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

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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.

Keywords: assistance; cycling; ageing; safety; support; accidents; elderly; mental workload; acceptance; lateral position.

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J.H. Buurke received his PhD in 2005 from the University of Twente for his work on recovery of gait after stroke. He is a Track Coordinator (Principal Investigator) of the Rehabilitation Technology Research cluster at Roessingh Research and Development, an Adjunct Professor at Northwestern University, Chicago, USA, a Senior Researcher at Roessingh Rehabilitation Centre, and he is affiliated to the Biomedical Signals and Systems Group of the University of Twente. He is specialised on human movement analysis. He is actively involved in a diversity of (inter)national projects focusing on motor control, movement analysis, rehabilitation robotics and active assistive devices.

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S.H.H.M. de Hair-Buijssen is a cycling safety expert. She is working on improving cyclist safety by development of user accepted technology measures, both can bound (the cyclist airbag & AEB) and bicycle solutions (intelligent bicycles). She integrates cross functional solutions to increase the joy of cycling, by using a parallel approach considering both technology and the user. She has a large cycling safety network, is cofounder of the International Cycling Safety Conference (ICSC) and was/is involved in many EU and national projects. She plays an integrator role bringing together research, industry and government. As a cyclist safety expert, she conducted effectiveness study on, analysed single bicycle accidents, developed an innovative intelligent bicycle, conducted and coordinated behaviour study on conflicts on cyclist paths, and advised the Dutch Ministry on the speed-pedelec helmet. Currently she is involved in the EU funded projects MeBeSafe and C-Mobile.

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1 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.

2 Method

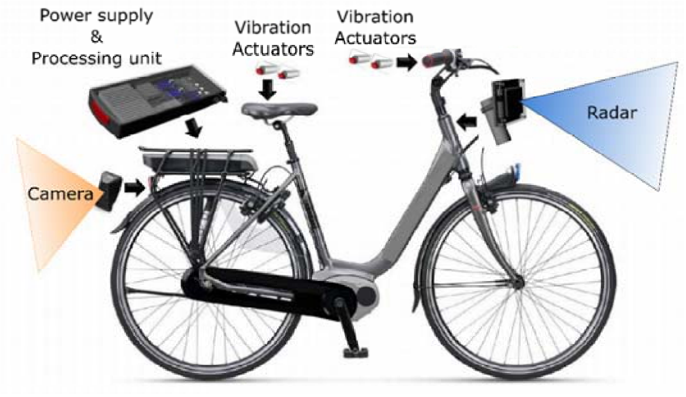
2.1 Participants

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).

2.2 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 (see online version for colours)



2.2.1 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.

2.2.2 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).

2.2.3 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).

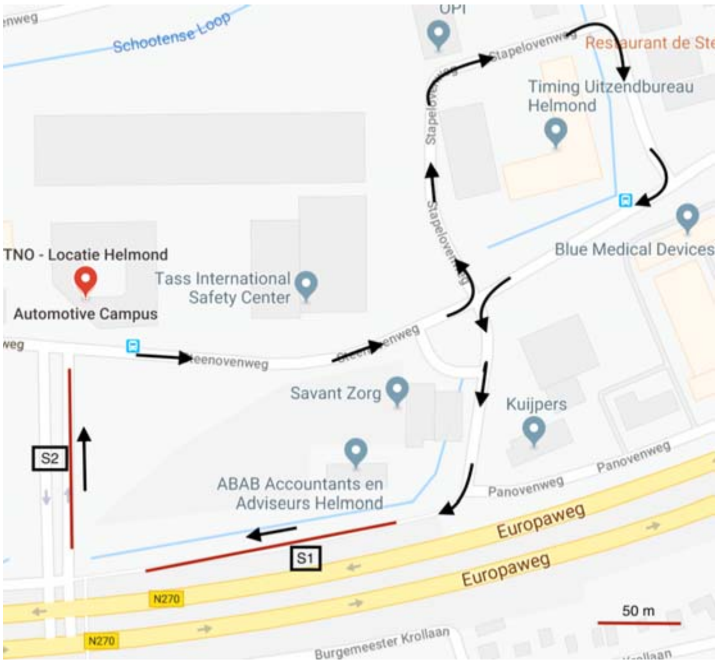
The timing of warning was triggered by critical time-to-collision (TTC) values. TTC is defined as the time it takes for a following vehicle to hit the vehicle in front, assuming they continue the same course and the same speed (Lee, 1976; van der Horst, and Hogema, 1993). The threshold TTC was set at 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.

