KEEP CYCLING

How Technology can Support Safe and Comfortable Cycling for Older Adults

Carola Engbers

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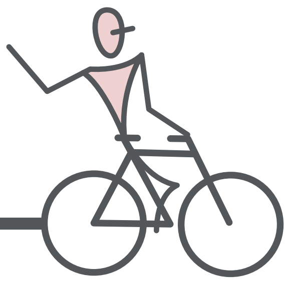

Chapter 1

General introduction

One of my first interviews with an older woman took place when performing a pilot-experiment with a simplified prototype version of a rear-view assistant for bicycles. This assistant could potentially warn the cyclist for approaching traffic from behind. The experiment was performed in a lab-setting, where the participant was equipped with all kinds of technology and the bicycle was fixated in a bicycle-standard. Corresponding road traffic was displayed on different screens and the participant was asked to evaluate different types of warning signals. She was put in an experimental setting, but she could not wait for the actual development of a rear-view assistant and wanted to buy it immediately.

"With this device I can finally cycle without help from my husband"!
(woman, 74 years old, who was not able to look over her shoulder).

Her enthusiasm made a lasting impression on me and her case was not unique. It reminds me of all the phone calls I received after a newspaper article or a tv-interview, showing one of the latest cycling supporting technological developments. The people who called had one thing in common: Dutch people really like to cycle. As long as they can, as far as they are capable of. To do their daily groceries or for recreational purposes. To be mobile, to be independent, to be environmental-aware, to have social contacts, to become or to stay healthy, to be outside, or because they are not able or do not want to ride a motorized vehicle.

This thesis will describe the research that was performed in order to develop such supportive technological innovations.

ACTIVE & HEALTHY AGEING

The population older than 60 years is growing faster than any other age group (World Health Organization, WHO, 2002). An important goal for modern societies is to support the mobility of this growing population of older adults (United Nations 2015; Rosenbloom, 2001), to maintain independence and increase quality of life for the older adult. In 2002, the World Health Organization described a policy framework for Active Ageing, defined as "*the process of optimizing opportunities for health, participation and security to enhance quality of life as people age"* (WHO, 2002). Although this framework focuses on the support that can be provided by the government, it is important to let older adults take responsibility in maintaining their own health. In 2015, the World Report on Ageing and Health introduced Healthy Ageing as "*the process of developing and maintaining the functional ability that enables wellbeing in older age"*" (WHO, 2015). This thesis will focus on cycling for older people, this means adults from 60 years and older, as cycling places older adults as active participants in sustaining and promoting their own health and cycling contributes positively to health (Oja et al., 2011). From 60 years of age the risk of falling increases for both men and women. Besides that, by choosing 60 years of age, both the ‘older elderly’ (from 75 years old who are most physically vulnerable), and the ‘younger elderly’ are included (SWOV, 2017).

CYCLING IN THE NETHERLANDS

In the Netherlands, cycling is one of the most important physical activities for the older population to remain healthy and mobile, as cycling is an efficient means of transportation (Hendriksen & Van Gijlswijk, 2010). A statistical analysis in the Netherlands with older people older than 65 years old showed that those elderly cycle frequently in the Netherlands, e.g. for short shopping trips, to visit friends and for recreation (CBS, 2007). Cycling contributes positively to health, mobility, and quality of life (Oja et al., 2011), while the loss of mobility can lead to depression and loneliness (Maratolli, et al., 1997; Buys et al., 2012; Whelan et al., 2006). Staying mobile is crucial for maintaining a social life and for the feeling of independence and for the quality of life of the older adults it is important to remain socially and physically active (Tacken, 1998; Rejeski & Mihalko, 2001). Van Cauwenberg et al. (2018) state that specifically the use of an e-bike should be stimulated to promote active ageing. However, in 2017 for the first time, there were more cycling fatalities than car fatalities in the Netherlands (CBS, 2017). Older cyclists also have a higher risk of falling with their bicycle and sustaining a serious injury, compared to younger cyclists (Kruijer, 2013). An injured older cyclist jeopardizes the mobility of this person, with severe consequences. Hence, prevention of bicycle accidents of older cyclists is obviously necessary.

Figure 1 presents the different factors which influence and are involved in cycling and the key research topics of this work. The first topic is the older cyclists and their characteristics. The second topic focusses on technology on the bicycle to support older cyclists; what are their wishes and requirements and specifically, how do older people respond to technology. The third area is addressed to the interaction with other road-users and the communication with them.

‘Safe and comfortable’ cycling, emerges in the overlapping area (see red-coloured part in Figure 1) between the three factors. Particularly, in this thesis it is investigated how technology can support safe and comfortable cycling in everyday life. In the next sections, each one of these topics is addressed in further detail.

The main aim of the thesis is to explore how technology can be used to support the older cyclists (60+) in traffic.

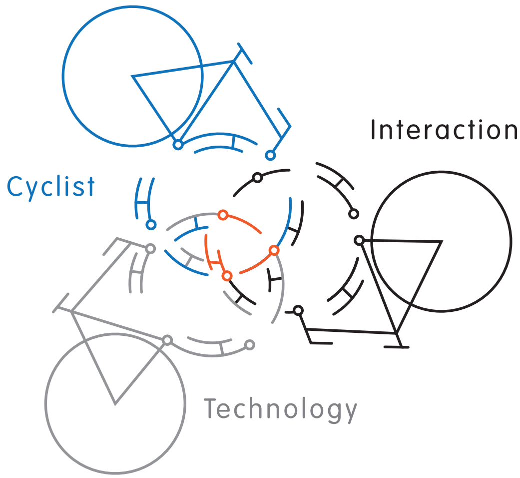

Figure 1: Different factors involved in cycling and the key research topics of this PhD thesis: safe and comfortable cycling for the older adult.

1. THE OLDER CYCLIST

Possible reasons to stop cycling reported in literature are medical limitations, heavy traffic and insecurity of the cyclist (Van Loon & Broer, 2006). Older cyclists experience more problems in complex situations in the selection of information and decision making (Hagenzieker, 1996). Besides that, problems with balance are reported (Scheiman et al., 2010; Mori and Mizohata, 1995; Ormel & Den Hertog, 2009). The rise of the electric bicycle has already solved some problems for older cyclists; these in particular compensate for loss of strength and physical endurance. On the other hand, with an electric bicycle older cyclist are able to reach higher speeds than before and need to handle heavier bicycles. Higher injury risks were found for electric bicycles, compared to conventional bicycles (Schepers et al., 2014).

When getting older, physical and mental decline often gradually take place. For every road user, loss of visual abilities is a complicating factor, which directly influences self-confidence in traffic (Charlton et al. 2006). Besides that, their hearing abilities can diminish, which can lead to problems for cyclists in general. The increased risk of falling for older cyclists may be the results of both cognitive and physical decline (OECD, 2001). Mental impairments, such as a decrease in concentration abilities, reduced working memory, performance or a slower reaction time, could also make cycling in traffic more mentally demanding. Physical factors, such as reduced (bone)strength may result in severe injuries after falling off a bicycle.

The last decade, a slight increase was observed for seriously injured victims per travelled kilometre by bicycle, irrespective of age (Weijermars, Bos & Stipdonk, 2016). However, focussing on bicyclist's fatalities, among all fatalities 67% was over 60 years of age. To illustrate this, when comparing car and cycling accidents with a fatal outcome, twice as much cyclists were fatally injured compared to car drivers of the same age (CBS, 2014). When comparing older (65+) and younger (65-) the risk is 2 to 5 times higher per kilometre cycled to sustain an injury due to an accident during cycling (Zeegers, 2010, Berveling & Derriks, 2012). Moreover, the chance of a fatality when involved in a cycling accident, is up to 17 times higher for cyclists aged 75 years and older compared to cyclists younger than 75 years (SWOV, 2009). Besides the risk of a fatal cycling accident, older cyclists are four times more likely to become hospitalized after visiting the emergency department when compared to a middle-aged group of cyclists (SWOV, 2009). The rise in number of victims in single sided accidents (i.e. where no other road user was directly involved) resulted from an increase in accidents of the older, more vulnerable cyclists (Van Norden & Bijleveld, 2011; Berveling & Derriks, 2012). Unfortunately, minor single-bicycle events are rarely registered in official road crash statistics (Schepers & Klein Wolt, 2012; Wegman, Zhang & Dijkstra, 2012), little is reported on this aspect. Most research focuses on accident characteristics. However, many (single-sided), accidents are not registered. Therefore, the first objective for this thesis is:

Objective 1: To investigate demographic, physical and mental characteristics of elderly cyclists, and to explore which factors are associated with self-reported cycling accidents in the Netherlands.

2. TECHNOLOGY

Because of decreased physical and cognitive skills, elderly cyclists are more prone to get involved in accidents and are more fragile than younger cyclists (Mori and Mizohata, 1995; Tacken, 1998; Horswill et al., 2008). However, even though older cyclists experience problems in traffic, they are at the same time excellent and experienced in avoiding many. Older cyclists use adaptive strategies to avoid potentially dangerous situations such as; avoiding cycling in the dark when they have problems with their sight. When facing an unstructured busy crossing, they take a little detour. When having problems with looking over their shoulder due to stiffness of the neck, they may use a rear-view mirror. Or, when they do not use a mirror and they have to turn left, older cyclists use the strategy to dismount their bicycle and walk with their bicycle (Hagemeister & Tegen-Klebingat, 2012). Another strategy can be to cross the street in two phases, instead of crossing diagonally. Others rely on their hearing abilities when turning left. These adaptive strategies are strategical clever solutions but could potentially lead to problems as well. Dismounting is a potential risk to fall for older cyclists since many accidents occur while mounting or dismounting their bicycle (Hagemeister & Tegen-Klebingat, 2012). Besides that, it is dangerous to rely entirely on auditory information for several reasons. First, for older cyclists, hearing abilities reduce with age (Gordon-Salant, 2005). Second, the increasing amount of silent motorized traffic (electric and hybrid cars and motorbikes) is a complicating factor (Stelling-Kończak, 2015; Schoon & Huijskens, 2011).

Using supportive technology, comparable to Advanced Driver Assistance Systems (ADAS) in cars, could be a potential solution for the older cyclists to cope with their limitations. ADAS, in cars, can provide personal assistance in a traffic environment (Davidse, 2007) and several studies have suggested that ADAS may be able to provide tailored assistance for older drivers (Dotzauer et al., 2015). However, handing over control to a device and automated functions are evaluated as negative aspects of assistance systems (Hoedemaeker, 1996; Hoedemaeker and Brookhuis, 1998).

Even though resistance by older adults against technological innovations in vehicles has been reported (Hancock and Parasuraman, 1992), the general consensus is that driver assistance systems have the potential to keep older drivers mobile up to higher age (Davidse, 2007) and that older drivers are more positive with regard to in-vehicle devices than younger drivers (Yannis et al., 2010). The question is whether this type of technology can be transferred to the bicycle. Supporting the older cyclist with technology, could make cycling more comfortable and may reduce injury risk for the older cyclist in traffic. With supportive technology, the need to rely on less effective anticipation strategies, such as relying on hearing could be reduced or eliminated.

So far, no studies have evaluated the usage of technological devices on bicycles. Hence, we do not know if such a system will be accepted by older cyclists and whether such a system would have the potential to enhance cycling safety.

Therefore, the second objective of this thesis can be stated as follows:

Objective 2: To investigate how technology can support safe and comfortable cycling for the older population

3. INTERACTION

In order to develop supportive technological devices for the older cyclists, it is essential to assess which factors play a role in the increased fall- and injury risk of older cyclists, for example interaction with infrastructure or other road-users. Westerhuis & De Waard (2014) investigated the effects of infrastructure characteristics on cycling behaviour. They found that preventing a cyclist to enter the verge is a useful intervention to prevent accidents. Regarding the infrastructure, they concluded that several factors could be distinguished to reduce the potential problems on cycling paths for older cyclists. Examples to increase safety include; wide cycling paths, no or as few bends as possible, no (abrupt) level differences between cycling path and the verge, reduce objects, and structured (over)view. Although infrastructure is very important and cannot be ignored, the focus of this thesis will be the interaction with other road users, as many other research has focussed on infrastructure before.

As a considerable amount of single-sided accidents is preceded by interaction with another road user, the interaction with other road-users is important for safety. Even though these other road users are not directly involved in single-sided accidents, it was found that they are indirectly involved in up to 80% of the accidents classified as single-sided (Kruijer 2013, Davidse, 2014, Westerhuis, 2014). It is estimated that similar interactions may have played a role preceding many of the reported single-sided accidents (Boele-Vos et al., 2017; Kruijer et al., 2012). Schepers et al. (2013) showed that separating motorised traffic and cycling traffic (i.e. unbundling), positively affects road safety for cyclists. This is confirmed in the Cruiser project (Westerhuis et al., 2016), where older cyclists mention that they have problems with 'shared space' locations, roundabouts and 'green-for-all'-crossings. Regarding the latter, only cyclists have green light on these specific kinds of crossing, unbundling motorised from non-motorised traffic. However, all the referred locations have one thing in common: the situation is unstructured and disorganized. From interviews with older and younger road-users, it could be concluded that these 'green-for-all' crossings were evaluated as negative by the older cyclists, while the younger road-users were very positive. The elderly cyclist also appreciates pedestrian crossings, crossings with traffic lights and cycle paths more than younger cyclists. They find it dangerous to cross a road without these amenities (Bernhoft & Carstensen, 2008).

According to previous studies (Westerhuis et al., 2016), the locations where many problematic interactions occurs between cyclists and other traffic are crossings and roundabouts. From literature it is known that on these crossings most interactions and accidents happen when a car driver turns right (Strauss et al., 2013; Pan & Cheng, 2011) while a cyclist goes straight, or with (2-sided) bicycle paths (Schepers et al., 2013; Fietsberaad, 2011). The second problematic location is the roundabout. In general, the more traffic, the more accidents happen on a roundabout (Hels & Orozova-Bekkevold, 2007). Trucks on roundabouts are 17 times more dangerous than other motorised traffic for cyclists (Fietsberaad, 2007). The accidents risk is highest when a cyclist is circulating while a car leaves or enters the roundabout (Møller & Helz., 2008; Sakshaug et al., 2010).

Another (potentially) problematic situation for the older cyclist is a dual directional cycling path, a type of cycling path that has become more and more standard in the Netherlands (Slütter & Koudijs, 2007). Examples include an unnoticed oncoming cyclist or a cyclist who is startled by a fast passing cyclist and ends up in the verge (Slütter & Koudijs, 2007). Westerhuis & De Waard (2017) concluded that it is very hard to predict the direction of a turning cyclist based on just visual cues before the turning manoeuvre is initiated. All the above referred situations are indications that it might be helpful to support the interaction between cyclists and other traffic and to investigate whether technology can improve communication.

Therefore, the third and last objective for this thesis is stated as follows:

Objective 3: To improve the interaction between older cyclists and other road-users with technology.

OUTLINE OF THIS THESIS

In line with objective 1, this research starts with an extensive questionnaire to reveal characteristics of older cyclists from age 59 in the Netherlands, who have been involved in a self-reported accident, and to explore which of these characteristics are associated with self-reported cycling accidents (chapter 2). This study focussed on exploring demographic, bicycle and personal factors related to self-reported bicycle falls, instead of focusing on accident characteristics.

Pursuing objective 2, studies were conducted to investigate how technology can support safe and comfortable cycling for the older population. Acceptance of two types of warning modalities of a prototype rear-view assistant was evaluated (chapter 3). An instrumented bicycle, with a front- and rear-view assistant, was evaluated on technical performance, user-experience and effects on lateral position (chapter 4).

Moving towards objective 3, it was investigated if and how interaction between the older cyclists and other road-users could be improved with a bicycle light communication system integrated in the front- and rear light, which communicated intentions and behaviour, such as acceleration, deceleration and turning (chapter 5). This study was divided into two parts. In an on-road experiment it was evaluated how older and younger cyclists, who are cycling near an equipped bicycle, experience the light signals of the systems. Subjective opinions regarding signal interpretation, visibility, ease of use, expected usefulness, and perceived safety enhancement were gathered. Furthermore, objective measurements were performed to assess whether the lights affected cycling behaviour. In addition, twelve older cyclists used an integrated bicycle for their personal cycling activities for one week, which was evaluated.

The final chapter (chapter 6) provides an overview of and highlights the most imported findings. It provides a discussion of the results of this research and places the results in a broader perspective with highlighting relevance for practice as well as for future research.

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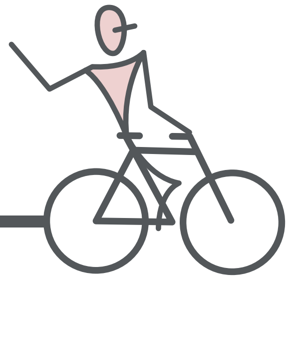

Chapter 2

Characteristics of elderly cyclists (65+) and factors associated with self-reported cycling accidents in the Netherlands

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ABSTRACT

Cycling supports the mobility, health and independency of the ageing population. However, older cyclists have an increased injury risk. On average, the risk of older people to sustain an injury in a cycling accident is three times higher per cycling kilometre than for middle-aged people and the injury risk increases with age. In comparison with middle-aged cyclists (<65 years), the risk of hospitalization is more than four times as high for older cyclists (>65 years). The aim of this study was to reveal characteristics of older cyclists in general and to explore which of these characteristics are associated with self- reported cycling accidents from age 59. More than eight hundred older cyclists (>65 years) filled out a questionnaire, which included questions on demographics, bicycle specifications and personal characteristics. By means of a logistic regression, the relationship between personal factors and self-reported bicycle falls were studied. The univariate models showed that age, physical and mental impairments, bicycle model, living environment, feelings of uncertainty of the cyclist and changed cycling behaviour (such as more patience, lower speed) were related to falling off a bicycle. From the multivariate model we can conclude that several factors are associated with falling off a bicycle in the older population: (1) every year the cyclists becomes one year older (from the age of 65), the chance they have fallen increases with 7.3%, (2) If cyclists have mental impairments, the chance they have fallen increases with a factor 2.5, (3) if cyclists were less than completely confident the chance they have fallen increases with factor 1.8, (4) if cyclists live in a rural environment compared to an urban environment the chance they have fallen increases with a factor 2.1. In conclusion, demographic, cycling and personal factors can be related to increased self-reported fall risk. It is advised to take these factors into account when implementing new cycling related safety measures.

INTRODUCTION

In the Netherlands cycling is a common mode of transport, and the Netherlands is a world leader in bicycle safety (Schepers et al., 2015). Conditions in the Netherlands are favourable for cycling as the consequence for several factors like climate, infrastructure, cycling facilities and the flat landscape (Heinen, Van Wee, & Maat, 2010; Ministry of Infrastructure and the Environment, 2009). The high amount of bicycle use increases safety, as it corresponds with a greater awareness of cyclists among drivers (Schepers, 2012). However, due to the ageing population, there are more older cyclists and they cycle longer into a higher age (Wegman, Zhang, & Dijkstra, 2012). It is important to make sure that the older population can continue cycling safely, as it contributes to physical health and overall fitness (Fishman, Schepers, & Kamphuis, 2015; Oja et al., 2011). Older adults experience increased feeling of independence and mobility, increased health and social contacts because of cycling (Fagerström & Borglin, 2010; Törnvall, Marcusson, & Wressle, 2016). However, while cycling supports the independence and health of the ageing population (Oja et al., 2011), older cyclists have an increased risk for being involved in a cycling accident (Martínez-Ruiz et al., 2014). In the Netherlands, 67% of all bicyclists fatalities were among cyclists aged 60 years and or older. This is more than twice as much as fatally injured car drivers within the same age group (CBS, 2014). On average, the risk of older people to sustain an injury due to a cycling accident is 2–5 times higher per cycling kilometre than for middle-aged cyclists (Berveling & Derriks, 2012; Zeegers, 2010). The probability of a fatal accident outcome for cyclists aged 75 and older is 17 times higher than for cyclists younger than 75 years (SWOV, 2009). Furthermore, the risk of hospitalization is more than four times as high for older cyclists after visiting an emergency department (SWOV, 2009), compared with middle-aged cyclists. The number of seriously injured victims per kilometre travelled by bicycle increased slightly over the last decade for all age groups (Weijermars, Bos, & Stipdonk, 2016). However, the rise in number of victims in single sided accidents (i.e. where no other road user was involved) resulted mainly from the older, more vulnerable cyclists (Berveling & Derriks, 2012; Norden & Bijleveld, 2011; Schepers & Vermeulen, 2012). For these reasons, cycling safety has become a focus point in Dutch policy.

Human performance can be described by the International Classification of Functioning, Disability and Health (ICF WHO, 2017). The ICF, is a classification of health and health-related domains. As the functioning and disability of an individual occurs in a context, ICF also includes environmental factors and personal factors. However, most research on cyclist safety focussed on bicycle accidents types and characteristics, mainly related to external factors, such as infrastructure. As said, the older cyclist is mostly the victim of a single-sided accident (Schepers & Wolt, 2012). Accidents studies on single-sided accidents report as frequent types of single-sided accidents; loss of balance, colliding with an obstacle or entering the verge (Schepers & Wolt, 2012). However, according to Davidse et al. (2014), a considerable number of single-sided accidents are preceded by interaction with another road user (see also Westerhuis & De Waard, 2016).

Literature on single-bicycle accidents is limited, which can be explained by the fact that minor single-bicycle accidents are rarely reported in official road crash statistics (Schepers & Wolt, 2012; Wegman et al., 2012). Cyclists accidents are more likely to be reported when the injury severity increases (Langley, Dow, Stephenson, & Kypri, 2003), and the rate of reporting is much higher for bicycle accidents with motor vehicles involved than for bicycle accidents with no motor vehicles involved (Kroon, 1990; Langley et al., 2003; Reurings & Bos, 2011; Schepers et al., 2015). The underreporting of crashes in police statistics and the selective reporting are complicating factors hindering insight in factors associated with falling of a bicycle. Despite many studies about (single-)bicycle accident types, insight in the personal factors that could play a role and information about non-reported mostly non-severe bicycle falls, is missing in the scientific literature.

The increased risk of falling for older cyclists off a bicycle may be the results from both cognitive and physical decline (OECD, 2001). Mental impairments, like a decrease in attention, working memory, and a lower reaction time, could also make cycling in traffic more mentally demanding. Physical factors, like reduced (bone)strength and increased stiffness, may result in more severe injuries after falling off a bicycle. By gaining knowledge about the factors associated to falling, cycling accidents might be prevented (Rijkswaterstaat, 2016). Insight in factors related to the higher fall risk of older cyclists may result in the design of measures to reduce the number of injured older cyclists. These factors could include personal, bicycle or infrastructural factors.

This study focusses on exploring demographic, bicycle and personal factors related to self-reported bicycle falls, instead of focusing on accident characteristics. The focus of this study is on (1) revealing characteristics of the older cyclist who has been involved in a self-reported falling accident, and (2) exploring factors associated with self-reported cycling accidents.

METHOD

Participants

In total, more than 2000 older cyclists from the Netherlands, aged 65 years and older were asked to complete a questionnaire. The only inclusion criteria were that the participants had to be aged 65 years or over and could ride a bicycle.

The participants were mainly (76.5%) recruited during Cycling School Lessons of the Dutch Cycling Union (Fietsersbond). These Cycling School Lessons days were informative and informal days to gather information about cycling to experience difference bicycle types, to cycle together and receive advice. The instructors of these cycling lessons distributed the questionnaire and a stamped return envelope on 52 occasions. A link to the online version questionnaire was also distributed by the Dutch Cycling Union. Other participants (23.5%) were recruited by including the questionnaire as an attachment to the monthly magazine of a senior association, at an e-bike convention and by distribution via personal contacts.

Questionnaire

The questionnaire consisted of 47 questions, and included items about demographics (age, gender, living environment), cycling behaviour (bicycle specifications, cycling frequency, cycling habits, cycling adaptations, traffic violations, fall experiences) and health (activity level, medication, mental and physical impairments, experience with falling). For each theme, approximately three questions were asked, and a large part of the questions are represented in Table 1. The questionnaire was developed based on literature of behaviour and fall- and accident risk on older cyclists. The questionnaire consisted of mostly closed-ended questions; i.e. questions with predefined answers and multiple answers were possible for most questions.

Data analyses

Participants were grouped as 'fallers' or 'non-fallers', based on the response to the question: ''have you ever fallen off your bicycle after you became 59 years old"? Normal distribution checks based on histograms were conducted first. Comparisons between groups were made using independent samples student's t test for normally distributed continuous variables and Chi-square tests were used for categorical variables. Many questions had multiple answer categories, so secondly, several variables were made dichotomous or restructured. This was needed, because otherwise there would not be enough cases for each answer category to study associations. The variables which were made dichotomous or restructured were; province (13 provinces recoded into north, middle, east); living environments (rural and village were combined versus urban); cycling adaptations (when 'yes' on 'low entry', 'mirrors' or 'side-wheels' it was recoded into 'adaptations' versus 'no-adaptations', 'folding bike' was seen as 'no adaptations'; taking weather and taking time of the day into account (when 'yes' on one of the different options it was recoded into 'yes, taking into account' versus 'no, not taking into account'); medicines that influences driving (when 'yes' on of the different medications it was recoded into 'yes, using medicine that influence driving' versus 'no'); cycling certainty & confidence in cycling (this 5-point Likert scale was made dichotomous by regrouping the four answers into 'less than completely confident/certain' versus 'completely confident/certain'); physical impairments & mental impairments (when 'yes' on one of the different impairments it was recoded into 'yes, physical or mental impairments' versus 'no physical or mental impairments'); adaptation to cycling behaviour (when 'yes' on one of the different adaptations, it was recoded into 'yes, adaptations in cycling behaviour' versus 'no adaptations in cycling behaviour'); violating traffic rules (when 'yes' on one of the different violations, it was recoded into 'yes, traffic violations' versus 'no, never traffic rules violations').

