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PC-based hazard anticipation training for experienced cyclists: Design and evaluation

N. Kovácsová[a,b,*], W.P. Vlakveld[b], J.C.F. de Winter[a,c], M.P. Hagenzieker[d]

[a] Department of Biomechanical Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, the Netherlands
[b] SWOV Institute for Road Safety Research, P.O. Box 93113, 2509 AC The Hague, the Netherlands
[c] Cognitive Robotics Department, Delft University of Technology, Mekelweg 2, 2628 CD Delft, the Netherlands
[d] Department of Transport & Planning, Delft University of Technology, Stevinweg 1, 2628 CN Delft, the Netherlands

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ABSTRACT

Research shows that the ability to anticipate safety-critical situations is predictive of safe performance in traffic. Thus far, hazard anticipation training has been developed mainly for car drivers. These training programs may not be appropriate for cyclists who are exposed to different types of hazards. This study aimed to develop a PC-based hazard anticipation training for experienced cyclists, and evaluate its short-term effectiveness using hazard anticipation tests. Sixty-six electric bicycle users completed either a hazard anticipation training or a control intervention. The hazard anticipation training consisted of videos divided into two modules (instructions and practice) and was designed using various evidence-based hazard anticipation educational methods such as a 'What happens next?' task, expert commentary, performance feedback, and analogical transfer between hazardous traffic situations. The evaluation of the training showed that cyclists from the training group identified hazards faster compared to the control group cyclists, but no significant difference was found in the number of detected hazards between the two groups. The training had a small positive effect on cyclists' prediction accuracy at safety-critical intersection situations. No effect was found on perceived danger and risk in hazardous traffic situations. Our results suggest that experienced cyclists' hazard anticipation skills can be improved with the developed PC-based training. Future research should evaluate the retention and transfer of learned skills.

1. Introduction

Hazard anticipation, defined as "the ability to read the road and anticipate forthcoming events" (McKenna et al., 2006, p. 2), is a crucial skill for safe performance in traffic. So far, the majority of knowledge on hazard anticipation, its acquisition, and its training has been generated for car drivers (Moran et al., 2019). Although the psychological mechanisms of hazard anticipation may be independent of the vehicle one is operating, traffic situations used in training interventions for car drivers may be inappropriate for other types of road users.

Commuting by bicycle is popular in countries such as the Netherlands and Denmark (Wegman et al., 2012), and the promotion of active forms of transportation is expected to further increase the number of cyclists in traffic (Schepers et al., 2014b). Accordingly, there is a significant need to understand which dangerous situations cyclists encounter and whether cyclists can benefit from hazard anticipation training. Recent naturalistic cycling studies indicate that typical cycling hazards are cars, other cyclists, and pedestrians (Dozza et al., 2016; Dozza and Werneke, 2014; Petzoldt et al., 2017). Furthermore, road safety statistics show that about two-thirds of serious cycling crashes involve a motorized vehicle (European Commission, 2018; Gehlert et al., 2018; Schepers et al., 2017). Interactions with car drivers at intersections are regarded as particularly hazardous (Petzoldt et al., 2017).

Cyclists usually acquire their cycling skills during childhood (Colwell and Culverwell, 2002; Rivara and Metrik, 1998). It may, therefore, be expected that adult cyclists have become competent in hazard anticipation through long-term exposure. Experienced road users have mental models of the traffic environment that allow them to predict hazardous situations effectively (Horswill and McKenna, 2004; Underwood, 2007). However, as argued by Horswill et al. (2013), the hazard anticipation skills of experienced road users are often sub-optimal. This argument is supported by evidence from car driving research showing that (1) expert drivers score better at hazard anticipation tasks than experienced drivers (Crundall et al., 2003; 2012), (2) experienced drivers still benefit from hazard anticipation training (Horswill et al., 2013, 2015), (3) no ceiling effect in hazard anticipation

* Corresponding author at: Department of Biomechanical Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, the Netherlands.
E-mail address: nataliakovacsova@gmail.com (N. Kovácsová).

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skill seems to exist (Horswill et al., 2013), and (4) learning through driving experience is a slow process, possibly due to the lack of performance feedback and the rarity of conflict situations (Horswill, 2016).

In line with research findings that hazard anticipation skills are under-developed even in experienced road users (Crundall et al., 2013; Horswill et al., 2010, 2013, 2015), we designed and evaluated a PC-based hazard anticipation training for experienced cyclists using video clips of hazardous situations collected during everyday commuting. A digital hazard anticipation training may represent a suitable alternative to traffic education (cf. Petzoldt et al., 2013) and may be appropriate for reaching road users who do not have to go through a licensing process, such as cyclists. Our evaluation of the hazard anticipation training was conducted among electric bicycle users, who seem more likely to be involved in severe crashes than persons riding a conventional bicycle (Gehlert et al., 2018; Schepers et al., 2014a). Electric bicycles have gained popularity over the last decades (Fishman and Cherry, 2016). The elevated risk of electric bicycles may be attributable to the decreased physical and cognitive functions of older people, who are frequent e-bike users, especially in the Netherlands and Austria (Van Boggelen et al., 2013; Wolf and Seebauer, 2014). The two questions addressed in this study are as follows:

1 How should a training program be designed for enhancing experienced cyclists' hazard anticipation?

We developed a PC-based hazard anticipation training that aimed to improve experienced cyclists' comprehension of the road environment and prediction of what might subsequently happen. The design of the training intervention was assessed using task performance measures, monitoring of cyclists' subjective state, and cyclists' feedback.

2 How does the training intervention affect cyclists' hazard anticipation skills and perceived risk?

We expected that the training would improve cyclists' hazard anticipation skills and perception of risk in safety-critical situations. Training effectiveness was assessed by measuring cyclists' hazard detection times, the number of detected hazards, prediction accuracy, and perceived danger and risk.

In Section 2, the design of the hazard anticipation training is described. Section 3 describes the methods of the evaluation experiment. The results and discussion for the two research questions can be found in Sections 4 and 5.

2. Hazard anticipation training design

2.1. Training methods

A variety of hazard anticipation training strategies have been developed, which aim to either teach visual search skills (e.g., McKenna et al., 2006; Meir et al., 2014), identify regions of the roadway where hazards could arise from (e.g., Fisher et al., 2002; Pollatsek et al., 2006), or improve the anticipation of other road users' actions (e.g., Petzoldt et al., 2013; Vlakveld et al., 2011; Wetton et al., 2013).

Hazard anticipation can be explained by the three-level situation awareness (SA) theory (Endsley, 1995). Level 1 SA is the perception of visual elements of the traffic situation, Level 2 SA involves the comprehension of their meaning, and at Level 3 the road user predicts the future status of the traffic situation. While novices may benefit from learning visual scanning strategies to detect important stimuli (Level 1 SA), experienced road users may benefit from learning to translate the detected visual stimuli into a correct prediction of others' future actions (Level 3 SA) (Crundall et al., 2012).

In hazard anticipation training/tests developed for car drivers, the user typically responds to three types of questions that probe SA: "*What is the hazard?*" (Levels 1 and 2 SA), "*Where is the hazard?*" (Levels 1 and 2 SA), and "*What happens next?*" (Level 3 SA) (Crundall, 2016; Jackson et al., 2009; Ventsislavova and Crundall, 2018). The questions are asked after watching footage of a hazardous traffic situation (i.e., the situation in which a crash is very likely if not anticipated), which cuts to a black screen when a hazard begins to develop. When responding to the questions, the participant has to reflect actively on the answer, which may benefit knowledge retention (Butler et al., 2007). Additionally, with a PC-based training program, it is possible to provide performance feedback (Petzoldt et al., 2013; Ventsislavova and Crundall, 2018), offering insight into one's performance and possibly reducing self-enhancement bias (Horswill et al., 2017). Furthermore, research has shown that an instructional component may be a useful addition to hazard anticipation training (Horswill, 2016). For example, a running commentary in which an expert points out situational cues has shown a positive effect on hazard perception skills and risk-taking behavior (e.g., McKenna et al., 2006; Wetton et al., 2013). Another training approach is to combine expert commentaries with trainee-generated commentaries to encourage active information processing (e.g., Horswill et al., 2013, 2015; Wetton et al., 2013).

