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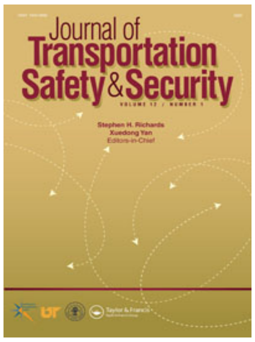

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Interactions between cyclists and automated vehicles: Results of a photo experiment*

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ABSTRACT

Cyclists may have incorrect expectations of the behaviour of automated vehicles in interactions with them, which could bring extra risks in traffic. This study investigated whether expectations and behavioural intentions of cyclists when interacting with automated cars differed from those with manually driven cars. A photo experiment was conducted with 35 participants who judged bicycle–car interactions from the perspective of the cyclist. Thirty photos were presented. An experimental design was used with between-subjects factor instruction (two levels: positive, neutral), and two within-subjects factors: car type (three levels: roof name plate, sticker – these two external features indicated automated cars; and traditional car), and series (two levels: first, second). Participants were asked how sure they were to be noticed by the car shown in the photos, whether the car would stop, and how they would behave themselves. A subset of nine participants was equipped with an eye-tracker. Findings generally point to cautious dispositions towards automated cars: participants were not more confident to be noticed when interacting with both types of automated cars than with manually driven cars. Participants were more confident that automated cars would stop for them during the second series and looked significantly longer at automated cars during the first.

KEYWORDS
cyclists; automated driving; autonomous vehicles; road safety; interaction; expectations; road user behaviour; external features

1. Introduction

Automated vehicles are gradually entering our roadway system. It is very likely that there will be a long period in which fully automated vehicles,

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partly automated vehicles, manually driven vehicles, and nonmotorised road users including cyclists and pedestrians, have to share the road environment, particularly in urban settings (Hagenzieker, 2015; Shladover, 2016). A great challenge for this transition period is to ensure that the interactions between automated vehicles and nonautomated road users do not induce extra risks. Extra risks could occur, for example, because nonautomated road users do not (yet) have correct expectations of the behaviour of automated vehicles and, consequently, respond differently and inadequately to them. So far very little is known about the interactions between conventional, nonautomated road users and (partially) automated vehicles (Vissers, Van der Kint, Van Schagen, & Hagenzieker, 2016). In the current study we focus on the cyclists' point of view and their interaction with automated vehicles in an urban setting.

In many countries, and in particular in towns and cities, cycling is an important mode of transport. According to the Eurobarometer (TNS Opinion & Social, 2014), on average around 8% of the European citizens use a bicycle as their primary means of transport. The study showed that there are substantial differences between countries. For example, The Netherlands have a cycling modal share of 36%. In Germany, around 30% of the households in big cities only own bicycles and no cars or other means of transport anymore (Destatis Statistisches Bundesamt, 2014). The importance of cycling is expected to grow (OECD/ITF, 2013). Reasons include increasing congestion in cities, health considerations, and national or local measures to reduce greenhouse gas emissions. Although the effects on health, environment, and urban traffic flow are generally positive (OECD/ITF, 2013; De Hartog, Boogaard, Nijland, & Hoek, 2010; Oja, Titze, Bauman, de Geus, Krenn, Reger-Nash, & Kohlberger, 2011; Grabow, Spak, Holloway, Stone, Mednick, & Patz, 2012), the safety of cyclists is and will be an area of concern. Cyclists are physically unprotected when participating in traffic, with the exception of when cycle helmets are used. This leads to a relatively high injury risk, in particular when colliding with a faster and heavier motorised vehicle (SWOV, 2013; Aarts & van Schagen, 2006). Hence, for road safety reasons it is important that the gradual introduction of automated vehicles does not lead to more or more serious crashes with cyclists.

A tremendous amount of research is going on in the area of automated vehicles. Most research focuses on technology, and more recently also on human drivers and their interaction with varying levels of automated vehicles (e.g., Toffetti et al., 2009; Vlakveld, Vissers, Hulleman, & Van Nes, 2015, Weyer et al., 2015; Seppelt & Leeb, 2015; Cunningham & Regan, 2015; Zeeb, Buchner, & Schrauf, 2016) and on user acceptance of automated vehicles (e.g., Bazilinksyy, Kyriakidis, & De Winter, 2015; Kyriakidis, Happee, & De Winter, 2015; Madigan et al., 2016). The interaction of automated vehicles and cyclists is not yet a common research topic. That does not mean that car manufacturers overlook this part of the traffic task. Many are developing safety and communication systems that aim at avoiding collisions with nonmotorised vehicles like cyclists. For example, full auto-brake systems can already detect cyclists (and other road users) on collision course and perform an emergency brake when needed. However, so far, these systems focus mainly on the perspective of the car, and on the car's sensors that aim to detect and respond to the environment.