The variables associated with falling ($p < 0.05$) were tested in a univariate and multivariate logistic regression analyses. In the univariate analysis, variables related to falling were identified and the odds-ratio assessed to identify risk of falling. Secondly, using these identified variables, stepwise backward logistic regression was used in order to make a multivariate model. Odds ratio with 95% confidence interval (CI) were calculated. Where multi-collinearity was present, the variable with the best model fit (based on 2 log likelihood), was retained. Statistical analysis was performed using Statistical Package designed for the Social Sciences (IBM SPSS 19.0 Statistics).

RESULTS

Within a period of four months, 2007 questionnaires were distributed. In total, 954 questionnaires (47.5%) were returned. From these, 75 did not meet the age inclusion criterion. From the remaining, 22 had not answered the question whether they had fallen since 59 years old, so they were also excluded. In result, 857 questionnaires were included for the description of population.

Description of the population

Table 1 presents the characteristics of the self-reported fallers (416) and the non-fallers (441). As can be studied in Table 1, for both groups, the distribution within a variable was (almost) equal for the variables: age, gender, provinces (north, middle, south), bicycle type (e-bike, c-bike, both) and physical impairments. However, the majority from this population are living in a rural environment, compared to an urban environment. The bicycle model on which this population cycled, was mainly a lady's model. In case of an electrical bicycle, more than half have their engine located in their front wheel, followed by rear-wheel. The cycling frequency during summer and winter is different: Most respondents cycle every day in the summer and cycle less in the winter. The vast majority take the time of the day into account, or the weather into account. More than 70% of the respondents state their own health as '(very) good', with a vast majority carrying out light activity or average activity in daily life. More than 70% do not use medication that influences driving. A higher percentage in the non-fallen group can be found on the variables 'cycling certainty' and 'cycling confidence', compared to fallers. This pattern can also be found at mental impairments, which are more present in the fallen-group, compared to the non-fallen group. Most mentioned mental impairments were 'feeling uncomfortable in complex and busy traffic situations', 'fear of falling' and 'having to focus to a large degree'. A low percentage of this population states to violate the traffic rules. Finally, it was found that a large proportion has changed their cycling behaviour since they became 50 years of age. Statistical significant differences ($p < 0.05$) between the two groups for the assessed variables can be found in the fourth column of Table 1.

Table 1. Characteristics for the entire group as for the fallers and non-fallers.

	Fallen n=416	Non-fallen n=441	p
Age (Mean in years, SD)	73.5 (5.9)	71.2 (5.2)	<0.001
Gender (n)	403	433	0.093
Male (n, %)	173 (42.9%)	211 (48.7%)	
Female (n, %)	230 (57.1%)	222 (51.3%)	
Province (n)	416	440	0.249
North	141 (33.9%)	163 (37.0%)	
Middle	146 (35.1%)	163 (37.0%)	
East	129 (31.0%)	114 (25.9%)	
Living environment (n)	404	429	<0.001
Rural	284 (70.3%)	348 (81.1%)	
Urban	120 (29.7%)	81 (18.9%)	
Bicycle type (n)	405	433	0.204
E-bike & C-bike	127 (31.4%)	116 (26.8%)	
E-bike	123 (30.4%)	127 (29.3%)	
C-bike	155 (38.3%)	190 (43.9%)	
Bicycle model (n)	399	434	<0.005
Ladies	304 (76.2%)	288 (66.4%)	
Gents	95 (23.8%)	146 (33.6%)	
Place of the engine (n) [a]	245	235	0.579
Front wheel	128 (52.2%)	126 (53.6%)	
Rear wheel	73 (29.8%)	74 (31.5%)	
Middle	25 (10.2%)	24 (10.2%)	
Don't know	19 (7.8%)	11 (4.7%)	
Cycling frequency winter (n)	413	438	0.390
Every day	146 (35.4%)	144 (32.9%)	
Min. once a week	184 (44.6%)	220 (50.2%)	
Min. once a month	41 (9.9%)	37 (8.4%)	
Don't cycle	42 (10.2%)	37 (8.4%)	
Cycling frequency summer (n)	414	439	0.186
Every day	276 (66.7%)	286 (65.1%)	
Min. once a week	120 (29.0%)	140 (31.9%)	
Min. once a month	14 (3.4%)	13 (3.0%)	
Don't cycle	4 (3.4%)	0 (0.0%)	
Takes time of the day into account (n)	408	437	0.301
No	254 (62.3%)	287 (65.7%)	
Yes *(such as, avoiding darkness)*	154 (37.7%)	150 (34.3%)	

(continued on next page)

2

Table 1 (continued)

	Fallen n=416	Non-fallen n=441	p
Takes weather into account? (n)	400	428	0.481
No	61 (15.3%)	73 (17.1%)	
Yes *(such as, avoiding snow/fog/rain)*	339 (84.8%)	355 (82.9%)	
General health perception (n)	412	440	0.034
Excellent	31 (7.5%)	53 (12.0%)	
Very good	91 (22.1%)	97 (22.0%)	
Good	232 (56.3%)	251 (57.0%)	
Fair	57 (13.8%)	37 (8.4%)	
Poor	1 (0.2%)	2 (0.5%)	
Activity level (max) (n)	402	433	0.028
Light movement *(activities such as easy walking, household work)*	161 (40.0%)	137 (31.6%)	
Average movement *(activities such as aerobics, swimming, brisk walking)*	186 (46.3%)	219 (50.6%)	
Intensive movement *(activities such as strenuous sports, running)*	55 (13.7%)	77 (17.8%)	
Uses medications that influence driving (n)	416	441	0.092
No	309 (74.3%)	349 (79.1%)	
Yes	107 (25.7%)	92 (20.9%)	
Certainty during cycling (n)	406	436	<0.001
Complete certain	193 (47.5%)	289 (66.3%)	
Less than complete certain	213 (52.5%)	147 (33.7%)	
Confidence in own cycling (n)	408	434	<0.001
Complete confidence	206 (50.5%)	315 (72.6%)	
Less than complete confidence	202 (49.5%)	119 (27.4%)	
Cycles less than when 50 years old (n)	411	429	<0.001
Yes	124 (30.2%)	82 (19.1%)	
No	287 (69.8%)	347 (80.9%)	
Cycles more than when 50 years old (n)	397	424	0.607
Yes	212 (53.4%)	234 (55.2%)	
No	185 (46.6%)	190 (44.8%)	
Physical impairments (n)	399	432	<0.001
No	163 (40.9%)	244 (56.5%)	
Yes	236 (59.1%)	188 (43.5%)	
Mental impairments (n)	397	429	<0.001
No	194 (48.9%)	332 (77.4%)	
Yes	203 (51.1%)	97 (22.6%)	

(continued on next page)

Table 1 (continued)

	Fallen n=416	Non-fallen n=441	p
Violating traffic rules (n)	410	433	0.082
No	318 (77.6%)	338 (78.1%)	
Yes	92 (22.4%)	95 (21.9%)	
Changed cycling behaviour since 50 years (n)	413	437	<0.001
No	43 (10.4%)	88 (20.1%)	
Yes *(such as more patience, lower speed, avoiding situations)*	370 (89.6%)	349 (79.9%)	
Bicycle adaptations (n)	408	433	<0.001
No	277 (67.9%)	343 (79.2%)	
Yes *(low entry, sidewheels, mirrors)*	131 (32.1%)	90 (20.8%)	

Note. E-bike is an electric bicycle and C-bike a common European City Bike; n = number of participants; min is minimum.

[a]Some categories do not add up to the total number of participants because of missing answers. For example; the number of respondents for 'place of engine' do not add up to the total number of participants who used an e-bike as there are missing answers for the question about 'bicycle type (e-bike and c-bike, e-bike, c-bike). This same applies to some other categories.

2

Univariate analysis comparing fallers and non-fallers

First a subset of independent variables, that were univariate associated with self-reported falling were identified, namely changed cycling behaviour (such as being more patient, cycling at lower speed, avoiding situations), physical impairments, health, bicycle model, bicycle adaptations (such as low entry, sidewheel, mirrors), activity level, age, mental impairments, living environment, confidence and cycling frequency.

The risk that somebody has fallen increases; with every year the cyclist gets older; when the cyclist has mental or physical impairments; when living in a rural environment; when less than completely confident or less than completely sure during cycling; with changed cycling behaviour since 50 years of age; with bicycle adaptations; with a fair general health perception and with a low activity level. The risk that a cyclist has fallen decreases; when the perception of general health is good; when using a gent's bicycle model and when the cyclist did not reduce cycling less since the age of 50. The results of the univariate regression analysis, comparing all self-reported fallers with non-fallers are shown in the three left columns in Table 2.

Multivariate analysis of fall factors

Second, stepwise backward logistic regression analysis was used in order to make a multivariate model. The univariate variables significantly related with a self-reported fall were included in the model. Because of multicollinearity between 'cycling confidence' and 'cycling certainty' only the variable with the best model fit was entered to the multivariate regression model, which was 'cycling confidence'.

The multivariate regression model revealed that the following four variables were significantly related to a self-reported fall. (1) Age, for each year the cyclist is older (starting at 65 years of age), the risk that they have fallen increases with 7.3%. (2) Mental impairments: in case of experience mental impairments, the risk they have fallen increases with a factor 2.5. (3) Confidence level: If cyclists are less than completely confident while cycling, the risk they have fallen increases with a factor 1.8. And (4) living environment: if cyclists live in a rural environment compared to urban environment, the risk they have fallen increases with a factor 2.1. The results comparing all fallers with non-fallers using multivariate logistic regression analysis are shown in the three right columns of Table 2.

Table 2. Univariate & multivariate logistic regression analyses of the variables related to self-reported falling within demographic, bicycle and personal factors. With CI = confidence interval, uOR = univariate Odds Ratio, mOR = multivariate Odds Ratio with corresponding p-value.

	uOR	95%CI	p	mOR	95% CI	p
Age	1.08	1.051-1.109	<0.001	1.07	1.042-1.106	<0.001
Mental impairments			<0.001			<0.001
No –	–			–		
Yes	3.58	2.654-4.834		2.51	1.79-3.52	
Physical impairments			<0.001			
No –	–	–				
Yes	1.88	1.426-2.476				
Bicycle model			=0.002			
Ladies –	–	–				
Gents	0.62	0.455-0.836				
Living environment			<0.001			<0.001
Rural	1.82	1.315-2.506		2.06	1.440-2.953	
Urban –	–	–		–	–	
Cycling confidence			<0.001			=0.001
Yes, completely –	–	–				
No, no completely	2.60	1.949-3.460		1.80	1.293-2.152	
Cycling certainty			<0.001			
Yes, completely –	–	–				
No, less than completely	2.17	1.643-2.865				
Changed cycling behaviour since 50 years			<0.001			
Yes	2.17	1.465-3.214				
No –	–	–				
Adapted Bicycle			<0.001			
Yes	1.80	1.320-2.461				
No –	-	-				
General health perception			<0.05			
Excellent	0.63	0.392-0.102				
Very good	1.12	0.724-1.422				
Good –	–					
Fair	1.67	1.062-2.616				
Poor	0.54	0.049-6.005				
Activity level			<0.05			
Light	1.38	1.025-1.868				
Moderate –	–	–				
Intensive	0.84	0.565-1.251				
Cycling less than at the age of 50			<0.001			
Yes –	–	–				
No	0.55	0.397-0.753				

DISCUSSION

The aim of this study was to gain insight into personal characteristics of older cyclists and factors associated with their bicycle fall risk. The current study sought to attain understanding of fall risk in this age group through the inclusion of general factors related to common cycling, personal factors related to the cyclists and living habits. Therefore, characteristics of older cyclists were assessed, by means of a questionnaire, and the relationship between these self-reported personal factors and self-reported cycling accidents were studied. In this study, 48.5% of the participants reported at least one fall since they became 59 years old. Univariate factors related to falling were: age, mental impairments, physical impairments, living environment, feeling not confident, or feeling uncertain, while cycling and adaptation of cycling behaviour. The actual variables, which were independently significantly related to a self-reported fall were age (for each year the cyclists are older (starting at 65 years of age), the risk they have fallen increases with 7.3%), mental impairments (in case of experience mental impairments, the risk they have fallen increases with a factor 2.5), confidence level (if cyclists are less than completely confident while cycling, the risk they have fallen increases with a factor 1.8) and living environment (if cyclists live in a rural environment compared to urban environment, the risk they have fallen increases with a factor 2.1).

Of the 2007 questionnaires that were distributed, 47.5% were returned. This high response rate could be due to a selective distribution, in which the cycling school could pay a role. In total, 857 older cyclists, aged 65 or over, completed the questionnaire about demographics, mental and physical impairments, cycling habits and cycling experiences. The respondents from this study were all frequent cyclists displaying common Dutch cycling behaviour. The mentioned physical and mental impairments are common for this age group (OECD, 2001). According to Fildes, Langford, Pronk, and Anderson (2000) the disabled conditions associated with ageing that have an impact on driving conditions or accident risk include sight- and hearing disabilities, cognitive and motor functions, and a decrease or loss of strength and endurance. This corresponds with the physical limitations of older cyclists in the Netherlands (SWOV, 2010, 2014), namely; reduced sight and hearing abilities, increased stiffness of the neck and decreased motor skills and strength. In general, the study sample is representative for the Dutch older cyclists' population.

The number of self-reported falls in this study is much higher than the official number in road accident statistics. This may be explained by the fact that serious injuries requiring medical treatment or medical damage not always occur after a self-reported fall and thus such falls are not reported as bicycle accidents in the accident database. The questionnaire did not address injury severity as result of their self-reported falls. A major strength of our study however is that it allows for the identification of personal factors associated with self-reported cycling accidents in the older population, by conducting this questionnaire in a very large group of older cyclists. These factors give more insight in accidents with not per definition, serious injuries as a result, but also minor consequences. These factors are expected to help answer a wide range of theoretical and practical questions concerning traffic psychology.

The results showed that older cyclists are at greater risk of having a self-reported fall for each year they become older. According with the literature, age is significantly associated with increased risk of falling off a bicycle (Boufous, de Rome, Senserrick, & Ivers, 2012; Bíl, Bílová, and Müller, 2010; Kaplan, Vavatsoulas, & Prato, 2014; Martinez-Ruiz et al., 2015; Martínez-Ruiz et al., 2014; Schepers & Vermeulen, 2012; Siman-Tov et al., 2012). From the literature it is known that with increasing age, cyclists are more likely to have more serious injuries when diagnosed at the emergency department after an accident (Kaplan et al., 2014; Siman-Tov et al., 2012). The latter may be explained by the fact that older adults are more vulnerable in general (Martínez-Ruiz et al., 2014). The findings in this study suggest that the higher risk of sustaining more serious injuries for older cyclists may not just be caused by the older cyclists being more vulnerable, but also when the cyclist ages, the higher the chance they have fallen off their bicycle. In general, it can be stated that when people cycle more or cycle more kilometres, they have more chance to fall, due to more exposure.

In addition to age, other important fall related factors are mental impairments and not being completely confident regarding cycling. This stresses the importance of keeping the older adult not only physically healthy, but also mentally healthy.

The finding that living in a rural environment is related to more self-reported falls is in can be explained by the study from Boufous et al. (2012), who concluded that cyclists are especially at risk in rural areas. Shown by Lawson, Ghosh, and Pakrashi (2015) was that preference to cycle in an urban environment was significantly improving the perception of cycling safety. Empirical studies show that fall risk decreased as exposure increases (Elvik, 2009), so cycling frequency seems to have an influence. Besides that, the Safety in Number phenomenon (Jacobsen, 2003) is a factor which normally contributes to a safer environment for cyclist safety in crowded traffic, as can be found in urban areas. This phenomenon refers to the adaptive behaviour of motorist when there is a high incidence of cyclists. However, in contrast with this, Hagemeister and Tegen-Klebingat (2012) found that in general cycling in the city is more dangerous than elsewhere. Reason for this can be that cyclists are especially at risk on intersections (Dozza & Werneke, 2014), at curves (Boufous et al., 2012) and on designated cycling infrastructure (Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert, 2015), which are all elements that are more common in urban areas than in rural areas. Perhaps, at such infrastructure, accidents occur more often with other road users, possibly leading to more severe injuries and thus are more frequently reported in accident analysis studies. Furthermore, we did not ask whether the respondents in this study cycled usually in a rural environment or in an urban environment: it is possible that some respondents avoided certain (urban) situations, like busy city centres or complex roundabouts. As know from Davidse (2007), older car drivers tend to compensate for their functional limitations, which can prevent safety problems. It is also possible that older cyclists spend more time in rural areas for example for recreational cycling. Environmental factors, like sharing the road with motorized traffic (Kaplan et al., 2014), involvement of other road users (Heesch, Sahlqvist, & Garrard, 2011), high speed limits (Boufous et al., 2012; Kaplan et al., 2014) are all related to an increased fall risk and injuries risk. Schepers and den Brinker (2011) investigated single-bicycle crashes types and characteristics in more detail. They concluded that the visibility of the infrastructure can play an important role in single bicycle accidents. Visibility might be a bigger issue in rural areas compared to urban areas for older cyclists. Concluding, the fact that the cycling infrastructure outside urban areas is different from the infrastructure in urban areas, may play a role with regard to falling off their bicycle in rural areas.

In this study, self-reported falls were not associated with violating traffic rules, which is not in agreement with the results from the study from Hagemeister and Tegen-Klebingat (2012), who found self-reported violating traffic rules as an important predictor in the accidents risk of the older cyclist in Germany. In agreement with Hagemeister and Tegen-Klebingat (2012), physical impairments and distance of cycling were not related to self-reported fall risk, however; physical impairments are related to problems with mounting and dismounting the bicycles, which are cycling tasks related to a higher accident risk (Ormel, Klein-Wolt, & Den Hertog, 2008). Furthermore, Hagemeister and Tegen-Klebingat (2012) found that cyclist who cycled daily or nearly daily had a higher accident fall risk than cyclists who cycled less often. This finding is not confirmed in our study, but this can be explained by the fact that the study population from our study were mostly frequent cyclists and that the German cycling infrastructure differs from the Dutch cycling infrastructure.

This study has some limitations. Despite we assume that the study sample in general is representive for the Dutch older cyclist's population, it should be kept in mind that the recruitment strategy could have had influence on the selection of respondents. The respondents were in the majority participants of the cycling lessons of the Dutch Cycling Union. It is possible that these older adults are more aware of their cycling behaviour and in particular of their limitations. They may feel more insecure while cycling and have therefore joined the cycling lessons. In addition, from the questionnaire responses we know if people had a falling accident after being 59 years of age, but we do not know at what exact age they had the accidents and how the exact situation was. We checked the characteristics for the participants recruited through the cycling lessons and compared them with the characteristics for the participants recruited in another way and there were no differences in percentages of falls and most of the other characteristics. The only characteristics that differed were 'gender (more women in the cycling lesson group), living environment (more rural in the cycling lesson group), place of engine (more front wheel in the cycling lesson group) and adaptations in cycling behaviour (more adaptations in the cycling lesson group).

As stated by Prati, Puchades, and Pietrantoni (2017), cyclists as a group of road users have been banned to a second position. In order to encourage safe cycling, we need to reduce the hazards that cyclists face. From the literature it is known that regular daily physical exercise through cycling has great health benefits, Fishman et al. (2015) claim that Dutch people have half-a-year longer life expectancy due cycling. It is therefore important to understand how cycling safety can be improved. By gaining knowledge about the factors that are associated to falling, it might be possible to prevent cycling accidents in future. Recommendations for practitioners could be to focus more on the mental health and level of confidence of older cyclists. For the cycling infrastructure it is be important to make the rural environment safer for the older cyclists. As found by Schepers, Twisk, Fishman, Fyhri, and Jensen (2017), a lower motor vehicle driving speed on so-called ‘mixed roads’, where cyclists are on same road as motor vehicles, contributed to a high level of cycling safety in the Netherlands. Future research should focus more on longitudinal quantitative research on personal factors that predict cycling fall accidents.

In conclusion, four characteristics of the older population and self-reported factors are associated to an increased risk of a fall accident: increasing age, experiencing mental impairments, lack of cycling confidence and living in rural environment. If possible, these factors should be taken into account when implementing new cycling related safety measures.

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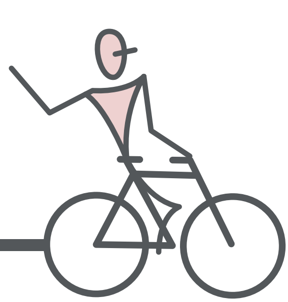

Chapter 3

The acceptance of a prototype rear-view assistant for older cyclists: two modalities of warnings compared

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ABSTRACT

The aim of this study was to evaluate the effects on behaviour, mental effort and acceptance of a simple prototype of an electronic rear-view assistance system designed for older cyclists that are at risk of falls. The prototype was incorporated into a simple cycling simulator and provided information about traffic from behind in two modalities: visual and haptic. Twenty-one older participants (>64 years) completed three conditions: warnings in two modalities and a control condition without warnings. Mental effort and acceptance were assessed using subjective rating scales and by monitoring changes in cycling speed. Less mental effort was reported when using the rear-view assistant. Significantly more correct decisions regarding a safe left turn were made with system advice. No significant speed differences were found between the two modality conditions. It is concluded that the electronic rear-view assistance system can potentially support the older cyclist successfully by warning for traffic coming from behind.

INTRODUCTION

People in the Netherlands have a strong cycling ethos. Thanks to the introduction of the electric bicycle, older cyclists (65 years and older) typically continue cycling for more years than previously. However, older cyclists are at increased risk of injury (van Boggelen et al., 2005; Ekman et al., 2001; Oxley et al., 2004). Cyclists have a mortality rate eight times as high as that of car occupants (CEC, 2000; Ekman et al., 2001). Besides that, the risk of older cyclists being injured in a cycling accident in the Netherlands is on average 3.2× higher than for younger cyclists (Zeegers, 2010). Also injury severity increases with age (Oxley et al., 2004; Twisk et al., 2013). Even more important is that older cyclists are overrepresented in the group of seriously injured cyclists involved in single-sided accidents (Berveling and Derriks, 2012); accidents in which there is no other party directly involved (Weseman and Weijermans, 2011).

Turning left on a crossing is in particular considered as a problem by older cyclists in right-hand drive countries (Goldenbeld, 1992; SWOV, 2013). Older cyclists may have difficulty looking over their shoulder due to stiffness of the neck. In such cases, older cyclists often use the strategy of dismounting their bicycle (Bernhoft and Carstensen, 2011). However, dismounting is a potential risk to fall for older cyclists since many accidents occur while mounting or dismounting their bicycle (Hagemeister and Tegen-Klebingat, 2012). Another strategy can be to turn left in two steps, that is first cross one street and then the other (Hagemeister and Tegen-Klebingat, 2011). Or, as a compensatory strategy, many older cyclists rely on their hearing ability when turning left (Goldenbeld, 1992). However, it is dangerous to rely entirely on auditory information for several reasons. First, for older cyclists, hearing abilities reduce with age (Gordon-Salant, 2005). Second, the increasing amount of silent motorised traffic (electric and hybrid cars and motorbikes) is a complicating factor (Schoon and Huijskens, 2011). Another way to handle the complex situation of deciding whether it is safe to turn, may be to reduce cycling speed and hence increase the time available to process traffic information. However, it can be questioned whether slowing down is the best strategy. With reducing speed, a bicycle becomes less stable, and therefore the risk of balance problems and consequently falling increases (Hubbard et al., 2011; Moore et al., 2011; Schwab et al., 2012).

Information about traffic approaching from behind could be made available to the cyclists in a straightforward way by adding a rear-view mirror to the bicycle. However, older cyclists often choose not to use a mirror as it confronts them with their limitations and makes this visible to others. Besides that, disabilities generally increase gradually and people like to hold on to old habits and behaviours (Berveling and Derriks, 2012). Furthermore, good mirrors in which traffic from behind is always visible are difficult to find (Fietsberaad, 2012). To increase the opportunity for older cyclists to continue cycling safely for as long as possible, a solution other than a mirror that can inform about traffic approaching from behind is therefore considered.

One possible way of making cycling for the elderly safer is to provide them with information about traffic approaching from behind. A so-called rear-view cycling assistance system could eliminate the need to look over one's shoulder or in a mirror. Although an actual rear-view cycling assistant or a working warning prototype is not available yet, in this study, such a system has been simulated to see how cyclists respond to it. This kind of technology is comparable to advanced driver assistance systems (ADAS), in-vehicle information systems and intelligence transport systems, such as collision avoidance systems in cars. ADAS can provide personal assistance in a traffic environment (Davidse, 2007). Several studies have suggested that ADAS may be able to provide tailored assistance for older drivers (Bekiaris, 1999; Dotzauer et al., 2015; Färber, 2000; Mitchell and Suen, 1997). However, handing over control to a device and automated functions are evaluated as negative aspects of assistance systems (Hoedemaeker, 1996; Hoedemaeker and Brookhuis, 1998). Therefore, during the design process of an assistance system, one has to take into account that end-user acceptance is an important prerequisite for implementation success (Brookhuis and van Driel, 2008; Van der Laan et al., 1997). In this sense, a rear-view cycling assistant system requires a design that is acceptable to its potential users in our case of older cyclists, and provides the optimal desired support.

A second issue that has to be considered when introducing ADAS is their impact on mental workload: the amount of information processing capacity that is used for task performance (Brookhuis and de Waard, 1993; 2000; de Waard, 1996). There is evidence that traffic communication and information systems can lead to an increased mental workload (Jahn et al., 2005), which might have a negative effect on safety (Verwey et al., 1996). Nevertheless, many positive examples of introducing ADAS in cars have been reported. Davidse (2007) concluded that information systems in cars can make the driving task easier without negative effects on workload. Brookhuis et al. (2008) stated that driving with a traffic-congestion assistant in cars potentially leads to decreased driver mental workload and acceptance is generally high after experiencing the system.