We designed a hazard anticipation training for experienced cyclists using various evidence-based methods mentioned above. The training consisted of two modules. Module 1 was an instructional module with expert commentary and the possibility of replaying the hazardous situations, and Module 2 was a practice module in which participants were encouraged to transfer what they have learned in Module 1 to different but conceptually similar hazardous situations. After the video clip of each traffic situation, the participant had to answer two questions "Where is the location of the hazard?" and "What happens next?" using a multiple-choice format. Visual and auditory feedback was provided after answering each question and could be either positive or negative. In Module 1, the active exploration of the hazard was facilitated by the possibility of viewing the video of the same traffic situation three times before revealing the correct answer.

2.2. Training program

The training intervention had a linear user flow in which each participant started with a login screen, followed by introduction videos, Module 1, Module 2, and a wrap-up video clip. The introduction videos provided a description of the application and a definition of hazard anticipation skills. After this introduction, the participant completed 16 trials (i.e., 16 different hazardous traffic situations) divided into the two modules. Each module consisted of one practice and seven training situations. Module 1 had to be completed to unlock Module 2.

The traffic situations were presented in the same order for each participant. In each module, each hazardous traffic situation was presented to the participant using four screens (Fig. 1):

Knowing the traffic environment. The participant was presented with a top-down view of the traffic environment that would be shown in the video clip later on. The screen showed an arrow indicating the direction in which the cyclist was riding, and a short description of the environment.

Experiencing the traffic situation. The participant watched a video that was recorded from the perspective of a cyclist in which one of the road users became a hazard. In Module 1, the video clip could be played three times, depending on the correctness of the participant's responses to the questions. During the second and third play, the video clip was occluded 1 s later than during the previous attempt. This means that three occlusion levels for each traffic situation in Module 1 were created (Fig. 2). This was based on the presumption that the temporally closer the cyclist is to the hazard, the more relevant visual information is available, resulting in a higher accuracy of the prediction (Farrow et al., 2005). In Module 2, the video clip of the traffic situation could be played only once.

Anticipating the hazard. As soon as a hazard started to develop, the video was occluded and a question screen appeared. The question

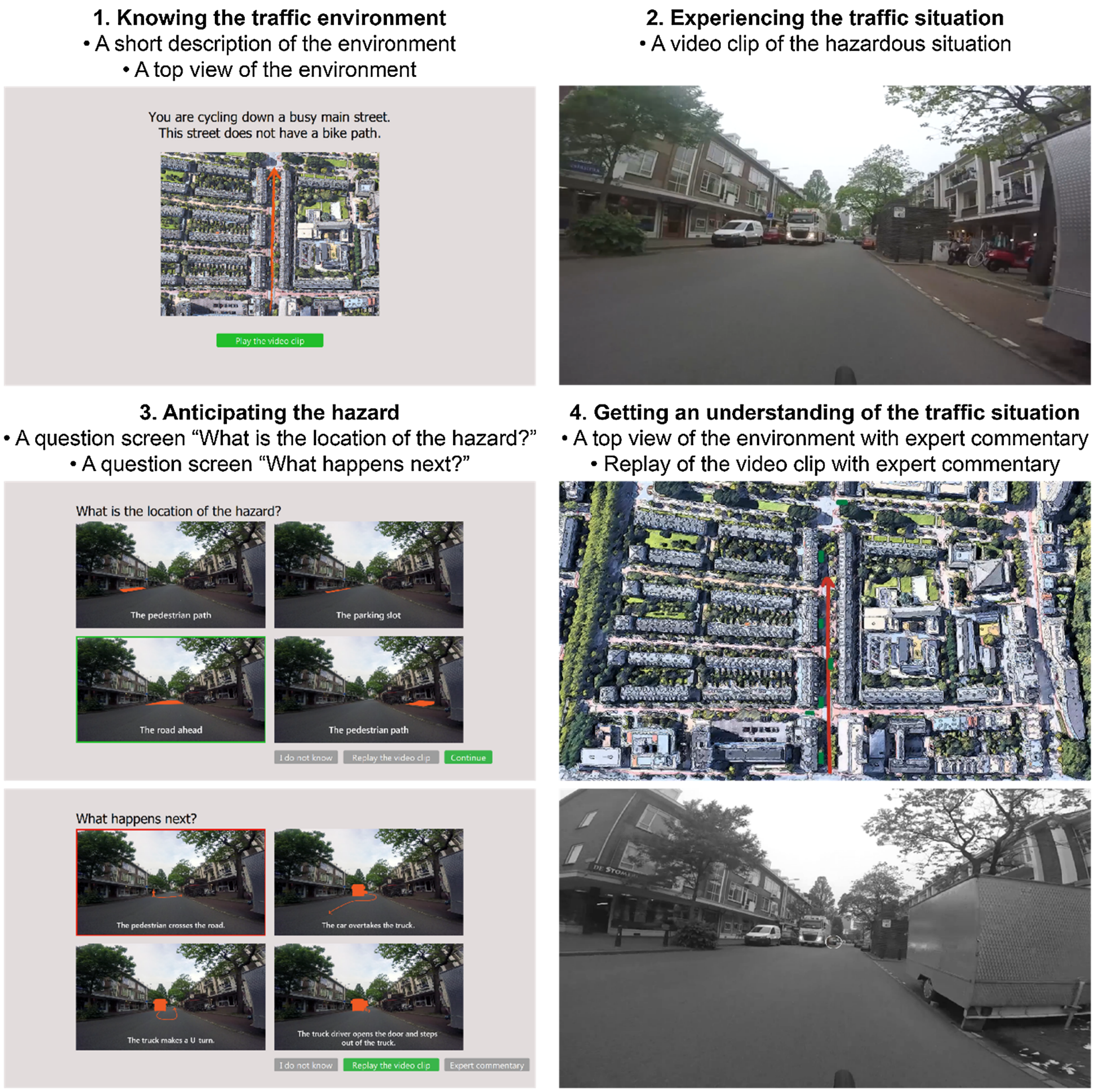

Fig. 1. Four screens in Module 1 (Situation 1, Occlusion level 2). The question screen "What is the location of the hazard?" shows an example of positive visual feedback (the green frame around the correct answer). The question screen "What happens next?" shows an example of negative visual feedback (red frame around the incorrect answer). Screens were presented in the Dutch language during the actual experiment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

screen included a picture of the same street the cyclist saw in the video clip, but without road users. The first task was to answer the question "What is the location of the hazard?" (hereafter abbreviated as '*Where*'). The participant could choose from four pictures in which an orange area was shown and described. The second task was to answer the question "What happens next?" (hereafter abbreviated as '*WHN*'). Again, the participant saw four pictures, but this time with a silhouette of the hazardous road user, an arrow indicating the future path of this hazardous road user, and a short description of what would happen next. In each case, there was only one correct answer, and there was always a possibility to answer "I do not know". In Module 1, the participant had to respond correctly to the *Where* question in order for the *WHN* question to appear. In Module 2, each question screen was shown only once.

Getting an understanding of the traffic situation. The participant watched a video clip of the entire situation with a commentary. In Module 1, the expert commentary video clip was composed of a top view of the traffic situation with trajectories of potential hazards, followed by a video clip of the entire traffic situation (Fig. 1, Screen 4). In Module 2, the expert-trainee commentary video clip was composed of a picture of the hazard and a short video clip of the matched hazard from Module 1. The commentary said for example: "*The hazard was a car that turned and had to yield* (referring to the hazard in Module 2, Fig. 2, bottom left). *This hazard developed similarly to the bus driver who turned and did not notice you* (referring to Module 1, Fig. 2, left). *Let's now watch the entire video clip.*" Next, a video clip of the entire traffic situation was played, which paused when the hazard started to develop. At this point, the participant was asked to produce a self-commentary for approximately 20 s, after which the remaining part of the video clip would be played.