2.3 Procedure

2.3.1 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 (see online version for colours)



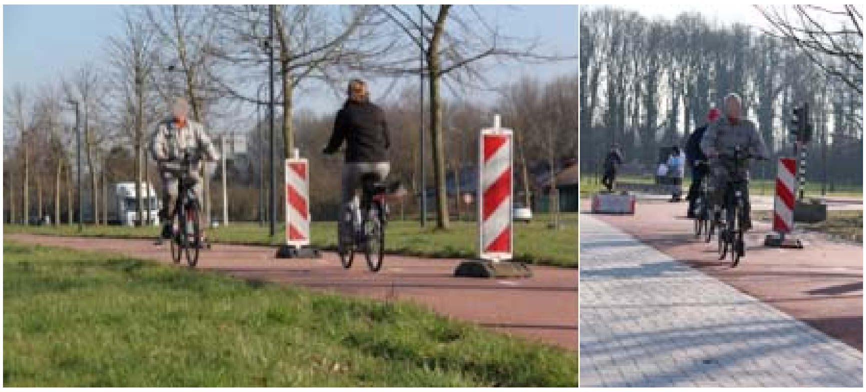
Source: Google Maps (2017)

2.3.2 Scenarios

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

- 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.
- 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.

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) (see online version for colours)



2.3.3 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.

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. 2.4 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.

2.4 Material

2.4.1 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.

2.5 Measures

2.5.1 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.

2.5.2 *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).

2.5.3 *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.

2.5.4 *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 2.6 for details.

2.5.5 *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.

2.6 Dependent 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.

3 Results

3.1 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.

3.2 Cyclists' lateral position

3.2.1 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).

3.2.2 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)

3.3 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.

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.

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)

3.4 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)

4 Conclusions

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 were 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 on 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.

5 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 could 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.

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References

Bekiaris, E. (1999) 'New driving assistance technologies for elderly drivers', *JIDITVA*'98 *International Days of Road Safety, Brussels, Belgium*, *26–28 October 1998* (Theme B: driving license), Institut Belge Pour la Sécurité Routière IBSR, Brussels.

Charmant (2016) *Kinovea (Version 0.8.25) [Computer Software]*, http.//www.kinovea.org/

Cruz, L. (2007) *Two Second Rule*, May, Retrieved from. http.//www.studydriving.com/safety-on-the-road/the-two-second-rule (15 December, 2017).

Davidse, R.J. (2007) *Assisting the Older Driver: Intersection Design and in-Car Devices to Improve the Safety of the Older Driver*, PhD thesis, University of Groningen.

Dotzauer, M., De Waard, D., Caljouw, S.R., Pöhler, G. and Brouwer, W.H. (2015) 'Behavioral adaptation of young and older drivers to an intersection crossing advisory system', *Accident Analysis and Prevention*, Vol. 74, pp.24–32.

Dotzauer, M., De Waard, D., Caljouw, S.R. and Brouwer, W.H. (2013) 'Longer-term exposure to an intersection assistant: effects of ADAS use on intersection performance of drivers diagnosed with Parkinson's disease', *International Journal of Human Factors and Ergonomics*, Vol. 2, pp.223–245.

Engbers, C., Dubbeldam, R., Buurke, J.H., Schaake, L., De Goede, M., Rietman, J.S. and De Waard, D. (2016) 'The acceptance of a prototype rear-view assistant for older cyclists: two modalities of warnings compared', *The International Journal of Human Factors and Ergonomics*, Vol. 4, pp.264–281.

Färber, B. (2000) 'Neue Fahrzeugtechnologien zur Unterstützung der Mobilität Älterer', *Zeitschrift Für Gerontologie Und Geriatrie*, Vol. 33, pp.179–185.

Google Maps (2017) Maps.google.com

Gordon-Salant, S. (2005) 'Hearing loss and aging: new research findings and clinical implications', *Journal of Rehabilitation Research and Development*, Vol. 42, No. 4, p.9.

Heinen, E., Maat, K. and van Wee, B. (2013) 'The effect of work-related factors on the bicycle commute mode choice in the Netherlands', *Transportation*, Vol. 40, No. 1, pp.23–43.

Hoedemaeker, M. (1996) *Behoeften, Rijstijlen En Meningen Ten Aanzien Van Automatische Voertuig Besturing (Needs, Driving Styles and Opinions Towards Automated Driving)*, Technical University Delft, Delft, The Netherlands. Report.

Hoedemaeker, M. and Brookhuis,K.A. . (1998) 'Behavioural adaptation to driving with an adaptive cruise control (ACC)', *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 1, No. 2, pp.95–106.

Horswill, M.S., Marrington, S.A., McCullough, C.M., Wood, J., Pachana, N.A., McWilliam, J. and Raikos, M.K. (2008) 'The hazard perception ability of older drivers', *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, Vol. 63, No. 4, pp.212–218.