So far, no studies have evaluated the usage of traffic information systems on bicycles, hence we do not know if such a system would be accepted by older cyclists nor if such a system would have the potential to enhance cycling safety. Therefore, the aim of this study was to evaluate the acceptance of a prototype rear-view assistance for older cyclists by comparing two warning modalities (visual-light, haptic-vibration) for traffic from behind, compared to a control condition. The two warning types were compared with regard to acceptance, effects on mental effort and cycling speed. Also the extent to which cyclists follow the advice (whether it is safe or not to cross an intersection) which is related to acceptance of the system was assessed. We focused on the effects of rear-view assistance on mental effort and acceptance of the system by older cyclists, because these two factors are crucial for the successful implementation of any new system. To analyse the safety potential of the system, cyclists' decisions to follow the advice of the system or not were related to whether it actually was safe or not to cross the intersection. Cycling speeds both before and after a warning for traffic from behind were compared to assess behavioural adaptation to these warnings. It was expected that taking the decision on whether it was safe or not to cross would be mentally demanding and accordingly respondents might compensate by slowing down.

METHOD

Participants

In total, 21 cyclists participated in this study. Participants were included if they were older than 64 years and cycled frequently (weekly) on a conventional or an electric bicycle. The included participants were between 64 and 78 years old and their average age was 69.8 years (SD: 4.4). Ten female participants and eleven males took part. Participants were recruited through a local newspaper advert and by the word of mouth. The participants were fully informed in advance and gave informed written consent to participate in the test. The test design, protocol and used equipment were approved by the regional Medical Ethics Research Committee. The participants were asked if they had difficulty looking at traffic approaching from behind when cycling.

Material

A simple and safe, cycling-in-traffic simulator was developed at Roessingh Research and Development that consisted of an instrumented bicycle, positioned on a cycle training stand (TACX T2650BluematicCycletrainer). The bicycle stayed firmly on the ground in the laboratory environment, but the front wheel was able to move. This setting was considered necessary to ensure sufficient safety during this stage of the design process. Furthermore, when cycling straight, the cycling motions are very limited (Moore et al., 2011). A fixed resistance was set up on the bicycle to simulate a natural cycling resistance. The instrumentation of the bicycle consisted of speed sensors built into the rear wheel of the bicycle. The rear-view assistant's feedback was evaluated in two modalities:

1 haptic vibration actuators (eccentric rotating mass pager motors) mounted in the handles
2 a visual LED display containing two red and two green LEDS mounted on the handle bar.

The bicycle was positioned in front of a large TV screen (65 inch) on which a video was shown. Two-and-a half metre behind the bicycle, a 71-inch screen was placed, on which a still picture of traffic from behind was shown. This set-up was chosen because, when normally cycling and looking over one's shoulder, there is only limited time, which is comparable to a still view. The participants had to anticipate for traffic coming from behind when turning left. The screen was placed under the angle of 67.5° from the bicycle. Together, the screens displayed a typical cycling environment (Figure 1). No traffic sound was available.

Figure 1. Experimental set-up. On the left a schematic overview, and on the right a close up of the vibrating handles and the LED display.

The software for the bicycle simulator was written in Python 2.6. The software controlled the display of the video in front of the bicycle and of the still image of the traffic situation behind the bicycle. The display speed of the video was matched to the cycling speed of the participant, so the video started when pedalling started. Steering did not affect the images displayed. Signals from the sensors from the instrumented bicycle were sampled at 1000 Hz using a NI USB-6008 12-bit multifunction DAQ (National Instruments, Austin, USA). The actuators were controlled by digital and analogue signals generated via the NI USB-6008 DAQ mentioned earlier.

Measures

Rating scale mental effort

The Rating Scale Mental Effort (RSME, Zijlstra, 1993) was used to assess mental effort, which was based on the cyclist's subjective rating of invested effort. The RSME is a unidimensional rating scale consisting a line with a length of 150 mm marked with nine anchor point, each accompanied by a descriptive label indication a degree of effort, ranging from 'no effort-some effort' (score 2/38) to 'extreme effort' (score 112, max score 150). The RSME has proven to be good self-report measure of mental workload (Zijlstra, 1993; Widyanti et al., 2013) and correlates well with other subjective methods to assess mental workload, such as the NASA TLX (Veltman and Gaillard, 1996).

Acceptance scale

Acceptance of the system was assessed using an acceptance scale (Van der Laan et al., 1997) after each test condition (vibration, light and control condition). This scale includes the following opposing items: 'useful-useless', 'pleasant-unpleasant', 'bad-good', 'nice-annoying', 'effective-superfluous', 'irritating-likeable', 'assisting-worthless', 'undesirable-desirable' and 'alertness increasing-sleep-inducing'. Each set of opposite items was scored using a semantically differential 5-point Likert scale. The scale results consist of two subscales that reflect acceptance in two dimensions: usefulness and satisfaction.

Cycling speed
A movement sensor in the rear wheel sampled the position of the wheel at 1000 Hz. Cycling speed was derived from this signal and expressed in metres per second (m/s).

Procedure
The experiments were carried out in a laboratory setting on the cycling-in-traffic simulator at Roessingh Research and Development in Enschede, the Netherlands. The video started when the participant started pedalling. The video showed the cyclist on a street approaching a non-priority intersection, meaning that priority should be given to traffic approaching from the right. At a predefined moment, the participants were asked whether it would be safe to either ‘cross the intersection’, ‘turn left’, or ‘turn right’. The participants were asked to just reply with ‘yes’ or ‘no’ and the experiment leader pressed a button when the answer was given. There were three conditions assigned in random order to each participant. Each condition was practised at least four times before the actual experiment started.

1 Light warning condition: the cyclist was warned about traffic from behind by LED lights on the handlebar (red: traffic from behind, green: no traffic behind). The warning signal only turned green or red in the vicinity of the intersection.

2 Vibration warning condition: the participant was warned for traffic from behind by vibrating handles. If there was no traffic behind, the situation was considered safe and no warning was given.

3 Control condition: no information was given and therefore the participant did not receive any warning.

In each condition, the participant could look over his or her shoulder to check the rearscreen to see if there was traffic approaching from behind. Within each condition, 14 different traffic situations were randomly assigned to the participants: eight of them were about turning left, four about going straight on and two about turning right. Each of the 14 videos lasted approximately 40 s and each condition lasted approximately 10 min. In both experimental conditions - light and vibration - participants received a warning of traffic approaching from behind in six of the scenarios. The warning (haptic or visual) was given based on the traffic situation that was behind them, independently of the turn instructions. Thus, if participants were asked whether they could turn right and there was traffic from behind, they were accordingly informed visually or haptically in both experimental conditions, but not in the control condition.

After each experimental condition, participants were asked to complete the RSME and the Acceptance Scale, with regard to acceptance of the rear-view assistant and the invested mental effort. Invested mental effort was also rated after the control condition. In total, the experiment lasted approximately one hour to one hour and a half.

Instructions
Before the experiment, it was explained that the experiment was about a simple rear-view assistance prototype. The participants were asked to mount the bicycle and there was time to get used to the bicycle and the situation. Before the start of every condition four example videos were played. The participants were informed that they would approach and cross an intersection and needed to answer the question whether it was safe to turn right, to turn left or to go straight. The participants were asked to reply with a simple 'yes' or 'no'. It was stressed that they needed to answer whether they experienced the manoeuvre to be safe or unsafe to actually perform. The participants were asked to make a similar decision as they would when cycling in the real world. Although we tried to make the simulation as realistic as possible, there was no possibility to merge to the centre of the road in this simulator and this was explained to them. The approached intersection in the simulator was a junction where priority should be given to traffic approaching from the right. The video stopped just after crossing the intersection.

Dependent variables and analysis
The four main outcome parameters were:

1. Subjective effort as assessed using the RSME.
2. Acceptance as assessed using the Acceptance scale (usefulness, satisfying).
3. Cycling speed, assessed as change in cycle speed from before to until 3 s after the question was asked.
4. Correctness of the decision on the question whether it was safe to cross the intersection, turn right or turn left ('safe-crossing question').

This is a measure of the extent to which cyclists use the information of the system. These four main outcome parameters were analysed in the following way:

1. The effects of the three test conditions on the scores of the RSME were analysed with a repeated measures generalised linear model, after the data were visually checked for normality. Sidak post-hoc tests were used to identify between which conditions significant differences existed.

2 The results of acceptance of the rear-view assistance system concern the scores on the two acceptance subscales, namely usefulness and satisfaction, obtained by implementing the procedure described in Van der Laan et al. (1997). Subscale averages were calculated for the two warning conditions. It was checked that there was not a period-effect in the data, meaning the order of the conditions did not lead to variability in the results. The data of the acceptance scale were not normally distributed; therefore a Wilcoxon ranked test was used to test for statistical differences.

3 Cycling speed. Baseline cycling speed was determined at 1 s before the 'safe-crossing question' was asked. One second was chosen as baseline speed in order to give participants enough time to reach a constant speed after a new scenario was started. We performed repeated measures analysis according to mixed model methods, during which we averaged baseline cycling speed per condition (average of 14 scenarios) comparing average cycling baseline speed per condition over all respondents. Cycling speed 3 s after the 'safe-crossing question' was determined and compared to baseline speed to assess the effect of the 'safe-crossing question' on cycling speed. Three seconds was chosen because this point is after the warning for traffic from behind (if applicable) and (usually) before answering the 'safe-crossing question'. It was expected that this moment would be mentally demanding and respondents might compensate by slowing down if mental workload was high. The difference in cycling speed 1 s before and 3 s after the 'safe-crossing question' was analysed with a 'Mixed Model' for a repeated measurement with baseline speed taken into account.

4 The experiment leader scored the answers to the question 'is it safe to turn left, turn right or go straight'. This can be used as the extent to which cyclists use the information of the system. The decision (on the 'safe-crossing question') was scored 'correct' or 'incorrect', which was judged on the traffic situation in which the participant was cycling and on behaviour that is considered to be appropriate in the Netherlands, like following the traffic rules. It was expected that more correct decisions would be made in the warning conditions compared to the control condition. The percentage of correct decisions (excluding missing answers) for the three corresponding scenarios was compared based on descriptive statistics.

All data were analysed using IBM SPSS 19.0 Statistics.

RESULTS

Participants

All participants (n = 21) finished the two experimental conditions, one participant did not complete the control condition because of dizziness. Eleven participants reported that they were able to look over their shoulder, nine reported having difficulties looking over their shoulder and one reported not being able to look over the shoulder at all.

Rating scale mental effort

In Table 1, an overview of the mean scores (range 0–150) on the RSME is given. A higher score on the RSME corresponds to higher experienced effort. 'Mixed Model' analysis displayed a significant difference between the three conditions ($F(2, 20.077) = 4.437$, $p = 0.025$).

Table 1. Overview of the results from the rating scale mental effort (RSME), mean and standard deviation (SD)

Condition	*RSME mean score (0-150) (SD)*	δ^{a}
Control	36.2 (5.3)	
Haptic warning: vibration	24.0 (3.4)	0.50
Visual warning: light	24.9 (3.8)	0.46

[a]Effect size compared to control condition.

Additionally, Sidak post-hoc tests were performed to identify conditions between which significant differences existed. The control condition without warning took significantly more effort than the light condition (Δ11.3; 95% CI: 1.3–21.3, $p = 0.024$). The control condition compared to the vibration condition did not reach the 5% level of statistical significance (Δ12.2; 95% CI: −1.5 to 26.0, $p = 0.092$). No differences were found between the two types of warning conditions.

Acceptance scale

Acceptance of the rear-view assistance systems was assessed with a simple acceptance scale that consists of two subscales; usefulness and satisfaction (Van der Laan et al., 1997). In general, the participants were very positive about the rear-view assistance system, both in terms of usefulness and satisfaction (scale range −2 to +2) and in both conditions (light and vibration); see Table 2.

Table 2. Median and interquartile ranges (ICR) for the van der Laan subscales (usefulness, satisfaction) (scale range −2 tot +2) and the results of the Wilcoxon ranked test

	Light	*Vibration*	*Z*	*P*
Usefulness median (IQR)	1.4 (0.6–1.9)	1.8 (0.8–2.0)	-1.616	0.11
Satisfying median (IQR)	1.25 (0.4 –2.0)	1.25(0.6–1.9)	-0.141	0.88

As can be seen in Table 2, no significant difference was found between the two versions of the rear-view assistant regarding the two subscales of usefulness and satisfaction, tested with a Wilcoxon ranked test. However, most participants reported that they appreciated the rear-view assistant and preferred the vibration over the light signal.

Cycling speed

Baseline speed

The average speed 1 s before the 'safe-crossing question' was used as the cycling baseline speed. During this stage, the participants did not receive a warning. Repeated measures analysis demonstrated there was no significant difference between the three conditions in baseline speed (Table 3).

Table 3. Baseline cycling speed in meters per seconds (m/s): cycling speed 1 s before the question was asked

Condition	*Avg. baseline speed (SD) (m/s)*	*Avg. speed after warning*	δ^a
Control	2.88 (0.10)	2.83 (0.09)	
Light	2.79 (0.08)	2.75 (0.07)	−0.02
Vibration	2.75 (0.10)	2.83 (0.08)	0.21

[a]Effect size compared to control condition.

No difference between conditions in change in cycling speed was found between the three different conditions ($F(2,20) = 1.636$, $p = 0.220$). So cycling speed did not differ between the different conditions after the respondents received a warning when there was traffic approaching from behind in the experimental conditions.

Correct decision on the 'safe-crossing' question

The experiment leader scored the answers to the question 'is it safe to turn left, turn right or go straight?' The answer in the experimental conditions reflects whether they used the information of the system. To analyse the answers given, the scenarios were grouped based on traffic coming from behind (safe-unsafe) and the decision of the turn (left, right, straight). In the end, we only analysed two situations:

1 the turn left-unsafe situation.
2 the turn right-unsafe situation.

Other situations could not be evaluated, because the scenarios did not correspond to each other, because there was too much difference in terms of risk and danger. In these cases, the situations were more ambiguous, so the researchers could not easily tell whether it was actually safe or unsafe to cross the intersection. For example, it depended on many other factors, such as a personal preference to let other traffic pass. In these situations, a decision could not be classified as 'correct' or 'incorrect'.

To determine if the rear-view assistant is helpful in taking the correct safety decision for the left-unsafe conditions, the percentage of correct decisions for the three corresponding scenarios was averaged and compared (Table 4). In all three reported scenarios for all conditions, there was traffic approaching from behind. Scenarios 1 and 2 were very similar to each other, both with an unsafe situation in front and behind of the cyclists, with traffic (different cars) approaching from both sides, which would make it unsafe to turn left, according to the traffic rules. The difference between the scenarios consisted of different types and colours of cars or another bicycle or motor driver. This set-up was chosen to obtain data for a critical situation with different traffic users. By using different types and colours of cars the respondents could not so easily recognise the situation as being the same.

Table 4. Percentages of the correct decisions for the ‘left-unsafe’ (traffic approaching from behind) scenarios in each condition

Scenario			*Results*		
			Control	*Vibration*	*Light*
Video	*Front*	*Behind*	*Correct decision (%)*	*Correct decision (%)*	*Correct decision (%)*
1.Is it safe to turn left?	Unsafe	Unsafe	61.9	85.7	89.5**
2.Is it safe to turn left?	Unsafe	Unsafe	57.1	71.4	89.5**
3.Is it safe to turn left?	Safe	Unsafe	45.0	95.2*	78.9**
Average			54.7	84.1	86.0

Note. The video in front of the participants and the picture behind the participants were judged separately on safety for the ‘crossing-left-situation’. Correct answer is always ‘no’

*Control vs. vibration scenario 3: (($\chi^2(1) = 12.489$, $p < 0.001$, $\Phi = 0.77$);

**Control vs. light scenario 1 (($\chi^2(1) = 4.043$, $p < 0.05$, $\Phi = 0.44$), scenario 2 (($\chi^2(1) = 5.230$, $p<0.05$) and scenario3(($\chi^2(1)=4.744$,$p<0.05$, $\Phi=0.48$)

As shown in Table 4, the participants more often gave correct answers in the warning light conditions (significant for scenarios 1, 2 and 3) and vibration conditions (significant for scenario 3) compared to the control condition.

The ‘turn right-unsafe situation’ is only represented by one scenario. In this situation, the participants received a warning because there was traffic approaching from behind, so in principle, ‘unsafe’ for the system. However, when turning right it should not matter whether there is traffic approaching from behind or not, as a safe turn to the right does not depend on whether or not traffic is approaching from behind. Therefore, the warning signal for traffic from behind is actually distracting and should be suppressed. Hence, the percentage of correct decisions represents possible distraction.

More correct decisions (to the question: ‘Is it safe to turn right?’) were given in the vibration (100%) and light (90.0%) condition in comparison with the control condition (73.7%). In this condition, there was traffic approaching from behind, so they received a warning. A significant difference was found between the vibration and the control condition ($\chi^2(1) = 6.316$, $p < 0.05$, $\Phi = 0.55$).

CONCLUSION

The aim of this study was to evaluate effects on behaviour, mental effort and acceptance of a prototype rear-view assistance system for older cyclists that gave warnings in two modalities for traffic approaching from behind. The two types, providing the cyclists with, respectively, haptic and visual warnings, were compared to each other and to a control condition for their effects on mental effort, acceptance and behaviour.

The subjective effort ratings showed that cyclists invested less mental effort with the rear-view assistant than without the assistant. It also turns out that they did not experience the rear-view assistant system’s warnings as mentally demanding, but merely as a device giving decision support. The cycling speed results confirm this subjective evaluation, reflected by no significant difference in cycling speed between the three different conditions. Cyclists were probably cycling at a preferred speed in all conditions, and did not have to protect performance by increased effort investment (Hockey, 1997). Subjective mental effort in the assist conditions was lower, not higher than in the control condition, thus not necessitating reducing mental workload by reducing speed. Nevertheless, it has to be mentioned that a few participants experienced the whole experiment as strenuous. Since we made no distinction in analysing the three different ‘safe-crossing questions’ (straight on, turn left, turn right) regarding the required level of effort, it may be possible that the rear-view system is less strenuous in situations where the support is needed (looking behind when turning left), but mentally disturbing in situations where it is not necessary, such as turning right. No distinctions were made because a real-life system cannot sense in which direction the cyclist is heading and will also always warn for traffic from behind. However, when participants received a warning when it was distracting and should be ignored (when turning right) this did not lead to more wrong decisions regarding to the ‘safe-crossing’ question. This is in an indication that irrelevant information by the system is not disturbing in the decision-making process.

In general, the rear-view assistance was experienced as both very useful and satisfying as measured by the two subscales from the user acceptance scale. The participants were very positive about both types of feedback, with a slight preference for the vibration feedback. In general, the participants reported that they appreciated the rear- view assistant and in particular the vibration signal since that did not require looking at the display. The participants who were still able to look over their shoulder were less positive with regard to the usefulness and satisfaction subscales, which may be because they did not need this warning.

With regard to follow-up decisions (on the safe-crossing question), participants gave more correct decisions in the two assisted conditions (80 and 84% correct follow-up answers) compared to the control condition (55%). It seems that the rear-view assistant is of added value in helping to make a safe decision, most importantly in the “left-unsafe” condition. In this case, important information was presented to the cyclists; information they might not have noticed without a warning. This was also demonstrated in the study of Schepers and den Brinker (2011) who studied what cyclists need to see to avoid single-bicycle crashes. Although Schepers and Den Brinker focus on the role of visual features of the infrastructure, their study indicates that an important condition for safe cycling is the visibility of critical information in the peripheral field. Even when the participants received a warning which was not relevant for that specific situation (when turning right), they were able to not follow up the advice given from the system in the experimental conditions. It can be tentatively concluded that the rear-view assistant can be ignored in situations where participants should not be distracted by it, namely when the warning is not relevant (e.g. when turning right). Long-term complacency and potential negative generalisation effects (ignoring all warnings), however, need to be studied in future research.

Some respondents mentioned they would have preferred to receive the warning earlier, since in real-life cycling they would look over their shoulder earlier. This is also important to take into account in future systems. In this experiment, we chose to ask the ‘safe-crossing question’ and give the warning at a fixed time that was the same for each trial. In real life, the moment of warning depends on the distance and the speed of the traffic approaching from behind. However, this was not possible in a simulated cycling environment.

DISCUSSION

The present study has some limitations. Some participants cycled at very low speed. Cycling outside the lab at a similar speed would probably impede balance. However, when questioned, the participants reported acting the same in this simulated situation as they would do when cycling outside. For example, some of them always stopped to let other traffic pass, some stood on the pedals so they could better look behind them and some indicated a change of direction with a hand signal, as one officially should. The overall impression is that, despite the simple set-up, the participants performed in a natural way. However, this experimental set-up, in which the participants’ movement was restrained as the bicycle could not move side-ways, did not allow the participants to move freely. This could have had an impact on their evaluation. A second limitation is that the participants in this study were first-time users, practice time was essential and the participants indicated that they needed time to get used to the rear-view assistant. Experience might change with repeated and longer usage. Further, although most respondents mentioned that they favoured the vibration warning, the participants only received information when there was traffic approaching. An advantage of the light warning is that participants also receive information, namely, a green light, when there was no traffic approaching. The light warning thus always gives feedback about the fact that the system is functioning. Finally, the average age of the participants in this study was almost 70, and therefore participants in this study can be considered ‘young elderly’. In future research, participants of higher age could be incorporated as the ‘older elderly’ may perceive this kind of traffic support as more strenuous, or on the other hand perhaps as more helpful.

Additional limitations from this simulation cycling environment were the lack of noise and a static screen behind the participants, which may have led to participants missing clues to judge speed. Furthermore, the participants could not merge to the centre of the road before turning. A cycling simulator with more advanced functions could provide these options and cover more complex dynamic situations.

No study has yet been done with an intelligent transport system on a bicycle, but the results are in line with studies on ADAS in cars driven by older people. In those studies, it was mentioned that ADAS may be able to provide useful personalised assistance for older drivers (Bekiaris, 1999; Davidse, 2006; Fäber, 2000; Mitchell and Suen, 1997; Shaheen and Niemeier, 2001). Resistance by older adults against technological innovations in vehicles has been reported (Hancock and Parasuraman, 1993), although the general consensus is that driver assistance systems have the potential to keep older drivers mobile for longer (Davidse, 2007) and that older drivers are more positive with regard to in-vehicle devices in comparison to younger drivers (Yannis et al., 2009). Although older people have a higher risk of getting injured in traffic, it is still important to keep the older people mobile, because poor mobility has negative consequences on the elderly, their environment and society (Oxley and Whelan, 2008).

In previous research it has been proposed that one has to be aware that information systems may increase mental effort (Jahn et al., 2005) and as a consequence have a negative effect on safety (Verwey et al., 1996). Davidse (2007) concluded that information systems in cars made the driving task easier and no effects on effort were found, which is in line with the results from our cycling study. Brookhuis et al. (2008) stated that acceptance is generally high after experiencing a traffic-congestion assistant for cars, and this high acceptance for a new type of technology is in line with the results of this study.

This study demonstrated the effect of rear-view assistance on mental effort, acceptance and cycling speed in a simple experimental set-up. Testing immediately in real life might have been dangerous because the effects of the rear-view assistance system on cycling performance were not yet well understood. Based on the current study, the next step - actually developing a more advanced rear-view assistant - could prove beneficial. Such a product should be evaluated in real traffic situations. As a consequence of the simulated environment, there was no danger, since the participants were not actually moving. Therefore, testing the rear-view assistant in real life remains important as there are factors that may influence perception of the signals of the rear-view assistant such as sunlight, environmental noise that causes distraction or non-level roads that induce steering vibration. Only in real life it can be judged and evaluated how the algorithm used in the rear-view assistant copes with unexpected, not previously simulated situations.

In conclusion, this study gives a first indication of use and acceptance of a rear-view assistant system that supports older cyclists in detecting traffic from behind. The results indicate that such a system can support the older cyclist successfully without increasing their mental effort. Further research in real traffic situations is needed to optimise the rear-view assistant in terms of timing of warnings, intensity of warnings and long-term and real-life effects.

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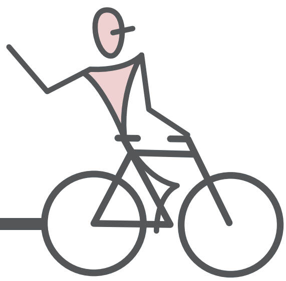

Chapter 4

A front- and rear-view assistant for older cyclists: evaluations on technical performance, user experience and behavior

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ABSTRACT

The older cyclist is more prone to get cycling accidents than younger cyclists. To support the older cyclist, a rear- and front-view assistant were developed that warns the cyclist of approaching traffic. User tests to evaluate system performance, user-experience and effects on behaviour were performed with 20 older cyclists (>64 years) on a predefined route outdoors with and without support from both assistants. During this route, the cyclist was confronted with two controlled scenarios with an overtaking and an oncoming cyclist. The participants' cycling behaviour was assessed by measuring lateral distance to the other cyclist, and distance maintained to the verge. The assistants had no effect on experienced mental workload. Both assistants received positive evaluations, although the rear-view assistant was experienced as more useful. Using the front-view assistant resulted in less lateral distance to the approaching oncoming cyclist, while the use of the rear-view assistant did not have effects on lateral distance.