Supplementary material provides a detailed overview of the user flow of the screens in Modules 1 and 2 and the components of the commentary videos.

Fig. 2. The three occlusion levels of hazardous situations in Module 1 (top three rows; Left: Situation 2; Right: Situation 6), and the occlusion moment of the matched situations in Module 2 (bottom row).

2.3. *Performance feedback*

Visual and auditory feedback was implemented to the question screens (i.e., Fig. 1, Screen 3). If a correct answer was selected, a green frame appeared around the response picture, and positive auditory feedback was provided. The cyclist received randomly one of nine slightly different positive messages (e.g., "That's correct!", "Well done!"). If an incorrect answer was selected, a red frame appeared around the response picture, and negative auditory feedback was triggered. The negative auditory feedback was randomly selected from twelve slightly different short recordings (e.g., "Try again!", "You didn't choose the correct answer.").

The correct answer would be shown (i.e., a green frame around the correct response picture) if the traffic situation had been played three times in Module 1, and always after an incorrect answer in Module 2. Selection of the "I do not know" button did not trigger auditory feedback but triggered a visualization of the correct answer (i.e., a green frame around the correct response picture) if the traffic situation could not be replayed anymore.

2.4. *Selection of video material*

Crundall et al. (2012) showed that the presence of a predictive element (*hazard precursor*) is vital to successful hazard recognition.

Acute hazards that appear unexpectedly are unlikely to be anticipated even by experts, and should therefore not be included in hazard anticipation training programs. A further distinction of predictable hazards has been made according to the relationship between precursor and hazard: Vlakveld et al. (2011) distinguished between *overt hazards* (i.e., visible road users whose action can be predicted from their behavior) and *covert hazards* (i.e., invisible road users whose future appearance can be predicted from other visible elements). The terms overt and covert hazards by Vlakveld et al. (2011) correspond to behavioral and environmental hazards as used by Crundall et al. (2012).

Approximately 120 h of video footage collected during a naturalistic cycling study (Stelling et al., 2017) was analyzed to select hazardous traffic situations. The videos were recorded with GoPro cameras mounted on the head tube of electric or conventional bicycles' frame. The video data collection took place in the Netherlands during regular commuting and included city cycling (e.g., The Hague, Delft, Haarlem), suburbs, and rural locations.

We initially selected 70 video segments in which cyclists interacted with hazardous road users for inclusion in the training program. The hazard could be either overt (i.e., visible) or covert (i.e., not visible) but the traffic scene had to include a predictive element in order to be eligible for inclusion in the training program. A hazard was defined as a road user on a collision course. Video segments of two types of interactions were selected. In the first type, a road user became a hazard, meaning that this road user crossed the cyclist's path and the cyclist performed an avoidance maneuver. In the second type, a road user did not materialize into a hazard, possibly because the road user had noticed the approaching cyclist or because of the situation-specific timing of events. The initial selection of 70 video segments was made by the first author. The selection of the final video clips was made by the first two authors by applying the above selection criteria and by observing similarities between matched hazardous situations.

The following selection criteria were further applied: (1) the video was captured during daylight with clear weather conditions, (2) hazard precursors were present, (3) a hazard or precursor was visible for at least 3 s, (4) a minimum of two traffic situations (*matched* situations) exhibiting similarities between the precursor and the hazard. Regarding the similarities between matched situations, we considered the locations of the precursors and hazards (e.g., a cyclist blocked the bike path because a tram was approaching from the opposite direction vs. a group of cyclists blocked the bike path because cars were approaching from the opposite direction), relationship between precursor and hazard (e.g., a pedestrian crossed the road while disappearing behind yielding cars vs. a pedestrian walked from a house towards the vehicle while disappearing behind a parked car), and behavior of the hazardous road user (e.g., a bus failed to yield to the cyclist while turning right vs. a car failed to yield to the cyclist while turning right).

The relationship between the hazards in the matched situations concerned the application of a strategy of hazard anticipation in Module 1 to a new hazardous situation in Module 2. Sixteen traffic situations (11 taken on an e-bike and 5 on a conventional bike) were selected for our training (see Table 1). The hazards in Module 1 situations always developed such that it provided the participant with feedback about what happened next; some of the hazards included in Module 2 (i.e., Situations 1, 4, and 7) did not develop.

2.5. Software and materials development

The training program was written in C++ using the cross-platform software Qt. The application ran on a desktop computer. The VLC media player was embedded in the software to play video clips and provide auditory feedback. The interface was designed to allow easy identification of tasks that had to be completed, and short texts were used. This design allowed users with low computer literacy to navigate through the application. User input and time spent on each screen were logged to a text file.

The audio/video material was edited using Audacity and Adobe Premiere Pro CC 2017 and stored with a resolution of 1920 × 1080 pixels at a frame rate of 60 fps. The schematic drawings (i.e., location areas and silhouettes of the hazardous road users) and short text descriptions were created using Adobe Illustrator. The audio from video clips of hazardous traffic situations was removed due to the protection of personal data in Stelling et al. (2017).

2.6. Pilot testing

Six one-to-one sessions with traffic safety researchers and two group sessions with seven cyclists per session were conducted to pilot the prototype of the software. The pilot participants independently completed the hazard anticipation training from beginning to end. During the group sessions, only Module 1 was used because of the impracticality of providing self-generated commentaries in a group setting. The one-to-one sessions followed the format of a think-aloud protocol, whereas the participants in the group sessions were observed by two researchers. Feedback was gathered in the form of questionnaires in the group sessions.

The following changes were implemented after the pilot testing to improve the use and experience with the training software: (1) reducing the duration of the introduction videos, (2) using a neutral voice in the positive and negative feedback recordings, (3) deactivating the response buttons until the moment they have to be used, (4) implementing a reload feature in case a user accidentally closes the program, and (5) correcting confusing drawings of hazard locations and road users.

3. Method

3.1. Participants

Sixty-six participants (36 females and 30 males) were recruited through flyers and a SWOV participant database. Flyers were distributed during a period of four months (October 2017–January 2018) in bicycle parking facilities in The Hague and Delft and their surroundings. The inclusion criteria stated on the flyer were (a) owning an e-bike and (b) cycling at least three times a week on this e-bike. However, participants using an e-bike on at least a weekly basis were still permitted into the study. The study was approved by the Human Research Ethics Committee of the Delft University of Technology (Ethics application no. 262, 2017) and by the SWOV Institute for Road Safety Research (Ethics application: Hazard anticipation training for e-bikers, 2017).

The participants were split into a training and a control group according to seven characteristics (see Table 2) using the Taves' method of minimization (Taves, 1974). The participants assigned to the training group were on average 58.40 years old ($SD = 13.14$, ranging between 26 and 80 years), and participants assigned to the control group were on average 57.82 ($SD = 16.39$, ranging between 19 and 80 years) years old. None of the cyclists had participated in a cycling training course before. Participants' demographic characteristics, cycling, and driving experience are shown in Table 2.

3.2. Materials

3.2.1. Training vs. control group interventions

For the training group ('*training*'), the application described in Section 2 was used. Participants completed both training modules in one session without a break. The video clips were played in full-screen mode.

For the control group ('*control*'), a simplified PC-based training course was created without the training methods used in the hazard anticipation training. The control intervention consisted of short clips of traffic scenes taken from a cyclist's point of view on Dutch roads. The control group was provided with 29 video clips divided into three categories: behavior (9 traffic situations), traffic rules (9), and situational

Table 1
Descriptions of the situations in the hazard anticipation training. The matched hazardous situations of Modules 1 and 2 are presented below each other. Note that the hazardous situations in Module 2 followed a different order than the order presented in this table. See Supplementary material for screenshots of the hazards.

