication for this finding is that with the addition of shoulder strips, cyclists use the available space on the cycle path more efficiently when these strips are applied and this could provide more room for overtaking or oncoming cyclists, both being difficulties that older cyclists experience (Westerhuis & De Waard, 2016). At the same time, the distance to the verge is also increased with a buffer zone between the cycle path and the verge.

In the 30 cm edge strip condition in Experiment 2, the cyclists were positioned approximately 8 cm further away from the verge than in the control condition. This seems as an opposite effect compared with the shoulder strips in Experiment 1, although it is important to note that the edge strip was painted on the cycle path surface itself and only visually decreases the total width of the cycle path, although it is still part of the cycle path's surface. This could mean that the edge strip is effective in moving a cyclist away from the verge without paving an additional strip next to the cycle path. This intervention is therefore more a relocation rather than a creation of space, and these effects are similar to increasing the size of the shoulder of car drivers by shifting the edge line towards the centre of the road (Mecheri, Rosey, & Lobjois, 2017).

The effects of the interventions in Experiment 1 on cycling speed were all large and consistent: in all intervention areas the cyclists rode slower. This can also be considered a safety increase because with a lower speed there is more time to correct a mistake compared to higher speeds. Furthermore, it is important to note that the cycling speeds were still sufficient to balance a bicycle (CROW 2007, cited in De Waard et al., 2010). In Experiment 2, however, limited effects of the interventions on cycling speed were found.

With regard to the type of bicycle (conventional or electric), it seems that the decrease in cycling speed on the Green Artificial Grass and Concrete Street-print interventions was stronger for cyclists with a conventional bicycle than for cyclists with an electric bicycle. It could be that the speed reduction for electric bicycles is less pronounced because these bicycles will keep providing some support even if a cyclist is only pedalling slower and not braking. However, it is unclear why this effect only occurred on these specific interventions. It could be that, because of the relative 'open' landscape that surrounded these interventions (i.e. relatively few trees and buildings), the wind had more influence on the speed of cyclists with a conventional bicycle than on cyclists with an electric bicycle. In particular when cycling against the wind, the support that an electric bicycle provides can assist with maintaining speed.

The 30 cm edge strip was also among the most positively evaluated interventions by the cyclists in Experiment 2. Because no clear subjective preference could be derived regarding the shoulder strip conditions in Experiment 1, the concrete street-print and the white chippings edge strip interventions seem to be the preferred options based on their effects on cycling behaviour and the subjective ratings. Also, because the placement of artificial grass requires a foundation made of concrete or a similar material, the concrete street-print strip is presumably the least expensive form of the shoulder strip conditions and provides the largest effects. Although the size of the lateral position effect of the edge strip is smaller than the shoulder strips of Experiment 1, this intervention could also be cheaper to construct and be less prone to subsidence. For this reason, it might be more suitable for locations where the available space next to a cycle path is restricted.

5.4.2. Limitations

There were also several limitations due to the study and its design. First, it is possible that the cyclists who participated in the study were relatively 'fit' compared to the 'average' older cyclist. A potential reason for this is that the study required participants to be able to cycle at least 12 or 6 kilometres, and that they could come to the research location with their own bicycle. We would have liked to also include cyclists that rarely cycle or struggle with cycling, but response rate to calls to participate of these people is low.

Because the participants were all asked to cycle the same route, they passed all the locations in the same order in each experiment. It could therefore be that participants' bias increased with the number of intervention conditions that they encountered because they could make an estimation of the goal of the study based on the interventions that were already passed (expectancy effect). Also the number of passed interventions alone can cause expectations and practice, independently of the content. The preferred option would be to present the conditions in a randomized order, but this was physically not possible in this research setting.

A third limitation is that all interventions were entirely new for the participants and that there might have been a novelty effect that influenced their behaviour. It could therefore be that the participants were looking at the interventions and that this lured them towards the edge of the road, automatically resulting in a different lateral position compared to a control condition. Although the researchers tried to control for these influences by filtering out overtaking and 'try out' manoeuvres, it cannot be ruled out that an influence of these novelties remains to exist. Additionally, it could be that cyclists were more 'used' to one condition than another because they had spent more time on longer intervention sections than sections that were shorter. Also, small gaps between interventions can make a new encountered intervention attract attention and influence behaviour. Although the researchers tried to maintain some distance between the measurement stretches of each condition, this was not always possible due to other factors such as limited space to perform measurements or the presence of curves that prevented measurements on part of the intervention areas. These factors could therefore have influenced the measurements, although the lengths of the sections should be sufficient to assess effects especially given the fact that this study was performed in a real-world situation. Further research to assess the long-term effects of the infrastructure interventions is also recommended because it is possible that cyclists get used to the different environments. As a consequence, it could be that the effects diminish over time.

5.4.3. Experimental control in applied research

With regard to the limitations, it should be noted that the researchers tried to gain as much experimental control as they could, although due to the applied character of this study this was not possible in all instances. However, because the interventions in this study were tested in a real cycling environment in which cyclists used their own bicycles, this is also considered a strength because of the high ecological validity.

In future studies, perhaps a more balanced approach of experimental control and applied, ecologically valid measurements can be used. For example, it could be possible to use a bicycle simulator to pre-select measures that are potentially the most effective in influencing cycling behaviour (e.g. O'Hern, Oxley, & Stevenson, 2017). Also because it is very expensive and time-consuming to construct these interventions on a real cycle path, a simulator could give insight into the expected effects of different interventions in the real world. In a simulator, it would be possible to test different interventions in exactly the same (virtual) environments, to balance order of conditions over participants, and construct the most effective interventions in larger areas on a real cycle path.

5.5. Conclusions

To the best of the authors' knowledge, this paper describes one of the first studies in which the effects of different edge lines, slanted kerbstones, shoulder strips, and edge strips on cycling behaviour are measured using a within-subjects experiment with older participants on their own bicycles. Although the effects of the edge lines and slanted kerbstones were inconsistent, large effects of the shoulder and edge strip conditions were found on cycling behaviour. In the interventions where shoulder strips were placed next to the cycle path, and contained a different type of surface than the main cycle path, cyclists maintained a smaller distance from the edge of the path and cycled at lower speeds compared to the control condition. However, because the shoulder strips were placed in-between the main cycle path and the soft verge, the net distance to the verge is increased because the average distance that cyclists moved to the right was less than the width of the shoulder strip. The white chippings edge strip condition, however, was not added next to the path but was part of the main cycle path's surface. This intervention therefore resulted in a larger distance from the soft verge compared to the control location, essentially drifting cyclists away from the verge without paving new strips in the shoulder of a cycle path: the path is only visually narrowed. The most preferred strip interventions were the concrete street-print shoulder strips and white chippings edge strips, because these seem to have the largest effects on lateral position, are presumably the least expensive to construct, and offer solutions for different types of locations.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Appendices

Appendix A: The questions of the post-ride interviews for Experiment 1 and Experiment 2.

Procedure Post-ride Interviews Experiment 1

1. Short verbal introduction of the area where the intervention was applied.
2. Question: "Can you remember this area?"
    If yes: the researcher continues with question 3.
    If no: the researcher shows a picture of the intervention and continues with question 3.
3. Question: "Could you describe what you have seen there?"
4. The researcher shows the video of the participant cycling past the modifications.
5. Question: "Could you describe your first reaction when you saw these modifications?"
6. Question: "What is your opinion about these modifications?"

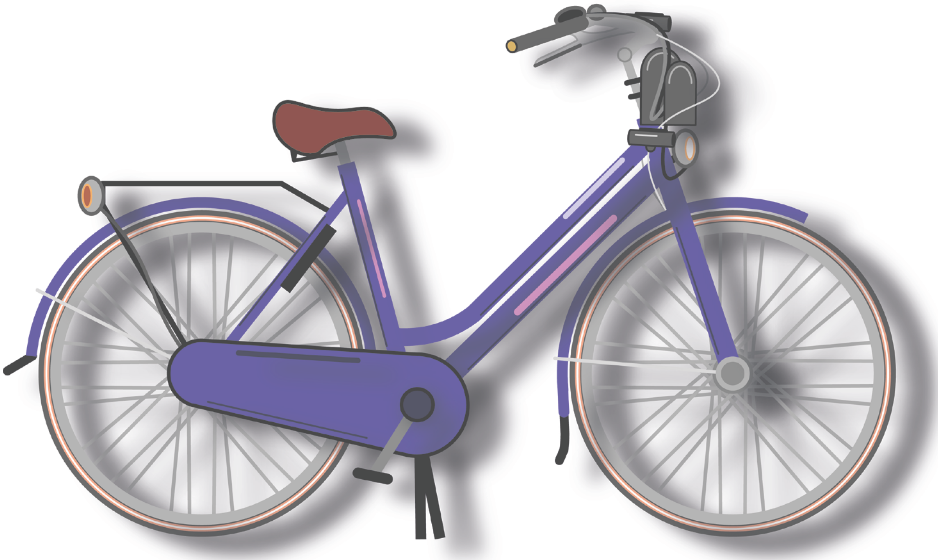
Procedure Post-ride Interviews Experiment 2

1. Researcher shows photo of the intervention location.
2. Question: "Can you remember this section?"
3. Question: "What do you think about this measure in general?"
4. The researcher monitors and writes down whether the participant's opinion is positive or negative.
5. Question: "To what extent do you believe that these modifications contribute to keeping cyclists on the cycle path?"
6. Question after all interventions were discussed: "Do you have a preference for one of the interventions?"

Appendix B: Exclusion criteria and the number of cyclists of whom (parts of the) measurements were discarded from the analyses.

Exclusion Criterion	Measures	Experiment	Condition(s)	N	Freq.
Overtaking	LP, SDLP, & Speed	1	ELC	1	1
			SK	1	1
			Grey AGS	2	2
			Green AGS	3	3
			CL 1	1	1
			CL 2	1	1
		2	ELI 5cm	1	1
			ELC 15cm	2	2
			WCES	1	1
			CL 3	1	1
Entering Strip(s)	LP, SDLP, & Speed	1	Grey AGS	2	2
			Green AGS	4	5
			CSS	3	3
		2	WCES	1	1
Speed Obstruction	Speed	1	CL 1	1	1

Chapter 6



Enlightening Cyclists

An evaluation study of a Bicycle Light Communication System aimed to support older cyclists in traffic interactions

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6. Enlightening cyclists: an evaluation study of a Bicycle Light Communication System aimed to support older cyclists in traffic interactions

Abstract

Introduction: In the Netherlands, older cyclists run a relatively high risk of bicycle crashes. Critical factors are interactions at low cycling speed, stopping, and dismounting (Ormel, Klein Wolt, & Den Hertog, 2008; Boele-Vos et al., 2017). There are also indications that the speed of electric bicycle riders is frequently misjudged (Dozza, Piccinini, & Werneke, 2016; Petzoldt, Schleinitz, Heilmann, & Gehlert, 2017). As relatively many older cyclists ride electric bicycles, safety may be enhanced by facilitating interactions and improving balance, while also providing other road users with additional information about cycling speed.

Methods: A Bicycle Light Communication System (BLCS) was developed to facilitate communication of cyclist's behaviour and to benefit balance. Different light-signals displayed riding speed, braking, and turning intentions. In an on-road experiment, 21 older and 20 younger cyclists observed BLCS-signals while following a lead cyclist and estimated the riding speed of an approaching cyclist, with and without a BLCS. An interview was conducted afterwards to assess general opinions. In a small follow-up study, twelve older cyclists used a BLCS-bicycle for one week to explore first user-impressions.

Results: The BLCS was evaluated positively by most participants, although this particularly concerned the turning indicator and the brake light components. The riding speed signals were difficult to interpret and evaluated more negatively. Even though the first user-impressions revealed that the direction indicator does not influence balance, the majority reported that they would like to use a BLCS on their own bicycle, should it become available.

Conclusions: Light signals displaying a cyclist's turning intentions and braking behaviour facilitate other road users to anticipate cycling manoeuvres. A turning indicator may be operated by older cyclists without influencing balance. The evaluated BLCS-signals did not have a positive effect on speed estimation and alternatives should therefore be studied to counteract speed misjudgements.

6.1. Introduction

In the Netherlands, cycling is a common mode of transportation and many people use the bicycle daily (Harms & Kansen, 2018). Cycling contributes positively to health, social participation, and quality of life (Oja et al., 2011; De Hartog, Boogaard, Nijland, & Hoek, 2010; Fishman, Schepers, & Kamphuis, 2015) and it is important that people keep cycling safely for as long as they wish (Tour de Force, 2017). A specific group that is currently of interest due to safety concerns, however, is older cyclists (Ministry of Transport, Public Works, and Water Management, 2008; Rijkswaterstaat, 2016). Since more older cyclists have continued to cycle over the recent years, their share in traffic has substantially increased (Kennisinstituut voor Mobiliteitsbeleid, 2017a; Schepers, Stipdonk, Methorst, & Olivier, 2017). This development is positive for healthy ageing as cycling benefits physical fitness (Ryan, Svensson, Rosenkvist, Schmidt, & Wretstrand, 2016) and increases the life space area of older people (Van Cauwenberg, Schepers, Deforche, & De Geus, 2019). However, age-related cognitive and physical decline are related to an increased risk of falling from the bicycle (Engbers et al., 2018a). Indeed, it is estimated that a large proportion of bicycle crashes in the Netherlands concern older cyclists (Schepers, Stipdonk, Methorst, & Olivier, 2017) and this group is susceptible to sustain severe injuries after a bicycle crash (OECD, 2001; SWOV, 2013). Even though the majority of these crashes are single-bicycle crashes (Schepers, 2013; Schepers et al., 2015), interactions with other road users are an important factor as well (Ormel, Klein Wolt, & Den Hertog, 2008; Westerhuis & De Waard, 2016; Boele-Vos et al., 2017; VeiligheidNL/Rijkswaterstaat, 2017). Several initiatives have therefore been started to investigate possibilities to support older cyclists with their interactions with other road users.

6.1.1. Keeping balance

One explanation for the risk of falling of older cyclists is that ageing may be accompanied by problems with motor coordination and balance (SWOV, 2013; VeiligheidNL/Rijkswaterstaat, 2017). For example, Ormel et al. (2008) found that in the Netherlands, approximately one quarter of bicycle crashes that required hospitalization of cyclists ≥ 55 years in 2008 occurred while mounting or dismounting the bicycle, and more recent studies show similar results (Kruijer, Den Hartog, Klein Wolt, Panneman, & Sprik, 2012; VeiligheidNL/Rijkswaterstaat, 2017; Scheiman, Moghaddas, Björnstig, Bylund, & Saveman, 2010; Hagemeister & Tegen-Klebingat, 2012). Contributing factors are that older cyclists not only mount and dismount a bicycle differently than younger cyclists (Dubbeldam, Baten, Straathof, Buurke, & Rietman, 2017), but also may have difficulties recovering from balance disturbances while riding at low speeds (Bulsink, Kiewiet, Van de Belt, Bonnema, & Koopman, 2016). Because interactions with other road users, such as giving priority or responding to actions of other road users, typically require cyclists to decrease speed or to stop and dismount the bicycle, such interactions are critical in bicycle crashes of older cyclists (Davidse, Van Duijvenvoorde, Boele, Duivenvoorden, & Louwerse, 2014; Davidse et al., 2014; Boele-Vos et al., 2017). These crashes may therefore be prevented by supporting older cyclists during similar interactions.