INTRODUCTION

In the Netherlands, cycling is one of the most common ways of transportation (Pucher and Dijkstra, 2003; Pucher and Buehler, 2008). The Dutch government is also actively promoting cycling, as continuing to cycle well into old age has health benefits (Heinen et al., 2013). However, the number of accidents involving cyclists also increases (Weijermans et al., 2016). This is particularly true for people of 65 years of age and over who, because of decreased physical and cognitive skills, are more prone to get involved in accidents and are more fragile than younger cyclists (Mori and Mizuhata, 1995; Tacken, 1998; Horswill et al., 2008). Turning left on an intersection, for example, is a problem in many right-hand driving countries. When turning left, the cyclist has to release one hand from the handlebars to indicate direction, look over the shoulder to see if there is traffic coming from behind and decide whether it is safe to cross the intersection. Since looking over their shoulder might be problematic for older cyclists due to stiffness of the neck, they may dismount their bicycle to look behind them. While, in principle, this is a safe strategy that also grants extra time for decision making, this action requires dismounting and mounting the bicycle, which is a frequent cause of reported accidents (Schepers and Klein Wolt, 2012). A second compensatory strategy when one is not able to look over the shoulder might be crossing an intersection in two steps, first cross one street and then the other. This strategy again requires additional (dis)mounting actions and takes more time. A third compensatory strategy is trusting on one's hearing ability. This strategy is not a safe option, as one may miss sounds (in particular now quiet electric cars enter traffic) while at the same time hearing abilities decrease when getting older (Gordon-Salant, 2005). Another (potentially) problematic situation for older cyclists is an unnoticed oncoming cyclist on a dual directional cycling path, a cycling path that has become more and more standard in the Netherlands (Slütter and Koudijs, 2007). In the Netherlands, the majority of the cycling accidents are single-sided accidents due to balance problems, collisions with an obstacle, or entering the verge (Schepers and Klein Wolt, 2012). However, Reurings et al. (2012) conclude that in about half of the injured bicyclists in single-sided accidents, the behaviour of another road user played a role in the incident: For example, an oncoming cyclist whose intention was misjudged or an approaching cyclist who was not noticed in time. Missed or late observation of oncoming traffic may occur especially in low visibility situations.

Giving information about traffic approaching from behind and from the front could make cycling more comfortable and may reduce injury risk for the older cyclist, as cyclists then become aware of the others in time, which is useful when the others for example, start to overtake them. With this information the need to rely on less effective anticipation strategies such as trusting on hearing can be reduced or eliminated.

Several warning options are possible such as providing the cyclist with information through assistive technological tools. In the car industry it has been proven that technology can provide personal assistance; Advanced Driver Assistance Systems (ADAS), in-vehicle information systems (IVIS) or intelligent transport systems (ITS) in cars. ADAS in cars can provide personal assistance in traffic (Dotzauer et al., 2013; Davidse, 2007). Information about traffic from behind could be made available to cyclists in a more traditional way, for example by adding a rear-view mirror to the bicycle. However, older cyclists often choose not to use a mirror as they experience this as stigmatising. Another disadvantage of a rear-view mirror is that is the user does not receive a warning and needs to look actively into the mirror, which shifts attention away from the road ahead. People lose attention by looking in the mirror and have less attention for steering and overseeing the traffic situation. To increase the opportunity for older cyclists to continue cycling safely for as long as possible, a solution other than a mirror must therefore be considered.

A rear-view assistance system for cyclists could minimise the need to look over the shoulder or in a mirror. A prototype of the present system with only the rear-view aid was evaluated on effects on acceptance, safe turn decision and mental workload, in a previous study (Engbers et al., 2016), as end-user acceptance is an important pre-requisite for implementation success (Brookhuis and van Driel, 2008; Van der Laan et al., 1997). In that study, high acceptance was found and less mental effort was reported when using the rear-view assistant with haptic feedback compared to a version that provided visual feedback. Significantly more correct decisions regarding a safe left turn were made with system advice. No effects on speed were found between the two modality conditions. It was concluded that such an electronic rear-view assistance system is a good option to support older cyclists by warning for traffic approaching from behind. However, the study by Engbers et al. (2016) demonstrated the effects in a laboratory experimental setup.

To test the user experience under more realistic settings, a prototype for a real bicycle was developed in the current study. This bicycle was equipped with both a rear- and a front-view assistant that warns for oncoming traffic and traffic approaching from behind. A front-view assistant can detect other road users earlier than older cyclists, in particular when they are distracted, and this is likely to reduce startled reactions resulting in sudden deviations that could cause a fall. The prototype bicycle was equipped with a radar and a camera to detect objects and used haptic feedback to warn cyclists for critical situations.

Vibrations in the saddle were used to convey the message that someone behind was detected, vibrations in the handlebars were used to communicate that somebody was approaching from the front. This deviates somewhat from the location where feedback was given in the precursor study, in which vibrations in the handlebars warned for traffic approaching from behind (Engbers et al., 2016), but that system did not contain a forward warning module. The current design was expected to be more user intuitive than the design used in the precursor study.

Several studies have suggested that ADAS may be able to provide tailored assistance for older car drivers (Bekiaris, 1999; Mitchell and Suen, 1997; Färber, 2000; Dotzauer et al., 2015). However, handing over control completely to a device and automated functions has been evaluated as a negative aspect of assistance systems (Hoedemaeker, 1996; Hoedemaeker and Brookhuis, 1998), although the device tested in this study is meant as a supportive device. To be of added value to the cyclists, the technology should provide accurate information to the user. Assistive tools that do not provide accurate information to car drivers negatively influence performance and attention (Schmidt et al., 2010). Accurately working assistive tools may reduce workload, so that users can use their remaining attention to keep track of other tasks they have to do (Parasuraman et al., 2000).

The literature described above focuses on the older car driver. So far, no studies have evaluated the usage of these kinds of assistive tools on bicycles in real traffic. The current study's aim is to evaluate effects of the two assistants on user experience (acceptance and effect on mental workload) in real traffic in controlled scenarios. To analyse the potential behavioural effects of the system, participant's lateral distance to another cyclist (involved in the experiment) when passing was measured, both in a situation with an overtaking cyclist and with an oncoming cyclist.

METHOD

Participants

In total, 20 cyclists participated in this study. Participants were included if they were older than 64 years and cycled frequently (weekly) on a conventional or on an electric bicycle. Participants were recruited by means of the websites of the 'Koninklijke Ouderen Bond' (Royal Elderly Federation), the municipality of Helmond, and the province of Noord-Brabant. People shorter than 170 cm were excluded from participation because of the frame size of the test bicycle. The participants were fully informed in advance and gave informed written consent to participate in the test. The test design, protocol and used equipment were approved by the regional Medical Ethics Research Committee of Twente. In the experiment, only males participated and they had an average age of 70.7 years old (range: 65–82).

Bicycle

The basis of this bicycle was a Dutch bicycle equipped with electrical power supply for adjustable pedalling support (Koga Miyata, e-Nova 2015, ladies' frame). Sensors and actuators were installed on this bicycle to enable experiencing the functionality of a rear- view-assistant and a front-view-assistant. The bicycle electric power supply was required as power supply for the technical equipment of the two systems. In the tests the electrical pedalling support was switched off. The focus was to develop a so-called 'proof of concept' or 'user-experience' prototype bicycle to enable the experience of the functionality of the two warning systems on a bicycle, as in previous studies it seemed hard for persons to imagine the (added) value of these systems. The components used on this prototype bicycle had been developed for the automotive industry and were therefore larger and asked for more power than a final design would aspire. In total the bicycle weighed 31.8 kilograms. In Figure 1 the bicycle with the added components is depicted.

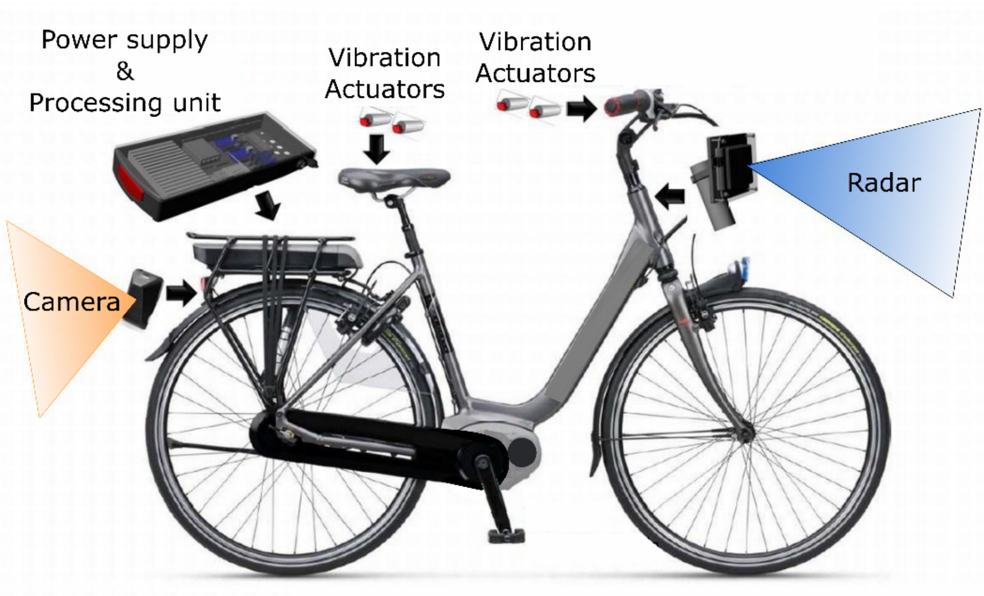

Figure 1. Instrumented bicycle with components that was used during the experiment.

Front-view assistant

The front-view assistant (FVA) used a radar (automotive radar; continental type 209-SRR) to detect oncoming road users approaching in front of the bicycle and to warn the user for a potential critical situation through vibration of the handlebars. The radar was chosen for the detection system, as this sensor is robust in diverse weather conditions and well capable of detecting moving objects. The radar was installed on the front of the bicycle.

Rear-view assistant

The rear-view assistant (RVA) used a camera to detect other road users approaching the cyclist from behind. It warned the user for potentially problematic situations through vibrations in the saddle. A camera was chosen as it is able to classify objects (pedestrians, cyclists, motorcyclists, cars or trucks). Furthermore, it provides speed and position information with respect to the bicycle. The camera (automotive camera: mobileye type 560) was installed on the back of the bicycle below the bicycle's rear lighting.

Haptic warnings can be perceived as long as a cyclist touches the saddle and handlebars. As showed in Engbers et al. (2016), less mental effort and a higher acceptance rate was found with tactile warning in comparison to visual warnings. Auditory and visual information as a solitary source of information ask more of a person attention-wise compared to tactile information (Posner et al., 1976).

Types of vibration signals and triggers

As the aim of the signal is to warn for a potentially problematic situation, a three-pulse vibration signal was chosen, since two and three-modal signals are experienced as more urgent than a single modal signal (van Erp et al., 2015).

The timing of warning was triggered by critical time-to-collision (TTC) values. TTC is defined as the time it takes for a following vehicle to hit the vehicle in front, assuming they continue the same course and the same speed (Lee, 1976; van der Horst, and Hogema, 1993). The threshold TTC was set at 2 seconds, which is in line with the advised following distance for car drivers (Cruz, 2007). The rear-view assistant had an additional software filter so that cyclists were not warned for the same object shortly in succession.

Procedure

Location

This study took place on public roads to make the context of the test as realistic as possible. During the predefined route, two specific scenarios were carried out at two fixed locations. There was only limited other traffic, as it was a quiet area and the experiment was conducted during in between morning and afternoon rush. This location was selected to have a context specific but relatively controlled environment, in which the repeatability of the tests could be safeguarded and at the same time limiting risks. The predefined route consisted of single direction roads, two-way roads, cycling paths (one and two-ways), a public road with a separate bicycle lane and a public road without designated cycling areas. The followed route is displayed in Figure 2.

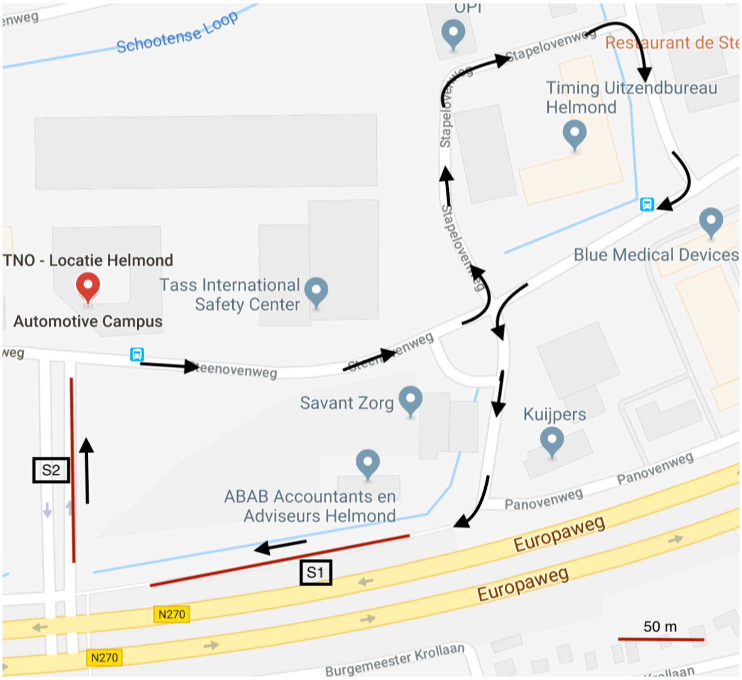

Figure 2. The predefined route consisted of single direction roads, two-way roads, cycling paths, public road with a separate bicycle lane and public road without designates cycling areas. Adapted from Google Maps (2017).

Scenarios

At two locations along the route, two specific scenarios were carried out respectively (see Figure 3).

1. In the first scenario (S1), participants were obliged to cycle on a narrow path. While cycling, another cyclist came from the opposite direction. The front-view assistant warned the participant for the oncoming cyclist by means of vibration in the handlebars.

2. In the second scenario (S2), the participant was overtaken by another cyclist. In this case, the rear-view assistant warned the participant by means of a vibrating saddle.

Procedure

Before the experiment, the participants received a letter containing a general description of the project and the planned test. Added to this letter were several questionnaires, which the participants were asked to fill in and bring with them on the day of the tests.

Upon arrival, participants received a more thorough explanation of the test procedure. After everything had been explained to them and all their questions had been answered, the participants were asked to sign an informed consent.

Figure 3. The two locations along the route where the two specific scenarios were carried out. Scenario 1 (front-view assistant): Cyclist approaching from the front and passing at a narrowed path (picture left). Scenario 2 (rear-view assistant): Cyclist approaching from behind and overtaking participants at a narrowed path (picture right)

After the introduction was completed, the participants could practice with the bicycle. They adjusted the saddle height to a comfortable height and were given the opportunity to get used to the vibrations of the rear- and front-view assistants. When the participants mentioned they felt comfortable using the bicycle, the experiment began. During the test, the cyclist's behaviour was recorded through the use of four video cameras (see par. '*Material*').

The participants cycled the predefined route twice (see Figure 2). They were instructed to follow the red arrows and not the blue arrows. Different coloured arrows were placed next to the road, to simulate route information similar to traditional road signs. The route was cycled once with the systems switched on and once with the systems switched off. Every odd numbered participant started with the experimental condition and the even numbered participant started with the control condition.

The participants were informed beforehand about these conditions:

- experimental condition: assistants on.

- control condition: assistants off.

In each condition, the participants were passed (S1) and were overtaken (S2) twice (see Figure 2) by another cyclist (involved in the experiment) in two controlled scenarios. The other cyclist would cycle normally but would make an effort to pass the participant at approximately the same location, in the areas where the two specific scenarios took place. No instructions to keep the same distance to the verge was given, as it is not easy to keep the task natural with the conscious process of keeping the same distance. In the experimental condition the cyclists were warned by the rear- and front-view assistant and in the control the condition the cyclists were not warned by the assistants. In both situations, the participants were of course able to notice other traffic themselves, although the front-view and rear-view-assistant would not warn them for oncoming traffic in the control condition. Since the experiment took place on public roads, the system could also identify other road users outside of the predetermined two scenarios. After each of the two conditions (with and without assistance) the Rating Scale Mental Effort was completed; participants evaluated the complete ride. After the cycling test, a final interview took place with the principal researcher.

Material

Video Cameras

During the experiment, video data were captured by four cameras. Two cameras (GoPro Hero 3) were mounted on the bicycle: one mounted on the handlebars and facing forward, one mounted on the luggage carrier facing rearwards. Two cameras (Go Pro Hero 2) were mounted to a lantern post to capture the oncoming (S1) and overtaking (S2) cyclists respectively. The lantern posts were close to the cycling path, set up in such a way that the video recorded a wide overview of the whole area of the scenario. The videos were recorded with a resolution of 1920 × 1080 pixels and with a frame rate of 25 frames per second. Around 680 h of video data were gathered during this experiment. The experiment was completed in February 2016, in dry weather conditions.

Measures

Technical performance of the assistants

Correctness of the assistants' warnings was assessed by using the bicycle mounted video cameras and the on-bicycle system logging. The video data were synchronised with the warnings logged on the system (on the bicycle). After that, each warning logged in the system was compared with the video-data and classified as follows: hit (a correct warning or true positive; situation in which the system warned correctly for an oncoming road user), false alarm (an unjustified warning or false positive; situation in which the user was warned for an oncoming

road user without that user being present) and a miss (the absence of a warning or a false negative; i.e., situations in which the user was not warned, but should have been warned for an oncoming road user). The system performance was
analysed for each participant within the two controlled scenarios.

Mental Effort

The Rating Scale Mental Effort (RSME, Zijlstra, 1993) was used to assess mental effort, which was based on the cyclist's subjective rating of invested effort after cycling the control condition and after cycling the experimental condition (that included both scenarios). The RSME is a unidimensional rating scale consisting of a line with a length of 150 mm marked with nine anchor points (scale range 0–150). The anchor points are accompanied by a descriptive label indicating a degree of effort, ranging from 'no effort- some effort' (scores 2 to 38 respectively) to 'extreme effort' (score 112). The RSME has proven to be a simple and valid self-report measure of mental workload (Zijlstra, 1993; Widyanti et al., 2013) and correlates well with other subjective methods to assess mental workload, such as the NASA TLX (Veltman and Gaillard, 1996).

Acceptance scale

Acceptance of the system was assessed using an acceptance scale (Van der Laan, Heino and de Waard, 1997) after the experimental condition (using the front- and rear-view assistant). This scale includes the following nine opposing items; 'useful-useless', 'pleasant-unpleasant', 'bad-good', 'nice-annoying', 'effective-superfluous', 'irritating-likeable', 'assisting-worthless', 'undesirable-desirable' and 'alertness increasing-sleep inducing'. Each set of opposite items was scored using a semantically differential 5-point Likert scale. The scale results in two measures, which reflect acceptance in two dimensions: Usefulness and Satisfaction.

4

Cyclist's lateral distance (to the other cyclist and to the pavement)

For the oncoming scenario, the distance between the front wheel of the passing cyclist and the rear wheel of the participant was measured once they were next to each other. The footage of the on-site video cameras mounted to the lantern posts was used for these analyses. The video data were analysed using the software program Kinovea (v0.8.25 for Windows; Charmant, 2016).

During the overtaking scenario the distance between the front wheel of the participant and the front wheel of the other cyclist was measured when they were next to each other.

The distance between the front wheel of the participant and the side of the cycling path was also calculated at that same moment. See paragraph '*dependent variables and analyses*' for details.

Interview
An open-interview was conducted with one of the researchers afterwards. The participants were asked about their general opinion of both assistants. An Acceptance Scale (Van der Laan et al., 1997) was also completed during this interview. Other topics discussed were visibility, time and type of warning and preference with regard to individual settings.

Dependant variables and analysis
The main dependent parameters were:

- technical performance of the system
- lateral position (relative to another cyclist and to the pavement)
- subjective mental effort
- acceptance in terms of usefulness and satisfaction.

All the data were analysed using SPSS (IBM SPSS 19.0 Statistics). These four main outcome parameters were analysed in the following way.

- The technical performance of the system (hits, misses) was evaluated for the two controlled scenarios. Therefore, the bicycle mounted video camera was synchronised with the on-bicycle logged signals from the rear view and front view assistant systems.

- Whether the use of either of the assistants resulted in different cycling behaviour, the lateral distance was compared between the participant and the other cyclist (involved in the experiment) in the experimental condition with the lateral distance in the control condition. Cycling behaviour was assessed by measuring lateral position (in centimetres), and by calculating SD of the Lateral Position (SDLP). Video data were loaded into the program, after which a perspective grid was placed over the cycling path. The dimensions of this grid were added in Kinovea by using real-life measurements taken beforehand, using the width of the cycling path and the length of each white line or the space between white lines to determine the length.

  A mixed-model analysis was used to see whether the distance between participants was significantly different in the experimental condition compared to the control condition. The t-statistic, level of significance (p), 95% confidence interval (CI) and effect size (δ) are reported.

- The effects of the both conditions on the scores of the RSME were analysed with a Wilcoxon signed-rank test, as the data were not distributed normally.

- User acceptance of the rear- and front-view-assistants was assessed by means of the two acceptance score subscales, namely Usefulness and Satisfaction, (Van der Laan et al., 1997). Subscale median and interquartile ranges were calculated for both assistants individually.

RESULTS

Technical performance

The logged warnings were checked on their correctness for the two controlled scenarios (see Table 1). Three types of warnings were discriminated: a hit, a miss and a false alarm.

Table 1. The performance of the both prototype assistant systems in the two controlled scenarios expressed in percentage, discriminating between hits, misses and false alarms

System performance	*Front-view assistant: scenario 1: oncoming cyclist*	*Rear-view assistant: scenario 2: overtaking cyclist*
Hits	83%	63%
Misses	13%	33%
False alarms	5%	5%

In total, for each condition and participant, 2 video segments were available for the oncoming scenario (S1) and 2 video segments for the overtaking scenario (S2). For the oncoming scenario (S1) three participants were excluded. Two were excluded because the video camera registration stopped in the middle of the experiment. Hence no video data were available for these participants. One participant had to be excluded because no accurate measurement could be made in Kinovea for three out of four scenarios, mainly because the camera view was blocked. In the overtaking scenario (S2), one participant was excluded because all actions took place outside the camera coverage area.

For the included participants, some video segments could not be used for different reasons. For example; not having video from both test conditions, which made comparisons of the conditions not possible. Other causes were a moving camera, which led to problems with the grid in Kinovea; or an obstructed view. In total, 48 segments were used for the oncoming scenario and 52 segments were used for the overtaking scenario.

As can be seen in Table 1, for the front view assistant, 83% hits were found, 5% of the warnings were false alarms and in 13% of the cases a warning was missed. The majority of the warnings (83%) were given at the right moment, when there was another road user on the video (for example an overtaking cyclist). The performance of the rear-view assistant (63% hits) was worse than the performance of the front view assistant (83% hits). The rear-view assistant warned cyclists correctly in 33% of the cases and false alarms were registered 5% of the time.

The false alarms for the front view assistant mainly occurred during the rides of two cyclists. Why the performance of the assistants was poor during these rides is not clear yet. For the rear-view assistant the suboptimal performance appears to have occurred randomly and cannot be clearly attributed to specific situations or behaviour.

Cyclists' lateral position

Front-view assistant: scenario 1: oncoming cyclists

Effects of the front-view assistant on the lateral position of the participants with respect to the other cyclist were analysed using a mixed-model analysis. As displayed in Table 2 the average lateral distance participants kept to the passing cyclist was less with the warning-system turned on in comparison with the warning-system turned off. The difference between these values was statistically significant, $t(15.04) = -2.36$, $p = 0.032$, 95% CI [−23.10, −1.17], $\delta = 2.82$.

Table 2. The average lateral distance between the participants and another oncoming cyclist from the front, while using the front-view assistant and while not using the front-view assistant (FVA)

Condition FVA on/off	*Cyclists lateral distance* (cm) (SD)
Experimental: FVA on	104.4 (3.02)
Control: FVA off	116.18 (4.97)

Participants using the front-view assistant held significantly less distance in respect to the other cyclist than participants who did not use the front-view assistant (see Table 2).

Rear-view assistant: scenario 2 overtaking cyclist

To evaluate the effects of the rear-view assistant on lateral position of the participants, both the distance between the wheels of the participants and the overtaking cyclists, and the distance between the participant and the side of the cycling path were analysed.

In the overtaking condition the average lateral distance between the cyclists, at the moment of overtaking, was l) with the system turned on, compared to when the system was turned off (see Table 3), These values did not differ significantly between conditions, $t(17.32) = 0.196$, $p = 0.847$, 95% CI [−10.19, 12.28], $\delta = 0.67$. The distance between the participant and the roadside, at the moment of overtaking, was on average 27.3 cm ($\sigma = 3.4$) with the system turned on and 26.2 cm ($\sigma = 3.4$) with the system turned off. See Table 3.

Participants did not hold significantly more distance to the verge, when using the system, $t(13.49) = 0.51$, $p = 0.618$, 95% CI [−8.78, 14.24], $\delta = 0.30$.

Table 3. The lateral distance between the participants and another overtaking cyclists from behind, and the lateral distance to the verge, while using the rear-view assistant and while not using the rear-view assistant (RVA)

Condition	*Lateral distance to another cyclist* (cm) (SD)	*Lateral distance to the verge* (cm) (SD)
Experimental: RVA on	94.36 (4.45)	27.26 (3.41)
Control: RVA off	91.63 (3.67)	26.22 (3.41)

Rating scale mental effort

In Table 4, an overview of the mean score (range 0–150) on the RSME is given. A higher score on the RSME corresponds to a higher experienced effort.