Situation/Module no.	Short description/Hazard type (overt, partially covert, covert)	Potential hazard	Precursor	Location	Bicycle facility
Practice/M1	A car failed to yield to the cyclist while turning right towards a gas station/Overt	Car	Car indicating the turn and turning	Urban area	Yes
Practice/M2	A car coming from the opposite direction was about to turn to a side street in front of the cyclist/Overt	Car	Car indicating the turn and turning	Urban area	Yes
1/M1	Cars overtook a refuse truck which was parked in the opposite lane/Partially covert	Cars	Parked truck in contraflow lane with lights on	City center	No
1/M2	A scooter in the opposite lane was about to perform an avoiding maneuver due to pedestrians who suddenly started to cross the bike path from the left/Overt	Scooter	A child followed by an adult entering the contraflow lane	Residential area	Yes
2/M1	A bus failed to yield to the cyclist while turning right at an intersection/Overt	Bus	Bus indicating the turn; Cyclist in a vehicle blind spot	Urban area	Yes
2/M2	A car failed to yield to the cyclist while turning right at an intersection/Overt	Car	Car indicating the turn; Cyclist in a vehicle blind spot	Urban area	Yes
3/M1	A car pulled out across the bike lane after giving right of way to other cyclists/Overt	Car	Moving car in front of a bike crossing	University campus	Yes
3/M2	A car pulled out across the bike lane after giving right of way to cyclists coming from the opposite direction/Overt	Car	A car stopped before a bike crossing, but the driver's view is obstructed	Residential area	Yes
4/M1	A distracted pedestrian followed another pedestrian who just crossed the road and was waiting there/Overt	Pedestrian	Another pedestrian waiting between parked cars	Residential area	No
4/M2	A child initially hidden behind a parked car was about to cross the road towards the man who was standing on the other side of the road/Covert	Pedestrian (child)	A man standing between parked cars with a pink school bag	Residential area	No
5/M1	A cyclist blocked the bike path because a tram was approaching from the opposite direction, and the cyclist could not cross the street/Overt	Cyclist	Cyclist yielding to an approaching tram	City center	Yes
5 /M2	A group of cyclists blocked the bike path because cars were approaching from the opposite direction, and cyclists could not cross the street/Overt	Cyclists	Cyclists yielding to the approaching cars	Suburban area	Yes
6/M1	A pedestrian crossed the road while disappearing behind yielding cars/Partially covert	Pedestrian	Stopped cars in front of the pedestrian crossing	Suburban area	Yes
6/M2	A pedestrian walked from the house towards the vehicle while disappearing behind a parked car/Partially covert	Pedestrian	Car blocking the road with lights on and open trunk	City center	No
7/M1	A car coming from the right initiated a left turn while being partially hindered by a parked vehicle and vegetation/Partially covert	Car	Partially blind right bend	Residential area	No
7/M2	A car coming from the right approached an intersection while being partially hindered by a parked vehicle and vegetation/Partially covert	Car	Partially blind right bend	Residential area	No

Table 2
Demographic characteristics, cycling, and driving experience of the participants assigned to the training or control group (N = 66). The first seven characteristics were used to split participants into the training and control groups.

		Training group	Control group
Gender	Female	18	18
	Male	15	15
Age (years)	≤39	3	5
	40–54	7	6
	55–69	17	14
	≥70	6	8
Eye problems	Chronic	2	2
	Myopia or Hyperopia	18	18
	None	13	13
Weekly cycling mileage (km)	≤30	11	11
	31–90	17	17
	≥91	5	5
Cycling frequency	1–4 dafys	14	14
	Every day	19	19
Driving license	Yes	30	30
	No	3	3
Yearly driving mileage (km)	0–5,000	16	17
	5,001–20,000	15	14
	≥20,001	2	2
Mean age of starting to cycle		5.0	6.1
Mean number of years of e-bike ownership		4.5	3.3
Bicycle as the primary mode of transportation		27	27
E-bike used more frequently than other types of owned bicycles		29	26
Bicycle accident involvement during the last 3 years		7	6

awareness (11). Sixteen of these video clips were the same as in the hazard anticipation training. More video clips were added to the control group training than to the hazard anticipation training group to compensate for the time difference to complete the training programs between the two groups (cf. Horswill et al., 2013).

Each category in the control intervention started with task instructions and a practice video. After each video, a question screen appeared. Questions were related to the behavior of other road users (e.g., “Did the cyclist look left before merging?”), right of way rules (e.g., “Do you have right of way on this crossing?”), and elements of the traffic scene (e.g., “Which one of these traffic signs was visible before the crossing?”). Depending on the question, the answers were in yes/no or multiple-choice formats. After the participant responded to the question, a short video sequence or a photo from the traffic situation was shown, thus providing the correct answer to the question. This control intervention took 30 min to complete. This intervention was shown to participants in the form of a webpage; the video clips were played in half-screen mode.

All participants sat in front of a 23-in. monitor, and they used a mouse and a keyboard to provide input. Sounds were provided using a headset, or speakers in case a participant wore hearing aids.

3.2.2. Evaluation phase (identical for the training and control groups)

3.2.2.1. Hazard detection test. Participants’ hazard detection performance was measured using 15 short video clips (1 practice and 14 assessment) of real-life cycling in which a hazard developed. Participants were instructed to press the spacebar if they felt that a situation might become dangerous. A maximum of four spacebar presses was recorded per video clip. After each video clip, participants answered the question “How dangerous did you find this situation?” using a 3-point scale ranging from *not dangerous* to *very dangerous*. This test was previously used by Twisk et al. (2018).

Similar to the training and control training programs, the hazard detection test consisted of hazardous situations encountered on Dutch roads. The cyclist taking the video footage was always using a bike lane/path, except for one situation. Regarding the hazards shown in the 14 assessment video clips, four hazards were cars, one was a moped, seven were cyclists or a group of cyclists, and two were pedestrians. Twelve hazards were overt, and two were partially covert (e.g., a car coming from the left was partially hindered by parked vehicles).

3.2.2.2. “What will the car driver do next?” questionnaire. A video-based questionnaire was used to examine how well the participants anticipated a driver’s right-of-way violation. The questionnaire consisted of one practice and five test video clips taken from a cyclist’s perspective on Dutch roads. The five test situations consisted of a safe situation (i.e., approaching car stopped in front of the bike path), three near-miss situations (car crossed the bike path without giving right of way, and the cyclist braked), and one crash situation (approaching car did not give right of way to the cyclist, resulting in a crash). Each video clip was played until 1.14 s before the car entered a bike path, and participants were asked questions about: (1) perceived risk, (2) cyclist’s (own) slowing down behavior, (3) prediction of the driver’s behavior, and (4) factors that contributed to the prediction of the driver’s behavior, (5) priority rules. The ‘what will the car driver do next?’ questionnaire was previously used by Kovácsová et al. (2019).

3.2.2.3. Dundee Stress State Questionnaire (DSSQ). The DSSQ (Matthews et al., 2002) is a 30-item scale for assessing an individual’s state before and after a task. The DSSQ distinguishes three dimensions: task engagement, distress, and worry. This questionnaire was used to monitor perceived stress and engagement while completing the training program. Participants were asked to indicate how accurately each of the 30 statements describes their feelings *at the moment* (prior to the training or control intervention) and *while performing the task* (administered two times: after the training or control intervention, and after the evaluation phase) using a 5-point scale ranging from *definitely false* to *definitely true*.

3.2.2.4. Evaluation questionnaire. A 9-item evaluation questionnaire was designed to obtain participants’ feedback about the training and control interventions. Participants could list positive and negative features of the intervention and indicate what they have learned. They were also asked whether the intervention met their expectations, how well they knew the filmed locations, and how well the video clips resembled situations they normally encounter. Last three items assessed perceived training effects (Horswill et al., 2013). Participants indicated their responses on a 5-point scale ranging from *not at all* to *very well/a great extent*. See Fig. 5 for the questions and rating scales.

3.3. Procedure

Before the test day, participants received a background questionnaire and an informed consent form via email. The experiment was conducted at two locations: SWOV, The Hague (22 cyclists in the training group and 23 in the control group) and TU Delft, Delft (11 cyclists in the training group and 10 in the control group). Participants could pick the testing location according to their convenience. Fig. 3 shows the experimental timeline.