Other safety-related interactions that may impact balance are looking over the shoulder and indicating direction (Johnsen & Funk, 2019). Every cyclist frequently has to look over the shoulder to monitor traffic from behind. This is particularly necessary before turning left (in right-hand traffic countries) and it is known that older cyclists find this a difficult manoeuvre to perform safely (Bernhoft & Carstensen, 2008). Instead, some choose to cross an intersection on foot even though this requires them to dismount their bicycle. Shortly before turning, one hand has to be taken off the handlebars to point into the intended direction. This gesture forces the rider to balance the bicycle with only one hand and is currently the only and official way for cyclists to indicate direction understandably (Walker, 2005). Even though some intentions might be derived from other observable cycling behaviours (Hemeren et al., 2014), not stretching an arm impairs other cyclists in predicting turning intentions, showing that it is indeed a crucial gesture (Westerhuis & De Waard, 2017). As balance problems are common in older cyclists, looking over the shoulder and indicating direction could increase their risk on falling. It may therefore be beneficial to provide older cyclists with alternative options for detecting traffic from behind as well as for indicating direction.

6.1.2. Electric bicycle

Thanks to the electric bicycle more older people cycle (Schepers, Fishman, Den Hertog, Klein Wolt, & Schwab, 2014). Compared to conventional bicycles, (older) cyclists may ride more frequently and further distances on electric bicycles because less physical effort is required to ride comfortably (Theurel, Theurel, & Lepers, 2012). Less physically fit people may therefore still be able to ride an electric bicycle if riding a conventional bicycle is not possible anymore (Johnson & Rose, 2015). Although cyclists tend to ride faster on an electric bicycle if they are physically capable of riding both an electric and a conventional bicycle, it seems that the riding speed of older e-cyclists is more comparable to the riding speed of younger cyclists, regardless of bicycle type (Vlakveld et al., 2015). Indeed, naturalistic cycling studies with older participants riding their own bicycles show no or small speed differences between electric and conventional bicycle riders, suggesting that some older people may use an electric bicycle to reach 'conventional' riding speeds (Westerhuis & De Waard, 2016; Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert, 2017). This could mean that electric bicycles support older cyclists with keeping balance because it easier to stabilise a bicycle at speeds ≥12km/h (Kooiman, Meijaard, Papadopoulos, Ruina, & Schwab, 2011). Although gaining sufficient speed from a standstill might also be performed more stably, most balance improvements of an electric bicycle occur while cycling at higher speeds (Twisk, Platteel, & Lovegrove, 2017). This is mainly due to the heavy weight and uneven weight distribution of the electric bicycle, making it more difficult to keep balance while riding at lower speeds (Haustein & Møller, 2016). It is therefore not surprising that mounting, dismounting, and keeping balance on an electric bicycle is also a difficulty for older cyclists that deserves attention (Schepers, Fishman, Den Hertog, Klein Wolt, & Schwab, 2014; VeiligheidNL/Rijkswaterstaat, 2017; Twisk, Platteel, & Lovegrove, 2017).

Another factor of the electric bicycle is that it is not necessary to pedal with high cadence (i.e. pedal rotation frequency) to reach comfortable speeds. Furthermore, from well-trained (sport) cyclists, it is known that particularly older cyclists benefit from lower cadences and apply this pedalling strategy more frequently than younger cyclists (Sacchetti, Lenti, Di Palumbo, & De Vito, 2010). Other road users, however, often use a cyclist's cadence as a visual cue to estimate riding speed (Schleinitz, Petzoldt, Krems, & Gehlert, 2016). Even though racing cyclists also tend to ride at high speeds with relatively low cadences, they are clearly recognisable as fast riders based on their appearance (e.g. posture, clothing, and bicycle design). E-cyclists, however, are becoming increasingly difficult to recognise as the design of electric bicycles is similar to conventional bicycles (Dozza, Piccinini, & Werneke, 2016). Therefore, other road users are at times surprised by the speed at which (older) e-cyclists approach them because low cadence generally indicates low effort and, as a result, a low riding speed (Haustein & Møller, 2016; Schleinitz, Petzoldt, Krems, & Gehlert, 2016). In turn, this may lead to underestimating the speed of e-bicycle riders (Petzoldt, Schleinitz, Heilmann, & Gehlert, 2017). Particularly at locations where people are under time pressure to make decisions (e.g. intersections), it is important that the speed of e-cyclists can be reliably estimated to enable other road users to choose safe crossing gaps (Dozza, Piccinini, & Werneke, 2016; Petzoldt, Schleinitz, Gehlert, & Krems, 2017).

6.1.3. On-bicycle solutions

Several on-bicycle solutions aimed at supporting older cyclists have been developed and tested. For example, difficulties with mounting and dismounting may be alleviated by adjusting the geometry of a bicycle and/or providing a saddle that automatically lowers its position while riding at lower speeds (Dubbeldam, Baten, Buurke, & Rietman, 2017). Furthermore, rear-view detection systems may assist older cyclists to detect traffic from behind (Engbers et al., 2016; Engbers et al., 2018b). Indicating direction by means other than releasing one hand from the handlebars, however, has not been implemented for most cyclists, despite the use of a direction indicator system being a globally accepted, well-known, and long-lasting obligation on most forms of motorised transport. There is little doubt that signalling is important because this enables car drivers, for example, to anticipate turning manoeuvres of lead vehicles, resulting in safer following behaviour (Muhrer & Vollrath, 2010). Analogously, it should be possible to implement a similar signalling system on bicycles. Apart from informing other road users, a signalling system could also improve balance as the operation does not require releasing one hand from the handlebars.

6.1.4. Bicycle Light Communication System

A Bicycle Light Communication System (BLCS) was developed to provide an alternative means for cyclists to show turning intentions and riding speed to other road users. This BLCS contained a turn indicator, speed indicator, and a brake light, all integrated in a front and a rear bicycle light unit. The system's main aim was to not only provide other road users with explicit light signals about turning intentions and riding speed, but also about acceleration, deceleration, and braking. By using explicit light signals, it was hypothesised that the speed of the rider could be estimated more accurately than on the basis of observable rider behaviour alone. Furthermore, it should no longer be necessary to signal with the arm, thus both hands can remain on the handlebars while turning. This should not only benefit keeping balance, but also enable other road users to anticipate a cyclist's turning intentions and adjust behaviour accordingly.

6.1.5. Research aim

The first and primary objective of this study was to explore how (naïve) older and younger cyclists experience and interpret light signals shown by a BLCS. For this reason, an on-site experiment was conducted in which older and younger participants were invited to cycle together with a researcher that used a BLCS on the bicycle (Study 1). Hereafter, a small group of older cyclists was invited to use a BLCS-instrumented bicycle for themselves to get first-hand experience as a BLCS-user, particularly with regard to the direction indicator and its perceived effects on keeping balance (Study 2).

6.2. Materials and Methods

In Study 1, effects of observing BLCS-signals on cycling behaviour were investigated and subjective opinions regarding visibility, interpretation, intention to use, mental effort, expected safety enhancement, and acceptance were collected. In Study 2, a small follow-up was performed with older cyclists using a BLCS-bicycle for their personal cycling activities during one week. Both studies were approved by the University of Groningen Psychology Ethics Committee (16414-O and 16415-O).

6.2.1. Study 1

6.2.1.1. Participants

As older cyclists are expected to benefit most from a BLCS, participants ≥ 60 years and capable of cycling independently were recruited. Younger cyclists (≤ 35 years) were also recruited because in particular communication between older and younger cyclists tends to be difficult (Ryan, Svensson, Rosenkvist, Schmidt, & Wretstrand, 2016). Older cyclists were recruited by distributing flyers in local shops and community centres in the city of Groningen. For younger participants, flyers were distributed in the main buildings of the University of Groningen and on Facebook groups with people from Groningen. All participants received a € 15 voucher for participation.

Twenty-one older and twenty younger cyclists participated in Study 1 (table 6.1). The majority lived in Groningen and brought their own bicycle. Two (younger) participants used a bicycle provided by the researchers.

Table 6.1: Demographical participant data of Study 1.

Group	Age		Gender	Living environment*			n
	M	S.D.	% Male	% Urban	% Village	% Rural	
Younger	25.5	3.9	40.0	90.0	5.0	5.0	20
Older	69.7	5.3	66.7	85.7	9.5	0.0	21
Total	48.1	22.9	53.7	87.8	7.3	2.4	41

** One participant did not provide any information concerning his or her living environment.*

6.2.1.2. The Instrumented BLCS-Bicycle

A bicycle (Gazelle Miss Grace, ladies' model, seven gears, 54 cm frame size) was instrumented with a BLCS that, apart from the main bicycle light in the centre of the unit, displayed several aspects of rider behaviour and intention (see figures 6.1 and 6.2). The light signals were shown by LEDs bundled in circles and triangles (arrows) on two units that were mounted as the front and rear bicycle lights. Different signals showed turning intentions (i.e. a turning indicator), braking, riding speed, or a flash-signal to draw the attention of other road users. The speed and brake signals were automatically controlled by a CPU located in a small bag below the handlebars. The cyclist controlled the turning indicator and the attention-signal with a small remote-controller located on the left-hand side of the handlebars (figure 6.3).

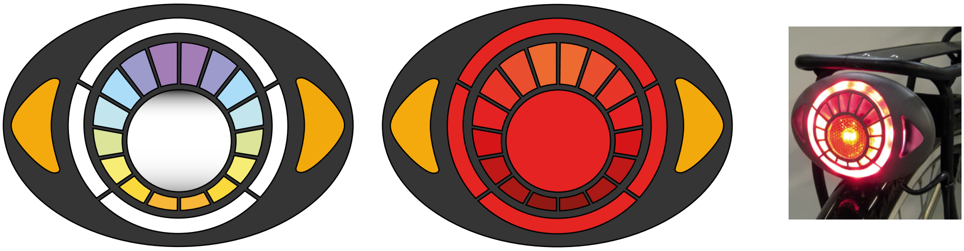

Figure 6.1: From left to right: the BLCS front unit, BLCS rear unit, and a close-up photo of the BLCS rear unit.

The turning indicators were not only located on the far-most left and right sides of the front and rear BLCS-units, but also in the grips of the handlebars (see figures 6.1 and 6.2). The indicators on the BLCS had amber-coloured LEDs in the shape of an arrow pointing in the intended direction. The indicators in the grips of the handlebars contained amber LEDs only. When enabled, the LEDs blinked similarly to indicators on cars and motorcycles and were disabled automatically after a turn was completed.

Figure 6.2: The instrumented BLCS-bicycle with activated indicators.

Figure 6.3: The BLCS remote-controller.

The BLCS also had a speed indicator which displayed the riding speed using graphical intervals. This feature had the visual shape of a ring located around the main bicycle light (see figure 6.4). The speed indicators had yellow-to-white-coloured and dark-to-light-red-coloured LED-rings on the front and rear units, respectively. The system continuously measured riding speed and conveyed this speed by lighting up (a selection of) LEDs in an upward direction as the cyclist reached higher speeds (figure 6.4). The idea behind this is that it would be recognisable, as with a dynamo the headlight would light up brighter with increasing speed.

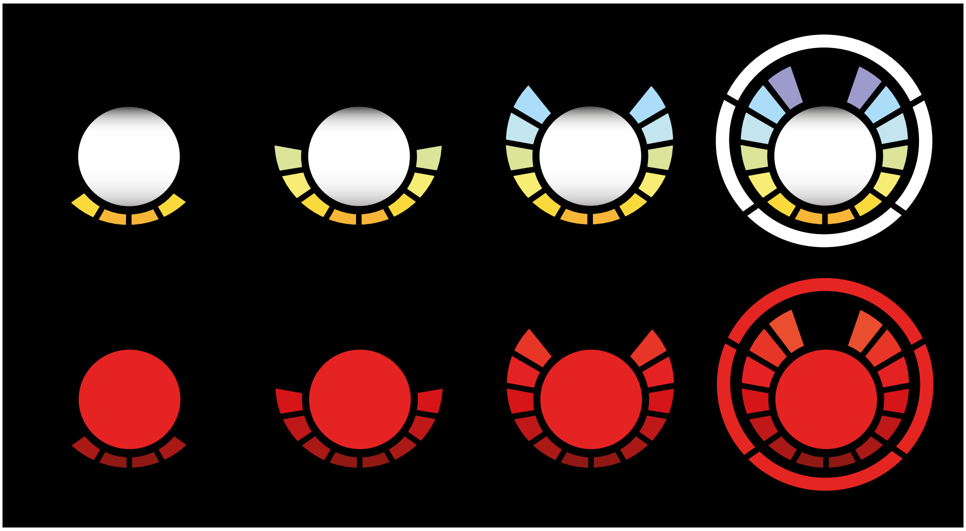

Figure 6.4: The light signals that displayed cycling speed. From left to right: very slow (± 7 km/h), slow (± 11-12 km/h), medium (± 17-18 km/h), and fast (± 21-22 km/h), with at the right the attention or brake light for the front (upper pictures) and rear (lower pictures) bicycle lights, respectively.

The last features of the BLCS were the attention and brake signals on the front and rear units, respectively. The attention-signal was incorporated in the front BLCS-unit as a white-lighted outer-ring placed between the speed and direction signals (figure 6.4, upper-right picture) and could be activated with the remote-controller. On the rear BLCS-unit, a brake light was installed at the same location (figure 6.4, lower-right picture). The brake light was automatically activated when the accelerometer exceeded a deceleration threshold of 1 m/s^2.

6.2.1.3. Location

To demonstrate the signals of the BLCS, two researchers rode a BLCS-bicycle at a quiet location in the city of Groningen. At this location, there were two separate one-way cycle paths, in reverse directions, surrounding a parking lot (see figure 6.5). Both paths were approximately 170 metres long and 2.3 metres wide. The paths were used in succession: a small 'circuit' was created by crossing the road.

6.2.1.4. Cameras

Cycling behaviour was recorded with three Contour+2™ digital action cameras with GPS. Two were mounted on the BLCS-bicycle and one on the participant's bicycle. On the BLCS-bicycle, one camera was directed forward and one to the side for the researchers to review the rides from 'their' point of view later. A third camera was mounted on the handlebars of the participant's bicycle and this camera was directed forward to record the BLCS-bicycle ahead of the participant.

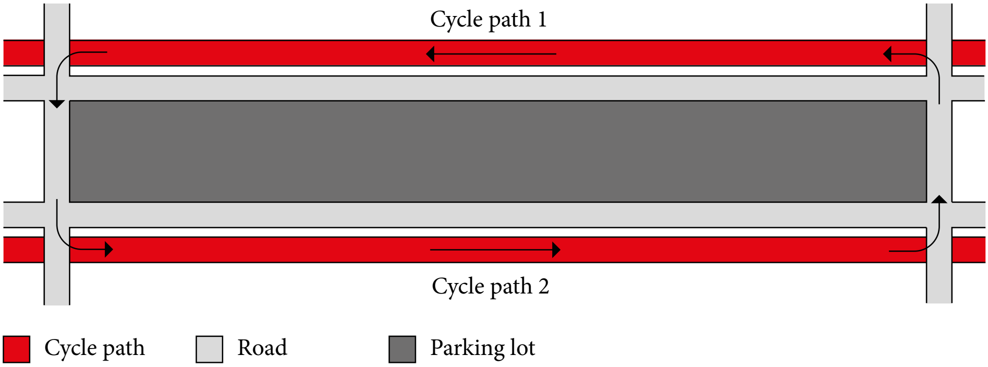

Figure 6.5: A schematic representation of the cycle paths in the experiment. The measurements were only performed on the two cycle paths (red). The road in-between the paths was used to cycle from one path to the other.