Table 4. Overview of the results from the rating scale mental effort (RSME), median and interquartile range (IQR) deviation (SD)

Condition	*RSME* (median – IQR)
Experimental: assistants on	14.00 (13.00–28.00)
Control: assistants off	14.00 (13.00–33.25)

No difference was found in mental effort between the control and the experimental conditions ($Z < 0.001$, $p = 1.00$).

These scores correspond with the interview afterwards. Participants mentioned that they did not experience the warning as mentally demanding, but more as a device giving them support or as a confirmation for something they already noticed themselves.

4

Acceptance scale

In general, the participants were very positive about the rear-view assistance system, both in terms of usefulness and satisfaction (range –2 to +2) and about the front-view assistant, however, less than about the rear-view assistant; see Table 5. The results were confirmed in the interviews, in which the participants were very positive about the intelligent bicycle in general. All participants made a positive remark about the fact that warnings were haptic and considered this very intuitive and easy to distinguish from other vibration signals, such as a bumpy road (even when wearing gloves).

As can be seen in Table 5, the rear-view assistant received a higher score than the front-view assistant, which is something participants confirmed in the interviews. They reported that they thought the rear-view assistant was more useful and user-friendly than the front-view assistant. However, there were some individual differences, such as a preference for getting warned for an actually overtaking cyclist or for receiving a warning when somebody was only cycling behind them.

Table 5. Median and interquartile range (IQR) for the van der Laan subscales (usefulness, satisfaction) (scale range –2 tot + 2)

	Front-view assistant	*Rear-view assistant*
Usefulness median (median, IQR)	0.20 (–0.40–1.00)	1.50 (1.00–1.95)
Satisfying median (median, IQR)	0.25 (0.00–1.00)	1.00 (0.56–1.75)

CONCLUSION

The aim of this study was to evaluate a front-view assistant and a rear-view assistant, which support the cyclist in traffic. The two warning-systems were evaluated objectively to assess potential effects on behaviour with regard to influence position on the road. The subjective effects of the two assistants were evaluated by assessing user acceptance and mental workload, both being crucial for a successful implementation of any new system.

Prototype systems were developed enabling testing with participants in realistic conditions. The situations where the front- and rear-view systems should be warning they did, so in situations where participants should be warned they got a warning. In this way, the participants were able to judge the warning for those cases when they needed to receive a warning. On the other side, the number of misses was quite high (13% for the front-view assistant and 33% for the rear-view assistant), and the number of false positives was 5% for both assistants. For user trust it is crucial that a device works at the right times. It is therefore very important that there are no false positives, as this undermines confidence. Although the warning systems were prototypes under development and did not perform flawlessly, the user experience was very positive, which can be seen as very promising.

With regard to lateral distance, no significant effect was found for the rear-view assistant. During this experiment, the lateral distance between the participants remained the same during overtaking and the participants kept the same lateral distance to the verge, regardless of the warning. It can therefore be concluded that the system did not affect position choice on the road or with respect to the overtaking cyclist. However, the cyclists were already cycling close to the pavement (about 30 cm) and the cycling path was quite narrow. It might be the case that it was not actually possible to continue cycling more closely to the pavement in a safe way.

In conditions where cyclists received a warning by the front-view assistant for an oncoming cyclist, it was found that cyclists kept less distance to the other cyclist, compared to the situation in which no warning was given. With the front-view assistant, participants might feel more secure and they were less anxious about the oncoming cyclist from ahead because of having noticed him or her far in advance. As older cyclists may enter the verge during daily cycling (Westerhuis and De Waard, 2016), it might be concluded that it might be a safe consequence that respondents do not move too much towards the curb. On the other hand, the distance to the pavement is determined by the position of both cyclists, so the behaviour of the other cyclist plays a role in the lateral position of the participant. As the lateral position of the involved cyclists in this research was not systematically determined, this should be taken into account in future studies.

The subjective effort ratings showed that cyclists experienced similar mental effort with and without support of the systems. It also turned out, that they did not experience the warning systems as mentally demanding, but merely as a device giving decision support or as a confirmation for what they had noticed themselves. Although both assistants did not lead to a lower mental effort investment, they did not add to workload either. Not adding to workload is important, since a warning device that increases workload could lead to problematic situations in traffic.

In general, the instrumented bicycle was experienced as useful and satisfying, as reflected by positive ratings on the two subscales from the user acceptance scale. The participants were also very positive about the haptic feedback. They mentioned that the feedback was intuitive and very easy to distinguish from other vibration signals such as a bumpy road. Participants mentioned it was very useful to get warned when somebody was overtaking them or when they wanted to turn left. In particular when they have hearing difficulties, the participants see added value. However, some participants mentioned that they would prefer no warning when somebody is not actually overtaking them, but was only cycling behind them. When warned, several participants looked over their shoulder to see why they received a warning, since they experienced no real threat. This can potentially lead to unsafe situations, because they would not have looked over their shoulder during cycling without the assistant. On the other hand, other participants mentioned that they prefer to know when there is somebody behind them, so they can anticipate on such information. The differences in preferences may require a need for individual settings.

The front-view assistant was experienced and evaluated positively, but less useful and satisfying, in comparison to the rear-view assistant. The front-view assistant was seen more as a system confirming what participants could notice themselves. During the tests, the cyclist was alert, it was dry and clear weather and the participants could see the other oncoming cyclists far in advance. For the cyclist, there was no real need for a warning for an oncoming road user they could easily see for themselves. However, in adverse weather conditions, in darkness or while being distracted, participants mentioned there would be a greater need for such a warning device.

DISCUSSION

The present study has some limitations. First, the warning systems used for the test were not commercially available warning systems, but prototypes, with components not ideally suitable for a bicycle regarding weight, energy supply and size as most of the components came from the automobile industry. For implementation of this technology steps need to be made, but technologically it seems feasible to develop such a system for a commercial bicycle in the future.

Second, it seemed to be difficult to find realistic ways to simulate situations in real traffic during which both assistants could be tested. The current way of simulating oncoming traffic could have influenced participants' judgements of the front-view assistant. The added value of the system could not be optimally proven, as therefore potentially unsafe test situations would have been required (e.g., a distracted cyclist who does not look in front of the bicycle). As stated before, in the tested conditions it was not really necessary because of good sight and good weather conditions resulting in no real need for a warning because it was easy to notice others. On the other hand, older adults mainly cycle during good and stable weather. Another limitation was, that in this experiment setting the participants cycled alone and were possibly more focussed because of the test-situation. Furthermore, the participants cycled the same route multiple times, so after a while they expected an oncoming cyclist. Although it was a public road, and other traffic could be encountered, the area was experienced as quiet. An advantage of the test location was that none of the participants were familiar with this route.

Additional limitations were that the participants for this study might not be representative for the population. Because of the frame height of the instrumented bicycle, we were not able to find women, older than 65 years and longer than 170 centimetres to participate in this study. In future studies, a more balanced distribution between males and females is desirable, as multiple studies have shown that women base their opinion for acceptation more on ease of use and social norm, while men base their opinion more on usefulness (Venkatesh and Morris, 2000; Venkatesh, Morris and Ackerman, 2000). Besides that, it might be possible that the men who participated in this study were more interested in new technology than the average male population.

Regarding the video analyses, we recommend using other video-cameras with GPS (see e.g., Westerhuis and De Waard, 2016), as that facilitates extraction of the speed of the cyclist, which could have given more information.

Implications for future research.
Based on the results of the current study, it is concluded that these types of warning systems have potential and do not distract users. Future research should focus on letting older cyclists experience this type of support system in their daily life. It is recommended to make sure that also older women and cyclists critical to or hesitant to using new technologies should try this

type of support system. Besides that, it would be interesting if people could implement and try the warning systems on their own bicycle. How the assistants' function in dense traffic is an issue that needs to be investigated in future research. Although this study now focused on older cyclists, it may be possible to broaden the target group, for example; young people with a disability, parents with child-seats, sports cyclists or people on a cycling holiday with large amounts of heavy luggage. Furthermore, research over a longer time period is needed to assess long-term effects.

Implications for practice.
The warning system requires further technological development. Requirements from technical and user-perspective need to be improved regarding functionality and the option to set individual preferences. For example, participants mentioned a wish for setting individual preferences for moment of warning and they would prefer switching it on or off at a moment at their own choice. Additionally, in the future the bicycle should have a function that would allow the user to know immediately that the system is active. Further, it is recommended for the forward assistant to focus more on warnings for stationary obstacles (for example bollards) in addition to other moving traffic participants.

In conclusion, this study demonstrated positive effects of rear- and front view assistance on mental effort, acceptance and lateral distance in a moderately semi-controlled setting. Technical performance was assessed as well. The results indicate that both systems can support older cyclists successfully without increasing mental effort.

ACKNOWLEDGEMENTS

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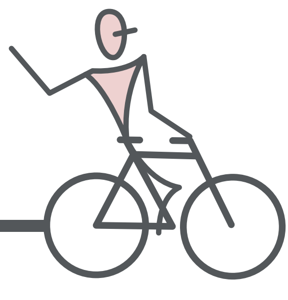

Chapter 5

Enlightening cyclists.
An evaluation study of a bicycle light communication system aimed to support older cyclists in traffic interactions

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ABSTRACT

In the Netherlands, older cyclists run a relatively high risk to be involved in single-sided accidents. Earlier studies found that specific interactions with other road users are related to these accidents. A Bicycle Light Communication System (BLCS) was therefore developed to improve the communication of intentions and behaviour of cyclists to other road users. Different LED light signals communicated turning intentions, braking, cycling speed, or a general 'attention' signal with a controller that eliminates the necessity to signal turns by extending the arm. In an on-road experiment, 21 older and 20 younger cyclists observed the light signals while performing three tasks: (1) following and (2) overtaking a lead cyclist, and (3) estimating the speed of an approaching cyclist who uses a BLCS. Subjective opinion and expected safety benefits were gathered in a semi-structured interview afterwards. In addition, twelve older cyclists used a BLCS-instrumented bicycle for their personal cycling activities during one week. The results indicate that the BLCS is evaluated positively by older and younger cyclists, in particular the turning indicator and the brake light were evaluated as useful. The cycling speed signals were found difficult to interpret. Suggestions for future development and implications for practice are discussed.

INTRODUCTION

Older cyclists in the Netherlands

In the Netherlands, older people ($\geq$ 65 years) cycle frequently (Harms & Kansen, 2018), for example, for shopping trips, to visit friends, for longer recreational trips, or as a sports activity. Cycling has positive effects on health, mobility, and quality of life (Oja et al., 2011; de Hartog et al. (2010). Older cyclists, however, have a relatively high risk of falling and sustaining a serious injury (VeiligheidNL, 2017). It is estimated that the majority of the cycling accidents with older cyclists are single-bicycle accidents, which are accidents where no other road user is directly involved (Schepers, 2013), and that the amount of these accidents is increasing (VeiligheidNL, 2016). A reduction of accidents of older cyclists is therefore necessary (Tour de Force, 2017).

Interactions with other road users

Naturalistic cycling studies (Westerhuis & de Waard, 2016) and accident analysis studies (Davidse et al., 2014a; Davidse et al., 2014b) have found that (near) single-bicycle accidents of older cyclists can be preceded or initiated by an interaction with another road user (BoeleVos et al., 2017). For example, a startle reaction caused by the sudden appearance of a fast riding cyclist or moped driver might lead to a "single-bicycle accident" when the steering reaction to avoid this road user results in a fall into the verge. It is estimated that similar interactions may have played a role preceding many of the reported single-sided accidents (BoeleVos et al., 2017; Kruijer et al., 2012).

In interviews in which older cyclists were asked whether specific road users, locations, or circumstances were related to experiencing difficult or (potentially) dangerous traffic interactions, it was found that older cyclists often experience the behaviour of other road users as difficult (Westerhuis et al., 2016). These experienced difficulties concerned in particular behaviour as overtaking, not giving right of way, and riding or driving at high speeds. For cyclists specifically, the participants rated behaviours as cycling in groups, having poor lights on the bicycle, not indicating direction, leaving little room for passing, and cycling at high speeds most frequently as difficult. These are behaviours that can be described as unexpected and potentially leading to uncertainty about the intentions of other road users (Westerhuis et al., 2016).

Another problem of older cyclists is that it is relatively difficult to maintain balance while cycling. Studies on single-sided accidents report that a loss of balance, colliding with an obstacle, or entering the verge are accident types that occur frequently (Schepers & Klein Wolt, 2012). On locations where relatively many cycling interactions take place, such as intersections, it is likely that the stability on the bicycle can be more difficult to maintain due to the occurrence of unexpected situations or due to distraction (Dozza & Wernike, 2014). Difficulties with maintaining balance can also appear if one hand has to be taken off the handlebars to signal direction, which is a legal requirement in many countries. For other road users, indicating direction is useful to predict and anticipate the upcoming direction of a turning cyclist and therefore facilitates predicting the flow of traffic. Arm signals are crucial, as it is very difficult to accurately predict the upcoming direction of a cyclist on the basis of other visual cues (Westerhuis & de Waard, 2017).

The Bicycle Light Communication System (BLCS)

To assist older cyclists to communicate intentions to other road users, a new Bicycle Light Communication System (BLCS) was developed. This system consisted of a front and rear bicycle light unit that can be mounted on any bicycle and contained an integrated speed indicator, a brake light, a turn indicator, and an attention signal. The main aim of these light signals was to communicate the behaviour and intentions of the cyclist such as acceleration, deceleration, braking, and turning to other road users which could assist in predicting their behaviour. Furthermore, by using light signals it would also not be necessary anymore to signal with the arm, thus releasing one hand off the handlebars, at an upcoming turn.

The BLCS prototype was designed by involving (older) cyclists and other road users during each step of the design process. For each design iteration, the product was changed to accommodate the feedback and wishes of the end-user, which is common in User-Centred Design (Gulliksen et al., 2003).

The objective of this study was to explore how older and younger cyclists experience a BLCS when these signals are shown by another cyclist. For this reason, an on-site experiment was conducted in which cyclists were invited to cycle together with a researcher to experience the light signals of a BLCS. Hereafter, a group of older cyclists was also asked to use a BLCS-instrumented bicycle for one week to gather insights into their experience as a user.

MATERIAL AND METHODS

In an experiment, effects of perceiving the signals of a BLCS on cycling behaviour were assessed. Furthermore, subjective opinions regarding signal interpretation, visibility, ease of use, expected usefulness, mental effort required, and expected safety enhancement were gathered. In addition, a follow-up user evaluation study was performed by asking several older cyclists to use the instrumented bicycle for their daily cycling activities for approximately one week. Ethical approval for both studies was obtained by the University of Groningen Psychology Ethics Committee (16414-O and 16415-O).

Participants

The target end-user group for the BLCS are older cyclists, therefore cyclists over 60 years of age were recruited as participants. Because younger cyclists will also experience the light signals if these are used in traffic, a group of cyclists below 35 years of age were recruited as participants as well. 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 Behavioural and Social Sciences faculty of the University of Groningen and on Facebook groups with people from Groningen. The participants were offered a voucher of €15 as a financial compensation for their participation.

Materials

Location

To demonstrate the signals of the BLCS, two researchers rode an instrumented bicycle on a relatively quiet location in the city of Groningen. On this location, there were two separate one-way cycle paths, in reverse directions, surrounding a parking lot (see figure 1). Both paths were approximately 170 metres long and 2.3 metres wide. The two cycle paths were used in succession: a small 'circuit' was created by crossing the road that connected the paths.

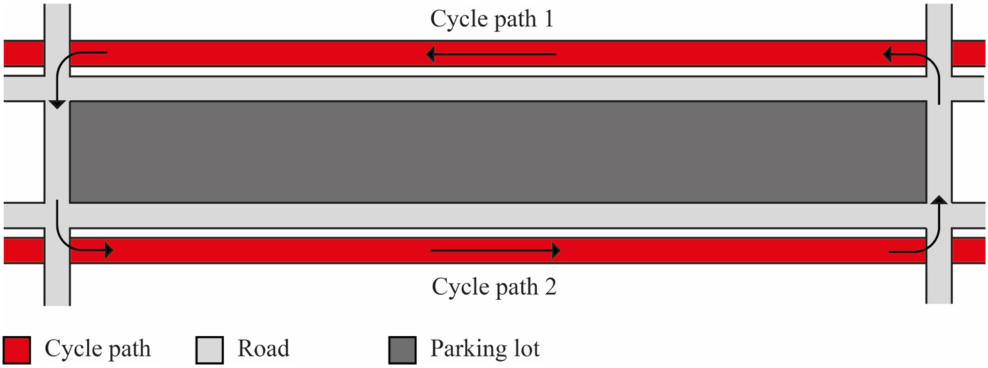

Figure 1. A schematic representation of the cycle paths that were used in the experiment. The experimental conditions and measurements were only performed on the two cycle paths (red). The road in-between the paths was used to cycle from one path to the other.

The Instrumented Bicycle

The instrumented 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, communicated different aspects of the rider's behaviour or intention (see figures 2 and 3). The light signals were shown by several LEDs bundled in two uniform devices that were mounted as the front and the rear lights of the bicycle. Different light signals communicated turning intentions (i.e. an indicator), braking, cycling speed, or a flash signal to draw the attention of other road users. The speed and brake signals were automatically controlled by a Central Processing Unit (CPU) located in a small bag mounted on the front of the handlebars. The cyclist controlled the indicator and the attention signal by means of a small three-button remote control located on the left-hand side of the handlebars (figure 4).

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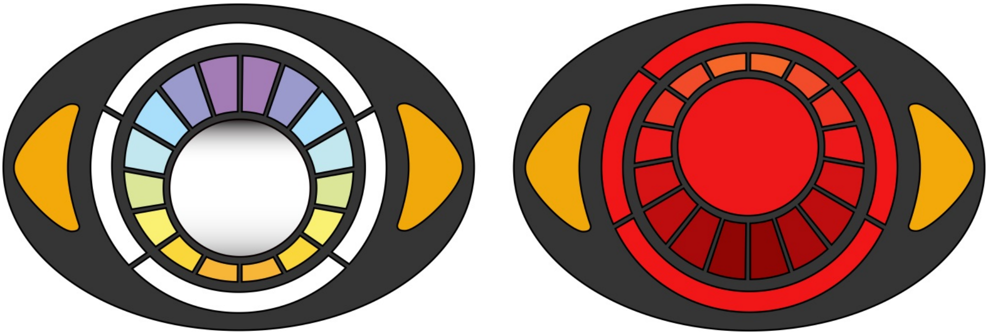

Figure 2. From left to right: the BLCS front and rear units.

The bicycle light's turning indicators were located on the far-most left and right sides of the front and rear BLCS units and in the grips of the handlebars (see figures 2 and 3). The indicators on the front and rear units had amber-coloured LEDs in the shape of a triangle pointing in the intended direction. The indicators in the handlebars contained amber LEDs only. When enabled, the indicator LEDs started blinking in a synchronised manner similar to conventional indicators on cars and motorcycles. The cyclist was also informed that the indicators were enabled by a blinking LED on the remote control unit on the handlebar (figure 4). After the cyclist completed a turn, the indicator was disabled automatically in a similar way to indicators in cars although it was also possible to manually deactivate it by pressing the same button.

Figure 3. The instrumented bicycle with activated indicators that was used in the experiment.

Figure 4. The remote control unit mounted on the left-hand side of the handlebars.

The light units also had a speed indicator that communicated the cycling speed using (graphical) intervals. This feature was designed in the shape of a ring and was located around the main bicycle light (see figure 5). The speed indicator had yellow-to-white-coloured and dark-to-light-red-coloured LED-rings on the front and rear units, respectively. The system's CPU measured the cycling speed with magnets mounted on the front wheel's spokes and conveyed this speed by lighting up (a selection of) LEDs ranging from the bottom to the top of the unit. As depicted in figure 5, more lights were enabled in an upward direction as the cyclist reached higher speeds.

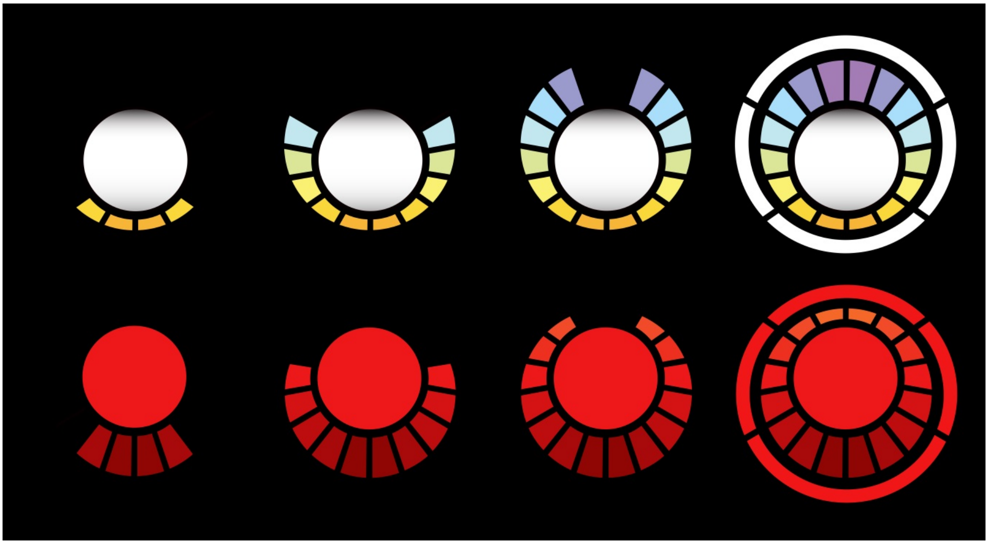

Figure 5. The light signals that indicated the cycling speed. From left to right: slow, medium, fast, and fastest with at the right the attention or braking light for the front (upper pictures) and rear (lower pictures) bicycle lights, respectively.

The last features were an attention signal and a brake signal on the front and rear units, respectively. The attention signal was incorporated in the front BLCS unit by a white lighted outer ring placed between the speed and direction indicator lights (see figure 5, upper-right picture) and could be activated with the central button on the remote controller. On the rear BLCS unit, a brake light was installed on the same location of the attention ring on the front unit (see figure 5, lower-right picture). The brake light was automatically activated by the CPU when the accelerometer reached the threshold of 1 m/s^2.

Cameras
Cycling behaviour of the participants was recorded with three Contour+2™ digital action cameras with GPS. Two of these cameras were mounted on the instrumented bicycle and one on the participant's bicycle. On the instrumented bicycle, one camera was mounted on the left-hand side of the handlebars and directed downward to make recordings which were used to measure the lateral distance to overtaking participants. The second camera was directed forward for the researchers to review the data collection process from 'their' point of view later. To measure the longitudinal following distance, a third camera was mounted on the handlebars of the participant's bicycle and this camera was also directed forward to record the researcher on the instrumented bicycle ahead of the participant.

Questionnaires
Subjective opinions regarding signal interpretation, visibility, ease of use, expected usefulness, and expected safety enhancement were gathered by means of a semi-structured interview. The participants were also asked about their general opinion, the expected pros and cons of the components, and their intention of using or buying a BLCS.

The general 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. The scale provides two measures: Usefulness and Satisfaction.

The mental effort was measured with the Rating Scale Mental Effort (RSME) (Zijlstra, 1993), which is a unidimensional rating scale on which participants can indicate their subjective rating of invested mental effort on a 150mm long line with nine anchor points. On these anchor points, concrete descriptions concerning the level of effort are provided, starting at 'no effort-some effort' (score 2/38) ranging to 'extreme effort' (score 112, max. score 150). The RSME was used because it is a straightforward and valid self-report measure of mental workload (Zijlstra, 1993; Widyanti, Johnson & de Waard, 2013), that correlates with other mental workload measures (e.g. the NASA TLX (Veltman & Gaillard, 1996).

Procedure

Introducing the instrumented bicycle

Before the experiment, the participants received a letter with a general description of the project and the planned test, and they were invited to bring their own bicycle. If a participant was unable to bring his or her own bicycle, a conventional and representative (city) bicycle was offered to use instead. Also, participants with an electric bicycle (pedelec) were asked to disable the electric support. At the day of the experiment, they received a more thorough explanation of the main goal of the experiment and the test procedure. After everything was clear, they signed an informed consent form.

Task 1: Following the instrumented bicycle with the BLCS

After the introduction, the participants were asked to take place on their own bicycle and to follow the test leader who was cycling on the instrumented bicycle (Following Task). Participants who had a speedometer on their bicycle were asked to turn it off or to block the display with a small piece of tape. The participants were asked to cycle as they would normally do and to maintain a following distance that felt comfortable. They were also told to adhere to the traffic rules and to give right of way to other traffic whenever this was necessary.

The Following Task was divided into two conditions with four scenarios per condition: the BLCS 'ON' and BLCS 'OFF' conditions. In the ON condition, all functions of the bicycle lights were active and therefore the participant could perceive the information concerning the cycling speed, turning intentions, and braking manoeuvres of the test leader riding the bicycle. The OFF condition was used as a control condition in which all bicycle light systems were disabled as if it were a conventional bicycle. After both the ON and the OFF conditions, the participant was asked to rate the amount of mental effort required to estimate the speed of the test leader on the instrumented bicycle who was cycling ahead of the participant. This was performed by filling in the RSME (Zijlstra, 1993).

During each condition, four scenarios were executed in which the test leaders differed their cycling speed based on the GPS speed provided by a TomTom Runner 2 GPS watch mounted on the handlebars. The four scenarios were defined as the 'Slow', 'Fast', 'Acceleration', and 'Deceleration' scenarios. The speed details for the scenarios are displayed in table 1. The order of presentation of the ON and OFF conditions was balanced between participants and the order of the speed scenarios was randomized within the conditions. Only in the Acceleration and Fast conditions it was possible to activate the brake light, because in the Slow and Deceleration conditions the speed at the end of the trajectory was too low to reach the threshold of the accelerometer.