A researcher was always present in the experimental room and intervened if the participant was not sure where to click or when self-generated commentaries were not performed. Participants assigned to the control group were offered to complete the hazard anticipation training at the end of the experiment (11 participants completed both interventions). The whole experiment lasted 2 h for the training group participants and 1.5 h for the control group participants. Participants were reimbursed with a gift card.

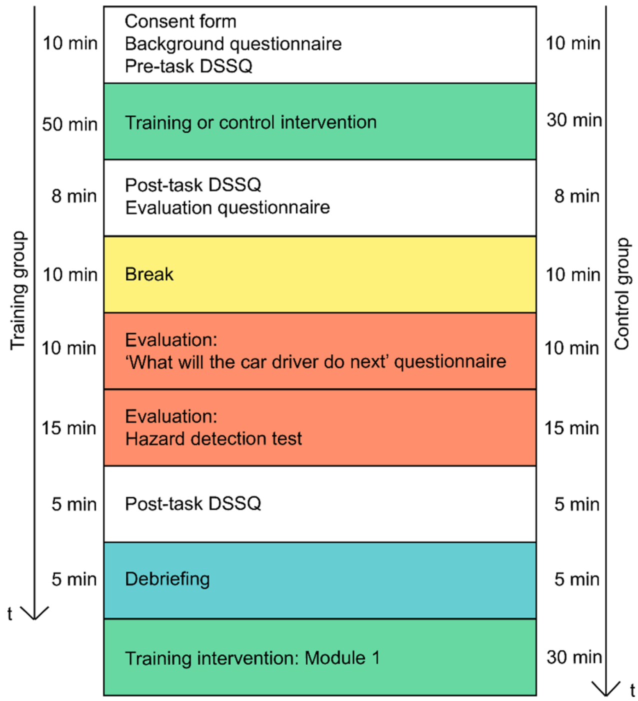

Fig. 3. The experimental timeline with durations for the training group (left) and the control group (right).

3.4. Measures and analyses

3.4.1. Hazard anticipation training measures

The following measures were recorded to monitor training progress and performance:

- *Time taken to complete the task (mm:ss)*. This measure indicates how much time it took to complete Module 1, Module 2, and the entire training.
- *Time taken to respond correctly (s)*. This measure indicates how much time participants spent on the 'Where' and 'WHN' questions from the moment the screen appeared until the correct response was selected. In Module 1, the time to respond correctly was calculated as the sum of the time spent on the 'Where' and 'WHN' screens.
- *Task success rate (%)*. The rate of the correct responses on the 'Where' and 'WHN' questions. A correct response was scored as *1* and an incorrect response as *0*. This score was summed per situation (range 0–2), per question in the module (0–7), and per module (0–14).
- *Number of video plays to the correct answer (#)*. This measure described how many video plays of the situation participants used to achieve the correct answer on the 'Where' and 'WHN' questions in Module 1. Three video plays were available per situation; the first play was mandatory.

3.4.2. Evaluation measures and analyses

The hazard detection test consisted of 14 hazardous situations (Twisk et al., 2018). A previous evaluation among 30 adult cyclists showed that, for 5 out of 14 hazardous situations, 8 or more participants did not press the spacebar, presumably because they did not consider the traffic situation shown in the video clip to be hazardous (Vlakveld, 2017). For completeness, we compared the two groups using both the 14-hazardous situation version and the reduced 9-hazardous situation version of the test, as previously suggested by Vlakveld (2017). For our total dataset ($N = 66$), Cronbach's alpha of the detection time scores was 0.84 if including all 14 situations, and 0.73 if including the 9 situations. An inspection of the Scree plot (eigenvalues of the correlation matrix) of the detection time scores for the 14 situations showed that a one-factor solution was most appropriate (the first, second, and third eigenvalues were 5.1, 1.7, and 1.3, respectively). The following hazard detection test measures were calculated using both versions of the test:

- *Hit rate in the interval (%)*. A time interval was created from the moment the hazard emerged until the moment the hazard was met by the cyclist, that is, when the cyclist arrived at the hazard or the hazard entered the cyclist's future trajectory (see Twisk et al. (2018) for details). The hit rate was defined as the percentage of identified hazards.
- *Total number of presses (#)*. The total number of space bar presses in the hazard detection test.
- *Detection time score*. The detection time represents the time between the moment the hazard emerged and the participant's first space bar press within the time interval, with a maximum of *1* (immediate detection) and a minimum of *0* (no detection) (Twisk et al., 2018). In case a participant did not press the space bar during the time interval, the hazard detection score was 0. The detection time score was defined as a sum of these scores.
- *Mean perceived danger*. The perceived danger represents a participant's self-reported danger in viewed hazardous situations. Participants reported perceived danger on a scale from *0* (not dangerous) to *2* (very dangerous).

In addition, the *mean perceived risk* measure was calculated for three types of intersection situations: crash, near miss, and safe. Participants reported perceived risk using an item "The situation was risky" which was evaluated on a scale from *1* (strongly disagree) to *7* (strongly agree) when completing "What will the car driver do next?" questionnaire.

Paired sample *t* tests were conducted to compare participants' performance between the two training modules. Independent samples *t* tests were used to compare questionnaire and evaluation results between the training and control groups. A 3 × 2 analysis of variance (ANOVA) was performed with the time condition as a within-subject factor (start, after intervention, end) and intervention group as a between-subjects factor (training vs. control) to examine participants' subjective state (i.e., DSSQ). Bivariate Spearman's rank-order correlations were calculated between hazard detection test measures (data from 9 hazardous situations) and participants' age ($N = 66$).

4. Results

4.1. Hazard anticipation training

The results for the training progress are shown in Table 3 and Fig. 4 (details per situation are provided in Supplementary material). Participants completed the training program, on average, in 50 min and 11 s ($SD = 4$ min 41 s). It took approximately two times longer to complete the instructional Module 1 than the practice Module 2 (Table 3). Participants took longer to correctly answer 'WHN' questions compared to 'Where' questions.

In Module 1, participants answered both the 'Where' and 'WHN' questions correctly on the first attempt in 21.2% of cases ($N = 231$), whereas in Module 2, the correctness of responses to the two questions was 37.2% ($N = 231$).

Participants had a higher task success rate in Module 1 than in Module 2 (means = 86.8 and 54.3 for Module 1 and Module 2, respectively). Furthermore, the task success rate was higher for 'Where' questions compared to 'WHN' questions in Module 1, whereas the opposite result was observed in Module 2. This can be explained by the number of video plays in Module 1, which was higher for 'Where' questions (mean = 1.65) and, thus, a lower number of replays was available for 'WHN' questions (mean = 1.45).

Participants' task success rate ranged between 60.0% and 100% for each question and situation in Module 1 (Fig. 4, left). The highest task success rate and the lowest number of video plays were observed for

Table 3

Means, standard deviations, minima, and maxima of hazard anticipation training measures according to Modules and response questions (N = 33).

		Mean	*SD*	Min	Max
Time taken to complete the task (mm:ss)					
Module 1		31:22	2:28	26:17	36:35
Module 2		16:31	2:42	13:37	28:36
Hazard anticipation training		50:11	4:41	41:57	65:54
Time taken to respond correctly (s)					
Module 1	Where	14.4	5.7	5.4	27.7
	WHN	16.2	7.2	5.8	31.6
	Where + WHN	30.6	12.0	11.6	59.2
Module 2	Where	7.1	4.0	2.8	17.9
	WHN	7.8	3.1	3.3	15.8
	Where + WHN	12.7	6.3	6.0	31.6
Task success rate (0–100)					
Module 1	Where	90.0	13.1	42.9	100.0
	WHN	83.6	16.8	9.52	100.0
	Where + WHN	86.8	14.4	35.7	100.0
Module 2	Where	50.2	14.8	14.3	71.4
	WHN	58.4	15.7	28.6	85.7
	Where + WHN	54.3	12.0	28.6	78.6
# of video plays to the correct answer (1–3)					
Module 1	Where	1.65	0.33	1.14	2.50
	WHN	1.45	0.26	1.00	2.00
	Total	2.07	0.30	1.50	3.00

Situation 4, in which a distracted pedestrian followed another pedestrian when crossing the road and for Situation 7, in which a partially hidden car coming from right initiated a left turn. The lowest score was observed for Situation 6, in which a pedestrian was crossing the road hindered by the yielding cars. In Module 2 (Fig. 4, right), low task success rates were observed for the far transfer Situations 1 and 4, and when a distractor road user was present ('Where' question in Situation 3 and 'WHN' question in Situation 7).