It is important to explore and define decision-making processes and behaviour of cyclists in the transition period when road traffic consists of automated and manually driven cars, explicitly taking the perspective of the cyclist. This is essential because cyclists may respond differently when interacting with an automated car that does not 'behave' as they are used to. Moreover, if it is unclear for cyclists whether they are dealing with an automated vehicle or a manually driven vehicle, they could become hesitant or, on the contrary, over-reliant. It is also possible that they want to 'test' automated vehicles to see how it responds by creating a near collision situation. Thus, though automated vehicles are now being programmed based on the current behaviour of road users (in this case cyclists), this behaviour might in the future actually turn out to be totally different.

In the current road system, traffic interactions are largely based on expectations, experience, and predefined routine actions (Räsänen & Summala, 2000). Expectations about the presence and behaviour of other road users have been found to affect one's own traffic behaviour (Theeuwes & Hagenzieker, 1993; Houtenbos, 2008). Road users mainly base their expectations of what another road user is going to do on existing traffic rules, the design of the road, and the current behaviour of the road user (Björklund & Åberg, 2005). Road users' decision making is generally based on existing formal traffic rules. For example, giving right of way to road users coming from the right, except when regulated otherwise (by either signs or traffic lights). Sometimes, however, traffic rules are more ambiguous or the traffic situation is more demanding or complex, and informal right of way rules are applied. Road users might then communicate nonverbally to clarify their intentions and ensure a smooth interaction (Schramm, Rakotonirainy & Haworth, 2008; Kitazaki & Myrhe, 2015). Nonverbal communication includes signalling devices such as blinkers and brake lights, the vehicle's position and speed, and behaviour of the road user such as eye contact, nodding, and hand gestures (Kitazaki & Myrhe, 2015; Walker, 2005; Malmsten Lundgren et al., 2017). Eye contact, nodding and hand signals are specifically relevant in driver–cyclist interactions because they well predict attention for and awareness of each other (Rakonitorainy, Feller & Haworth, 2008; Sucha, 2014).

These traditional, well-proved mechanisms for interacting in traffic are only partly useful in situations with automated vehicles. Expectations of the behaviour of an automated vehicle might be incorrectly based on the expectations of a manually driven vehicle or of unproven, possibly unrealistic characteristics. For example, what will happen when cyclists blindly assume that self-driving cars will yield and stop for them at intersections and when turning? Nonverbal communication between road users will become more or less useless. What is the effect of making eye contact with the driver (controller) of an autonomous vehicle, if this person is actually not the person deciding when to brake? Another important challenge, especially for the transition period, is to ensure that road users can distinguish (partly) automated cars from manually driven cars.

The main aim of the current study was to investigate whether cyclists' expectations and (self-reported) behaviour when interacting with an automated vehicle differ from those when interacting with a manually driven car. A photo experiment was developed in which participants had to judge different bicycle–car interaction situations from the perspective of the cyclist. In two thirds of the cases the car was an automated car (recognisable by two different external features that are described in the Method section) and in one third the car was a manually driven car. Several studies have indicated that people widely differ in the belief in (the trustworthiness of) automated cars (Bazilinksyy, Kyriakidis, & De Winter, 2015; Kyriakidis, Happee, & De Winter, 2015; Schoettle & Sivak, 2014). To see whether this affects the expectations and behaviour of cyclists, the study aimed to manipulate the belief in automated cars by presenting their characteristics in either a positive or a more neutral way.

The traffic situations studied included situations with priority for the car and situations with priority for the cyclist. Furthermore, the photos represented situations where the car approached from behind or as oncoming traffic in front of the cyclist (i.e., parallel) as well as where the car approached from a side road. We looked whether these situational characteristics had an effect on the responses of the participants. Finally, we also looked whether some personal characteristics, notably the participants' overall trust in (new) technology, their trust in automated cars, and sensation seeking had an effect on their responses.

2. Method

2.1. Participants

Participants were recruited at the Delft University of Technology through social media, flyers and personal invitations. Participants had to be older than 18, master the Dutch language, and have cycling experience. A total of 35 people participated: 17 women with an average age of 29.7 years ($SD = 13.1$; range = 19–58) and 18 men with an average age of 28.8 years

Table 1. Bicycle use of the participants.