Table 1. An overview of the speeds (in km/h) that were maintained during each scenario.

Scenario	Starting Speed	Ending Speed	Brake Light
Slow	13	13	No
Acceleration	13	21	Yes
Fast	21	21	Yes
Deceleration	21	13	No

Task 2: Overtaking the instrumented bicycle

After the Following Task was finished, the participants were asked to follow the test leader again. However, they were now asked to overtake the test leader when they could (Overtaking Task). They were asked to overtake the test leader four times in total, two times per condition ON and OFF. During this task, only the 'Slow' and 'Fast' scenarios were performed of which the order of presentation was also counterbalanced between participants. The participants were also told explicitly that if they felt uncomfortable or unable to overtake the test leader, they were not obliged to do so. Lateral passing distance was assessed during this task.

Task 3: Estimating the speed of the instrumented bicycle

After completing the first two cycling tasks, the participant was asked to stand still at a fixed location next to the cycle path. While standing, one of the researchers cycled towards the participant from a distance of approximately 60 metres and the participant was asked to estimate the researcher's cycling speed in km/h. During this Speed Estimation Task, the participant was asked to make six estimations in total: three times while the BLCS was enabled and three times while it was disabled: the ON and OFF conditions, respectively. Per condition, three different speed scenarios were presented in random order, these were the 'Slow' (12 km/h, gear 3), 'Average' (17.5 km/h, gear 5), and 'Fast' (21 km/h, gear 7) scenarios. The researchers used different gears per scenario to ensure that the pedal frequency (cadence) was similar for all scenarios. The participant could answer at any moment he or she preferred.

Concluding semi-structured interviews

After completing the three tasks, one of the researchers conducted a concluding interview with open-ended questions. The participants were asked about their general opinion, the expected pros and cons of the different BLCS components, and how they experienced the signals as another road user (i.e. only perceiving the signals). Discussed topics were visibility, expected traffic safety, and possible intention of using or buying a BLCS for themselves. Lastly, the participants were asked to again fill in the Acceptance Scale (Van der Laan, Heino & de Waard, 1997) with regard to the entire bicycle light system to assess acceptance, now after they had obtained experience with the system.

Data Analyses

Cycling behaviour was measured by scoring the (longitudinal) following distance and (lateral) overtaking distance of participants by using Kinovea™ for Windows™. For both measures, a perspective grid was created first which was corrected for the camera's lens distortion using Kinovea's™ camera calibration function.

Following distance and Overtaking distance

During Task 1, two videos recorded from the participant's bicycle were used to measure the following distance. With the first video, the camera's perspective was shortly recorded to generate and calibrate a perspective grid that enabled measuring the distance between the researcher's and the participant's bicycle. The second video contained the experimental rides and were used for the actual measurements by importing the perspective grid that was generated with the first video. For each scenario, seven following distance samples were measured on fixed locations. The Mean and Standard Deviation of the following distance were calculated with Microsoft™ Excel™. The effects of the BLCS ON and OFF conditions on the perceived mental effort for estimating the speed of the test leader were analysed with a Wilcoxon signed-rank test because the data were not normally distributed. The overtaking distance was measured using the lateral downward directed camera mounted on the instrumented bicycle. The measurement process was similar to the following distance procedure, although the perspective grid was recorded on the left-hand side of the instrumented bicycle. A semi-automatic tracking method was used to record the lateral position of the overtaking manoeuvre (see figure 6).

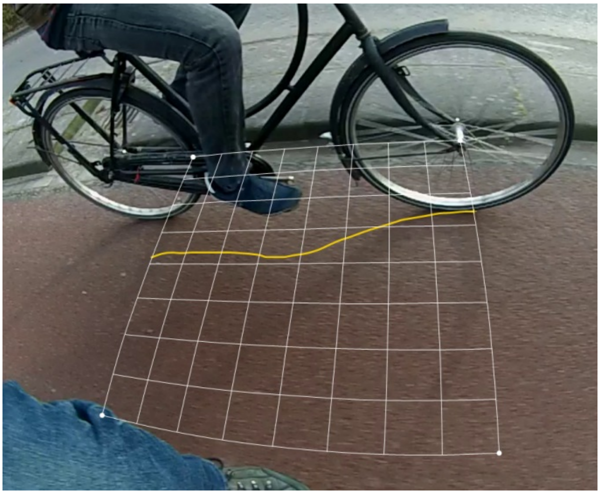

Figure 6. An example of a (semi-automatically) tracked overtaking distance measurement.

Estimating speed

To determine whether participants made more accurate estimations about the speed of the researcher who was approaching them on the instrumented bicycle, it was investigated to what extent the estimated speed and the true cycling speed differed. To reveal potential differences between the conditions, a Wilcoxon signed-rank test was performed because the data were not normally distributed.

Interviews
To determine the general opinion of the respondents about the different components of the light units, the mentioned feedback in the final open interview was audio-recorded. These recorded interviews were analysed after the experiment by summarizing the given answers and counting the specific remarks for all respondents. With regard to the Acceptance Scale (Van der Laan, Heino & de Waard, 1997), the median and interquartile ranges were calculated for both subscales and both age groups.

BLCS User Evaluation
After the experiment, cyclists aged 60 years or older were recruited to experience the BLCS by using an instrumented bicycle for approximately one week. Participants were recruited in the cities of Groningen and Enschede and were provided with a BLCS-instrumented bicycle that was similar to their own bicycle. Subjective opinions regarding usability, balance, and expected usefulness and safety enhancement were gathered. This evaluation mainly focussed on the turning indicator because this was the only element a participant could operate. The participants were instructed to cycle as they normally would and they were not obliged to use the indicator if they were not comfortable with it. The participants received instructions beforehand about operating the BLCS device and gave written informed consent. After the week, a final interview was conducted to assess the participant's experiences.

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

RESULTS

Participants
Forty-one participants were recruited for the experiment: 21 older and 20 younger cyclists (see table 2). The majority of all participants lived in the city of Groningen and brought their own bicycle. Two (younger) participants used a bicycle provided by the researchers.

Twelve older cyclists were recruited to test an instrumented bicycle for approximately one week. The participants lived in the city of Enschede (N = 5) or in the province of Groningen (N = 7). None of the participants had physical complaints while cycling and were all able to look over their shoulder.

Table 2. Demographical participant data.

Part of the Study	Group	Age		Gender	Living environment*			N
		M	S.D.	% Male	% Urban	% Village	% Rural	
Experiment	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
User Evaluation	Older	68.8	4.3	58.3	83.3	16.7	0.0	12

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

Cycling behaviour

The following distances and overtaking distances were measured per condition (ON and OFF) and per scenario (Slow, Accelerating, Fast, and Decelerating). The measurements of three participants were fully removed from the analyses due to failed video-recordings. Additionally, the 'decelerating' condition of one participant was removed from the analysis because the view was obstructed by another cyclist. The analyses indicated no significant differences between the ON and OFF conditions for each group or scenario on mean following and overtaking distance (see figure 7). The mean overall overtaking distance was 106 cm (SD: 11.4 cm).

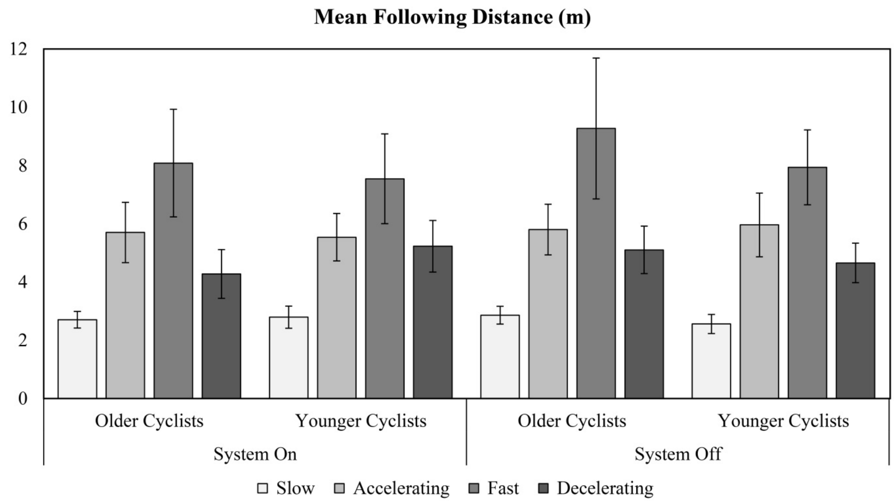

Figure 7. The Mean Following Distance for the conditions System On and Off, per scenario Slow, Accelerating, Fast, and Decelerating. The error bars represent the Standard Error of the Mean (S.E.).

Mental Effort

During Task 1, the participants were also asked to rate the amount of mental effort required to estimate the speed of the test leader they were following. An overview of the RSME scores

(Zilstra, 1993) are displayed in table 3. A medium and significant effect on mental effort was found between the ON and OFF conditions in the overall participant group. The participants experienced less mental effort when estimating the speed of the lead cyclist with the bicycle light system enabled. No effects on mental effort were found within the age groups.

Table 3. Overview of the results from the Rating Scale mental effort (RSME), 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

Estimating speed

The estimations of one (older) participant were removed from the analyses because this participant only gave a concrete speed estimation in one condition and was reluctant to give concrete estimations in the remaining five conditions. On average, the lowest speed (12 km/h) was overestimated (M_{ON} = 12.5, $S.D._{ON}$ = 3.2; M_{OFF} = 12.9, $S.D._{OFF}$ = 3.8), the average speed (17.5 km/h) was underestimated (M_{ON} = 14.8, $S.D._{ON}$ = 3.8; M_{OFF} = 15.1, $S.D._{OFF}$ = 3.1), and the highest speed (21 km/h) was also underestimated (M_{ON} = 17.9, $S.D._{ON}$ = 4.1; M_{OFF} = 17.5, $S.D._{OFF}$ = 3.5). No differences were found between the ON and OFF conditions in any of the scenarios (see table 4).

When exploring within the age groups, a significant medium effect was found only within the older group when they were estimating the cycling speed of the test leader in the 'average speed' scenario. The differences between the actual cycling speed and the estimations were larger when the BLCS was enabled ($Z = -2.14$, $p = .032$, $r = 0.48$).

Table 4. The Median, Interquartile Ranges, and Wilcoxon Signed Rank Test Results for the effects of the BLCS system on the accuracy of estimating the speed of an approaching cyclist in the slow, average, and fast speed conditions.

Condition	Slow	Average	Fast
Variable	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

User experience

General opinion

In total, none of the participants evaluated the bicycle light system negatively while 16% of the participants were positive to very positive about the complete system. Another 37% of the participants was also very positive about the BLCS system, although they mentioned that they would prefer the BLCS without the speed indicator. Another 13% would prefer the turning indicator only and 8% gave a neutral response. A final 26%, all being younger participants, also positively evaluated the BLCS although only because it can be used by others: they would not use a BLCS for themselves.

Intention to use and traffic safety

Of all participants, 63% indicated that they would like to use the light system for themselves and 87% would like other road users to use it. Furthermore, 87% thinks that the system would probably increase traffic safety, at times added with a remark that everybody should use it or that it requires getting accustomed to.

5

Visibility

In total, 76% and 89% of the participants rated the visibility of the front and rear lights (respectively) as (very) good. One participant did not see the turning indicator and one participant stated that it was not clearly visible. All other respondents mentioned that the turning indicator was easily visible. Additionally, 66% mentioned the brake light to be well visible and 8% mentioned that the brake light was not sufficiently visible. A final 26% reported that they did not see the brake light at all.

Turning indicator

A majority (74%) is positive or very positive about observing the turning indicator, 13% believes it is mostly useful for older cyclists, 11% would prefer to indicate a turning manoeuvre by extending the arm, and 3% gave a neutral response. Positive remarks were that the light signals attract immediate attention, are safer on roundabouts, are easily seen in dark conditions, and are very intuitive. Another remark was that cyclists can keep both hands on the handlebars while indicating direction. Negative remarks were that people have to get used to it and participants were afraid that one might not use the indicator or forget to use it.

Brake light

A small majority (55%) is (very) positive about the brake light, compared to 11 % who mentioned that they have doubts about this signal on the bicycle. One third of the participants did not sufficiently see the brake lights and therefore was not able to give an opinion. The positive remarks include that the brake light immediately attracts attention and that it can be used as an extra warning signal. Negative remarks were that it requires much focus and that it was not clearly visible.

Speed indicator

Of all participants, 58% evaluated the speed indicator as negative, 16% rated it as positive, and 26% found the idea behind it interesting although some adjustments should be made. In general, the speed indicator on the front BLCS-unit was evaluated more positively than the speed indicator on the rear unit. Negative remarks were that it was not sufficiently visible and that the differences between the signals were too small to convey the different speeds. It was also mentioned that there was a perceived discrepancy between the actual cycling speed and the displayed signals on the BLCS: the participants were expecting a higher cycling speed when the ring was half-way lit, for example. For many participants, this signal also required a vast amount of attention, was distracting, and was not intuitive. Most participants used other cues for estimating the cycling speed of the test leader, such as the movement speed of the legs and pedals.

Positive remarks were that the speed indicator could be helpful for estimating the speed of people riding electric bicycles, because the assumption is that they can maintain a higher speed than conventional cyclists and that they can cycle faster than people would expect based on pedal movement speed. Participants also mentioned that the speed indicator could be more useful during twilight or in the dark because other cues are not as easily perceived in low light conditions.

Acceptance

All participants were very positive about the BLCS in terms of usefulness and satisfaction after they observed the test leader on a BLCS-instrumented bicycle (see table 5). A Wilcoxon ranked test revealed significant effects of age on both subscales: older cyclists rated the light system as more useful and satisfying than younger cyclists.

Table 5. Median and Interquartile Ranges (IQR) for the Acceptance subscales (Usefulness & Satisfaction; scale range -2 tot +2) (Van der Laan et al., 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

User Evaluation

After having used an instrumented bicycle for one week, all participants (N = 12) mentioned that they used the turning indicator (almost) always. Four participants (33%) also used the arm when they were unsure that other road users saw the turning signal or because it was their routine, and one participant (8%) still also extended the arm in all situations. Ten participants (83%) believed that the turning indicator was clearly visible and also believed that other road users could estimate their intentions correctly. Although five participants (42%) received some remarks from other road users, most participants could not say whether other road users reacted differently on the turning indicator.

Seven participants (58%) mentioned that the turning indicator did not influence their balance while cycling and half of the participants felt safer while using the turning indicator. One participant (8%), however, felt unsafe while using the turning indicator because it took too much effort and habituation. Five participants (42%) mentioned that the turning indicator was mainly useful while cycling in the dark. Nine participants (75%) would like to have the turning indicator on their own bicycle, although two of them (17%) would only like to have it after they start experiencing problems with extending their arm. Three participants (25%) mentioned, however, that they feel slightly overconfident while using the turning indicator because they thought that "*people will see me anyway*".

Technical remarks mostly concerned the controller. Six participants (50%) stated that the turning indicator was easy to operate although wearing gloves, a rain poncho, or cycling over an uneven road surface, for example, could cause difficulties. Also six participants suggested changing the controller: one idea was to use separated controllers on the left and right-hand sides of the handlebars.

DISCUSSION

The aim of this study was to evaluate the BLCS for communicating intentions and behaviour of cyclists to other road users. In an experiment, 21 older and 20 younger cyclists perceived the signals of BLCS bicycle while performing three tasks: following, overtaking, and estimating the speed of the test leader on a BLCS-instrumented bicycle. Effects on cycling behaviour, mental effort, acceptance, subjective opinion, and a speed estimation task were measured. Additionally, twelve older cyclists used a BLCS-instrumented bicycle for their everyday cycling activities for approximately one week, after which their evaluations of the system were gathered.

Main findings

The first analyses were aimed to explore potential effects of the BLCS signals on cycling behaviour when the participants were cycling behind or overtaking a lead cyclist. No significant differences on following distance and lateral overtaking distance were found between the conditions in which the BLCS was enabled or disabled. This could mean that the BLCS does not influence the cycling behaviour of a fellow cyclist on a one-way cycle path. A possible explanation for the absence of effects on following distance could be that the cyclists were not tempted to approach the instrumented bicycle to see the light signals more closely. This may confirm that the visibility of the light units was sufficient, which was also mentioned by the majority of the participants during the interviews. The limited width of the cycle path could have been a restricting factor for the available room for overtaking. Although it would be preferred to use different sized cycle paths, the researchers used this path because it was similar sized to conventional one-way cycle paths in the Netherlands.

Participants did not experience the BLCS as a more mentally demanding device for estimating the speed of a lead cyclist than a conventional bicycle. That the system did not require more mental effort investment is important, because an increase in mental workload could lead to potential safety problems during cycling, in particular if more cyclists would use the system at the same time. As stated by Jahn et al. (2005), a car driver’s mental workload can increase while using communication and information systems. However, the results of this study are in line with Davidse (2007), who concluded that in-car information systems can make it easier to drive while having no effects on mental effort.

The following part of the study was aimed to assess whether the BLCS signals are helpful in assisting cyclists in estimating the speed of an approaching cyclist. The analyses revealed no significant effects of the BLCS light signals on the accuracy of estimating the speed of a cyclist who is cycling with a low, average, or high speed, after comparing with the control condition. This indicates that the estimation accuracy between perceiving the BLCS signals and conventional bicycle signals (e.g. pedal frequency) are similar and that the system could have no additional value. Perhaps it was of influence that the participants were standing still during this experiment and that they could use all of their attention to estimate the speed of the cyclist, also in the control condition. It could be more difficult to estimate the speed of other cyclists while cycling and monitoring a traffic situation at the same time. Also, clear light signals that convey the speed could perhaps be processed faster than observing pedal movements of one or more cyclists in a real traffic situation. However, there was a perceived discrepancy between the actual cycling speed and the way the current BLCS displays these: many participants reported that this was not clear or intuitive.

An important factor was that many participants mentioned that it was very difficult to give speed estimations, regardless of the condition or their age. Furthermore, the experiments were performed during daytime and sometimes the sun light was disturbing, although the majority did indicate that the BLCS signals were clearly visible. The participants who used a BLCS bicycle for a week also reported that the speed indicator was felt to be more useful in faded lighting conditions. This could, however, indicate that it might still be helpful to support the cyclist with estimating the speed of other cyclists in traffic because older cyclists report they can have difficulties with cyclists or other road users that maintain high speeds (Westerhuis et al., 2016). Also, younger cyclists mention that they pay extra attention to older cyclists but they are often surprised about the high speed with which older cyclists are approaching them because the movement of their legs does not correspond to their speed. This could point out a desire for providing and receiving more information about cycling speed than a conventional bicycle offers today and that the BLCS should be developed further.

In general, the BLCS was experienced as a useful and satisfying device as indicated by positive ratings on the two subscales from the user acceptance scale and evaluations in interviews. The participants were mainly positive about the turning indicator and the brake light both as a user and as an observer. The speed indicator was evaluated less positively and could be improved. In general, the BLCS system only meets a few of the wishes; i.e. predicting intention and behaviour and balance improvement by the use of the indicator and the brake light.

Limitations

The present study has some limitations. The first was that the BLCS not always worked perfectly. For example, the brake light was not activated by enabling the brakes but only when the bicycle was significantly decelerating. The finding that not every participant saw the brake light could therefore also be a result of the system not being sufficiently triggered to enable the brake lights, even if the test leader was braking. In a future system, the brake light should therefore be activated by using the brakes and not by deceleration thresholds. Although the BLCS tested in this study was a prototype, it is particularly important for safety systems to function properly because the user will have to rely on the signals being shown to other road users (Parasuraman & Wickens, 2008).

Although the researchers tried to simulate a realistic traffic environment while performing a controlled experiment, the mere fact that the cyclists were participating in an experiment could have made them more focussed on the light signals than they would be in a regular traffic situation. The experiment was also performed during dry, stable weather with good visibility conditions. In particular during faded or dark light conditions the evaluation can be different, although many older cyclists mainly cycle during the day and take the weather conditions into account (Engbers et al., 2018).

Future research could focus more on the consequences of using a BLCS in daily life. For example, it is still unknown how people respond to these kinds of communication systems in real traffic situations when they are not informed beforehand. It could also be interesting to repeat this experiment in less advantageous lighting situations. Although it is known that older cyclists can be hesitant to cycle in the dark or with decreased visibility (Engbers et al., 2018), it could be that they avoid these circumstances for safety reasons.

Although this study focused on (older) cyclists, it would also be interesting to see how other road users, such as car drivers, respond to the signals of the BLCS. Additionally, it might be possible to broaden the target group to cyclists who are afraid to lose their balance while cycling or have difficulties with looking over their shoulder. Furthermore, research over a longer time period is necessary to assess long-term effects.

Conclusions and implications for practice

A BLCS that allows a cyclist to communicate his or her intentions, and therefore facilitates other cyclists to anticipate their behaviour, seems to be a promising concept. Based on the current findings, turning indicators and brake lights can display valuable information of a cyclist's behaviour that might otherwise be less explicitly visible. Furthermore, the turning indicator can be operated by the cyclist without influencing balance. Signals conveying speed information were difficult to interpret, however, and therefore seem to be a less valuable addition. Lastly, it is crucial that such a safety system should operate reliably in all circumstances and thorough (technological) development is therefore necessary before implementation can be considered.

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DECLARATION OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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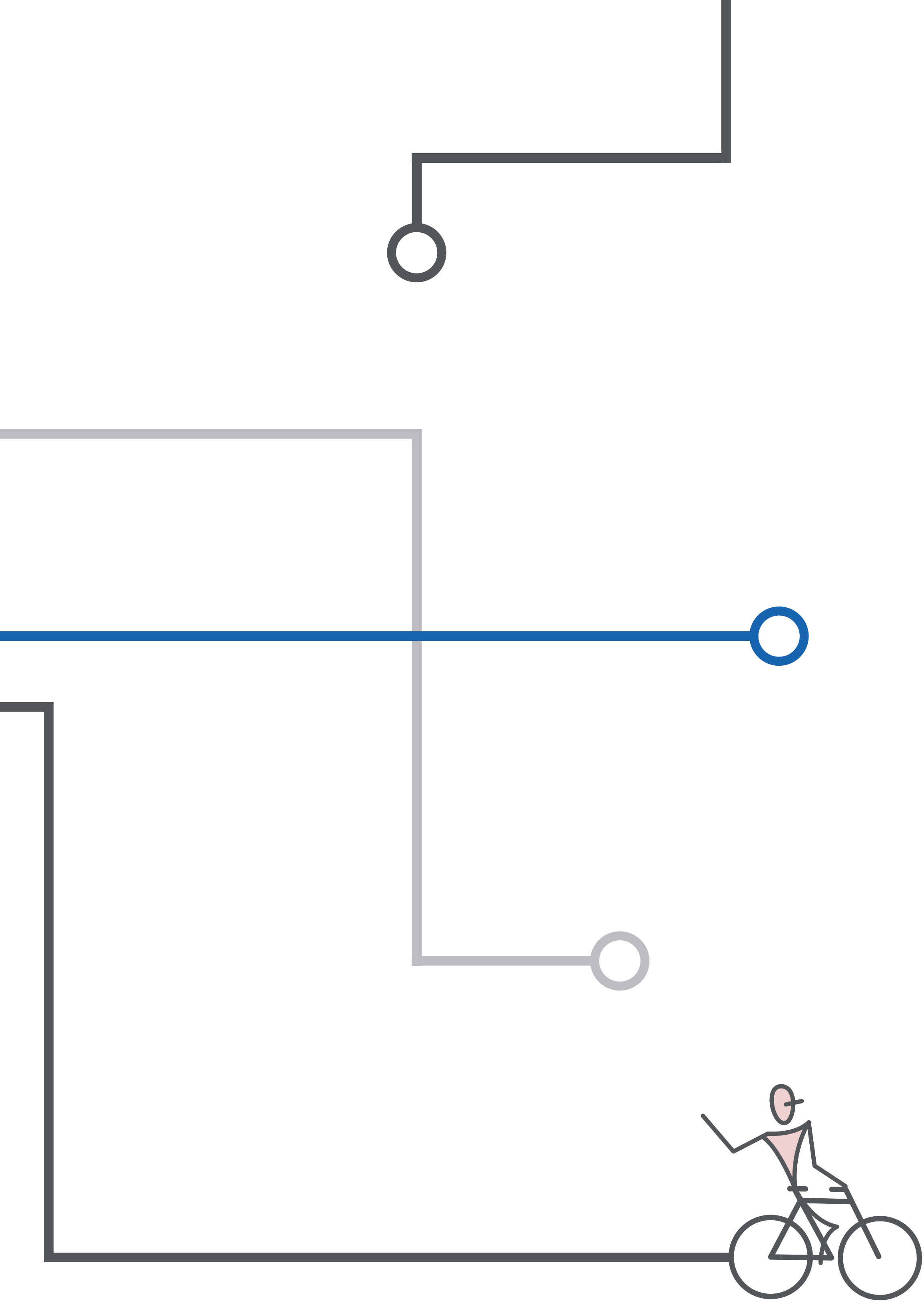

Chapter 6

General discussion

The main objective of this thesis was to explore if and how technology can support the older cyclist in traffic and if technology can be utilized for promoting safe and comfortable cycling. Cycling contributes to improved health and quality of life and is therefore encouraged in people of all ages (Pucher, Dill, & Handy, 2010). However, due to an increased accident risk for people older than 55 years of age (Consumer Safety Institute, 2010), there is a real need for making cycling safer, yet still comfortable. To accomplish this, characteristics of older cyclists were investigated, it was evaluated what supportive technology should look like, and the interaction with other road-users was researched (see Figure 1).