4.2. Evaluation: Cyclists' feedback and subjective state

The control training met participants' expectations better than the hazard perception training, but the effect was not statistically significant (means = 2.67 vs. 3.12 for training and control group, respectively; $t(64) = -1.959$, $d = -0.482$, $p = 0.054$). Frequently mentioned critiques of the hazard anticipation training were related to the video clips and were as follows: poor visibility (e.g., hazards too far), the height of the camera recordings, speed of the video recordings (or speed of the bicycle), and the lack of the traffic sound. On the other hand, participants liked the realism of the traffic situations (Fig. 5), the expert commentary, and the focus on practice.

Fig. 5 shows the mean ratings of the perceived intervention benefits. There were no statistically significant group differences in Items 4–6 between the two groups ($p \geq 0.121$). The analysis of the responses to the open-ended question "what did you learn during the training?" revealed that participants in both groups mentioned they had learned to pay more attention to the traffic. Training participants further mentioned better anticipation, looking further ahead, assessing the situation, and defensive cycling. Control participants reported learning about being alert, looking at the traffic signs, and giving right of way.

The results of the DSSQ showed that participants had high task engagement (Fig. 6). Statistically significant differences were observed between the time conditions for the distress ($F(2, 116) = 6.640$, $\eta_p^2 = 0.103$, $p = 0.002$) and worry subscales ($F(2, 110) = 50.518$, $\eta_p^2 = 0.479$, $p < 0.001$). Specifically, participants reported higher distress after completing the interventions compared to the Start ($p = 0.059$) and End conditions ($p = 0.002$). Further, participants reported higher worry at the beginning of the experiment compared to the other two time conditions ($p < 0.001$). No significant differences were observed between the training and control groups ($p \geq 0.222$).

4.3. Evaluation: Effect of training on hazard anticipation and perceived danger and risk

4.3.1. Hazard detection test: Spacebar task

In the hazard detection test consisting of 14 video clips, only 10.6% of participants (5 training vs. 2 control) identified all 14 hazards during the time intervals. When the shorter form of the hazard detection test was used, 25.6% of participants (10 training vs. 7 control) identified all shown hazards during the time intervals. As can be seen in Table 4, participants in the training group had a higher hit rate and a higher number of space bar presses compared to the control group. However, these differences were not statistically significant. The training group reacted significantly faster to the hazards compared to the control group ($t(64) = 3.028$, $d = 0.745$, $p = 0.004$).

Correlations between hazard detection test measures and participants' age were significant. More specifically, older participants had a lower hit rate ($\rho = -0.37$, $p = 0.002$), pressed space bar less frequently ($\rho = -0.38$, $p = 0.002$), and detected hazards later in time ($\rho = -0.42$, $p < 0.001$).

4.3.2. "What will the car driver do next?" questionnaire: Prediction and slowing-down behavior

Fig. 7 shows the percentage of participants who correctly predicted that the car driver would not let the cyclist cross first (i.e., crash and

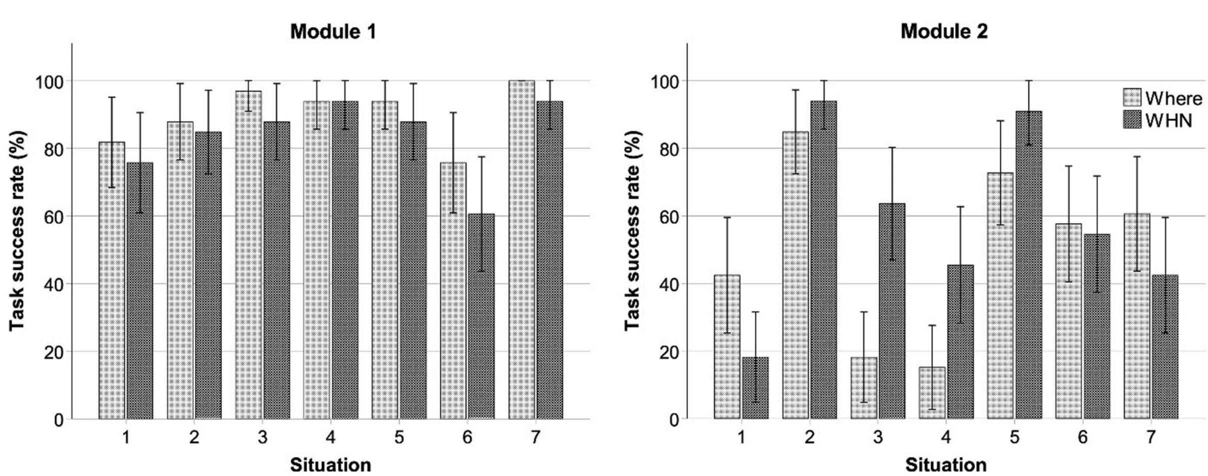

Fig. 4. Mean task success rate in 'What is the location of the hazard?' ('Where') and 'What happens next' ('WHN') questions per seven hazardous traffic situations per module. Error bars are ± 1.96 times the standard error of the mean. Note that participants could watch the video clip of each traffic situation three times to answer the questions in Module 1, whereas they watched the traffic video clip only once in Module 2.

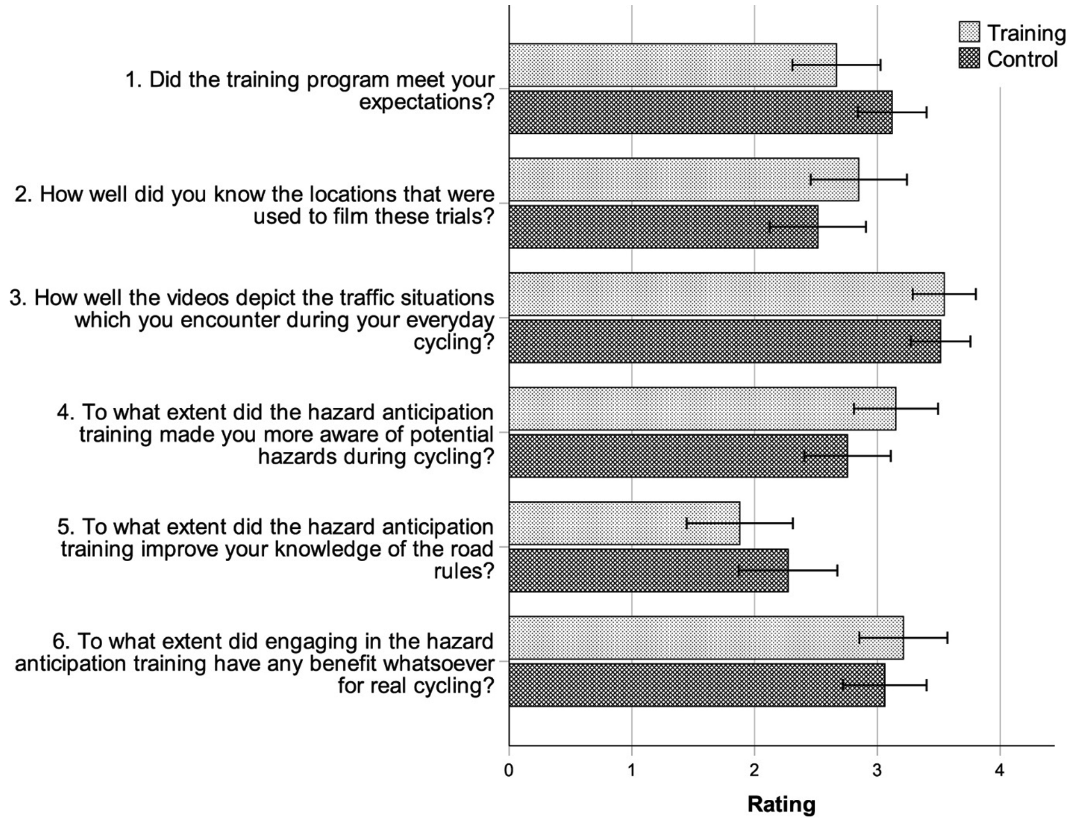

Fig. 5. Mean ratings of the six items in the evaluation questionnaire. Error bars are ± 1.96 times the standard error of the mean. Items 1–3 were rated on a scale from *0 = not at all* to *4 = very well*, and Items 4–6 were rated from *0 = not at all* to 4 = *to a great extent.*

near-miss situations) and the percentage of participants who reported that they would slow down in these situations. The safe situation was used as a control situation.