Bicycle use frequency	*n*
Every day	21
4-6 days per week	9
1-3 days per week	2
Less than once a week	3

($SD = 13.2$; range: 18–61). All participants owned a bicycle and the majority used their bicycle regularly (see Table 1).

Self-estimated average cycling speed ranged from 14 km/h to 30 km/h ($M = 19.1$), which can be considered common riding speeds for this age group (Vlakveld et al., 2015). For their participation, the participants received a gift-coupon worth 10 euro.

2.2. Design

The photo experiment used a design with a between-subjects factor instruction (with two levels), and two within-subjects factors: car type (three levels: roof name plate, sticker, traditional car), and series (two levels: first and second). One group received instructions containing positive information ($n = 16$, seven men and nine women), another group more neutral information about the characteristics of automated cars ($n = 19$, 11 men and eight women). The three levels of car type represented an automated car recognisable by either a roof name plate with the text 'self-driving,' an automated car with the text 'self-driving' written on the side of the car, and a 'traditional' manually driven car without any additions. The photos were presented twice, in two series; after the first series, participants were asked whether they had seen the different (manipulated) car types. Moreover, for reasons to be explained in Section 2.4.1 below, the design consisted of two additional within-subject factors: approach angle with two levels and priority with two levels.

2.3. Dependent variables

The dependent variables were the answers to three questions per photo: two on expectations of the behaviour of the car, and one on the participant's self-reported behaviour as a cyclist (see Materials).

2.4. Materials

2.4.1. Photos

Ten photos were taken from the viewpoint of the cyclist, suggesting an interaction with a car to come up. The photos were taken during daytime using a Canon 1000 D. The ten photos represented five different situations related to angle of approach (parallel; from left or right) and priority (either for cyclist or car):

1. Car approaching from behind aiming to turn right and cross the cycle path. Cyclist has priority because she/he is cycling straight ahead. (Three photos; parallel, same direction).
2. Car approaching from front (oncoming) aiming to turn left and cross the cycle path. Car has priority because the cycle path contains a yield line and the cyclist has to give right of way to the car. (Two photos; parallel, opposite direction).
3. Car approaching intersection from the right. Car has priority because it is coming from the right and the intersection is uncontrolled. One photo.
4. Car approaching intersection from the left. Car has priority because the cycle path contains a yield line and the cyclist has to give right of way to the car. Two photos.
5. Car approaching roundabout with cyclist on roundabout. Cyclist has priority because the cycle path on the roundabout has priority and a yield line is marked on the roads entering the roundabout. Two photos.

Subsequently, each photo was manipulated, using Photoshop, to transfer the original 'traditional' car into an 'automated' car by either 1) adding a roof name plate with the text 'Self-driving' or 2) adding the text 'Self-driving' on the side of the car (see Figure 1a-c). The original photos served as the baseline, which resulted in a total set of 30 photos.

2.4.2. The photo test

The photo test was created using Qualtrics survey software and presented on a laptop with a screen size of 23 inches. Photos were presented in random order. The intended direction or manoeuver of the car was described underneath the photos. The position of the cyclist was indicated by a red cross on the cycle track (see Figure 1a-c). Furthermore, the distance to where the car and cyclist would meet was about the same on all photos. This way the cyclists' expectations and behaviour could not be affected by the distance to the car. Each photo was shown for 8 seconds. The photo then very briefly disappeared and re-appeared again at a reduced size with the three questions displayed together underneath the (reduced size) photo:

1. How sure are you that the car noticed you? (Q1)
2. How sure are you that the car will stop if you continue cycling? (Q2)
3. What would you do as a cyclist in this situation? (Q3)

(a) (b) (c)