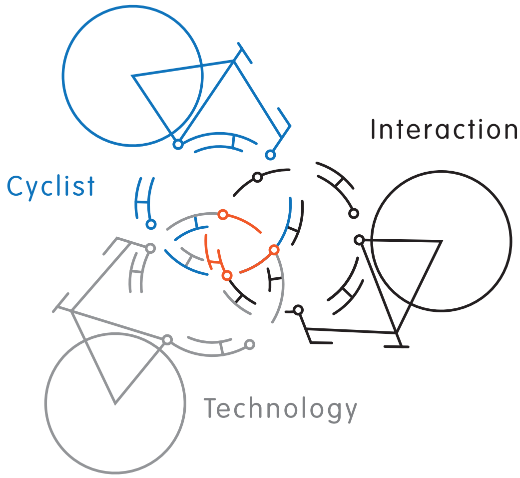

Figure 1: Different factors involved in cycling and the key research topics of this PhD thesis: safe and comfortable cycling for the older adult.

1. THE OLDER CYCLIST

Objective 1: To investigate demographic, physical and mental characteristics of elderly cyclists, and to explore which factors are associated with self-reported cycling accidents in the Netherlands.

A first step in answering the main research question how technology can support safe and comfortable cycling is to investigate the characteristics of the older cyclist. Characteristics and factors associated with self-reported falls play an important role in defining supportive technology.

From the multivariate model, described in Chapter 2, it was concluded that four factors are related to the increased self-reported cycling fall risk of older adults: 1) Age: With every year the cyclist is one year older from the age of 65, the chance they have fallen increases with 7.3%, 2) Mental impairments: If cyclists have mental impairments, the chance they have fallen increases with a factor 2.5, 3) Confidence level: if cyclists were less than completely confident, the chance they have fallen increases with factor 1.8, 4) Environment: If cyclists live in a rural environment compared to an urban environment, the chance they have fallen increases with a factor 2.1. These insights are valuable as self-reported falls are underrepresented in official road accident statistics. The self-reported falls do not always require medical treatment, so many accidents are not officially registered.

Effect of age on fall risk

The above results are in line with what is known from other research. Age is not only significantly associated with falling off a bicycle (Bil et al., 2010; Boufous et al., 2012; Siman-Tov et al., 2012; Kaplan et al., 2014; Martinez-Ruiz et al., 2014, Martinez-Ruiz et al., 2015): the literature shows that there is also a higher fall risk for elderly during gait. Physiological factors, such as visual and hearing ability, reaction time, short-time memory and muscle strength play an important role here (van Schoor et al., 2002; Stalenhoef et al., 2002; Swanenburg et al., 2009; Swanenburg et al., 2010; Lajoie & Gallagher, 2004). Older adults are also more vulnerable when driving a car. According to Davidse (2007), the high fatality rate of older drivers (in developed countries), is mainly the result of their increased physical vulnerability in the event of a crash. From literature is known that with increasing age, cyclists are more likely to have more serious injuries when diagnosed at the emergency department after an accident (Kaplan et al., 2014; Siman-Tov et al., 2012). This is in line with Martínez-Ruiz, et al. (2014), who found that older adults are more vulnerable in general. However, the findings in this thesis (Chapter 2) suggest that the higher risk of falling with a bicycle for elderly cyclists may not just be caused by the older cyclists being more vulnerable, but also when the cyclists ages, the higher the chance they will experience a fall.

Effects of mental impairments and confidence on fall risk

The results in this study indicate that the decrease in physical factors are not the only reason for a high reported fall-risk. Mental aspects are another important cycling fall risk related factor. Most mentioned mental impairments were 'feeling uncomfortable in complex and busy traffic situations', 'fear of falling' and 'having to focus to a larger degree'. These mental impairments could make cycling more mentally demanding and directly influence experiencing positive emotions like calmness. As confirmed by Cabrita (2017) positive emotions (e.g. joy and calmness) showed positive correlations with being able to perform activities of daily living independently. Cycling can be seen as one of those daily activities. According to Oja et al. (2011) cycling represents a potentially powerful way to meet the recommended levels of physical activity for many populations. The theories of positive psychology state that people who experience positive emotions might adopt protective behaviours that delay functional decline and ultimately prevent illness (Veenhoven, 2007). This also supports the scientific evidence that positive emotions increase resilience (Salovey et al., 2000; Tugade & Fredrickson, 2007), i.e.

the ability to cope in moments of adversity and stress (APA, 2016). It may be possible that if older cyclists are confronted with their (mental) limitations, they feel less self-confident and in this way experience fewer positive emotions, which affects the level of daily activities like cycling. Keeping the older adult not only physically healthy, but also to focus on positive emotions, may enhance the ability to adopt strategies to cope in moments of not feeling self-confident. This is important because not feeling self-confident has a negative association with self-reported falls in the elderly cycling population. Knowing more about the potential fall-risk can focus potential technological solutions on the specific problems of elderly cyclists. Developing safe technological supportive devices alone is not enough, to make sure that the mental health from older cyclists is optimal, there should be equally attention for making technology comfortable.

Implications for future supportive technology

The results from this study are important as older cyclists themselves indicate that medical or health issues are the most important reasons to give up cycling (Zeegers, 2010). Often ageing is associated with ‘decline’ and and ‘vulnerability’. Cycling could play a role in prevention of those negative associations, as there are many positive aspects and effects of cycling at a higher age, in line with Oja et al. (2011), who concluded that cycling contributes positively to health, mobility, and quality of life. By compensating for their physical limitations, it might have effect on their feeling of confidence, as it supports the cyclists in complex situations and reduces the need to focus. As stated by Charlton et al. (2006) loss of visual abilities in traffic influences self-confidence. This can directly influence their fear of falling. When supportive devices promote their self-confidence as well, they have potentially positive effects taking into account their physical limitations. A question that remains is which supportive technology would be most effective in improving their safety and improving comfortable cycling.

2. TECHNOLOGY TO SUPPORT SAFE AND COMFORTABLE CYCLING

Objective 2: To investigate how technology can support safe and comfortable cycling for the older population.

In the development process of possible technological solutions to support safe and comfortable cycling it is important to make sure that the technology meets the wishes and needs of the target-group. Therefore, in all [experimental] studies in this thesis, older cyclists were involved in the process from the beginning.

Wishes and needs in the development process

The findings in these studies show that when the technology fits the wishes, needs and limitations of the users, the acceptance of the product is high. Almost all respondents in the studies were very positive about the evaluated new technologies aimed to support them to keep cycling. From the studies in this thesis it was found that early in this process, at the time there was only a conceptual idea of a technological supportive system, respondents were more reluctant to this kind of new technologies. This is confirmed by Hancock & Parasuraman (1992), who stated that elderly people are afraid of and reluctant to use new technology. It could be said that older adults are often seen as the most difficult target group to design technology for. However, a selection bias may have influenced the results in this thesis, as for the studies in this thesis mostly fit and interested older adults participated. According to Stave et al. (2014) there is resistance to changes in general. However, this resistance to change is more about getting used to the new situations and accepting new techniques. It is likely that older people find it difficult to imagine a hypothetical potential supportive device without an actual physical product to experience. In addition, during the explorative stages of the studies, many respondents mentioned that it was important that new technologies must be easy to use and understand and they expected them to be expensive. Stave et al. (2014) also found that elderly think that new technologies are expensive and difficult in use. It was first assumed and later proven that elderly see the advantages of new technologies in particular after having actually experienced these systems themselves, and thereby compensating for their weaknesses. As confirmed by Yannis et al. (2010) & De Waard et al. (1999), elderly are often enthusiastic after experiencing a new product, as long as it is tailored to their specific needs. It can be compared with the development of the electric bicycle, which fits the limitation of the bicyclist, by compensating for the loss of strength and physical endurance.

Rear-view assistance supportive technology

To help older cyclists deal with a situation that is potentially difficult for them, namely turning left; a prototype rear-view assistant system was developed and tested in a lab-setting. In chapter 3 effects on behaviour, mental effort, and acceptance were discussed. Less mental effort was reported when using the rear-view assistant and significantly more correct decisions regarding a safe left turn were made with the system's advice compared to no system's advice. This study was very valuable to let the older adult actually experience a product and gather more information about their specific wishes and needs. However, it should be kept in mind that it was a prototype and it was tested in a lab environment. In this study, it was concluded that the electronic rear-view assistance system could potentially be a helpful support system for the older cyclist by warning them for traffic coming from behind. It supports the older cyclist in decision making in a complex situation, which is targeted to their specific needs. The supportive device counteracts relative weaknesses of the older cyclist, e.g. difficulties when turning left. In this case, a shift takes place from compensation mechanism from the older cyclist (avoiding difficult situations), to compensation for limitations in the functional ability of the cyclists. In this way, the cyclist can more easily perform the activity.

Rear- and front-view supportive technology

To compensate for relative weaknesses, another supportive technology was added: a front-view assistant. The front-view assistant aimed to detect other road users earlier than the older cyclist does, in particular when they are distracted, and this is likely to reduce startle reactions that may result in sudden deviations potentially ending in a fall. These two warning-systems were evaluated in realistic settings with regard to effects on lateral distance to the other cyclist. The subjective effects of the two assistants were evaluated positively, by assessing user acceptance and mental workload, both being crucial for a successful implementation of any new system. Although no difference in cycling behaviour was found, respondents had a very positive attitude towards this type of technology, which can be seen as very promising. It is hoped that this positive attitude leads to more confidence of the older cyclist, which promotes safe cycling behaviour. Both devices provided more decision-making time for the cyclist, by compensation for their limitations, which is added value.

However, the warning systems were prototypes under development and did not perform flawlessly. The performance of the rear-view assistant was worse than the performance of the front view assistance. Both assistants gave too many false positive and false negative warnings during this experiment. Important is that in situations where both assistants should have warned, participants did receive a warning. In this way, the participants were able to judge the warning for those cases when they needed to receive a warning. This can explain the positives remarks participants made about the rear-view assistant. Nevertheless, it is very important that there are no false positives or false negatives warnings, as this undermines trust. A system should approach flawless operation for implementation to the market. The positive effects on subjective measures are promising as they indicate that both systems can support the older cyclists successfully without increasing mental workload.

Effects on workload

The subjective effort ratings in the studies in this thesis showed that cyclists experienced similar (or less in the lab-study) mental effort with and without support of the systems. Although both assistants, in the realistic cycling experience, did not lead to a lower mental effort investment, they did not add to workload either. Not adding to workload is crucial, since a warning device that increases workload could lead to problematic situations in traffic. Supportive systems can also negatively influence performance and attention (Schmidt et al., 2010). A previous study associated a higher workload of older cyclists with increased accident risk (Vlakveld et al., 2015), which is an important factor to keep in mind when developing technological supportive devices. However, it might be possible that the effects on mental effort can be different in more complex, busy, or unexpected situations, or when the cyclist is distracted. During the test, the cyclists were alert, it was dry and clear weather and all participants had a good overview. Although an effort was made to simulate a more realistic setting; the results on subjective evaluation and mental workload can be different in adverse weather conditions, in darkness or while being distracted, conditions in which support is actually much needed.

3. INTERACTION BETWEEN CYCLIST AND OTHER ROAD USERS

Objective 3: To improve the interaction between other older cyclists and other road-users with technology.

As the environment of the cyclist and other road-users also influences the behaviour of the older cyclist, a Bicycle Light Communication System (BLCS) was developed and evaluated to improve the communication of intentions and behaviour of older cyclist to other road-users (Chapter 5). This system consisted of a light system integrated in the front- and rear light, which communicated intentions and behaviour, such as acceleration, deceleration and turning. This turning indicator eliminated the necessity to signal turns by extending the arm. A BLCS that allows a cyclist to communicate his or her intentions, and therefore facilitates other cyclists to anticipate their behaviour, seems to be a promising concept. Turning indicators and brake lights can display valuable information of a cyclist's behaviour that might otherwise be less explicitly visible and was evaluated positively by older and young cyclists. The cycling speed signals were found to be difficult to interpret.

Brake light and turning indicator

In particular, the brake light and turning indicator were positively evaluated. It was mentioned both attract immediate attention and with the turning indicator cyclists can keep both hands on the handlebars when indicating direction. However, the cycling behaviour of the participants did not change as participants kept the same distance when following or overtaking, regardless of receiving information about acceleration, deceleration or braking. This could mean that the BLCS does not influence the cycling behaviour of a fellow cyclist on a one-way cycle path. As confirmed by the participants, the light signals visibility was sufficiently as they were not tempted to approach the instrumented bicycle, which can be seen as promising. A possible explanation for the absence of effects on following distance could be that the cycling situation did not require adaption of cycling behaviour, as for example; the limitation width of the cycling path could have been a restricting factor for overtaking. In this study, it is confirmed that it is difficult to optimally test these kinds of supportive devices in real traffic situations, without compromising safety. However, for a first impression of this kind of technology on a bicycle, the subjective evaluations from the cyclists should perhaps be weighed heavier.

Cycling speed indication

In addition, no significant effects of the BLCS light signals were found on the accuracy of estimating the speed (when standing still) of a cyclist who is cycling with a low, average, or high speed, after comparing with the control condition. This indicates that the estimation accuracy between perceiving the BLCS signals and conventional bicycle signals (e.g. pedal frequency) are similar and that the evaluated system has no additional value. As confirmed during cycling, when following an instrumented bicycle with a speed-indicator, it was mentioned by participants that the overall interpretation of the different speed signals was perceived difficult to understand. However, there may be need for this kind of support, as younger cyclists mention that they pay extra attention to older cyclists using an electrical bicycle, because they are often surprised about the high speed with which they approach them because the movement of their legs does not correspond to their speed (Westerhuis et al., 2016). A similar effect was also found for car-drivers, where the motorist's passing distance was affected by the bicyclists' wheel angle, speed, and speed variation (Chuang et al., 2013). In the case of an electrical bicycle, there is usually a high cycling speed with a seemingly low pedal frequency as a result of the electrical support, but also with a conventional bicycle pedal movement does not always correspond to actual cycling speed as when people use a high gear, they have a low pedal frequency. This is similar to the findings of Schleinitz et al. (2016), who concluded that perception of reduced effects on a bicycle (i.e. lower pedalling frequency) was related to later Time To Arrival estimates regardless of bicycle type (conventional or electric). A clear light signal that conveys the speed could perhaps be processed faster than observing pedal movements of one or more cyclists in a real traffic situation. If so, then the speed indication of the BLCS could still be useful to support the cyclist with estimating the speed of other cyclists in traffic because older cyclists themselves also report they can have difficulties with cyclists or other road users that maintain high speeds. Besides that, a reduction in mental effort was found when estimating the speed of a lead cyclist on a bicycle with the BLCS enabled. A decrease in mental workload could be beneficial in situation where many traffic interactions take place and where it is difficult to get an overview (Westerhuis et al., 2016; Dozza & Werneke, 2014). This finding confirms again that it is important to test these kinds of supportive devices in a realistic setting, as an increase in mental workload could lead to potential safety problems during cycling, in particular if more cyclists would use the system at the same time. Although a light signal might be processed faster than observing pedal moments, it is an unknown signal. It is possible that it took time, for the participants, to get used to this non-familiar signal.

Implications for future supportive technology

As interaction between older cyclists and other road users is inevitable, it is important to evaluate technological innovations with other road users as well. It seemed that that there is a desire for improved communication between road users. In general, the BLSC was experienced as useful and satisfying and specially the feature braking light and turning indicator were evaluated positively. The speed indicator seems to be difficult to interpret and if maintained, should be improved. There was a perceived discrepancy between the actual cycling speed and the way the current BLSC displayed it. So, in its present format it did not work optimally, which could have influenced evaluations as in this testing situation it may not have fitted the user's personal needs. However, it seems to be important to provide information about cycling speed more than a conventional and an electrical bicycle offers todays. The BLSC should be developed further with improving speed indication and the brake light should be activated by using the brakes, instead of deceleration thresholds, as was in current prototype. Thereby, the BLSC should be evaluated with other road-users, such as car drivers and with participants that were not informed beforehand. Future research should be evaluated in a more challenging environment where, for example, mental workload is higher. It would be interesting to see what influences acceptance and whether information is intuitive to interpret in more demanding settings. Evaluation of consequences and acceptance in daily life and would be most valuable, but it is crucial that such a system should operate reliable in all circumstances and thorough (technological) development is therefore necessary before implementation can be considered.

LIMITATIONS

This thesis has some limitations. First, the supportive technologies in this research were not commercially available systems, but prototypes. Hence, the aimed functionality in terms of appropriate warnings (in dense traffic), constant accurate speed indication or a sufficiently triggered brake light was not always achieved. Under performance of the systems could have influenced the results as cyclists should be able to trust these systems. It is important for safety systems to function properly because the user will have to rely on the signals being shown to other road users (Parasuraman & Wickens, 2008). This is in line with Davidse (2007) who concluded that driver assistance systems should be used and trusted and the information that they provide should be understood by its users.

In addition, the participants of the studies in this thesis often had to use a bicycle in a way they were not used to, i.e. in the first study the bicycle was in a bicycle-standard. In other studies, an instrumented bicycle was adapted as much as possible to the participants but was not one they used in daily life. Or they did use their own bicycle, but then, for example, without electrical support or instrumented with cameras. This all may have caused discomfort while riding the bike. Second, controlled experiments can never simulate all real-traffic situations that a cyclist can face in real traffic situations. And although the use of lab-experiments to evaluate supportive devices has several advantages over tests in the real world, such as lower costs, experimental control, and cyclists' (or driver) safety (Kaptein, Theeuwes, & van der Horst, 1996; Lee, Cameron & Lee, 2003), it also has disadvantages. One of the major concerns in ADAS-research for cars, in using driving simulators to measure road-behaviour is the generalizability of research results to real traffic. So far, no studies have evaluated the usage of Advanced Cyclist Assistance Systems on bicycles in real-life situations. In this thesis the supportive device was preferably experienced and evaluated, by the users, in the real end-user environment, making the task more complex as there are other road users, and requiring the participants to keep balance and follow traffic rules. Although a dual-task (e.g. navigating) was added in the experiment with the rear-and front-view assistant, the added value of some supportive systems could not be optimally proven, as potentially unsafe test situations would have been required, which would make ethical approval of the study unlikely.

Weather and time conditions in which the experiments took place, could have influenced the results. The participants cycled mostly alone, in dry weather, and were participating in an experiment and therefore potentially extra focused. It was observed that respondents took the experiments very seriously and most of the respondents mentioned added value of the technology. They were motivated, enthusiastic cyclists who had a positive attitude towards research and technology in general. Many of the older cycling participants were willing to use these systems in daily life, however, results and conclusions from these studies cannot be simply generalised to a wider population, as a participation selection bias may have influenced the results. Another point to consider is that the studies provide a lot of subjective data, which have proven to be very valuable but also have limitations. Participants could have given social-desirable answers. Finally, the studies performed were mostly brief experiments, and users experienced the systems only for a brief period of time. Although some technology was used for a short period in their own cycling routine, long term usage may result in different behaviour and opinions. As these were first experiments, participants were not used to this type of technology and (understandably) may not completely have trusted it. First time use is likely to lead to more focus and concentration and increased awareness.

FUTURE WORK

Supportive technology, such as a rear-view assistant or a light-communication system, could be ideal for older cyclists with physical and mental limitations to enable continuation of safe and comfortable cycling. Systems should comply with several key user requirements. For example; they should be easy to use, cyclists should be able to set their personal preferences, and they should be light and easy to mount (if not already mounted). It was experienced that older adults are willing to use technology on their bicycle when it fits their personal needs. Future research should focus more on the consequences of using supportive technologies in real-life challenging situations, during every day and natural cycling behaviour. The effects in dense traffic, and when other traffic users are not informed beforehand, would be interesting to evaluate. In addition, research should focus more on the effects in rural versus urban environments, as in this thesis it was found that living in a rural environment is related to more self-reported falls. Some studies confirm this statement (Boufous et al., 2012) while others found that in general cycling in the city is more dangerous than elsewhere (Hagemeister & Tegen-Klebingat, 2012). However, more self-reported falls cannot directly be linked to less general cycling safety, as other factors can also be of influence. As the cycling infrastructure outside urban areas is different from the infrastructure in urban areas more research is needed in different environments.

In the future, cooperation with manufacturers of bicycles should be made, or intensified, to further develop this kind of devices and optimise technical performance. Manufacturers can ensure that these products become available on the commercial market. This should be combined with more evaluation research where acceptance, cycling behaviour and mental workload is evaluated by the users and other road-users. For example; cameras can be placed on a crowded crossing to evaluate effects. This knowledge can be used to anticipate on potential problems that may arise. These insights can be transferred to advice for cycling lessons for elderly, during driving-licence lessons or during traffic-education at schools. It would be interesting to study long term effects by integrating a supportive system in the daily cycling routine of older cyclist. Would, for example, older cyclists then make less use of compensation strategies, such as avoiding certain situations? Will there be an increase in self-confidence after actually using and trusting a technological device? It would be interesting to evaluate behavioural adaptation (Rudin-Brown & Jamson, 2013) when testing these supportive devices in daily life. Behavioural adaptation sometimes causes safety measures not to have the full positive results that were expected. For example, with the introduction of ABS many car-drivers took more risks in the sense of braking later (Aschenbrenner & Biehl, 1994). Next to this, future research should also focus on more challenging and potentially dangerous cycling situations. It would be preferable to perform more experiments in a realistic setting, where parameters can be controlled. For example, testing in a cycling simulator or in a realistic virtual reality environment. Factors like weather and other road users can then be influenced and controlled. Despite the limitations, supportive technology on the bicycle has certainly potential for older cyclists to stay or become (more) independent in daily life. However, an active and pleasant life is not only important for older cyclists, these kinds of supportive technologies can probably be extended to other populations who have trouble cycling for different reasons, such as persons with disabilities or impairments or other target groups like parents with child seats, who might have balance problems. In addition, it would be interesting to combine the technical innovations from this thesis and evaluate effects when the older adult is supported by multiple devices. This type of supportive technology on the bicycle requires further technological development. Requirements from technical and user-perspective need to be improved regarding functionality and the option to set individual preferences.

Research in this thesis focused on supportive technology, but this is not the only solution to keep older people mobile. There should also be attention for optimizing infrastructure (by for example, increasing safety margins) and creating less complex routes. In addition, as this supportive technology should be seen literally as ‘supportive’, not ‘taking over’, perhaps sometimes it is better to conclude that another means of transport might be more suitable at a certain moment.

CONCLUSION

Studies in this thesis have generated knowledge on characteristics of the older cyclist and how technology can support safe and comfortable cycling for the older adult. The overlap between three topics was explored: the cyclist, technology, and the interaction with the cyclist’s environment. Several factors are associated with self-reported falling of their bicycle; age, mental impairments, being less than completely confident and living in a rural environment. To compensate for some of these physical and mental impairments, supportive technology was developed to support the older cyclists in traffic. This technology assisted the older cyclists by warning them for approaching traffic from behind and upfront (rear- and front view assistant), or it communicated their intentions and behaviour by a front- and rear light (Bicycle Light Communication System (BLCS)). Positive evaluations were found, but cycling behaviour was not affected in negative nor positive ways as a result of these new technologies. The supportive technologies have potential to lead to more comfortable cycling for the older adult.

This supportive technology potentially can meet wishes of the older cyclists by reducing or eliminating the need to rely on anticipation strategies, such as cycling with a partner, preventing cycling in the dark, crossing a street in two times instead of diagonally or trusting on their hearing abilities when turning left. Older cyclists are willing to use this technology as long as the technology is designed to their needs and has the potential to support the older adults in independent cycling. As the elderly population is growing and the cycling paths in the Netherlands become more and more crowded it is important to look broader than only at conventional passive methods. Those methods mostly focus on prevention of severe injuries, such as wearing a helmet. Other methods of prevention are needed, which is an incentive to invest in developing technological devices for bicycles comparable to ADAS in cars.

"With this device I can finally cycle without help from my husband"!
(woman, 74 years old, who was not able to look over her shoulder).

This thesis outlines to integrate this kind of supportive technology on a bicycle and the advantages for the older cyclists are promising. After all, Dutch people really like to cycle.

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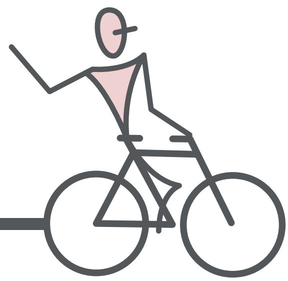

Appendices

Summary
Samenvatting
Dankwoord
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Progress range

SUMMARY

In the Netherlands cycling is important, there are even more bicycles than people. For the older population, cycling is one of the most important physical activities to remain healthy and mobile. Cycling contributes positively to health, mobility, and quality of life and staying mobile is crucial for maintaining a social life. However, older cyclists (60+) also have a higher risk of falling with their bicycle and sustaining a serious injury, compared to younger cyclists. Injury jeopardizes the mobility of this person, with severe consequences, such as depression and feelings of loneliness. Hence, prevention of bicycle accidents of older cyclists is obviously necessary.

In this thesis, the main aim was to investigate how technology can support safe and comfortable cycling to support the older cyclists (60+) in traffic. In **Chapter 1,** the key research topics of this thesis are described, as different factors affect cycling. The first topic covers the characteristics of older cyclists. The second topic focusses on technology related to the bicycle to support older cyclists; what are their wishes and requirements and specifically, how do older people respond to these types of technologies. The third topic covers the interaction of cyclists with other road-users and the communication with them. 'Safe and comfortable' cycling, emerges in the overlapping area between the three topics. The following objectives are described as part of the main aim.

Objective 1: To investigate demographic, physical and mental characteristics of elderly cyclists, and to explore which factors are associated with self-reported cycling accidents in the Netherlands.

Objective 2: To investigate how technology can support safe and comfortable cycling for the older population.

Objective 3: To improve the interaction between older cyclists and other road-users with technology.