As can be seen in Fig. 7, small differences were observed between the training and control groups in prediction accuracy and in self-reported slowing-down behavior. Participants assigned to the training group were on average more accurate in their predictions and reported to slow down more frequently. Supplementary material provides further details about the participants' reported cues and traffic rules knowledge in the 'What will the car driver do next?' questionnaire situations.

4.3.3. Perceived danger and risk

As can be seen in Table 4 (Hazard detection test measures), there were no significant differences in perceived danger between the two groups in nine everyday hazardous situations ($p = 0.417$). The results for the perceived risk in safety-critical intersection situations showed that training participants perceived higher risk in crash, near-miss, and safe situations compared to the control participants (Table 4, "What will the car driver do next?" questionnaire: Perceived risk). The training participants reported significantly higher perceived risk than the control participants in the crash situation ($p = 0.044$).

5. Discussion

Previous research has shown that hazard anticipation training can be valuable for enhancing car drivers' anticipation skills (Horswill, 2016; McDonald et al., 2015). However, knowledge of how to enhance the hazard anticipation skills of cyclists is scarce. Earlier attempts have been made to develop hazard anticipation training for child cyclists (Lehtonen et al., 2017; Zeuwts et al., 2017; 2018). Herein, we developed and evaluated a PC-based hazard anticipation training for experienced adult cyclists.

We evaluated our training program among electric bicycle users, a group that is over-involved in serious crashes as compared to conventional bicycle users (Gehlert et al., 2018; Schepers et al., 2014a). Our participant recruitment strategy resulted in a representative sample of electric bicycle users, consisting of a large share of females and relatively old people (cf. Hendriksen et al., 2008; Van Boggelen et al., 2013). Hazard anticipation skills that involve visual attention, processing of relevant information, and executive function are likely to decline with age (Anstey et al., 2005; Horswill et al., 2008). Our results showed that older cyclists had a slower reaction time to hazards, and identified fewer hazards during the hazard detection test. However, as shown by Horswill et al. (2010, 2015) among car drivers, experienced older adults' hazard anticipation skills can still be improved by means of training.

The first aim of this study was to evaluate the design of the training program. The self-reports showed that participants did not appreciate our hazard anticipation training any better as compared to the more basic training of the control group. In fact, the results showed a tendency that the expectations of the participants of the control group were better met as compared to the participants of the training group. The participants perceived the expert commentaries in Module 1 as positive, but self-generated commentaries showed a less positive acceptance. The instructional video of Module 2 asked participants to generate commentaries, but participants still had to be reminded by the experimenter to try to generate these commentaries. Consistent with Wetton et al. (2013), we argue that self-generated commentaries may not be a useful addition to the training.

In Module 1, a higher task success rate was observed for 'Where' compared to 'WHN' questions (cf. Gugliotta et al., 2017). In Module 2, however, a higher success rate was observed for 'WHN' than 'Where' questions in the near-transfer situations, a finding that can be attributed to analogical transfer. The presence of a distractor in the video clip, which could also become a hazard, created a confusing element when

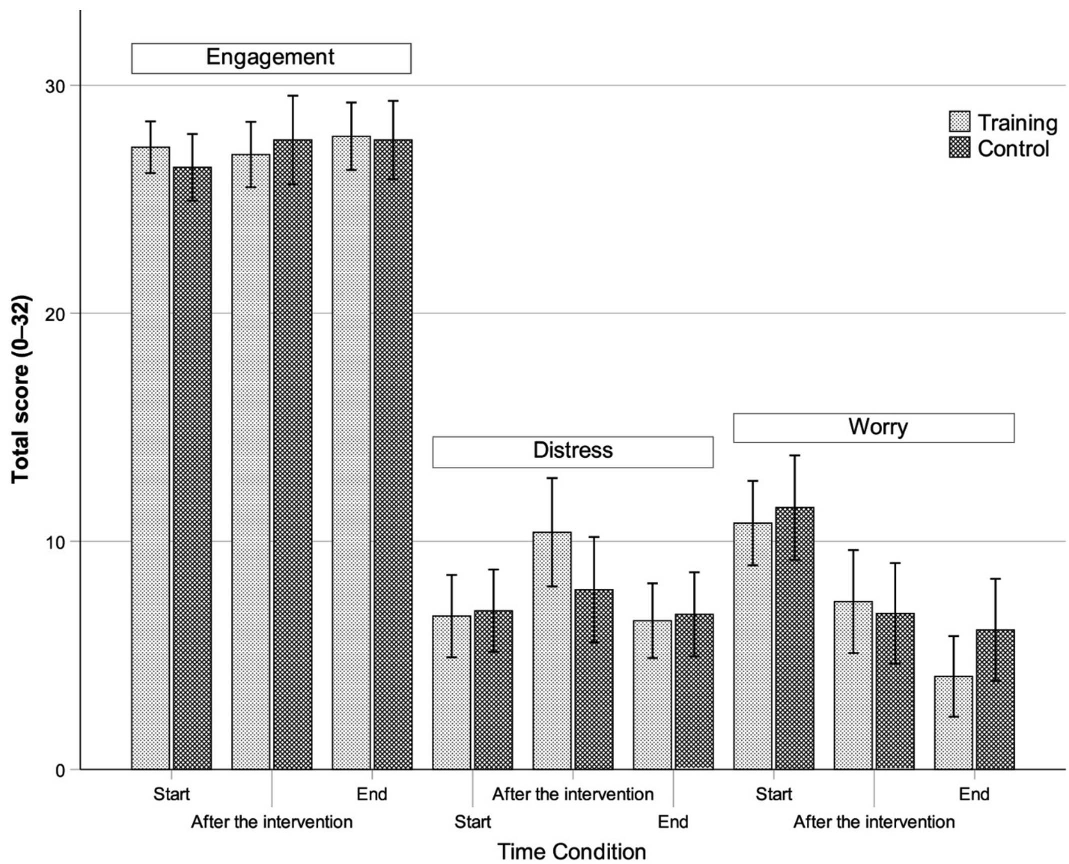

Fig. 6. Mean total scores of engagement, distress, and worry scales of the DSSQ administered prior to the intervention (*Start*), *After the intervention*, and at the end of the experiment (*End*) per intervention group. Scores range from *0* to *32*. Error bars are ± 1.96 times the standard error of the mean.

included in the picture responses. We observed high success rates in Module 2 (suggesting successful transfer between Modules 1 and 2) in two situations: Situation 2 (a bus/a car failed to yield to the cyclists while turning at the intersection) and Situation 5 (a cyclist/a group of cyclist blocked the bike path because another road user was approaching from the opposite direction and the cyclist(s) could not cross the street). Possible reasons for this result could be the similarity of the situations (creating near transfer), situational characteristics that could have led to better remembrance of the hazard, or methodological factors related to the wording of the provided answers.