6.2.1.5. Questionnaires

Subjective information regarding visibility, signal interpretation, intention to use, and expected safety enhancement was gathered by means of a semi-structured interview. Furthermore, the acceptance of the system was assessed using a brief acceptance scale (Van der Laan, Heino, & De Waard, 1997) after demonstrating the front and rear bicycle lights. Mental effort was measured with the Rating Scale Mental Effort (RSME; Zijlstra, 1993).

6.2.1.6. Procedure

Before the experiment, participants received a letter with a general description of the study and an invitation to bring their own bicycle. If the latter was not possible, a conventional bicycle was offered to use instead. If participants had an electric bicycle (pedelec), they were asked to disable the electric support. At the experiment, the main goal of the research and the test procedure were explained. The BLCS-bicycle was shown to the participants and a researcher demonstrated all components. The speed indicator was demonstrated by rotating the BLCS-bicycle's front wheel while showing the lights. The participants were told that more lights corresponded to an increase in cycling speed. Hereafter, the participants could try the controller for the direction indicator. Remaining questions were answered and participants signed an informed consent form.

6.2.1.7. Task 1: Following the researcher riding the BLCS-bicycle

After the introduction, the participants mounted their own bicycle and followed the test leader who rode the BLCS-bicycle (Task 1). Participants with a bicycle speedometer were asked to disable it or to cover the display. Further instructions were limited: 'please follow the test leader, cycle as you usually do, and maintain a following-distance that feels comfortable'. Participants were also told to adhere to the traffic rules and to give priority whenever necessary.

Task 1 was divided into two conditions: the 'BLCS ON' and 'BLCS OFF' conditions. In the 'ON' condition, all BLCS-functions were active and participants could observe BLCS-information about riding speed, turning intentions, and braking of the BLCS-bicycle rider. The 'OFF' condition was the control condition in which the BLCS was disabled as if it were a conventional bicycle. After both conditions, participants were asked to rate the amount of invested mental effort to estimate the speed required for comfortably following the test leader. This was performed with the RSME (Zijlstra, 1993). The order of presentation of the conditions was counterbalanced. Within each condition, four riding speed scenarios were randomly presented: the 'Slow', 'Accelerating', 'Fast', and 'Decelerating' scenarios (see table 6.2 for details). Only at the end of the 'Accelerating' and 'Fast' scenarios, the brake light was also presented because in the 'Slow' and 'Decelerating' scenarios the speed was too low to reach the activation threshold before coming to a standstill.

Table 6.2: An overview of the speeds (in km/h) in each scenario.

Scenario	Starting Speed	Ending Speed	Brake Light
'Slow'	13	13	No
'Accelerating'	13	21	Yes
'Fast'	21	21	Yes
'Decelerating'	21	13	No

6.2.1.8. Task 2: Estimating the speed of the BLCS- bicycle

After Task 1, the participant was asked to stand at a fixed location next to the cycle path. While standing, one of the researchers riding a BLCS-bicycle approached the participant from 60 metres and the participant was asked to estimate the researcher's riding speed in km/h (Task 2). These estimations were performed six times: three times while the BLCS was enabled ('BLCS ON') and three times while it was disabled ('BLCS OFF'). Per condition, three speed scenarios were randomly presented: 'Slow' (11-12 km/h, gear 3), 'Medium' (17-18 km/h, gear 5), and 'Fast' (21-22 km/h, gear 7). The researchers used different gears per scenario to ensure that the pedal rotation frequency (cadence) remained as constant as possible. The participant could answer at any moment he or she preferred.

6.2.1.9. Semi-structured interviews

After Task 2, a concluding interview with open-ended questions was conducted in which participants were asked to give their overall opinion about the BLCS. Discussed topics were visibility, interpretation, expected safety enhancement, and possible intention of using or buying a BLCS. Lastly, participants were asked to fill in the Acceptance Scale (Van der Laan, Heino, & De Waard, 1997) with regard to the BLCS as a complete system.

6.2.1.10. Data scoring and analyses

During Task 1, two videos were recorded from the participant's bicycle. With the first video, the camera's perspective was captured to generate and calibrate a perspective grid in Kinovea™ (Charmant, 2016). In the second video, this grid was used to measure the distances between the rear wheel of the BLCS-bicycle and the front wheel of the participant's bicycle during the experimental rides (i.e. the following-distance). Seven measurements were sampled on fixed locations during each scenario (i.e. seven lampposts, each 24 metres apart). The mean and standard deviation of the following-distances were calculated with Microsoft™ Excel™ and the effects of the BLCS on mental effort were tested with a Wilcoxon signed-rank test for non-normally distributed data. To investigate riding speed estimation accuracy with the support of a BLCS, the differences between the estimated and true riding speeds in Task 2 were calculated and Δ-values were compared between the 'ON' and 'OFF' conditions for each scenario. As the data were non-normally distributed, a Wilcoxon signed-rank test was performed. Lastly, the feedback from the final interviews was audio-recorded and analysed after the experiment. The answers were summarized and specific remarks for all respondents were counted. With regard to the Acceptance Scale (Van der Laan, Heino, & De Waard, 1997), the median and interquartile ranges were calculated for both subscales and age groups.

6.2.1.11. Statistical analyses

Statistical tests were performed with an α-value of .05. Additionally, r effect sizes for non-parametric data were calculated and interpreted: $r \geq .1$ was considered a small effect, $r \geq .3$ a medium effect, and $r \geq .5$ a large effect (Fritz, Morris, & Richler, 2012).

6.2.2. Study 2

6.2.2.1. Participants

After Study 1, twelve cyclists ≥ 60 years were recruited to test a BLCS-bicycle for one week. Participants came from Enschede ($n = 5$) or the province of Groningen ($n = 7$). Their mean age was 68.8 years (S.D. 4.3) and 58.3% was male. In total, 83.3% lived in an urban and 16.7% in a rural environment. None of the participants had physical complaints while cycling and all were able to look over their shoulder.

6.2.2.2. Materials

Participants were provided with a BLCS-bicycle similar to the BLCS-bicycle described in paragraph 6.2.1.2. Seven BLCS-bicycles were available in different forms and sizes, all being conventional (non-electric) bicycles. Participants could choose a bicycle that was most similar to their own. Subjective opinions regarding usability, visibility, balance, safety enhancement, and intention to use a BLCS in the future were gathered by means of a structured interview. The evaluation mainly focussed on the turning indicator because this was the only component a participant could operate.

6.2.2.3. Procedure

A BLCS-bicycle was brought to the participant's home by a researcher and instructions about operation and functions were provided. Participants were instructed to cycle as they normally would and that they were not obliged to use the turning indicator, or the BLCS in its entirety, if they did not feel comfortable with it (anymore). Hereafter, the participants gave written informed consent. After a week, the researcher returned to collect the BLCS-bicycle and conducted the interview.

6.3. Results

6.3.1. Study 1

6.3.1.1. Task 1: Following-distance and mental effort.

For Task 1, the following-distance measurements of three participants were removed from the analyses due to failed video recordings. Furthermore, the 'decelerating' condition of one participant was discarded because the view was obstructed by another cyclist. The analyses revealed no significant effects of the BLCS on mean following-distance for each group or scenario (figure 6.6). Furthermore, participants rated the amount of mental effort required to estimate the speed of the test leader to follow him or her comfortably (see table 6.3). A medium and significant effect was found between the 'ON' and 'OFF' conditions in the overall participant group: participants experienced less mental effort while estimating the speed of the lead cyclist with the BLCS enabled. No significant effects were found within the age groups.

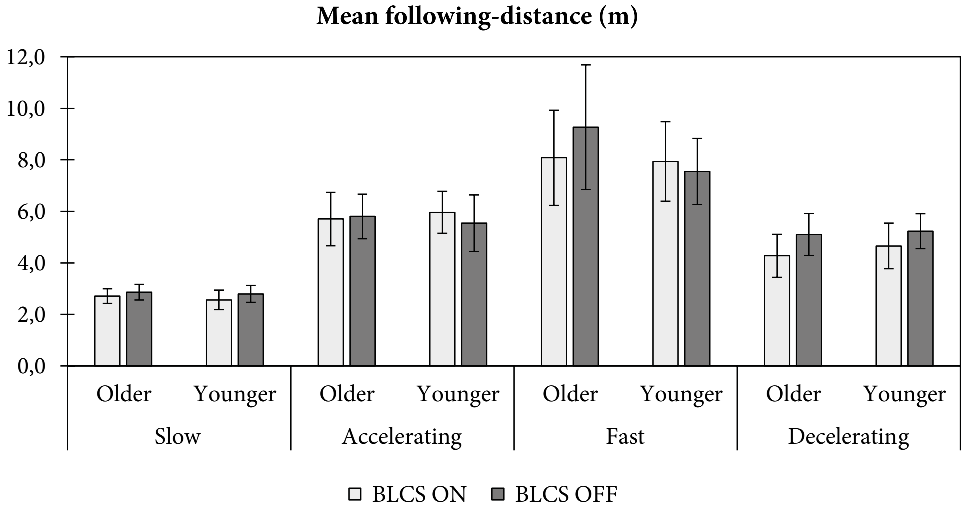

Figure 6.6: The Mean following-distance for the conditions BLCS ON and OFF, per scenario Slow, Accelerating, Fast, and Decelerating. The error bars represent the Standard Error of the Mean (S.E.).

Table 6.3: Overview of the results from the Rating Scale mental effort (RSME; Zijlstra, 1993), median and interquartile range (ranging from 0 to 150).

Group	All (Median, *IQR*)	Young (Median, *IQR*)	Old (Median, *IQR*)
BLCS 'ON'	26 (12.75 – 48)	33 (15 - 51)	22 (11.5 - 47.5)
BLCS 'OFF'	32.5 (22 - 63.75)	44 (26 - 76)	29 (22 - 50)
Z	-2.20	-1.54	-1.53
p	.03	.12	.13
r	0.35	0.35	0.33

6.3.1.2. Task 2: Riding speed estimations

The riding speed estimations of one (older) participant were discarded because this participant only gave one estimation in one scenario and felt unable to judge the other scenarios. On average, the slow speed (12 km/h) was overestimated (M_{ON} = 12.5 ± 3.2; M_{OFF} = 12.9 ± 3.8), the medium speed (17.5 km/h) was underestimated (M_{ON} = 14.8 ± 3.8; M_{OFF} = 15.1 ± 3.1), and the high speed (21 km/h) was also underestimated (M_{ON} = 17.9 ± 4.1; M_{OFF} = 17.5 ± 3.5). Comparisons of the Δ-values between the 'ON' and 'OFF' conditions revealed no significant differences in any of the scenarios (see table 6.4).

Table 6.4: The Median, Interquartile Ranges, and Wilcoxon Signed Rank Test Results for the effects of the BLCS-system on the deviation between the actual and estimated speed of an approaching cyclist in the slow, medium, and fast speed conditions.

Condition	Slow	Medium	Fast
Δ-values	Median (*IQR*)	Median (*IQR*)	Median (*IQR*)
BLCS 'ON'	2 (1 – 3.875)	2.5 (1.5 – 5.25)	4 (2 – 6)
BLCS 'OFF'	2 (2 – 4)	2.5 (1.5 – 4.5)	3.75 (2 – 6)
Z	-1.83	-1.02	-0.69
p	.07	.31	.49
r	0.29	0.16	0.11

6.3.1.3. Subjective evaluations

Due to failure of the recording equipment, the interviews of three older participants could not be processed. Analyses were therefore based on 38 participants. The majority reported that the overall visibility of the BLCS was good (see figure 6.7). Even though the brake light appears to be the least visible, the majority still believed this was good.

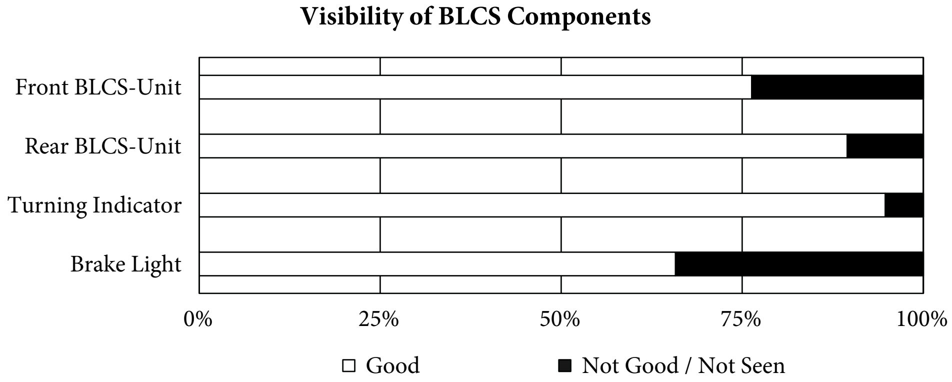

Figure 6.7: Participants' opinions (in percentages) about the visibility of BLCS components.

Content-wise, none of the participants evaluated the full BLCS-system negatively (figure 6.8). Half of all (positive) participants, however, indicated a clear preference for one or more components. Indeed, 37% (*n* = 14) suggested removing the speed indicator and 13% (*n* = 5) preferred the turning indicator only. This is also reflected in the evaluations of the individual components: the turning indicator received most positive evaluations, followed by the brake light, while the speed indicator received most negative feedback (see figure 6.8). Firstly, the turning indicator was praised for being an "attention grabber", safer on roundabouts, easily seen in the dark, very intuitive, and an opportunity for keeping both hands on the handlebars. Negative comments include believing that people have to get used to it, that some might not use it, or forget to use it. Secondly, even though half of the participants reported not having seen the brake light properly, a small majority was nevertheless positive about this component. Reasons for this were that the brake light attracts attention and provides an extra warning-signal. Contrary opinions suggested that it requires too much focus and was not clearly visible. Thirdly, most participants evaluated the speed indicator negatively because it was not sufficiently visible or understandable. Specifically, the differences between the signals seemed too small to distinguish different speeds and there was a perceived discrepancy between the true riding speed and the displayed BLCS-signals (e.g. the cyclist was expected to ride faster when the ring was half-way lit). Furthermore, for interpretation a vast amount of attention was required, it was considered to be distracting, and not intuitive. Some participants mentioned using other cues for estimating the speed of the BLCS-bicycle rider, such as the movement speed of the legs and pedals. Positive comments revealed that the speed indicator might be helpful for estimating the speed of electric bicycle riders, as some believe that they not only ride faster than conventional cyclists, but also faster than expected based on their pedal movement speed. Potential usefulness in low light conditions was also mentioned.