As it is important that technology is targeted at the end-users, it is crucial to continuously involve the older cyclist in this development process from the beginning. The research in this thesis therefore starts with investigating the wishes, needs and limitations of the older cyclists. In **Chapter 2**; demographic, bicycle and personal characteristics of older cyclists were revealed, and it was explored which of these factors were associated with self-reported cycling accidents from age 59 in the Netherlands. This study focussed on exploring demographic, bicycle and personal factors related to self-reported bicycle falls, instead of focusing on accident characteristics.

More than eight hundred older cyclists (>65 years) filled out a questionnaire, which included questions on demographics, bicycle specifications and personal characteristics. By means of a logistic regression, the relationship between personal factors and self-reported bicycle falls were studied. From the multivariate model it was concluded that four characteristics of the older population and self-reported factors are associated to an increased risk of a fall accident: increasing age, experiencing mental impairments, lack of cycling confidence and living in a rural environment.

However, even though older cyclists experience problems in traffic, they are at the same time excellent and experienced in avoiding many of these problems. Even though this compensation strategy can be very effective, it can be questioned whether this is the best solution for them. This thesis looks further than the traditional ways of supporting the older cyclists in their limitations. Supportive technology, comparable to Advanced Driver Assistance Systems (ADAS) in cars, could be a potential solution for the older cyclists to cope with their limitations, which makes cycling more comfortable and may reduce injury risk for the older cyclist in traffic. With supportive technology, the need to rely on less effective compensation strategies, such as relying on hearing, could be reduced or eliminated.

Pursuing objective 2, studies were conducted to investigate how technology can support safe and comfortable cycling for the older population. In the following chapters, results are described from studies that were conducted to investigate if and how technology that helps older cyclists deal with a situation that is potentially difficult for them, is accepted, and what their effects are on mental workload and behaviour.
In **Chapter 3**, a simple prototype rear-view assistance system was designed, to warn for traffic approaching from behind, and tested in a lab-environment. In this way, an older cyclist could experience this kind of supportive device in a safe setting. Before actually developing technological devices, it is crucial to take the opinion and experiences of the targeted end-users into account. Turning left on a crossing is in particular considered as a problem by older cyclists (in right-hand drive countries), as older cyclists may have difficulty looking over their shoulder due to stiffness of the neck. To increase the opportunity for older cyclists to continue cycling safely for as long as possible, a solution other than a mirror, that can inform about traffic approaching from behind, was therefore considered. A so-called rear-view cycling assistance system could eliminate the need to look over one's shoulder or in a mirror. The rear-view assistance was evaluated on the effects on behaviour, mental effort and acceptance. This supportive technology warned the cyclist, on a simple cycling simulator, for traffic from behind by LED lights on the steering wheel or by vibrating handlebars. The warning (haptic or visual) was given based on the traffic situation that was behind them, independently of the turn instructions. Thus, if participants were asked whether they could turn right and there was traffic from behind, they were accordingly informed visually or haptically in both experimental conditions, but not in the control condition. Significantly more correct decisions regarding a safe left turn were made with system advice and less mental effort was reported when using

the rear-view assistant. The warning signal by vibration handlebars was evaluation more positive than the led-lights warning signal. It was concluded that the electronic rear-view assistance system can potentially support the older cyclist successfully by warning for traffic coming from behind, without increasing their mental effort. This study gave a first indication of use and acceptance of a rear-view assistant system that supports older cyclists in detecting traffic from behind.

Giving information about, not only, traffic approaching from behind, but also from the front, could make cycling more comfortable and may reduce injury risk for the older cyclist. In this case, cyclists then become aware of others, from both directions in time. A front-view assistant can detect other road users earlier than older cyclists, in particular when they are distracted, and this is likely to reduce startle reactions resulting in sudden deviations that could cause a fall. In **Chapter 4,** an instrumented bicycle, with a front- and rear-view assistant, was evaluated on technical performance, user-experience and effects on lateral position under more realistic settings. Vibrations in the saddle were used to convey the message that someone coming up from behind was detected and vibrations in the handlebars were used to communicate that somebody was approaching from the front. The results indicate that both systems can support older cyclists successfully without increasing mental effort. Both assistants received positive evaluations, although the rear-view assistant was experienced as more useful. This chapter also presented the results in cycling behaviour; using the front-view assistant resulted in less lateral distance to the approaching cyclist, while the use of the rear-view assistant did not have effects on lateral distance. In conclusion, this study demonstrated positive effects of rear- and front view assistance on mental effort, acceptance and lateral distance in a moderately semi-controlled setting.

Finally, it is important to improve communication between road-users. Moving towards objective 3, it was investigated if and how interaction between the older cyclists and other road-users could be improved. Although older cyclists run a relatively high risk to be involved in single-sided accidents, other road users have been related to such single-sided accidents. **Chapter 5,** therefore describes the results of a Bicycle Light Communication System (BLCS), which was developed to improve the communication of intentions and behaviour of cyclists to other road users. This system consisted of a light system integrated in the front- and rear light, which communicated intentions and behaviour, such as acceleration, deceleration and turning. This turning indicator eliminated the necessity to signal turns by extending the arm.

In an on-road experiment, 21 older and 20 younger cyclists observed the light signals while performing several (cycling) tasks. In addition, twelve older cyclists used a BLCS-instrumented bicycle for their personal cycling activities during one week. A BLCS that allows a cyclist to communicate his or her intentions, and therefore facilitates other cyclists to anticipate their behaviour, seems to be a promising concept. Turning indicators and brake lights can display valuable information of a cyclist’s behaviour that might otherwise be less explicitly visible and was evaluated positively by older and young cyclists. The cycling speed signals were found difficult to interpret.

Finally, **Chapter 6** provides an overview of and highlights the most imported findings. It provides a discussion of the results of this research and furthermore it placed the results in a broader perspective with highlighting relevance for practice as well as for future research. Additionally, limitations of the studies in this thesis were discussed. Here, it was shown that technology should work flawlessly, so it does not undermine safety-effects.

In short, this thesis has generated knowledge on characteristics of the older cyclist and how technology can support safe and comfortable cycling for the older adult. The overlap between three topics was explored: the cyclist, technology, and the interaction with the cyclist's environment. Several factors were associated with self-reported falling of the bicycle; age, mental impairments, being less than completely confident and living in a rural environment. To compensate for some of these physical and mental impairments, assistive technology was developed to support the older cyclists in traffic. These supportive technologies have potential to lead to more comfortable cycling for the older adult, as the supportive devices were evaluated very positively. The advantages for the older cyclist are promising.

SAMENVATTING

Nederland is een fietsland. Er zijn zelfs meer fietsen dan mensen. Voor de oudere bevolking is fietsen een van de belangrijkste fysieke activiteiten om gezond en mobiel te blijven. Fietsen draagt op een positieve manier bij aan gezondheid, mobiliteit en kwaliteit van leven en daarnaast is het behouden van mobiliteit cruciaal voor het behoud van sociale participatie. Echter, oudere fietsers lopen, in vergelijking met jongere fietsers, een groter risico om met hun fiets te vallen en ernstig letsel op te lopen. Een ongeval brengt de mobiliteit van de fietser in gevaar, met gevoelens van eenzaamheid en depressie als gevolg. Preventie van fietsongevallen bij oudere fietsers is daarom noodzakelijk.

Om deze reden was het belangrijkste doel van dit proefschrift het onderzoeken of en hoe technologie kan ondersteunen in veilig en comfortabel fietsen voor oudere fietsers (60+) in het verkeer.

Verscheidene factoren zijn van invloed op fietsen. **In hoofdstuk 1** worden daarom de belangrijkste onderzoeksthema's van dit proefschrift beschreven. Het eerste onderwerp beschrijft de kenmerken van oudere fietsers. Het tweede onderwerp richt zich op technologie met betrekking tot de fiets ter ondersteuning van oudere fietsers. Wat zijn hun wensen en eisen en specifiek, hoe reageren ouderen op dit soort technologieën? Het derde onderwerp behandelt de interactie van fietsers met andere weggebruikers en de communicatie tussen hen. 'Veilig en Comfortabel' fietsen, komt naar voren in het overlappende gebied tussen de drie onderwerpen. De volgende doelstellingen zijn opgesteld als onderdeel van de hoofdvraag:

Doelstelling 1: Het achterhalen van demografische, fysieke en mentale kenmerken van de oudere fietser en onderzoeken welke factoren verband houden met zelf-gerapporteerde fietsongevallen in Nederland.

Doelstelling 2: Onderzoeken hoe technologie, veilig en comfortabel fietsen voor de oudere fietsers, kan ondersteunen.

Doelstelling 3: Het verbeteren van de interactie tussen oudere fietsers en andere weggebruikers met behulp van technologie.

Het is van cruciaal belang om de oudere fietser vanaf het begin continu bij het ontwikkelingsproces te betrekken, aangezien de technologie aan moet sluiten bij de eindgebruiker. Het onderzoek in dit proefschrift begint daarom met het onderzoeken van de wensen, behoeften en beperkingen van oudere fietsers. In **hoofdstuk 2** werden kenmerken van oudere fietsers beschreven en er werd onderzocht welke van deze factoren verband hielden met zelf-gerapporteerde fietsongevallen vanaf 59 jaar in Nederland. Deze studie richtte zich op het

verkennen van demografische, fiets- en persoonlijke factoren die verband houden met zelf-gerapporteerde fietsvallen, in plaats van te focussen op kenmerken van ongevallenstatistieken.

Meer dan achthonderd oudere fietsers (> 65 jaar) vulden een vragenlijst in met betrekking tot demografische gegevens, fietskenmerken en persoonlijke kenmerken. Door middel van een logistische regressie werd de relatie tussen persoonlijke kenmerken en zelf-gerapporteerde val-van-de-fiets-incidenten bestudeerd. Uit het multivariate model werd geconcludeerd dat vier factoren van de oudere populatie geassocieerd zijn met een verhoogd risico op een valongeval: een toenemende leeftijd, het hebben van mentale beperkingen, gebrek aan volledig vertrouwen op de fiets en wonen in een landelijke omgeving.

Ondanks dat oudere fietsers problemen ervaren in het verkeer, zijn ze echter tegelijkertijd uitstekend in het compenseren van veel van deze problemen. Hoewel deze compensatie-strategieën zeer effectief kunnen zijn, kan worden betwijfeld of dit de beste oplossing voor hen is. Dit proefschrift kijkt verder dan de conventionele manieren om oudere fietsers te ondersteunen voor hun beperkingen. Ondersteunende technologie, vergelijkbaar met 'rij-hulp-systemen' in auto's, kan een mogelijke oplossing zijn voor oudere fietsers om met hun beperkingen om te gaan. Hierdoor kan fietsen comfortabeler worden en het letselrisico voor oudere fietsers in het verkeer wellicht afnemen. Met ondersteunende technologie kan de noodzaak om te vertrouwen op minder effectieve compensatiestrategieën, zoals vertrouwen op gehoor, worden verminderd of geëlimineerd.

In het kader van doelstelling 2 werden onderzoeken uitgevoerd om te onderzoeken hoe technologie kan ondersteunen in veiliger en comfortabeler fietsen voor de oudere volwassene. In de volgende hoofdstukken worden de resultaten beschreven van de studies die zijn uitgevoerd om te onderzoeken of er technologie mogelijk is die de oudere fietser ondersteunt in het verkeer. Effecten op hun gedrag, acceptatie en hun mentale werkbelasting werden onderzocht.

In **hoofdstuk 3** werd een eenvoudig prototype van een achteruitkijk-assistent ontworpen, die waarschuwt voor van achteren naderend verkeer, en getest in een lab-omgeving. Op deze manier kon een oudere fietser dit soort ondersteunende technologie in een veilige omgeving ervaren. Alvorens daadwerkelijk technologische apparaten te ontwikkelen, is het cruciaal om rekening te houden met de wensen en behoeften van de beoogde eindgebruikers. Linksaf slaan op een kruising wordt met name beschouwd als een probleem bij oudere fietsers (in landen waarbij men aan de rechterkant van de weg rijdt), omdat oudere fietsers moeite kunnen hebben om over hun schouder te kijken vanwege toenemende stijfheid van de nek. Om de mogelijkheid voor oudere fietsers, om zo lang mogelijk veilig te blijven fietsen, te vergroten, werd daarom een andere oplossing dan een spiegel overwogen. Zo kan er informatie worden gegeven over het verkeer dat van achteren nadert. Een zogenaamde achteruitkijk-assistent zou de noodzaak om over de schouder of in een spiegel te kijken overbodig maken. De effecten van deze

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technologie werd geëvalueerd op gedrag, mentale inspanning en acceptatie. Deze ondersteunende technologie waarschuwde de fietser, op een eenvoudige fietssimulator, voor achteropkomend verkeer door LED-lampjes op het stuurwiel of door middel van een trilling in het handvat. Deze haptische of visuele waarschuwing werd gegeven op basis van de verkeerssituatie achter de fietser. Aan de deelnemers werd gevraagd of ze veilig af konden slaan. Wanneer er verkeer van achteren naderde, werden ze ofwel visueel, ofwel haptisch, geïnformeerd tijdens beide experimentele condities, maar niet in de controle conditie. Meer correcte beslissingen met betrekking tot het veilig linksaf slaan werden gemaakt met behulp van deze technologie. Tevens werd er minder mentale inspanning gemeld werd bij het gebruik van de achteruitkijk assistent. Het waarschuwingssignaal door middel van trilling werd positiever geëvalueerd dan het waarschuwingssignaal door middel van de ledverlichting. Geconcludeerd werd dat de achteruitkijk-assistent een oudere fietser in het verkeer mogelijk succesvol kan ondersteunen door te waarschuwen voor verkeer dat van achteren komt, zonder hun mentale inspanning te vergroten. Deze studie gaf een eerste indicatie van het gebruik- en de acceptatie van een achteruitkijk-assistentiesysteem die oudere fietsers ondersteunt bij het detecteren van verkeer van achteren.

Door informatie te geven over verkeer dat niet alleen van achteren, maar ook van voren nadert, kan fietsen comfortabeler worden en kan het letselrisico voor oudere fietsers verminderen. In dat geval worden fietsers zich vervolgens bewust van anderen weggebruikers vanuit beide richtingen. Deze vorm van ondersteunende technologie kan wellicht andere weggebruikers eerder detecteren dan de oudere fietser zelf, met name tijdens afleiding. Hierdoor kunnen potentiele schrikreacties, die kunnen resulteren in die een val, worden verminderd. In **hoofdstuk 4** werd een geïnstrumenteerde fiets met een vooruitkijk- en een achteruitkijk-assistent, beoordeeld op technische prestaties, gebruikerservaring en effecten op de laterale positie in een meer realistische omgeving. Trillingen in het zadel werden gebruikt om te waarschuwen voor verkeer van achteren en trillingen in het stuur werden gebruikt om te communiceren dat iemand vanaf de voorkant naderde. De resultaten geven aan dat beide systemen oudere fietsers succesvol kunnen ondersteunen, zonder de mentale inspanning te vergroten. Beide assistenten kregen positieve evaluaties, hoewel de achteruitkijk-assistent als nuttiger werd ervaren. Dit hoofdstuk presenteerde ook de resultaten in fietsgedrag; het gebruik van de vooruitkijk-assistent resulteerde in minder laterale afstand tot de naderende fietser, terwijl het gebruik van de achteruitkijk assistent geen effect had op de laterale afstand. Concluderend; deze studie liet positieve effecten zien van de vooruitkijk- & de achteruitkijk-assistent op mentale inspanning, acceptatie en laterale afstand in een semi-gecontroleerde omgeving.

Tevens is het belangrijk om de communicatie tussen weggebruikers te verbeteren. In het kader van doelstelling 3 werd onderzocht of- en hoe de interactie tussen de oudere fietsers en andere weggebruikers zou kunnen worden verbeterd. Oudere fietsers lopen een relatief hoog risico het slachtoffer te worden van een enkelzijdig ongeval; een ongeval waarbij niet direct een andere verkeersdeelnemer betrokken is. Echter gaat hier vaak interactie met een andere weggebruiker aan vooraf, zonder dat dit tot een daadwerkelijke botsing leidt. **Hoofdstuk 5** beschrijft daarom de resultaten van een 'Verlichting Communicatie-systeem' dat is ontwikkeld om de communicatie van intenties en het gedrag van fietsers naar andere weggebruikers te verbeteren. Dit systeem bestond uit een lichtsysteem, geïntegreerd in het voor- en achterlicht, dat verscheidene intenties en gedragingen communiceerde; zoals versnellen, vertragen, remmen en afslaan. Door het gebruik van een richtingaanwijzer was het richting aangeven door middel van een hand uitsteken niet meer nodig.

In een experiment op de weg observeerden 21 oudere en 20 jongere fietsers de lichtsignalen tijdens het uitvoeren van verschillende (fiets)taken. Daarnaast hebben twaalf oudere fietsers gedurende een week een fiets met het verlichtingssysteem gebruikt tijdens hun dagelijkse fietsactiviteiten. Dit verlichtingssysteem, waarmee een fietser zijn of haar intenties kan communiceren en daardoor andere fietsers helpt om te anticiperen op hun gedrag, lijkt een veelbelovend concept. De richtingaanwijzer en het remlicht lijken waardevolle informatie te geven over het gedrag van een fietser, wat anders minder expliciet zichtbaar zou zijn. Deze beide functionaliteiten werden positief geëvalueerd door zowel oudere als jonge fietsers. De snelheidsindicatie bleek moeilijk te interpreteren.

Tot slot geeft **hoofdstuk 6** een overzicht van de meest belangrijke bevindingen. Dit hoofdstuk beschrijft de belangrijkste resultaten van dit proefschrift en plaats de resultaten in een breder perspectief, met relevantie voor de praktijk en suggesties voor toekomstig onderzoek. Tevens worden hier de beperkingen van de studies in dit proefschrift besproken. Benoemd wordt dat ondersteunende technologie in het verkeer foutloos zou moeten werken, zodat het veiligheidseffecten niet ondermijnt.

Kort gezegd heeft dit proefschrift kennis opgeleverd over kenmerken van de oudere fietser en hoe technologie kan ondersteunen in veilig en comfortabel fietsen. De overlap tussen drie onderwerpen werd verkend: de fietser, technologie en de interactie met andere weggebruikers. Verschillende factoren zijn geassocieerd met een zelf-gerapporteerde val met de fiets; toenemende leeftijd, mentale beperkingen, gebrek aan volledig zelfvertrouwen en wonen in een landelijke omgeving. Om voor een aantal van deze fysieke en mentale beperkingen te compenseren, is ondersteunende technologie ontwikkeld om oudere fietsers in het verkeer te ondersteunen. Deze ondersteunende technologieën kunnen leiden tot comfortabeler fietsen voor de oudere volwassene, omdat de ondersteunende apparaten zeer positief werden geëvalueerd. De voordelen voor de oudere fietser zijn veelbelovend.

DANKWOORD

Normaal schrijven velen een dankwoord denk ik achteraf. Als de commissie het proefschrift heeft goedgekeurd. Als een datum voor de verdediging gepland staat. Als het eigenlijk niet meer mis kan gaan.

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Tot dusver zijn er veel parallellen te leggen tussen een lange reis en een PhD-traject. Reizen geeft een open kritische blik en deze kijk gebruik ik ook dagelijks in mijn onderzoekswerk. Maar niets hiervan was mogelijk geweest zonder de hulp van vele mensen om mij heen. Na drie keer een langere periode in het buitenland verbleven te zijn, deel ik graag de overeenkomsten en de personen die hierbij een belangrijke rol spelen.

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Kapot gaan en euforie

Deze gaan bijna altijd samen en graag citeer ik hierbij mijn vader: "Het is heel leerzaam om af en toe even helemaal kapot te gaan".
Van kapot gaan heb ik geleerd dat je altijd nog dat stapje verder kan zetten dan je denkt. Van kapot gaan weet ik dat je jezelf een schop onder de kont kan geven. En bij het uiteindelijk behalen van mijn doel; zoals het beklimmen van de Kilimanjaro of het plannen van een promotiedatum, leerde ik dat het behalen zo'n enorme voldoening geeft. Dit wetende kreeg ik alle motivatie om door te zetten. Het geeft zoveel zelfinzicht om te ontdekken dan je meer kunt dan je denkt; dat je jezelf kan verbazen. Dat je naderhand trots kan zijn op jezelf. Inmiddels is, mede door dit inzicht, dus de introductie en discussie geschreven en staat de verdediging gepland.

Thuiskomst

Maar een persoon heb ik nog niet genoemd omdat hij niet bij 1 onderwerp past. Als een rode draad door alle onderwerpen hier loopt mijn grote liefde Joost. Mijn reismaatje, maar ook de rots in de branding thuis en de meest vriendelijke persoon die ik ken. Joost, het woord 'bedankt' voelt niet als toereikend voor alles wat ik zeggen wil. Jij maakt alle goede dagen mooier en alle mindere dagen minder slecht. Jouw vertrouwen in mij, je geduld, je eindeloze energie, gefluit en vrolijkheid betekenen veel. De afleiding die je bracht in de vorm van rondjes hardlopen, fietsen en vakanties waren essentieel voor mij, maar ook de pizza's en cappuccino's thuis hebben dit proefschrift mede mogelijk gemaakt. Bedankt voor de rust en positiviteit die je brengt. Met dit proefschrift sluiten we een hoofdstuk af; al hoop ik dat fietsen altijd centraal in ons leven blijft staan. Ik kijk uit naar de rest van ons leven samen. Of we nou slapen in een tent, een berghut, een camperbusje of gewoon in het mooie Twente; bedankt dat ik bij jou mag thuiskomen.

ABOUT THE AUTHOR

Carola Engbers was born in Enschede, the Netherlands, on May 22nd 1988. After attending high school at 'Het Stedelijk Lyceum Kottenpark' in Enschede, and a year of traveling and working in Australia and New Zealand, she obtained her VWO-diploma from VAVO (adult school) in 2008. Carola obtained her bachelor's degree in Psychology at the University of Twente, during which she did an international minor in Ghana for 3 months. In 2011 she moved to Groningen to study Social Psychology at the University of Groningen, where she obtained her master's degree in 2012. Hereafter, Carola worked at the University Medical Center Groningen as a research-assistant. Simultaneously, she started to work as junior researcher at Roessingh Research & Development for the 'Veilig & Bewust'-project. In 2015 Carola moved back to Enschede and continued to work at Roessingh Research and Development where she was appointed to the 'Cruiser'-project. The results of both projects are presented in this thesis. Her PhD project was about supporting the elderly cyclist in traffic. In 2018, Carola took a year off to travel around the world. Currently she is employed as a psychologist at DBC-Reintegratie in Enschede.

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Conference contributions

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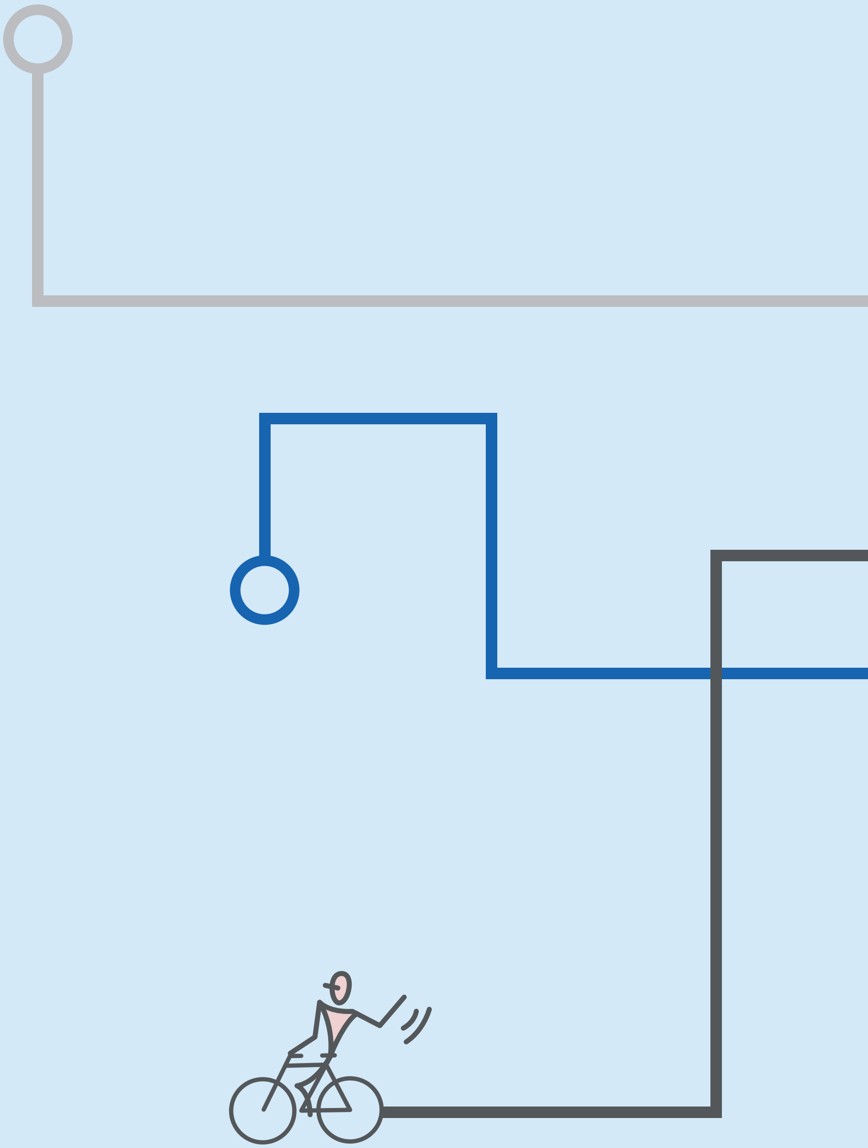

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