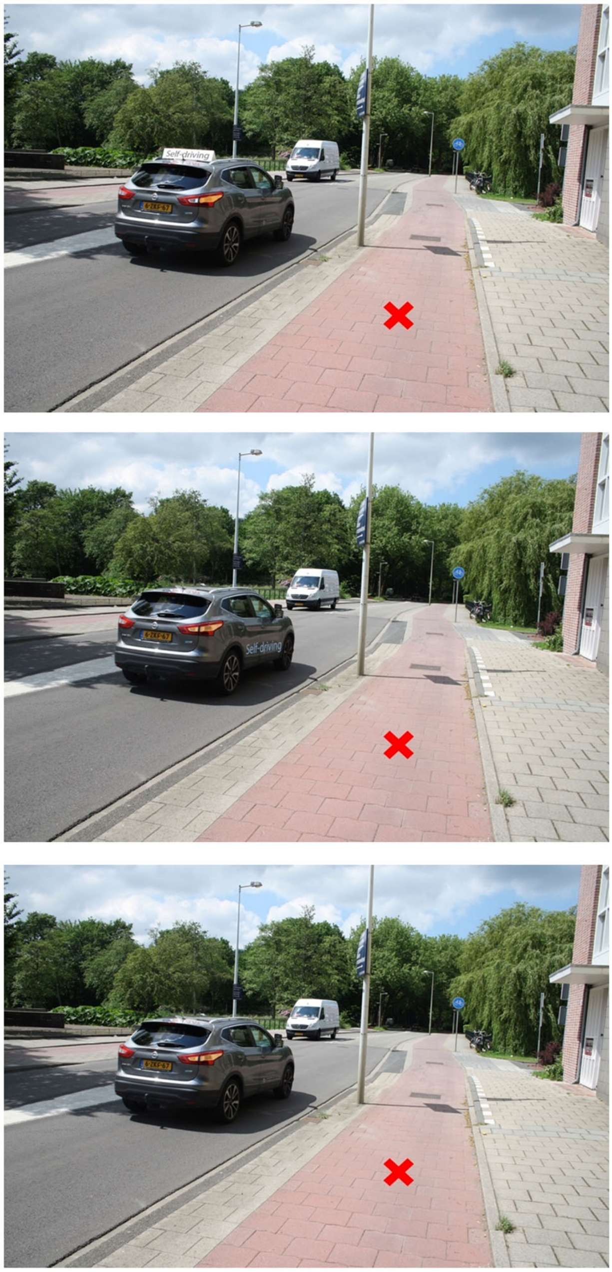

Figure 1 **(a).** A car with a roof name plate that says 'self-driving.'. **(b).** A car with a sticker on the side that says 'self-driving.' **(c).** A car without manipulation, a manually driven car.
"You cycle straight ahead, the car wants to turn right."

The first two questions had to be answered by marking a box on a 10-point bipolar bipolar? Please confirm this conveys your intent Likert-type scale ranging from *unsure* (1) to *sure* (10). For the third question participants had to indicate the answer that was most appropriate for them. Participants had to choose an answer from the scale below:

- I would increase my cycling speed so I can pass in front of the car.
- I would continue the same speed, because there is no need to accelerate or decelerate.
- I would stop active cycling in order to let the car pass in front of me.
- I would brake in order to let the car pass in front of me.
- I would get off the bike and I wait until the car has passed.

2.5. Instructions and questionnaire

Participants were randomly assigned to one of two instruction conditions. Both instructions contained the same information about the photo experiment and the participant's task but differed in the description of self-driving cars. One condition had a rather positive description of the concept of automated cars whereas the other condition contained a description that was more neutral or reserved. Below the instructions are presented with the general part first that was equal to both instructions, the positive description of the self-driving car (condition A) and the neutral description of the self-driving car (condition B; see Box A, text translated from Dutch).

Box A. Descriptions of self-driving cars used in instructions to participants: general first part used in both, positive description of the self-driving car (condition A) and neutral description of the self-driving car (condition B; text translated from Dutch).

SWOV is interested in how cyclists react when interacting with cars in traffic. In this experiment two sets of 30 photos of different bicycle-car interactions will be shown from the perspective of the cyclist. In random order photos of interactions with manually driven cars and self-driving cars will be shown. By manually driven cars we mean those as they participate in traffic nowadays. With self-driving cars we mean cars that will encounter traffic in the (near) future. These automated cars are vehicles equipped with sensors and computer- and communication systems which carry out the entire driving task. Self-driving cars drive to a predestined location and perform all tasks the driver normally does, like steering, controlling speed, keeping distance, overtaking etc.

Condition A: positive description of self-driving car

Self-driving cars are expected to make traffic safer. The self-driving car will not get tired, will not speed because it is in a hurry, will not be aggressive, and will not drive under the influence of alcohol or psychoactive substances. Automated cars include 360-degree sensors that continuously scan the surrounding road environment and will stop in time in case the car has to give priority, the car has to stop for a red traffic light or when the vehicle needs to brake when a child is suddenly crossing the road. Furthermore, the self-driving car is programmed to basically obey all traffic rules.