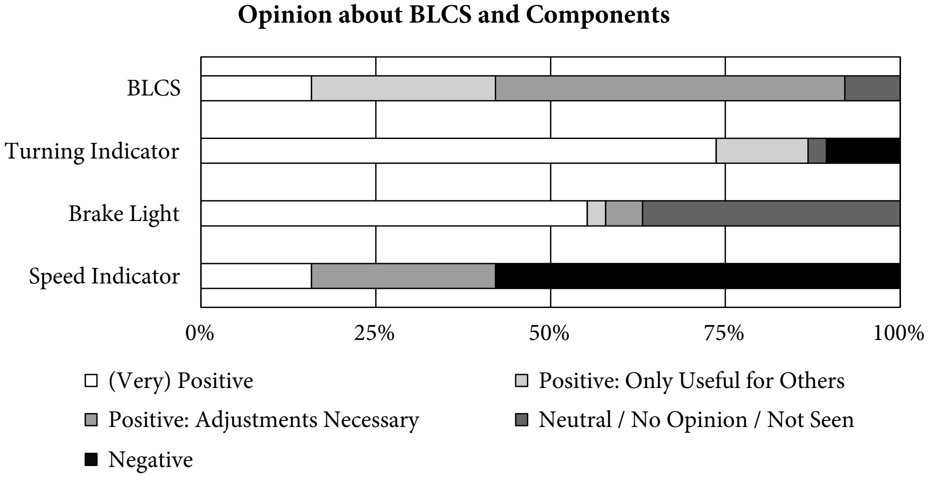

Figure 6.8: Participants' opinions (in percentages) about the BLCS-system as a whole and its individual components.

In total, 63% (*n* = 24) of all participants mentioned that they would like to use a BLCS for themselves and 87% (*n* = 33) would like others to use it. Furthermore, 87% (*n* = 33) believes that a BLCS could increase traffic safety, at times added with the remark that everybody should use it and that it is expected to require habituation. With regard to acceptance, all participants were positive about the BLCS in terms of usefulness and satisfaction (table 6.5). In addition, older cyclists expected the BLCS to be more useful and satisfying than younger cyclists.

Table 6.5: Median and Interquartile Ranges (IQR) for the Acceptance subscales (Usefulness & Satisfaction; scale range -2 to +2; Van der Laan, Heino & De Waard, 1997) and the results of the Wilcoxon ranked test for both age groups.

Group	Usefulness (Median, *IQR*)	Satisfying (Median, *IQR*)
Young	1 (0.8 - 1.6)	0.75 (0.5 - 1.5)
Old	1.8 (1.3 - 2.0)	1.5 (1.125 – 2.0)
Z	-2.75	-2.88
p	.006	.004
r	0.43	0.46

6.3.2. Study 2

6.3.2.1. First user-impressions

After using a BLCS-bicycle for one week, all participants (*n* = 12) mentioned that they used the BLCS turning indicator (nearly) always. One third (*n* = 4) also signalled with one arm if they were unsure that other road users saw the signals or because it was their routine, and 8% (*n* = 1) kept extending the arm in all situations. A majority (83%; *n* = 10) believed that the turning indicator was clearly visible and that other road users could estimate their intentions correctly.

Regarding balance, 58% (*n* = 7) mentioned that using the turning indicator did not influence their balance. Furthermore, half of the participants (*n* = 6) felt safer while signalling with the turning indicator. One participant (8%), however, felt unsafe because the turning indicator took too much effort and required habituation. Remarks stating that the turning indicator was mainly useful while cycling in the dark were given by 42% (*n* = 5). Nine participants (75%) would like to have the turning indicator on their own bicycle, although two of them (17%) would only like this after experiencing problems with extending their arm. However, 25% (*n* = 3) mentioned that they might feel overconfident while using the turning indicator because "*people will see me anyway*".

Technical feedback mostly concerned the remote-controller. Half of the participants (*n* = 6) stated that the turning indicator was easy to operate although wearing gloves, a rain poncho, or cycling over uneven surfaces could cause difficulties. Also, 50% (*n* = 6) suggested a different controller (e.g. separate controllers on the left and right-hand sides of the handlebars).

6.4. Discussion

The primary aim of this study was to evaluate the potential of a BLCS to explicitly show cyclists' turning intentions and riding speed to other road users. In Study 1, 21 older and 20 younger cyclists performed two tasks: (1) following and (2) estimating the speed of the test leader on a BLCS-bicycle, followed by an interview to gather subjective evaluations. In Study 2, twelve older cyclists used a BLCS-bicycle for one week to explore their first user-impressions.

6.4.1. Main findings

The first analyses revealed that older and younger cyclists maintain similar following-distances from a lead cyclist, regardless of presenting a BLCS. Cyclists did not approach a BLCS-bicycle more closely than a conventional bicycle, which means that the visibility of the BLCS-signals was sufficient from a 'normal' following-distance. This was also confirmed by the majority of participants. Furthermore, the BLCS-signals were evaluated as less mentally demanding for estimating the riding speed of a lead cyclist, compared to observing the same cyclist on a conventional bicycle. This finding could be important, because a decrease in mental workload is particularly beneficial in situations where it is difficult to gain an overview, for example at intersections (Dozza & Werneke, 2014; Westerhuis, Engbers, Dubbeldam, & De Waard, 2016). Such situations are, however, not limited to cycling behind other cyclists, and the second analyses revealed that the BLCS-signals did not assist participants with correctly estimating the riding speed of approaching cyclists. Indeed, many participants reported that they perceived a discrepancy between the observed speeds of the approaching cyclist and the displayed BLCS-signals: these were not clear or intuitive, explaining many of the negative subjective evaluations. Although some mentioned that BLCS speed information might be useful in faded lighting conditions, these findings indicate that the presented BLCS-signals displaying riding speed did not provide sufficient additional value compared to solely observing rider behaviour.

Despite the speed signal, the BLCS was evaluated as a useful and satisfying device mainly because of other components. Indeed, positive to very positive ratings were given about the brake light and the turning indicator, implying that these could be valuable features for (older) cyclists. Particular qualities such as intuitiveness and quickly attracting the attention of other road users seem useful and desired. Furthermore, the first user-impressions showed that the turning indicator was used by most participants and even though the majority did not report improvements in keeping balance, many would like to use it on their own bicycles. It should be kept in mind, however, that none of the participants of Study 2 suffered from balance problems. Taken together, the BLCS seems to meet only few of the wishes: it provides support with indicating direction and explicitly shows braking behaviour to other road users, but it does not provide suitable information to improve the estimation of a cyclist's riding speed.

It should be noted that in Study 1, many participants mentioned that it was generally difficult to estimate riding speeds with certainty, regardless of providing BLCS-signals. Because only riding speeds and the availability of BLCS-signals differed between scenarios and conditions, it seems likely that other cues are more distinctive or relied upon. As the researchers made sure that cadence was similar in all scenarios, it might be that differentiating riding speeds was too difficult with this specific cue made unavailable. Indeed, in line with the findings of Schleinitz et al. (2016) and Haustein and Møller (2016), it seems that cadence, or perceived effort investment, is predominantly used for estimating riding speed. Even though this could mean that the experimental manipulation was successful (i.e. keeping cadence constant in all scenarios), this also confirms that the BLCS did not provide usable information instead. However, because cadence is also not a sufficiently reliable cue for estimating riding speed (Dozza, Piccinini, & Werneke, 2016; Petzoldt, Schleinitz, Heilmann, & Gehlert, 2017), it may still be beneficial to develop alternative cues or signals to counteract riding speed misjudgements.

6.4.2. Limitations

The present research has some limitations. Firstly, the BLCS was a prototype and prototypes do not always work perfectly. For example, the brake light was not activated by enabling the brakes but only when the BLCS-bicycle was decelerating beyond a threshold. It could therefore be that the system was not yet triggered to show the brake light even if the test leader was braking, which might have influenced following-behaviour and visibility ratings. Secondly, the researchers tried to simulate a realistic traffic environment while performing a controlled experiment. This setting could have made participants more focussed than in a non-research setting, also because they did not have to react or make a manoeuvre. Specifically, in Task 2 participants stood still and could pay full attention to the approaching BLCS-cyclist. Real traffic situations, however, tend to be denser, more crowded, and require riding and monitoring simultaneously, making it more difficult to focus on one signal. Thirdly, Study 1 was only performed in stable weather with clear visibility conditions although in real life, these conditions differ. For example, evaluation could be different in faded light conditions because lights become more visible while other cues become less visible, which was also mentioned by several participants. Favourable visibility conditions were preferred because particularly older cyclists mainly cycle during the day and in pleasant weather conditions (Engbers et al., 2018a). Fourthly, the used BLCS-bicycles were all conventional bicycles even though misinterpretations of riding speeds seem to occur mainly with electric bicycles. Nevertheless, conventional bicycles were used because of availability reasons and their usability for demonstrating lower speed scenarios. Furthermore, effects of bicycle type on signal perception should be limited, because modern electric bicycles look similar to conventional bicycles (Dozza, Piccinini, & Werneke, 2016). Lastly, the researchers asked the participants in Study 1 with an electric bicycle to disable their electric support if possible. Even though none of these participants had any problems with this, in hindsight, this may have affected their cycling behaviour, particularly at low speeds.

Even though Study 1 was performed near a city and on a well-reachable location, the majority of older participants may have been relatively fit compared to the 'average' older cyclist. Because Study 1 mainly concerned perception, it is expected that the influence of physical fitness on the results of that study is limited. However, also because the sample of Study 2 was partly drawn from Study 1, it could be that the relative fitness of older participants influenced the results of Study 2. Particularly regarding balance, it may have been more informative to include cyclists with balance difficulties. For ethical and safety reasons, however, it was not possible to request people with profound difficulties to test a first prototype BLCS-bicycle in real traffic. Because Study 2 suggests that indicating direction with a BLCS does not influence balance (i.e. no increase, but also no *decrease* in balance), a next step might be to study a BLCS with cyclists who are afraid to lose balance or struggle with looking over their shoulder.

Future research could also focus on the consequences of using (components of) a BLCS in daily life. For example, it is unknown how other road users (e.g. car drivers or pedestrians) respond to such signals from a bicycle. Furthermore, it should be noted that safety effects might also be negative in real traffic. For example, if many BLCS-bicycles simultaneously convey numerous signals, these might lead to visual clutter and cognitive overload, which should be prevented.

6.5. Conclusions and implications for practice

Dedicated light signals displaying a cyclist's turning intentions and braking behaviour could facilitate other road users with anticipating their behaviour, because this information might otherwise be less explicitly visible. Furthermore, a turning indicator is appreciated by (older) cyclists and may have a positive effect on balance of older cyclists. Reliably estimating riding speed remains difficult regardless of presenting BLCS-signals. It may, however, still be beneficial to explore alternative options to counteract speed misjudgements.

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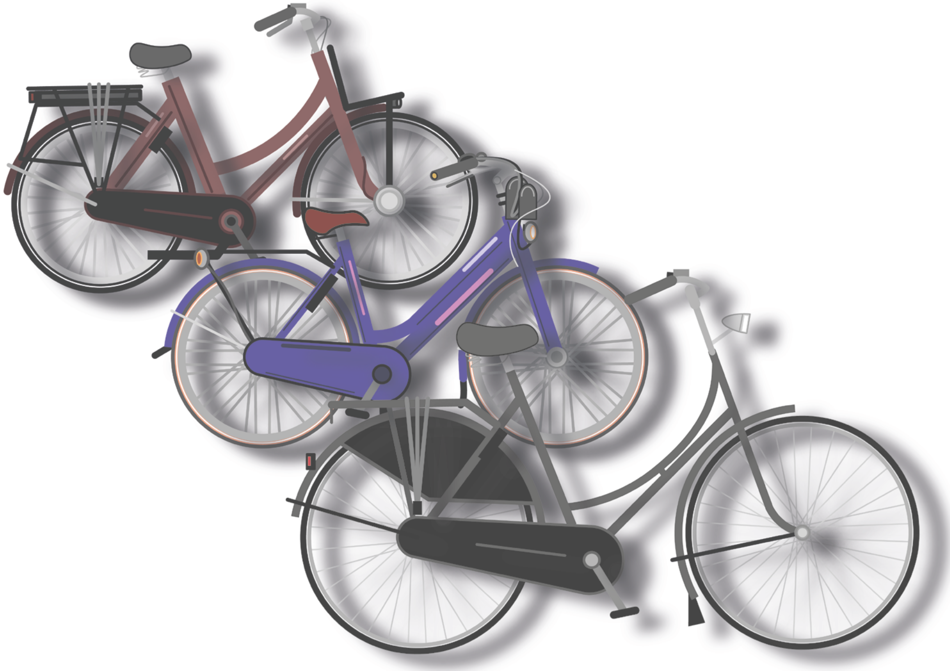
Declaration of interest statement

The authors have no conflict of interest to declare.

Chapter 7



General Discussion

7. General Discussion

7.1. Objectives

The first objective of this thesis was to identify difficulties that older cyclists face during their everyday cycling trips. For this reason, a naturalistic cycling study was performed in which 30 older cyclists could indicate any discomforts or problems with (parts of) the infrastructure that they experience. Reported difficulties and findings from the literature were used to generate interventions or modifications to support older cyclists and improve their safety in traffic. Interventions were either implemented in the infrastructure or on the bicycle and, for the second objective of this thesis, their effects on cycling behaviour were assessed in experimental studies.

7.2. Difficulties of older cyclists

7.2.1. Naturalistic cycling research method

Naturalistic studies are generally performed because these yield ecologically valid and relevant data (Hoc, 2001). However, because the gained knowledge is based on personal, predominantly location-specific information and opinions, it is meaningful to first consider the limitations of this research method and, in particular, the circumstances under which the data are acquired. Compared to other research methods, naturalistic cycling studies are very time consuming while the sample size is frequently limited (e.g. Gustafsson & Archer, 2013; Dozza & Werneke, 2014). For these reasons, it could be that the obtained insights may only be relevant for the cyclists in the sample and their personal environment. Furthermore, earlier research on participation of older people in studies that required physical exercise indicated that relatively many participants who are sufficiently fit and maintain a physically active lifestyle decide to volunteer (de Souto-Barreto, Ferrandez, & Saliba-Serre, 2013). It could therefore be that participation bias prevents generalisation to less fit and less active cyclists, and also to cyclists in other cities or locations. It is therefore useful to consider additional sources of research to determine whether the findings from naturalistic studies are also relevant on a national or international level. Examples of complemental sources may be post-crash questionnaires, statistics, in-depth (case) studies, and observational studies. In essence, *Chapter 2* aimed to provide pre-crash information with regard to a cyclist's behaviour and the circumstances that may contribute to a conflict or a crash, which is information that is in general difficult to acquire after a crash has already occurred (Johnson, Charlton, Oxley, & Newstead, 2010; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006).

7.2.2. Infrastructure-related difficulties

Based on *Chapter 2*, older cyclists reported experiencing problems due to obstacles, poor road surface conditions, sharp bends, slopes, or narrowness of cycle paths. Although in *Chapter 2* these factors did not lead to a crash, parts of these factors are similar to the ones that Boele-Vos et al. (2017) identified as frequently contributing to bicycle crashes of older cyclists in the Netherlands (see table 7.1). Furthermore, 18% of another sample of Dutch older cyclists reported in a post-crash survey that the surface of the road was a key factor for their crash, 14% collided with a kerbstone, and 8% collided with posts (Ormel, Klein Wolt, & Den Hertog, 2008). Also manoeuvres such as turning, ascending, and descending were reported (table 7.1). In *Chapter 2*, several of these manoeuvres were observed leading to cyclists accidentally entering the verge (i.e. while cycling through a sharp curve ($n = 2$), downhill ($n = 1$), or on a narrow path ($n = 1$)). These manoeuvres accounted for half of the occurrences in which cyclists entered the verge described in *Chapter 2*.