Future prototypes of the training could take into account the current hazard anticipation skills of the participant by means of pre-testing and a corresponding baseline occlusion level. For example, participants scoring poorly in hazard anticipation could watch the first video clip play until a later moment than participants with high hazard anticipation skill. Although the results showed that on average participants' anticipation skills improved during the training between Module 1 and Module 2, relatively low success scores were observed in Module 2. These low scores may be caused by the training method, the types of hazards, or by the cyclists' suboptimal hazard anticipation skills.

Table 4
Means and standard deviations of the hazard detection test (top) and perceived risk (bottom) measures administered after the training interventions for the training and control groups, and results of the independent samples *t* tests for these measures. Statistically significant results are depicted in boldface.

		Training		Control		Training vs. Control		
	Range	Mean	*SD*	Mean	*SD*	*t (df)*	*d*	*p*
Hazard detection test measures								
HPT9: Hit rate in the interval	0–100	82.2	19.8	75.1	21.2	1.401 (64)	0.345	0.166
HPT14: Hit rate in the interval	0–100	78.8	20.1	69.9	22.7	1.682 (64)	0.414	0.098
HPT9: Total number of presses	0–36	13.27	4.54	11.55	4.68	1.522 (64)	0.375	0.133
HPT14: Total number of presses	0–56	18.97	6.48	16.36	6.88	1.584 (64)	0.390	0.118
HPT9: Detection time score	0–9	4.33	1.46	3.29	1.33	3.028 (64)	0.745	**0.004**
HPT14: Detection time score	0–14	6.24	2.15	4.73	2.31	2.754 (64)	0.678	**0.008**
HDT 9: Mean perceived danger	0–2	1.02	0.35	1.09	0.32	−0.817 (64)	−0.201	0.417
HDT 14: Mean perceived danger	0–2	0.89	0.30	0.97	0.32	−1.141 (64)	−0.281	0.258
"What will the car driver do next?" questionnaire: Perceived risk								
Crash: Mean perceived risk	1–7	3.30	1.65	2.50	1.50	2.051 (63)	0.509	**0.044**
Near miss: Mean perceived risk [a]	1–7	4.64	1.55	4.11	1.49	1.383 (63)	0.343	0.172
Safe: Mean perceived risk	1–7	2.97	1.57	2.56	1.48	1.075 (63)	0.267	0.286

Notes. HDT 9 – Hazard perception test consisting of 9 video clips, HDT 14 – Hazard perception test consisting of 14 video clips.
[a] Responses were averaged across the 3 near-miss situations.

Fig. 7. Results for the 'What will the car driver do next?' questionnaire. Left: Percentage of participants who reported "no" to the question "Imagine that the cyclist in the video will continue cycling at this speed. Will the car driver let the cyclist cross first?" as a function of the situation and participant group. Right: Percentage of participants who reported "yes, I would slow" down to the question "Imagine that you are the cyclist in the video. Would you slow down?" as a function of the situation and participant group.

Further research is required to set the optimal level of difficulty for the response task taking into account participant's skills.

In the first training prototype, the hazard selection was limited to video recordings from a recent naturalistic cycling study (Stelling et al., 2017). Regarding cyclist-car driver situations, typical collision scenarios such as blind-spot collisions and situations where a cyclist is not given right of way by a car driver (Schepers et al., 2011; Summala et al., 1996; Twisk et al., 2013) were included in the training program. The frequency and severity of cyclist-cyclist and cyclist-pedestrian conflict situations are not well known because of the underreporting of these collisions to the authorities (Wegman et al., 2012), which prevents us from drawing conclusions about how representative the situations included in this training program were. Another type of hazards encountered by cyclists are road furniture hazards such as bollards or uneven road surfaces contributing to single-bicycle accidents (Boele-Vos et al., 2017; Schepers and Klein Wolt, 2012). We have not included these types of hazards in our training as they are related to visibility/vision issues than prediction skills (Schepers and Den Brinker, 2011).

The second aim of this study was to evaluate the effect of our training on hazard anticipation skills and perceived risk. The training group detected hazards significantly faster compared to the control group. The group differences in the number of detected hazards were also in favor of the training group, but not statistically significant. These results suggest that our training improved participants' visual skills to detect hazards rapidly (Level 1 SA) or improved participants' processing and prediction strategies (Level 2, 3 SA) to anticipate rapidly that an object develops into a hazard. Overall, our results suggest that PC-based hazard anticipation training enhances the acquisition of situational awareness.

The examination of hazard anticipation skills in safety-critical intersection situations (i.e., near miss, crash), showed small differences between the two groups. One plausible explanation can be that the training targeted rather everyday hazardous situations than severe crash situations. The second explanation can be that safety-critical intersection situations do not include perceivable elements which cyclist can reliably use to predict a driver's right-of-way violation.

As research among car drivers has shown some evidence that individuals who perceive high risk are less likely to show risky behavior in traffic (Deery, 1999), and hazard anticipation training can reduce risk-taking behavior among car drivers (McKenna et al., 2006), the effect of hazard anticipation training on perceived risk and danger was investigated. No significant group differences were found in perceived danger and risk, except for the perceived risk in the 'crash' situation. The perceived danger item and perceived risk items were taken from different previous studies, so the terminology differed. The difference in results between the danger and risk items may have arisen due to chance, or due to the fact that participants' interpretation of the terms risk and danger is not the same. Further, the results suggest that our hazard anticipation training targets primary cognitive skill. The non-significant group differences in perceived risk and the high frequency of self-reported slowing down behavior suggest that the skill training did not cause overconfidence.

The training program in this study was evaluated using objective (e.g., hazard detection times) and subjective (e.g., participants' feedback) measures. The results showed a discrepancy between these two types of evaluation: compared to the control group, our training program tended to yield lower subjective ratings, but significantly improved hazard detection times. Subjective ratings are vital for judging the acceptability of a training program and for predicting possible disuse in the long term. However, subjective feedback is not informative about actual training effectiveness. The relatively low subjective ratings may be because of usability issues of the software. Future research should examine how a training program should be designed so that participants' expectancies are met.

Several limitations have to be considered when interpreting the results of this study. First, no hazard anticipation test was administered prior to the training. Second, the training was evaluated in the short-term and in a laboratory setting. It is necessary to obtain a better understanding of how our training would affect hazard anticipation skill during real cycling in the longer term, and whether our training is an effective addition to existing bicycle handling and traffic skills interventions for cyclists (e.g., Johnson and Margolis, 2013; Rissel and Watkins, 2014). Third, the training was evaluated among Dutch electric bicycle users, and video clips of traffic situations were captured on the Dutch roads. Future research would be needed to test the training method using traffic situations from other countries, and to evaluate the training among a more diverse sample. The training was developed for cyclists using different types of bicycles (i.e., video footage was collected on conventional and electric bicycles). Future research should evaluate the training program also among conventional cyclists. It can be expected that Dutch conventional bicycle users will have a similar level of experience as participants in this study, but their average age will be lower. A final limitation is that the hazard detection test included hazardous situations only; future research could include a small number of control scenarios without hazard to obtain an index of participants' response bias.

6. Conclusions and practical applications

Poor hazard anticipation skill is associated with crash involvement, but limited research exists on how to enhance this skill among cyclists.

A PC-based hazard anticipation training has been developed and evaluated to understand whether experienced cyclists benefit from a short intervention. The results showed that the hazard detection time of experienced cyclists was improved with our training intervention. The training consisted of a combination of educational methods, including a 'What happens next?' task, commentary video clips, analogical transfer, and performance feedback. Future research is needed to determine the optimal occlusion points for video clips in training. A longer-term evaluation, as well as an examination of the training effects on real cycling performance, are necessary to determine whether such training contributes to cycling safety.

Compared to car drivers, cyclists do not have to go through a licensing process, which creates challenges regarding how to deliver training programs to this group. Digital media may be a suitable option to make traffic education accessible to cyclists. The self-administration and immediate performance feedback may make the hazard anticipation training an appropriate online educational application.

Supplementary materials

Supplementary analyses and materials to this article are available at http://doi.org/10.4121/uuid:df0dcb4f-6064-4712-969e-3cf6fa25a9a2.

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