Lee, D.N. (1976) 'A theory of visual control of braking based on information about time-to-collision', *Perception*, Vol. 5, No. 4, pp.437–459.

Mitchell, C.G.B. and Suen, S.L. (1997) 'ITS impact on elderly drivers', *Proceedings of the 13th International Road Federation IRF Word Meeting, Toronto, Ontario, Canada, June 16 to 20, 1997 [CD-ROM]*, International Road Federation, I.R.F., Genève, Switserland.

Mori, Y. and Mizohata, M. (1995) 'Characteristics of older road users and their effect on road safety', *Accident Analysis and Prevention*, Vol. 27, No. 3, pp.391–404.

Parasuraman, R., Sheridan, T.B. and Wickens, C.D. (2000) 'A model for types and levels of human interaction with automation', *IEEE Transactions on Systems, Man and Cybernetics-Part A: Systems and Humans*, Vol. 30, No. 3, pp.286–297.

Posner, M.I., Nissen, M.J. and Klein, R.M. (1976) 'Visual dominance: An information-processing account of its origins and significance', *Psychological Review*, Vol. 83, No. 2, p.157.

Pucher, J. and Buehler, R. (2008) 'Making cycling irresistible: lessons from the Netherlands, Denmark and Germany', *Transport Reviews*, Vol. 28, No. 4, pp.495–528.

Pucher, J. and Dijkstra, L. (2003) 'Promoting safe walking and cycling to improve public health: lessons from the Netherlands and Germany', *American Journal of Public Health*, Vol. 93, No. 9, pp.1509–1516.

Reurings, M.C.B., Vlakveld, W.P., Twisk, D.A.M., Dijkstra, A. and Wijnen, W. (2012) *Van Fietsongeval Naar Maatregelen: Kennis En Hiaten. [From Bicycle Crash to Measures: Knowledge and Knowledge Gaps]*, *S*WOV-rapport R-2012–8, Institute for Road Safety Research (SWOV), Ed, 203, Leidschendam.

Schepers, P. and Wolt, K.K. (2012) 'Single-bicycle crash types and characteristics', *Cycling Research International*, Vol. 2, No. 1, pp.119–135.

Schmidt, A., Dey, A.K., Kun, A.L. and Spiessl, W. (2010) 'Automotive user interfaces: human computer interaction in the car', *CHI'*10 *Extended* Abstract*s on Human Factors in Computing* Systems, ACM, April, pp.3177–3180.

Slütter, M. and Koudijs, M. (2007) 'Fietsers in de file', *VogelVrije Fietser*, Vol. 32, pp.10–13.

Tacken, M. (1998) 'Mobility of the elderly in time and space in the Netherlands: An analysis of the Dutch National Travel Survey', *Transportation*, Vol. 25, No. 4, pp.379–393.

Van der Horst, R. and Hogema, J. (1993) *Time-to-Collision and Collision Avoidance Systems*, pp.109–121.

Van der Laan, J.D., Heino, A. and De Waard, D. (1997) 'A simple procedure for the assessment of acceptance of advanced transport telematics', *Transportation Research Part, C*, Vol. 5, No. 1, pp.1–10.

Van Erp, J.B., Toet, A. and Janssen, J.B. (2015) 'Uni-, bi-and tri-modal warning signals: Effects of temporal parameters and sensory modality on perceived urgency', *Safety Science*, Vol. 72, pp.1–8.

Venkatesh, V. and Morris, M.G. (2000) 'Why don't men ever stop to ask for directions? Gender, social influence and their role in technology acceptance and usage behavior', *MIS Quarterly*, pp.115–139.

Venkatesh, V., Morris, M.G. and Ackerman, P.L. (2000) 'A longitudinal field investigation of gender differences in individual technology adoption decision-making processes', *Organizational Behavior and Human Decision Processes*, Vol. 83, No. 1, pp.33–60.

Westerhuis, F. and De Waard, D. (2016) 'Using commercial GPS action cameras for gathering naturalistic cycling data', *SICE Journal of The Society of Instrument and Control Engineers*, Vol. 55, pp.422–430.

Widyanti, A., Johnson, A. and De Waard, D. (2013) 'Adaptation of the Rating Scale Mental Effort (RSME) for use in Indonesia', *International Journal of Industrial Ergonomics*, Vol. 43, pp.70–76.

Zijlstra, F.R.H. (1993) *Efficiency in Work Behavior: A Design Approach for Modern Tools*, PhD Thesis, Delft University of Technology, Delft University Press, Delft, The Netherlands.