Table 7.1: An overview of infrastructure-related factors that are perceived as difficult and/or contribute to bicycle crashes, based on three studies. Similar categories are matched per row.

Naturalistic Cycling[1]	%	In-depth crash analyses[2]	%	Questionnaires[3]	%
Obstacles	37	Obstacles	17-20	Kerbstones	14
				Posts	8
Road Surface	30			Road Surface	18
Sharp Bends	17			Turning Right	11
				Turning Left	7
Slopes	17	Steep Slope	15-17	Descending	6
				Ascending	3
Limited Space	10	Narrow Facilities	29		
		Poor Quality Shoulder	7-10		
		Traffic Sign Missing	7-10		

1: Westerhuis & De Waard (2016; Chapter 2 of this thesis): Self-reported difficulties of cyclists ≥ 50 years ($N = 30$) with regard to the cycling infrastructure. The percentages represent the proportion of all participants that reported each difficulty.

2: Boele-Vos et al. (2017): Road factors that most frequently contributed to bicycle crashes of cyclists ≥ 50 years without high-speed motorized vehicle involvement ($N = 41$). The percentages represent the proportion of investigated crashes that were influenced by each factor.

3: Ormel et al. (2008): Most frequently self-reported infrastructure-related factors and/or circumstances that contributed to SBCs of participants ≥ 55 years (age-specific sample size not specified, total $N = 723$). The percentages represent the proportion of participants > 55 years that reported each factor contributing to their bicycle crash.

Although not specifically aimed at SBCs (Single-Bicycle Crashes) or older cyclists, it is also known from international naturalistic cycling studies that issues with the surface of the road are related to safety problems and strongly increase the risk for a critical event (Gustafsson & Archer, 2013; Dozza & Werneke, 2014; Werneke, Dozza, & Karlsson, 2015). These studies are therefore in line with the finding that the design of the infrastructure is important (Schepers, 2008; Schepers & Klein Wolt, 2012), although they state that the risk of a severe crash seems particularly high near intersections. Potential infrastructure-related reasons for this increase are an obstructed line of sight or collisions with stationary objects (Dozza & Werneke, 2014; Werneke, Dozza, & Karlsson, 2015). Poor road surface was mostly linked to SBCs, while the increased risk near intersections was mostly related to interactions with other road users.

7.2.3. Interactions and interaction-related difficulties

With regard to interactions, half of the observations in *Chapter 2* of cyclists entering the verge was related to an interaction with other cyclists or pedestrians. These interactions were changing course for an oncoming cyclist (n = 1), for an overtaking cyclist (n = 1), for pedestrians (n = 1), or while cycling with a companion (n = 1). Boele-Vos et al. (2017) found approximately the same proportion of interaction involvement: nearly half of the bicycle crashes they investigated were related to a responsive action due to the behaviour of another road user (table 7.2). However, the percentage of self-reported interactions in *Chapter 2* and Ormel et al. (2008) were considerably lower. These differences may be explained by the methods, sample sizes, or timing of the different studies. *Firstly,* the results of *Chapter 2* are based on participant-reported difficulties and not on officially reported bicycle crashes. Since difficulties or safety-critical events do not lead to crashes most of the time, it is expected that these are reported more often than crashes (Dozza & Werneke, 2014). *Secondly,* it may be important to realize that the main objective of *Chapter 2* was to gather information about infrastructure and this was explicitly instructed to the participants. Given the fact that some participants still reported difficult interactions, despite the (instructed) goal of the study being otherwise, may show that these interactions were of significant importance for them. Moreover, this could also mean that other participants did experience difficulties with interactions as well but did not report these because it would not fit the goal of the study. More older cyclists may therefore actually experience difficulties with interactions than the percentages reported in *Chapter 2* suggest. With regard to the studies by Ormel et al. (2008) and Boele-Vos et al. (2017), both were based on post-crash retrospective data of officially reported bicycle crashes. In Ormel et al. (2008), however, the details of these crashes were solely reported by the victims themselves and in Boele-Vos et al. (2017), an expert-team was mainly responsible for determining relevant factors. *Thirdly,* the total number of cyclists in the Netherlands has increased over the recent years (Harms & Kansen, 2018). One may assume that this also has led to an increase in interactions while cycling. Indeed, in 2016, cyclists of all ages reported the factor 'behaviour of another road user' more frequently as contributing to a bicycle crash than in 2008 (Ormel, Klein Wolt, & Den Hertog, 2008; VeiligheidNL/Rijkswaterstaat, 2017). Although the 2016 study does not provide specific numbers on older cyclists, this may indicate that the behaviour of other road users has become a more important factor for bicycle crashes over the years.

Table 7.2: An overview of interactions or interaction-related factors that are perceived as difficult and/or contribute to bicycle crashes, based on three studies. Similar categories are matched per row.

Naturalistic Cycling[1]	%	In-depth crash analyses[2]	%	Questionnaires[3]	%
Conflict or Near collision	23	Behaviour of another road user	46-49	Behaviour of another road user	14
Hit by another cyclist	3			Evaded another road user	12
Busy traffic	17				
Being overtaken	3			Overtaking	<1
		Distraction	12-27		

1: Westerhuis & De Waard (2016; Chapter 2 of this thesis): Self-reported difficulties of cyclists ≥ 50 years (N = 30) with regard to the cycling infrastructure. The percentages represent the proportion of all participants that reported each difficulty.

2: Boele-Vos et al. (2017): Road factors that most frequently contributed to bicycle crashes of cyclists ≥ 50 years without high-speed motorized vehicle involvement (N = 41). The percentages represent the proportion of investigated crashes that were influenced by each factor.

3: Ormel et al. (2008): Most frequently self-reported infrastructure-related factors and/or circumstances that contributed to SBCs of participants ≥ 55 years (age-specific sample size not specified, total N = 723). The percentages represent the proportion of participants > 55 years that reported each factor contributing to their bicycle crash.

International naturalistic cycling studies also indicate that interactions, particularly near intersections, may lead to an increased risk for bicycle crashes (Johnson, Charlton, Oxley, & Newstead, 2010; Gustafsson & Archer, 2013; Dozza & Werneke, 2014; Dozza, Piccinini, & Werneke, 2016). Insufficient visibility of cyclists and incorrect expectations that other road users have about their behaviour seem to be important factors. For example, car drivers might not expect that cyclists are near and unintentionally cut their road while turning, or leave little room while overtaking (Johnson, Charlton, Oxley, & Newstead, 2010). Dozza and Werneke (2014) found that cycling on intersections generally increases the likelihood of a safety critical event, especially if there is visual occlusion. A possible explanation is that some road users may not pay sufficient attention to cyclists and could have incorrect expectations about whether to expect them. In a follow-up study, Dozza, Piccinini, and Werneke (2016) found that the risk of electric bicycle riders may even be higher compared to conventional cyclists. They argue that, for other road users, it may be difficult to recognize whether a cyclist is riding an electric bicycle. In turn, this could hamper estimating the speed at which they approach an intersection, because their riding speed may be higher than the pedal-rotation frequency suggests (Dozza, Piccinini, & Werneke, 2016; Petzoldt, Schleinitz, Heilmann, & Gehlert, 2017).

Although these international naturalistic cycling studies did not particularly concern SBCs of older cyclists, their findings do contain similarities with the results of interviews with 27 older cyclists (≥ 60 years) from the Netherlands (Westerhuis, Engbers, Dubbeldam, & De Waard, 2016). From these interviews, it was concluded that unexpected behaviours of other road users and uncertainty about their intentions are problems that older cyclists encounter while interacting in daily traffic. Furthermore, the majority of the study sample (85%; n = 23) mentioned that most interaction-related difficulties occur on intersections. Specific interactions such as being overtaken or cut in unexpectedly were mentioned, but also rule infringements by other road users such as not watching out, ignoring traffic rules, and not indicating direction seem to cause difficulties while cycling (Westerhuis, Engbers, Dubbeldam, & De Waard, 2016).

Stretching an arm into the intended direction of travel is the official way of explicitly indicating directions for cyclists, which is an action that is also easily perceived and interpreted by other road users (Walker, 2005). However, observations on an intersection in the city of Groningen revealed that the majority of cyclists who turned left or right did not indicate direction explicitly at all (Viersma, 2018). As a potential alternative, earlier research indicated that it may be possible to predict cycling intentions implicitly by taking a cyclist's appearance into account or by looking at specific cues such as position on the road, head movements, or speed (Walker, 2007; Hemeren et al., 2014). The results of *Chapter 3,* however, indicate that from a cyclist's perspective, it is very difficult to accurately predict the upcoming direction that a cyclist will choose by just observing behaviour other than indicating with the arm. Although some behaviours might increase the chance of performing a correct prediction (e.g. head movements and observed riding speed), the results suggest that cyclists from all age groups struggle with predicting correctly. For this reason, it should be useful to provide older cyclists, but also other road users, with information that may assist with detecting cyclists and correctly assessing their intentions.

7.2.4. Objective 1

With regard to the first objective of this thesis, evidence was found that important infrastructure-related factors that contribute to SBCs of older cyclists are obstacles, road surface issues, sharp curves, level differences, unforgiving shoulders, visual occlusions, and limited space. In terms of interaction-related difficulties, crashes may originate from not timely detecting other road users, being surprised by an (abrupt) action of another road user, or forming incorrect expectations about another road user. Although the abovementioned findings suggest that there is a strict separation between infrastructural and interaction-related factors, it is meaningful to realise that in practice, a crash scenario is often determined by a combination of these factors. For example, a narrow cycle path may not lead to problems per se, but if a cyclist overtakes another cyclist and the narrow path limits the available space to make room for this interaction, a cyclist may enter the verge and fall (Boele-Vos et al., 2017). However, for application purposes, it may be helpful to provide this distinction in order to provide companies and authorities with targeted interventions to potentially implement.

7.3. Interventions

The following paragraphs provide an overview of potential measures to increase the safety of older cyclists. Although the focus of these interventions is on older cyclists, it may also be that these measures increase the safety of cyclists in general. The list of potential measures was not only developed in our project studies (Westerhuis & De Waard, 2014b; Westerhuis & De Waard, 2016; Westerhuis, Engbers, Dubbeldam, & De Waard, 2016; Westerhuis & De Waard, 2017), but also stem from the literature (Johnson, Charlton, Oxley, & Newstead, 2010; Schepers & Den Brinker, 2011; Schepers & Klein Wolt, 2012; Gustafsson & Archer, 2013; Schepers, 2013; Davidse, Van Duijvenvoorde, Boele, Duivenvoorden, & Louwerse, 2014; Davidse et al., 2014; Dozza & Werneke, 2014; Werneke, Dozza, & Karlsson, 2015; Dozza, Piccinini, & Werneke, 2016; Boele-Vos et al., 2017; Petzoldt, Schleinitz, Heilmann, & Gehlert, 2017).

7.3.1. Infrastructural interventions

Based on the findings from *Chapter 2* as well as from Davidse, Van Duijvenvoorde, Boele, Duivenvoorden, and Louwerse (2014), Davidse et al. (2014), and Boele-Vos et al. (2017), it is concluded that interventions in the infrastructure may for example be aimed at preventing crashes by increasing the visibility of a road and its users, offering opportunities to correct for errors, or limiting the (physical) impact of crashes. Advantages of infrastructural interventions are that these potentially affect a large number of cyclists simultaneously and that specific risk-locations may benefit from a targeted approach. However, it should also be noted that infrastructural interventions in general are financially expensive to construct and their effects are limited to one location. Examples of possible infrastructural interventions are the following (in no particular order):

- Implement and maintain surfaces that provide sufficient grip for cycling.
- Periodically remove sand, stones, leaves, and other forms of clutter from the surface.
- Experiment with surface types that limit an injury after a fall.
- Provide sufficient space: use wide cycle paths and prevent narrow, sharp curves. Also provide sufficient space for cycling with a companion.
- Prevent or limit the number of slopes and level differences, especially on

locations where cyclists have to regularly mount or dismount their bicycles.
- Make sure that critical infrastructure can be overseen early and easily.
- Provide clear marking to guide the trajectory of cyclists.
- Ensure that the cycle path's main surface is level with the shoulder.
- Provide firm, forgiving shoulder surfaces that are obstacle-free.
- Remove or limit the number of kerbstones or apply slanted kerbstones.
- Remove or limit the number of objects such as posts or bollards, increase the conspicuousness of objects that are absolutely necessary, or use objects that form no threat for cyclists.

In the project "The Forgiving Cycle Path", a selection of interventions was conceptualized and a sub-selection was implemented on test-locations in the Netherlands (The Forgiving Cycle Path, 2018). These interventions were aimed on preventing verge-related crashes of older cyclists and consisted of edge lines, slanted kerbstones, shoulder strips, edge strips, and virtual objects. The behavioural effects and safety implications of these interventions are discussed in the following paragraphs and summarized in tables 7.3, 7.4, and 7.5.

7.3.2. Edge lines and slanted kerbstones

The main goal of edge lines is to increase the visibility of a road's edge in order to prevent run-off crashes (Steyvers & De Waard, 2000). The white slanted kerbstones provide, in addition, a gradual transition between two differently levelled surfaces (e.g. between a cycle path and the pavement) and should prevent cyclists from falling due to hitting a kerbstone. Even though it is known that car drivers increase their distance from a road's edge when edge lines are applied (e.g. Steyvers & De Waard, 2000; Mecheri, Rosey, & Lobjois, 2017), the studies in *Chapter 5* revealed that this may not be true for all cyclists or on all types of cycle paths (see table 7.3). Moreover, the majority of the observed edge-lined locations (i.e. Experiment 2) did not reveal any effects on cycling behaviour at all, which was inconsistent with the findings from Experiment 1. An explanation for these inconsistencies may be found in additional location-related factors.

From a methodological perspective, care was taken that all measurements were performed on relatively straight cycle path sections with similar lay-outs and surroundings to isolate effects of the interventions. In practice, however, locations always differ at least to some degree and, in hindsight, the edge-lined and slanted kerbstones locations in Experiment 1 may have contained some critical differences from the control location. In particular the presence of objects near the cycle path (i.e. a bus stop and several lamp posts) may have restricted the view or resulted in participants increasing their distance to avoid hitting these objects. Furthermore, it was observed that several participants cut the curve just before the start of the edge-lined and slanted kerbstones sections. This could mean that some of them applied an anticipatory steering strategy by cycling more towards the centre of the path, thus increasing their lateral position as well (Vansteenkiste, Van Hamme, Veelaert, Philippaerts, & Cardon, 2014). Therefore, cycling behaviour near edge lines was additionally observed at locations where the abovementioned factors were not present, the surroundings were more similar, the observed locations were longer, and more variants were available (i.e. Experiment 2). These measurements revealed hardly any effects of the intervention, making it more likely that the confounding factors in Experiment 1 indeed affected the measurements there. For this reason, it is concluded that there is insufficient evidence that edge lines generally affect lateral position and swerving behaviour on well-visible, straight cycle path sections. In line with Experiment 1, however, it cannot be ruled out that edge lines or white slanted kerbstones might affect cycling behaviour at locations that differ from the observed locations.

Even though interviews with the cyclists in Experiment 2 revealed that the edge lines were conspicuous, they do not affect cycling behaviour the same way as driving behaviour (Steyvers & De Waard, 2000; Mecheri, Rosey, & Lobjois, 2017). It should be acknowledged, however, that cycling is also not the same as car driving. Not only do cyclists maintain lower speeds than car drivers, they also have a greater lower visual field because this is not obstructed by a vehicle (Schepers & den Brinker, 2011). This additional information from the visual periphery might indicate that edge lines are less critical for cyclists than for car drivers on straight roads or paths. Indeed, because the current observations were limited to relatively straight sections with clear lines of sight, it could be that edge lines do provide visual guidance while cycling through curved sections where the course of the path is less predictable, or when the contrast between the cycle path and the verge is lower than in the observed locations (Schepers & den Brinker, 2011). Given the finding that many verge-related crashes occur in curves (Schepers & den Brinker, 2011), it should be useful to investigate whether edge lines provide safety benefits at such sections. Furthermore, the current sample did not contain cyclists with severe visual impairments and according to Jelijs, Heutink, De Waard, Brookhuis, & Melis-Dankers (2019), road markings are an important factor for visually impaired cyclists to cycle safely. As visual impairments are also related to age (OECD, 2001; SWOV, 2015), future research may address the effects of edge lines on cycling behaviour of this specific group.

7.3.3. Shoulder strips and edge strips

Further results of the study reported in *Chapter 5* show that both the edge strips and the shoulder strips do significantly affect the lateral position of older cyclists, albeit not in the same direction (see table 7.3). Although with edge strips, the absolute increase in distance from the verge seems small (8 cm), it is a 10% increase compared to the average lateral position in the control condition. Analogously, this should mean that cyclists have 10% more space to correct for a mistake before entering the verge. In the shoulder strips conditions, older cyclists were found to decrease their average distance to the edge of the main cycle path with 11-15 cm, however (table 7.3). Even though this may seem as an effect that reduces the available space, the additional 50 cm of space provided by the shoulder strips results in 35-39 cm extra space to safely return to the cycle path. Indeed, the average distance to the soft verge increases from 73 cm in the control condition to 108-112 cm in the shoulder strip conditions. In addition, participants rode significantly slower on both intervention locations and, therefore, both seem to not only increase the distance of older cyclists to the verge, but also increase the available time to perform corrections because of a lowered cycling speed. This means that the distance both in time as well as in space is increased between the cyclist and the verge, implying increased safety margins compared to the control condition (Näätänen & Summala, 1976, cited in Kulmala & Rämä, 2013).

The lateral position effects in the edge and shoulder strips interventions may be explained by several mechanisms (see table 7.4 and 7.5). First, the edges of the cycle paths are made more visible, although this was also expected with the edge lines and slanted kerbstones interventions. For this reason, edge and shoulder strips may provide increased visual guidance for cyclists, probably more than the edge lines and slanted kerbstones because the strips cover larger areas and offer more visual input. With regard to the edge strips, the results suggest that the visual reduction of a cycle path's width drifts cyclists more towards the centre of the path, similar to effects found in car driving (Steyvers & De Waard, 2000). With regard to the shoulder strips, the found effects are also in line with increasing the size of shoulders for car drivers (Bella, 2013; Mecheri, Rosey, & Lobjois, 2017) and it may be important that there is a well-visible *clear zone* available without obstacles or objects (Fitzpatrick, Samuel, & Knodler Jr., 2016). The increased visibility of the cycle path's edge does not seem to be the most important factor for the effects of shoulder strips, however, because the green artificial grass strip also yielded similar effects as the other variants while the contrast and colour did not differ much from the verge. It is therefore more likely that the explicit availability of a *clear zone* is more important than the increased visibility of the cycle path's edge (Fitzpatrick, Samuel, & Knodler Jr., 2016).

The results further show that, in practice, edge strips are more suitable for wide cycle paths (e.g. ≥ 3m) while shoulder strips may be implemented on cycle paths that are narrower. As edge strips seem to divert cyclists more towards the centre of the path, it is important that there is sufficient space to prevent conflicts with oncoming cyclists and that cycling with a companion is still possible safely (Westerhuis & De Waard, 2016). If this space in the centre is not available, shoulder strips may be implemented because they divert cyclists more towards the edge of the path, while increasing the total distance to the verge at the same time. This also means, however, that there needs to be sufficient space to construct the shoulder strips which could be problematic particularly in dense, urban areas.

In general, even though edge strips and shoulder strips are financially the most expensive of the tested interventions, they most likely increase the safety of older cyclists by offering a well-visible, obstacle-free zone on the edge or next to a cycle path (see table 7.4 and 7.5). Furthermore, the provision of visual guidance may also contribute to forming an overview of the course of a cycle path. In addition, shoulder strips in particular should assist older cyclists with attention because they provide a warning signal by means of audio and vibrotactile sensations should they (unintentionally) drift off the cycle path. Lastly, because shoulder and edge strips provide increased safety margins to safely correct for errors (i.e. more time, space, and grip near the edge), there is more time and less need to react strongly and abruptly. This may be particularly helpful for older cyclists with decreased reaction speed and/or physical strength.

7.3.4. Virtual objects

The last infrastructural measure to discuss is the most experimental one: virtual objects based on optical illusions. It was hypothesized that cyclists would increase their distance from these virtual objects in order to prevent a collision, even though there were no physical objects to collide with. The experiments reported in *Chapter* 4 indicate, however, that these objects were not effective as visual stimuli to affect cycling behaviour and therefore do not contribute to cycling safety.

The reason for the absence of effects is uncertain, although interviews with older cyclists revealed that the visibility of the virtual objects may have been insufficient and caused confusion. Most participants reported not having seen the virtual objects, but the cyclists who did report seeing them, were found to be cycling closer to the edge of the cycle path than cyclists who did not report this. It is unclear, however, whether the closer lateral position to the edge of the cycle path was an effect of the virtual objects, or that the visual detection of the virtual objects was an effect of cycling closer to the cycle path's edge. The first option may negatively affect cycling safety because this could mean that the virtual objects lured some cyclists to the edge of a cycle path, which is the opposite of what the intervention aimed to achieve. However, if the second mechanism is true, this could mean that the virtual objects were rather inconspicuous and perhaps designed too conservatively to be seen and function properly.

Because there is little research available on the effects of similar optical illusions on cycling behaviour, the objects were designed to be relatively unobtrusive to ensure that cyclists would not be startled by them. It would be unethical to implement an experimental intervention that could shock naïve cyclists riding towards their daily destinations. As a consequence, however, this could also mean that the visibility of the virtual objects was too insufficient to reach the threshold of detection. It may therefore be a possibility to increase the contrast with the cycle path's surface to verify whether this does yield effects. Another option would be to create virtual objects in more recognisable forms such as painted manhole covers or cracks in the surface, which are conditions that may affect cycling behaviour more directly because they should be recognisable as direct threats (Westerhuis & De Waard, 2016). However, given the large uncertainties that the current virtual objects serve the purpose of increasing cycling safety, for now it is concluded that these are not an effective intervention to implement in the cycling infrastructure.

7.3.5. On-bicycle interventions

On a bicycle, it is possible to implement interventions capable of assisting the rider specifically and/or other road users that interact with the rider. A major advantage of this approach is that these interventions, as opposed to infrastructural interventions, are not limited to one location and contribute to the rider's safety and comfort throughout entire cycling journeys. However, this also means that effects are only exclusive for the rider and other road users nearby. Examples of on-bicycle interventions are mentioned below, again in no particular order, based on the same sources as mentioned in paragraph 7.3:

- Increase the visibility of cyclists to emphasize their presence.
- Provide means for explicit communication of cycling behaviour in order to facilitate forming correct expectations (e.g. about cyclists' speed and/or intentions).
- Prevent balance loss due to bicycle characteristics, defects, or specific manoeuvres.
- Facilitate the detection of objects and/or warn the cyclist accordingly.
- Make sure that the bicycle properly fits the rider.
- Equip bicycles with airbags.

7.3.6. Bicycle Light Communication System

The investigated on-bicycle intervention was the Bicycle Light Communication System (BLCS; *Chapter 6*) from the CRUISer project (CRUISer, n.d.). The results indicate that, although the idea of providing explicit information about riding speed was generally welcomed and appreciated by older cyclists, the presented signals of the BLCS were too unclear to provide more speed-related information than a conventional bicycle already does. Instead, many participants reported looking at the pedal rotation speed (i.e. cadence) of the BLCS-cyclist to estimate his or her speed. However, because cadence is also not a reliable cue for this purpose (Schleinitz, Petzoldt, Krems, & Gehlert, 2016; Haustein & Møller, 2016), it should nonetheless still be useful to search for other, perhaps more familiar and intuitive signals to provide information about riding speed, particularly for electric bicycle riders. For example, light intensity could be a useful mechanism as this is analogous to the functioning of a classical dynamo to power bicycle lights. As such, an increase in cycling speed may be indicated by an increase in luminance. Other options may be considered as well, such as displaying light signals on a helmet (e.g. Lumos Helmet, 2019) or using numerical values to communicate riding speed (e.g. Mykle Systems Labs, 2007). However, it is also important to prevent introducing too many new signals in a traffic environment, as there is a risk that these may actually increase visual distraction and mental workload which could, in a negative scenario, decrease traffic safety (Verwey, 1990, cited in De Waard, 1996).

The results concerning the direction indicator and brake lights of the BLCS support the finding that familiarity and intuitiveness are indeed important prerequisites for light signal comprehensibility and acceptance. Since these signals are already implemented on countless other (mainly motorised) vehicles, they seem useful for a bicycle as well. Indeed, the majority of older cyclists rated the direction indicator as useful and intuitive and would like to install this on their own bicycles in the near future, if possible. A smaller proportion of cyclists, although still the majority, was also positive about the brake light, which indicated that these functions of the BLCS are most promising for implementation in the future (see table 7.3).

In general, a BLCS may assist older cyclists by contributing to the overall visibility of themselves and other cyclists around them (table 7.4). Furthermore, a BLCS may also assist with attention, memory, and reaction speed because a change in direction (and potentially speed, if displayed with an intuitive signal) of a nearby cyclist is communicated conspicuously and early, preferably some time before this cyclist acts (table 7.5). This may grant an (older) cyclist more time to anticipate or prepare a responsive action and, therefore, reduces the need for fast reaction speeds. Furthermore, because a BLCS keeps sending signals about the turning intentions of other cyclists repeatedly, these may be used to refresh memory in case there are many road users to consider simultaneously. As a consequence, however, it is required that other cyclists actually use a BLCS because the signals would otherwise simply not be visible.

A potential BLCS safety benefit that is not dependent on the use of the system by other cyclists may be improved balance while indicating direction on the bicycle. Although the results from *Chapter 6* did not indicate that a BLCS improved balance of the older cyclists from the sample, cyclists with profound difficulties regarding balance or motor coordination may nonetheless benefit from a dedicated controller on the handlebars. Because the participants were relatively 'fit' older cyclists with sufficient physical capabilities, future research should indicate whether (older) cyclists with physical impairments do benefit from an increase in balance and motor control when indicating direction with a BLCS, compared to using their arms.

7.3.7. Objective 2

The second objective of this thesis was to assess to what extent infrastructural and on-bicycle interventions are able to improve the safety of older cyclists. It is concluded that the tested infrastructural interventions were more successful than the on-bicycle interventions as they provide most safety improvements by means of visual guidance and increased safety margins. The most promising interventions are the edge and shoulder strips interventions: the first increases the safety margins towards the path's edge and the second, in addition, also increases the safety margins towards oncoming cyclists. Furthermore, it should be noted that the effects of most infrastructural interventions did not differ between conventional or electric bicycle riders. In particular, one may expect that e-bicycle riders generally ride faster than conventional bicycle riders (see e.g. Dozza, Piccinini, & Werneke, 2016), but this effect was not found in the naturalistic cycling study in *Chapter 2*. Moreover, hardly none of the experimental measurements in this thesis revealed significant differences between conventional and electric bicycle riders, which also means that the effects of the interventions are comparable and should, therefore, be suitable for both types of bicycles and their riders.

7.4. Strengths

A major strength of this research is that the majority of studies took place under realistic cycling circumstances. Difficulties in cycling were assessed by means of the naturalistic cycling method and the effects of interventions were measured on real cycling locations while participants were cycling on their own bicycles. Moreover, most of the observed intervention locations could be matched to a highly similar control location. The only exception regarding a naturalistic research-setting was the study described in *Chapter 3*. The videos that were used in this study, however, were gathered in naturalistic circumstances: the camera position on the front of the bicycle enabled recording from a viewpoint similar to that of a real cyclist. Furthermore, footage used was of cyclists who did not know that they were filmed to ensure natural behaviour and no specific cyclists were selected for the survey-items. Also, no selection was applied with regard to behavioural cues that were visible in the videos.

To the best of the author's knowledge, this thesis is the first to apply a measurement technique with small GPS-action cameras on participants' own bicycles of which the recorded videos, by means of calibrating real-world distances before each individual bicycle ride, were used to measure lateral position, swerving, and speed afterwards. This method has proven to be a well-balanced mixture of video-based observations and measurement accuracy. As during the experiments, the researchers made sure that the camera could hardly move after it was calibrated with the measurement tool, this method enabled measuring the lateral position and speed with relatively high accuracy even when using a participant's own bicycle.

Table 7.3: Behavioural effects, subjective ratings, aims, usability, and relative financial costs of the investigated interventions.

Intervention	Behavioural Effects[a]			Subjective Ratings	Main Purpose	Immediately Usable	Financial Costs[e]
	LP[b]	SDLP	Speed	% Positive			
1. Infrastructure							
a. Edge Lines	x / ↑[c]	x / ↑[c]	x / ↑ / ↓[c]	44% - 92%[d]	Error Prevention	Yes	Low
b. Slanted Kerbstones	↑	↑	↓	N.A.	Error Prevention	Yes	Medium
c. Shoulder Strips	↓	x	↓	36% - 40%[d]	Error Recovery	Yes	High
d. Edge Strips	↑	x	↓	87%	Error Recovery	Yes	High
f. Virtual Objects	x	x	x / ↑[c]	0%	Error Prevention	No	Medium
2. On-Bicycle BLCS							
a. Turning Indicators	N.A.	N.A.	N.A.	74%	Error Prevention	Yes	Low
b. Brake Light	x	x	x	55%	Error Prevention	Yes	Low
c. Speed Indicator	x	x	x	16%	Error Prevention	No	Low
d. Signal Light	N.A.	N.A.	N.A.	N.A.	Error Prevention	N.A.	Low

Abbreviations: BLCS = Bicycle Light Communication System; LP = Lateral Position; N.A. = Not Available (not measured or assessed in this thesis); SDLP = Standard Deviation of the Lateral Position (amount of swerving).

[a] *: Statistically significant increase (↑) or decrease (↓) compared to the control condition;* x *= no effect.*

[b] *: Increased (↑) LP = further from edge of the cycle path; Decreased (↓) LP = closer to edge of the cycle path.*

[c] *: Conflicting findings over different versions of the intervention.*

[d] *: Range over different versions of the intervention.*

[e] *: Relative financial costs between interventions.*

Table 7.4: An overview of the investigated interventions' potential safety improvements for older cyclists.

Intervention	Improved Balance / No Decreased Control	Improved Road Course Visibility	Increased Safety Margins	Improved Grip / Reduced Skidding	Improved Visibility of the Cyclist	Rotating the Neck / Looking over the Shoulder [1]	Not Having to Use the Arm	Increased Situation Awareness	Improved Intention Prediction
1. Infrastructure									
a. Edge Lines	No	Yes	No	No	No	No	No	Indirectly [d]	No
b. Slanted Kerbstones	No	Yes	No	No	No	No	No	Indirectly [d]	No
c. Shoulder Strips	No [a]	Yes [b]	Yes	Yes [c]	No	No	No	Indirectly [d]	No
d. Edge Strips	No [a]	Yes	Yes	No	No	No	No	Indirectly [d]	No
f. Virtual Objects	No	No	No	No	No	No	No	No	No
2. On-Bicycle BLCS									
a. Turning Indicator	No	No	No	No	Yes	No	Yes	Yes	Yes
b. Brake Light	No	No	No	No	Yes	No	No	Yes	Yes
c. Speed Indicator	No	No	No	No	Yes	No	No	Possibly [e]	Possibly [e]

Abbreviations: BLCS = Bicycle Light Communication System.

[1] : *Provides support or reduces the need to rotate the neck or look over the shoulder.*

[a] : *Keeping balance or control may be supported indirectly by means of preventing a cyclist from entering the verge.*

[b] : *With the exception of green coloured artificial grass strips.*

[c] : *In the shoulder.*

[d] : *Because the course of the road should be better visible, compared to no delineation, with the exception of green coloured artificial grass strips.*

[e] : *If provided with a signal that is easily interpretable.*

Table 7.5: Potential domains through which the investigated interventions are perceived and/or provide support for older cyclists.

Intervention / Assists with	Vision	Hearing	Attention	Memory	Motor Coordination	Reaction & Motor Speed	Muscle Stiffness	Muscle Strength
1. Infrastructure								
a. Edge Lines	+	-	-	-	-	-	-	-
b. Slanted Kerbstones	+	-	-	-	-	-	-	+/-
c. Shoulder Strips	+	+/-	+/-	-	-	+	-	+/-
d. Edge Strips	+	+/-	+/-	-	-	+	-	-
f. Virtual Objects	+/-	-	-	-	-	+	-	-
2. On-Bicycle BLCS								
a. Turning Indicators	+	-	+	+	+	+	-	-
b. Brake Light	+	-	+	-	-	+	-	-
c. Speed Indicator	+	-	+	-	-	+	-	-
d. Signal Light	+	-	+	-	-	+	-	-

Abbreviations: BLCS = Bicycle Light Communication System.

+ : *The intervention provides support and/or is fully perceived through this domain.*

+/- : *The intervention provides indirect support and/or is partly perceived through this domain.*

- : *The intervention does not provide support and/or is not perceived through this domain.*

7.5. Limitations and suggestions for future research

Many of the investigated interventions were new and therefore the long-term effects of these are still unknown. Future research should indicate whether the interventions actually decrease the amounts of SBCs over time. Indeed, dedicated studies with regard to crash statistics at intervention locations should be performed, preferably also including SBCs that do not lead to hospitalization. Furthermore, it should be investigated whether cyclists are indeed supported by the interventions during a critical event, interaction, or while being distracted (e.g. while cycling with a companion). For this reason, additional observations of passing cyclists, for example on more crowded cycle paths, should be performed to confirm whether the interventions indeed contribute to preventing a SBC after a critical event, sudden manoeuvre, or any other situation potentially leading to a SBC.

Even though in *Chapter 3* naturalistic video footage from a cyclist's viewpoint was used, the test situation in which the participants gave their predication was nonetheless artificial (i.e. behind a computer screen). Participants may therefore not have been able to see all cues that they would normally see when cycling in the real world, which could have influenced the results. For this reason, it may be feasible to present video stimuli by means of 360° videos on VR-headsets. This approach may have major advantages compared to observing smaller video fragments from a fixed viewpoint because VR-headsets are able to approximate a larger field-of-view and may give participants the opportunity to move their head and look around in 360°. This way, participants have more options to apply a looking strategy that approximates their looking strategy while cycling through real traffic.

Even though many video-based measurements that were carried out in this thesis were supported by semi-automated motion tracking algorithms (Charmant, 2016), the majority of on-bicycle measurements were still performed by hand because of software and/or video limitations. This procedure is very time consuming and therefore, future research should address additional means of automated measurement-algorithms to increase the efficiency of this type of research. This way, video-based naturalistic and experimental studies could be performed in less time while measurement accuracy may be further increased.

7.6. Conclusions

Older cyclists experience infrastructure-related difficulties due to obstacles, sharp curves, level differences, road surface issues, and limited space. Some of them were found to unintentionally enter the verge during regular everyday cycling trips. For this reason, a possibility to reduce the number of SBCs of older cyclists is by adjusting the infrastructure. Several interventions designed to decrease the risk on verge-related crashes were investigated, and the results show that in particular shoulder strips and edge strips are effective in increasing the safety margins of older cyclists.

Interaction-related crashes may occur due to being unaware of the presence of other road users or being surprised by unexpected actions (e.g. turning intentions and riding speed). In order to support older cyclists with explicitly indicating direction and displaying riding speed, the effects of a Bicycle Light Communications System (BLCS) were investigated. The results show that light signals displaying turning intentions and braking manoeuvres are useful for older cyclists and suitable for practice, while the signals displaying riding speed were not usable.

Taken together, this thesis provides not only older cyclists, but also (local) governments, engineers, and spatial planning professionals with specific suggestions for interventions in the infrastructure or on a bicycle, and which effects on cycling behaviour and traffic safety may or may not be expected after implementation. With this information, this thesis contributes to the overall improvement of the safety of older cyclists.

Summary

English
Summary

Summary

In the Netherlands, people of nearly all ages cycle frequently and for many it is an important mode of daily transportation. However, cyclists are vulnerable road users and cycling in traffic is therefore not without risks. Particularly older cyclists have a high risk on sustaining severe injuries due to Single-Bicycle Crashes (SBCs): crashes in which no other road user is involved. Since cycling generally benefits healthy ageing, it is important that older people can cycle safely for as long as possible and that such crashes are prevented. For this reason, the main objectives of this thesis were the following:

Objective 1: The identification of elements in the infrastructure and interactions with other road users that may lead to problems and increased crash risk for older cyclists.

Objective 2: The assessment of the effectiveness of interventions aimed at increasing the safety of older cyclists.

Chapter 1 not only emphasizes the purpose, usefulness, and advantages of cycling for older people, but also describes risks and examples of frequent SBCs and contributing factors according to the literature. Earlier research states that the risk older cyclists run may be explained both by physical vulnerability and age-related decline in motor and cognitive abilities. For example, difficulties with motor coordination and keeping balance may explain SBCs such as falling while getting on or off the bicycle, or while riding at low speeds. Furthermore, collisions with obstacles or falls due to entering the verge may stem from problems with vision, attention, or psychomotor reaction speed. Most data on SBCs of older cyclists originate from post-crash retrospective studies of officially reported SBCs, but the majority of SBCs are underreported in the overall bicycle crash statistics. For this reason, naturalistic cycling data of 30 Dutch older cyclists were collected in **Chapter 2**. These data were used to assess which elements in the cycling infrastructure may lead to problems for older cyclists, and to explore potential pre-crash events and behaviour that might lead to SBCs. The findings were in line with the literature and confirm that obstacles, cycle path surface irregularities (e.g. holes, cracks), sharp curves, slopes, and restricted space may cause difficulties for older cyclists. Furthermore, observations revealed that some older cyclists may accidentally enter the verge unintentionally during an everyday bicycle ride. These incidents were found to be not only related to the infrastructure, but also to the behaviour other road users.

Because a considerable part of SBCs is preceded by an interaction with another road user and unexpected behaviour and incorrect expectations about cyclists contribute to conflicts and crashes, **Chapter 3** investigated whether it is possible to successfully predict other cyclist's intentions based on implicit visual cues only. By means of an online questionnaire, participants of all ages were asked to predict in which direction a lead cyclist would move in short video clips. The results suggest that it is difficult to predict the upcoming direction of a cyclist if he or she does not use an arm to indicate direction the official way. Although some observable behaviours may increase the chance of a correct prediction (e.g. looking over the shoulder, maintaining or reducing cycling speed), the overall inability in predicting a cyclist's upcoming direction may reveal the unexpectedness of their behaviour, which in turn may play a role in conflicts. For this reason, it seems useful to emphasize the use of arm signals to indicate direction. However, since giving directions may negatively impact balance if (older) cyclists have to take one hand off the handlebars, it could be helpful to provide on-bicycle support systems that are able to provide clear and explicit signals about the intentions and behaviour of cyclists to other road users.

The behavioural effects of infrastructural interventions were studied first and these interventions were mainly aimed at increasing the available space for cyclists, enlarging their room to correct for errors, and stimulating cyclists to keep a safe distance from the verge. Interventions were applied on actual cycle paths and cycling behaviour was measured by means of fixed-camera or on-bicycle camera observations. During these studies, nearly all participants used their own bicycle. Lateral position (LP), swerving (Standard Deviation of the Lateral Position, SDLP), and cycling speed were defined as objective variables of cycling behaviour and questionnaires and interviews were conducted to collect subjective opinions.

The first intervention that was investigated consisted of virtual objects that resembled three-dimensional blocks that a cyclist would normally try to avoid (**Chapter 4**). Different variants of these virtual objects were applied in the shoulder of a cycle path and it was hypothesised that cyclists would enlarge their lateral distance from these objects while cycling by. However, based on the fixed-camera and on-bicycle camera experiments, none of the investigated virtual objects were effective in influencing the overall LP or SDLP of cyclists. Although red-coloured virtual objects (with white stripes) were related to a significantly increased cycling speed, this was the only exception and the effect size was too small to relate this to the virtual object's 3D-properties. Additional analyses revealed that limited visibility of the virtual objects may have had influence, as cyclists who reported having seen the virtual objects rode closer to the objects than cyclists who did not see these. Another possibility is that the applied virtual objects in the form of small blocks were not perceived as sufficiently threatening to increase safety margins. Therefore, virtual holes or cracks in a cycle path might potentially be more effective. However, for now, due to the absence of (safety improving) effects on cycling behaviour, it is concluded that the tested virtual objects are not an effective intervention to stimulate cyclists to keep a safe distance from the edge of a cycle path.

In **Chapter 5**, the effects of edge lines, slanted kerbstones, shoulder strips, and edge strips were studied using the on-bicycle camera method with cyclists ≥ 50 years.

Analyses on LP and SDLP revealed inconsistent effects of edge lines and slanted kerbstones. However, cyclists positioned themselves consistently and significantly closer to the edge of the main cycle path's surface in all shoulder strip conditions. A different outcome, however, was found for the edge strips: with this intervention, cyclists positioned themselves further away from the edge of the cycle path compared to the control condition. Although the effects of shoulder and edge strips on LP seem opposite, their implications for safety may be similar. Since the shoulder strips were placed in-between the cycle path and the verge and the edge strips were placed on the cycle path surface itself, both interventions seem to increase the total distance to the verge. With regard to cycling speed, cyclists rode significantly slower in the shoulder and edge strip conditions than in the control conditions. These findings show that the cycle path was used more efficiently while the buffer zone prevented entering the soft verge. It is therefore concluded that shoulder and edge strips are suitable interventions for increasing the safety margins between older cyclists and the verge.

The last intervention of this thesis was aimed at the bicycle. To support (older) cyclists with unexpected and difficult interactions, **Chapter 6** assessed the effects of a Bicycle Light Communication System (BLCS). The main aim of this BLCS was to facilitate communication between cyclists and other road users by means of light signals. A conventional, non-electric bicycle was therefore instrumented with a BLCS-unit that showed cycling speed, braking, and turning intentions explicitly. An experiment was performed in which 21 older and 20 younger cyclists individually rode along with a researcher and their cycling behaviour, opinion, and perceived mental effort were assessed. The results indicate that the specific light signals that conveyed information about cycling speed were difficult to interpret and, therefore, will not provide valuable information to other road users. However, older cyclists generally liked the option to indicate turning intentions by means of an indicator because this way, they do not have to use their arm to point into the direction of the turn. Furthermore, the light signals that indicated turning and braking were experienced as useful and intuitive because these are similar to the light signals as used on motorised vehicles, including scooters and mopeds. Although the BLCS was a prototype, the majority of older cyclists was interested in using such a system when it would become available for their bicycles and in particular the indicator and brake light are promising features to support older cyclists.

In conclusion, **Chapter 7** indicates that particularly shoulder strips and edge strips are infrastructural interventions that increase the safety of older cyclists. These interventions enlarge safety margins for verge-related critical events not only by increasing the general cycling distance to the verge in time and space, but also by supporting older cyclists with attentional and visual guidance. No consistent effects of edge lines were found, although future studies should determine whether this intervention might increase cycling safety in curves, for example. With regard to the BLCS, it is concluded that the direction indicator and the brake light are able to support older cyclists with attention and situation awareness without influencing balance. Taken together, this thesis provides not only older cyclists, but also (local) governments, engineers, and spatial planning professionals with specific suggestions for interventions in the infrastructure or on a bicycle, and which effects on cycling behaviour and traffic safety may or may not be expected after implementation.

Dutch Summary

Nederlandse Samenvatting

Samenvatting

In Nederland fietsen veel mensen op regelmatige basis, ongeacht hun leeftijd. Voor velen is de fiets dan ook een essentiële vervoerswijze. Fietsers zijn echter kwetsbare verkeersdeelnemers en fietsen in het dagelijkse verkeer is dan ook niet zonder risico's. In het bijzonder oudere fietsers hebben een verhoogd risico op zware verwondingen na een enkelvoudig fietsongeval: een fietsongeval waar geen andere verkeersdeelnemers bij betrokken zijn. Omdat fietsen bijdraagt aan gezonde veroudering is het belangrijk dat oudere mensen zo lang mogelijk veilig kunnen fietsen en dat dergelijke ongevallen worden voorkomen. De doelstellingen van dit proefschrift luiden daarom als volgt:

Doelstelling 1: Het identificeren van elementen in de infrastructuur en interacties met andere weggebruikers die tot problemen en een hoger ongevalsrisico voor oudere fietsers kunnen leiden.

Doelstelling 2: Het vaststellen van de effectiviteit van maatregelen om de veiligheid van oudere fietsers te verbeteren.

In **Hoofdstuk 1** wordt niet alleen het doel, de bruikbaarheid, en de voordelen van fietsen voor oudere mensen benadrukt, maar worden ook de risico's, risicofactoren, en voorbeelden van veelvoorkomende enkelvoudige fietsongevallen op basis van de wetenschappelijke literatuur beschreven. In eerdere onderzoeken is gevonden dat het ongevalsrisico van oudere fietsers verklaard kan worden door de toegenomen fysieke kwetsbaarheid, alsmede door leeftijd gerelateerde achteruitgang van motorische en cognitieve vaardigheden. Problemen met motorische coördinatie en het behouden van balans kunnen enkelvoudige fietsongevallen, zoals vallen tijdens het op- en afstappen of tijdens het fietsen met lagere snelheden, verklaren. Daarnaast kunnen botsingen met obstakels of het vallen van de fiets nadat de fietser in de berm is gereden mogelijk verklaard worden door problemen met zicht, aandacht, of psychomotorische reactiesnelheid. De meeste kennis met betrekking tot enkelvoudige fietsongevallen is echter afkomstig van retrospectieve studies die zijn uitgevoerd nadat een ongeval reeds heeft plaatsgevonden en officieel is gerapporteerd, terwijl de meerderheid van de enkelvoudige fietsongevallen niet worden gerapporteerd in de officiële ongevallenstatistieken. Hierom zijn er in **Hoofdstuk 2** "natuurlijke" fietsgegevens verzameld van 30 oudere fietsers in Nederland. Deze data zijn gebruikt om vast te stellen welke elementen in de fietsinfrastructuur mogelijk leiden tot problemen bij oudere fietsers, en zijn potentiële situaties en gedragingen die vooraf kunnen gaan aan een enkelvoudig fietsongeval verkend. De bevindingen kwamen in grote lijnen overeen met de literatuur en bevestigen dat obstakels, onregelmatigheden in de verharding van fietspaden (bijvoorbeeld gaten en scheuren), scherpe bochten, hellingen, en beperkte ruimte kunnen leiden tot problemen bij oudere fietsers. Daarnaast is op basis van video observaties gebleken dat sommige oudere fietsers per ongeluk in de berm belanden tijdens een reguliere fietsrit. Deze incidenten bleken niet alleen gerelateerd aan de infrastructuur, maar ook aan het gedrag van andere weggebruikers.

Omdat een aanzienlijk deel van de enkelvoudige fietsongevallen voorafgegaan wordt door een interactie met een andere weggebruiker, en onverwachte gedragingen van en onjuiste verwachtingen over fietsers bijdragen aan conflicten en ongevallen, is in **Hoofdstuk 3** onderzocht in hoeverre het mogelijk is om met succes het gedrag van andere fietsers te voorspellen op basis van alleen visuele aanwijzingen. Met behulp van een online vragenlijst zijn deelnemers van alle leeftijden gevraagd om op basis van korte videofragmenten de richting te voorspellen die een voorliggende fietser zou kiezen. De resultaten tonen dat het moeilijk is om deze richting te voorspellen wanneer de fietser niet expliciet richting aangeeft middels het officiële handgebaar. Hoewel het detecteren van enkele gedragingen de kans kan vergroten dat er een juiste voorspelling wordt gedaan (bijvoorbeeld het kijken over de schouder en het aanhouden of verlagen van de fietssnelheid), toont het algemene onvermogen om succesvol het gedrag van de fietser te voorspellen aan dat fietsers onvoorspelbaar zijn in hun gedrag, wat mogelijk een rol speelt bij verkeersconflicten. Hierom is het nuttig om te benadrukken dat fietsers expliciet richting aangeven met behulp van het officiële handgebaar. Echter, omdat het uitsteken van de hand mogelijk een negatief effect heeft op de balans van oudere fietsers, zij moeten dan immers één hand van het stuur halen, zou het nuttig kunnen zijn om hulpsystemen voor op de fiets te ontwikkelen die het mogelijk maken om duidelijke, expliciete signalen te tonen aan andere weggebruikers over de intenties van de fietser.

De gedragseffecten van infrastructurele maatregelen zijn eerst onderzocht. Deze maatregelen waren erop gericht dat er meer beschikbare ruimte is voor fietsers, dat zij meer ruimte hebben om fouten te herstellen, en dat zij gestimuleerd worden een veilige afstand tot de berm aan te houden. De maatregelen zijn toegepast op echte fietspaden en fietsgedrag is gemeten met behulp van vaste camera observaties en camera's op de fiets. Tijdens de onderzoeken hebben vrijwel alle deelnemers hun eigen fiets gebruikt. Laterale positie (LP), slingergedrag (Standaard Deviatie van de Laterale Positie, SDLP), en fietssnelheid zijn gedefinieerd als objectieve variabelen voor fietsgedrag. Daarnaast zijn vragenlijsten en interviews afgenomen om subjectieve meningen te verzamelen.

De eerste onderzochte maatregel bestond uit virtuele objecten welke driedimensionale blokken representeerden die een fietser normaal gesproken zou willen vermijden (**Hoofdstuk 4**). Verschillende varianten van deze virtuele objecten werden toegepast in de berm van een fietspad en de hypothese was dat fietsers hun afstand tot deze objecten zouden vergroten wanneer zij erlangs fietsten. Echter, op basis van de vaste camera observaties en observaties vanaf de fiets, is gebleken dat geen van de onderzochte virtuele objecten effectief waren voor het beïnvloeden van de LP of SDLP van respectievelijk fietsers in het algemeen of fietsers ouder dan 50 jaar.

Hoewel het passeren van de rood-wit gekleurde virtuele objecten wel samenging met een significante verhoging van de fietssnelheid, was deze variant de enige uitzondering en was de effectgrootte te klein om deze geringe snelheidstoename aan de 3D-eigenschappen van de objecten toe te schrijven. Op basis van aanvullende analyses is gebleken dat de beperkte zichtbaarheid van de virtuele objecten van invloed kan zijn geweest, omdat de fietsers die rapporteerden dat ze de objecten hebben gezien dichterbij de objecten hebben gereden dan fietsers die deze niet hebben gezien. Een andere mogelijkheid is dat de toegepaste virtuele objecten in de vorm van relatief kleine blokken niet voldoende bedreigend waren om de veiligheidsmarges te vergroten. Hierom is het mogelijk dat virtuele gaten of scheuren in een fietspad wellicht effectiever zijn. Echter, omdat er geen (veiligheid verhogende) effecten zijn gevonden, wordt vooralsnog geconcludeerd dat de onderzochte virtuele objecten geen effectieve maatregel zijn om fietsers te stimuleren meer afstand te houden van de rand van een fietspad.

In **Hoofdstuk 5** zijn de effecten van kantbelijning, schuine trottoirbanden, bermstroken, en kantstroken bestudeerd met dezelfde observatiemethode op basis van camera's op de fiets van fietsers ≥ 50 jaar. De analyses met betrekking tot LP en SDLP resulteerden in inconsistente effecten van kantbelijning en de schuine trottoirbanden. De fietsers positioneerden zichzelf echter consistent en significant dichterbij de rand van het fietspad in alle bermstroken condities. Dit is een andere uitkomst vergeleken met de kantstroken: hierbij werd gevonden dat fietsers, vergeleken met de controle conditie, juist verder van de rand vandaan gingen fietsen. Hoewel de effecten van de kantstroken en bermstroken tegenovergesteld lijken te zijn, blijken de implicaties voor veiligheid vergelijkbaar. Omdat de bermstroken tussen het fietspad en de berm zijn geplaatst en de kantstroken onderdeel zijn van de fietspadverharding, vergroten beide maatregelen de totale afstand tot de berm. Wat de fietssnelheid betreft werd er significant langzamer gefietst in zowel de berm- als kantstrook condities, vergeleken met de controlecondities. Deze bevindingen tonen aan dat de ruimte op het fietspad efficiënter gebruikt wordt terwijl een bufferzone ervoor kan zorgen dat het betreden van de berm wellicht wordt voorkomen. Hierom wordt geconcludeerd dat berm- en kantstroken geschikte maatregelen zijn om de veiligheidsmarges van oudere fietsers tot de berm te vergroten.

De laatste maatregel van dit proefschrift betreft een ondersteuningssysteem op de fiets. Om (oudere) fietsers te ondersteunen bij onverwachte en problematische situaties op de fiets, zijn in **Hoofdstuk 6** de effecten onderzocht van een Fietslamp Communicatie Systeem (Bicycle Light Communication System; BLCS). Het hoofddoel van de BLCS was om communicatie tussen fietsers en andere weggebruikers te faciliteren met behulp van lichtsignalen. Een reguliere, niet-elektrische fiets werd hierom geïnstrumenteerd met een BLCS-module dat de fietssnelheid, remgedrag, en het aangeven van richting weergaf. Er werd eerst een experiment uitgevoerd waarin 21 oudere en 20 jongere fietsers individueel meefietsten met een onderzoeker waarbij hun fietsgedrag, mening, en ervaren mentale belasting werden gemeten. De resultaten tonen dat lichtsignalen die snelheidsinformatie overbrachten moeilijk te interpreteren waren en hierom geen waardevolle informatie bieden voor andere weggebruikers. Oudere fietsers bleken echter wel enthousiast over de mogelijkheid om richting aan te geven middels een knipperlicht, omdat zij op deze manier niet hun arm hoeven uit te steken. Verder werden de lichtsignalen met betrekking tot richting aangeven en remmen als bruikbaar en intuïtief ervaren omdat deze vergelijkbaar zijn met lichtsignalen die gebruikt worden op gemotoriseerde voertuigen, waaronder ook scooters en brommers. Hoewel de BLCS een prototype was, waren de meeste oudere fietsers wel geïnteresseerd in een dergelijk systeem mocht deze op de markt komen. In het bijzonder de richtingaanwijzer en het remlicht lijken veelbelovende onderdelen om oudere fietsers te ondersteunen.

Ter conclusie wordt in **Hoofdstuk 7** uiteengezet dat met name berm- en kantstroken infrastructurele maatregelen zijn die de veiligheid van oudere fietsers kunnen verhogen. Deze maatregelen vergroten de veiligheidsmarges voor berm-gerelateerde kritieke gebeurtenissen door niet alleen de afstand in tijd en ruimte tussen de fietser en de berm te vergroten, maar ook door fietsers te ondersteunen middels het trekken van de aandacht en het bieden van visuele geleiding. Er werden geen consistente effecten van kantbelijning gevonden, wellicht kunnen toekomstige studies aantonen in hoeverre deze maatregel effectief is in bochten, bijvoorbeeld. Wat de BLCS betreft wordt er geconcludeerd dat de richtingaanwijzer en het remlicht geschikt zijn om oudere fietsers te ondersteunen op het gebied van aandacht en bewustzijn van de verkeerssituatie, zonder dat het bedienen van het systeem de balans beïnvloedt. Afsluitend zijn de in dit proefschrift aangereikte maatregelen en suggesties niet alleen relevant voor oudere fietsers zelf, maar bijvoorbeeld ook voor (lokale) overheden, ingenieurs, en ruimtelijke ordening experts. Met de opgedane inzichten over welke gedragseffecten wel en niet verwacht kunnen worden n.a.v. de maatregelen, kan deze kennis bijdragen aan gerichte programma's ter bevordering van de fietsveiligheid.

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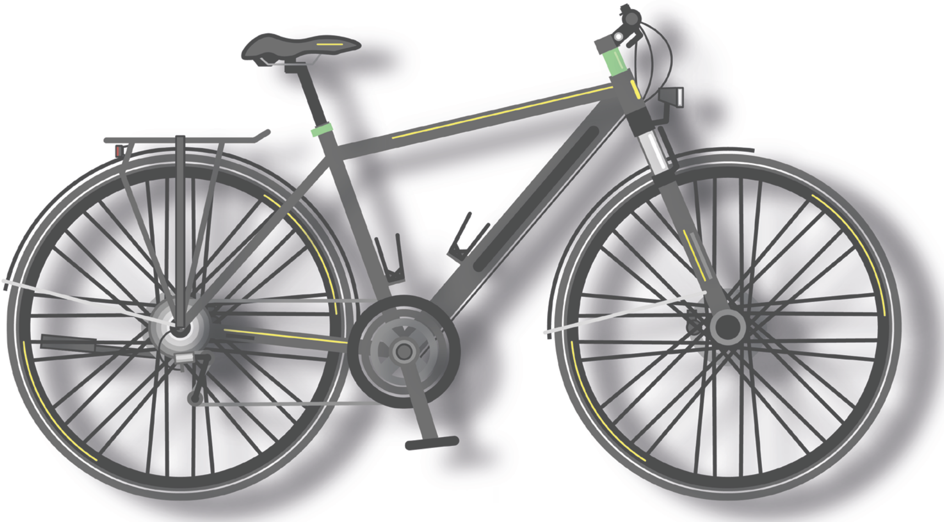

Dankwoord

Dankwoord

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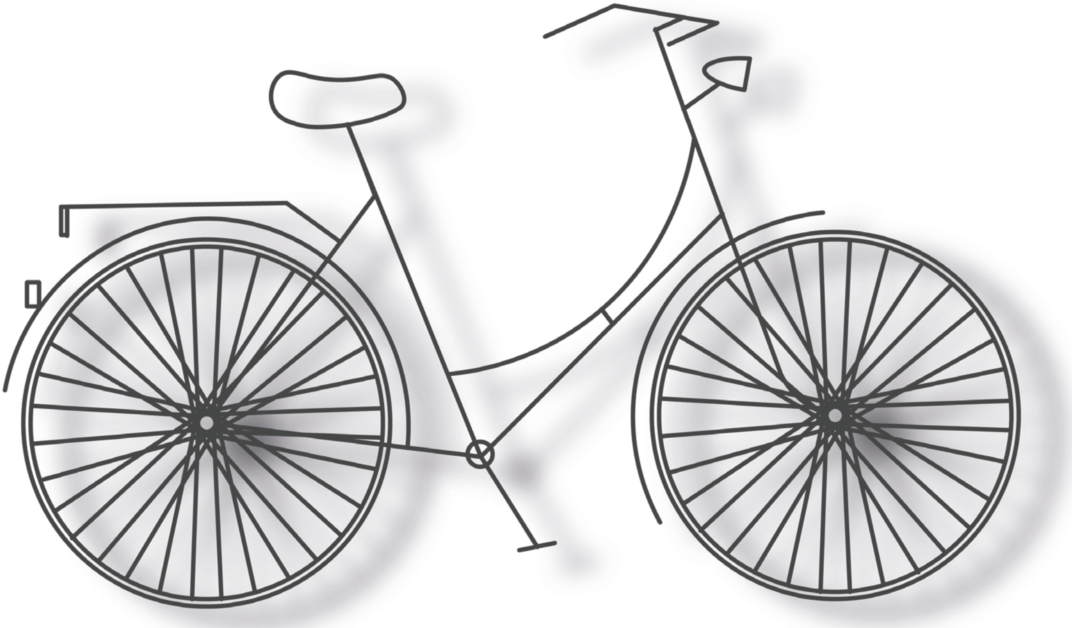

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Curriculum Vitae

Frank Westerhuis (Groningen, the Netherlands, 1988) started studying psychology at the University of Groningen in 2009. After obtaining his BSc. degree in Psychology in 2012, he received his MSc. degree in Clinical Neuropsychology in 2013. During the last phase of his study, he started working as a student-assistant in the Traffic Psychology group at the Department of Clinical and Developmental Neuropsychology of the same University. His main focus is on traffic psychology: primarily older cyclists and their experiences in the cycling infrastructure. After graduating, he was appointed as a researcher and contributed to the 'Forgiving Cycle Path' project, aimed at improving the current Dutch cycling infrastructure to increase the safety of older cyclists. In 2015, he became a PhD student and contributed to the 'CRUISer' project by expanding his area of research to traffic interactions of older cyclists with other road users. The results of both projects are presented in this thesis. In addition, he also supervised students during research practicals, BSc. theses, and MSc. theses. In 2018, he further expanded his line of research by contributing to the project 'Mobiliteitsbehoud bij Complexe Comorbiditeit', in close collaboration with Royal Dutch Visio. This project was aimed at studying fitness to drive of visually impaired people with cognitive comorbidities. Furthermore, in 2019 and 2020, he contributed to projects regarding Human Factors Guidelines of Advanced Driver Assistance Systems (ADAS) in collaboration with Rijkswaterstaat and TNO. In 2021, he completed writing his thesis 'Advancing the Age of Cycling', of which the defence takes place on October 14th, 2021.