Condition B: neutral description of self-driving car

Several experts expect automated cars not to make mistakes in traffic and thus contribute to road safety. The idea is that self-driving cars will include sensors that scan the surrounding road environment and can perform an emergency brake in case the car has to give priority, the car has to stop for a red traffic light, or when the vehicle needs to brake when a child is suddenly crossing the road. In principle, the self-driving car is programmed to obey all traffic rules. Although a person is sitting on the "driver's seat." he/she is not the one driving the car. The vehicle decides which manoeuver to perform when interacting with other road users.

Participants had to complete three short questionnaires that explored their trust in technology in general, their trust in self-driving technology, and their inclination to sensation seeking. Scores on these tests were related to participants' answers in the photo test. The trust-in-technology questionnaire was adapted from (Merritt, Heimbaugh, LaChapell & Lee, 2013); 'trust in machines' was changed 'machines' into 'technology' because this was more in line with our study subject and practically has the same meaning. The questionnaire we used consisted of four items of the originally six items. Two items were removed because they were considered irrelevant for our purposes. Respondents had to answer according to a 5-point Likert = type scale (ranging from *strongly agree* to *strongly disagree*) on items like "I usually trust technology until there is a reason not to" and "My tendency to trust technology is high."

The questionnaire on trust in self-driving technology was adapted from Payne, Cestac, and Delhomme (2016). This questionnaire focuses on people's trust in fully automated driving and consisted of six randomised questions. For example, this scale included items like, "Globally I trust the automated driving system" and "I trust the automated system to keep a lane." Again a 5-point Likert-type scale was used ranging from *strongly agree* to *strongly disagree*.

The third questionnaire was the Brief Sensation Seeking Scale (BSSS-8) developed by Hoyle, Stephenson, Palmgreen, Lorch, and Donohew (2002). The BSSS-8 consists of eight items that together measure whether a person is a sensation seeker or not (e.g., people that have a strong preference for adventures and new experiences). Respondents had to answer on a 5-point Likert-type scale to what extent they agreed (*strongly agree* to *strongly disagree*) with items like 'I like wild parties' and 'I would like to explore strange places.'

2.6. Eye-tracker

A subgroup of nine out of the 35 participants were equipped with a Pupil Lab's head mounted binocular eye tracker (Kassner, Patera, & Bulling, 2014) to explore where and how participants looked at the various car types while watching the photos and answering the questions. It uses dark pupil position corneal reflection to determine the direction of the gaze. It consists of one outside 'world' camera and two infra-red eye cameras. The output consisted of the world camera on which the gaze position was superimposed. After a brief calibration, the eye-tracker accurately tracks the subject's eye moments and gaze direction with a refresh rate of 60 Hz.

The group of nine consisted of three females (age: $M = 25.7$, $SD = 2.7$, range = 25–32) and six male participants (age: $M = 25.7$, $SD = 2.7$, range =

25–32). Five participants received a more positive instruction and four participants received a neutral instruction. The total average time participants spent looking at an area of interest (Salvucci & Goldberg, 2000) was the dependent variable. First, the cars were defined as the areas of interest (AOIs). This was chosen instead of solely the manipulations (roof name plate or sticker) because these were too small in the photo to be confidently detected by the eye-tracker. Then, on the cars, any fixation that occurred during the first 8 seconds was noted for each condition (roof name plate, sticker, and manually driven cars). Additionally, a fixation had to have a duration longer than 200 ms or when there were multiple fixations within the time window at the AOI, which together were longer than 200 ms (Velichkovsky, Rothert, Kopf, Dornhöfer, & Joos, 2002). Fixations that did not meet these requirements were not included. These fixation times were summated for all photos to create a total fixation time per car condition per participant. The scores were then aggregated by taking the means, resulting in three variables that contain the total average time each participant looked at the three car manipulations.

2.7. Procedure

Participants were tested individually at the Delft University of Technology in the presence of an experimenter. Each participant first read the instructions and then signed the informed consent form. The experiment started with completing a few background questions (age, gender, bicycle use, bicycle speed). For the nine eye-tracker participants, then the eye tracker was mounted and calibrated. Subsequently, the photo test started, which consisted of two series of the 30 photos. Before the first series of 30 photos was presented, one practice photo was administered. After the first complete series of 30 photos, the experimenter asked the participant if she/he had noticed that some of these photos contained self-driving cars (all participants answered confirmatively). At this stage the experimenter also asked which indication of 'self-driving' the participant preferred: the text on the side of the car or on a roof name plate. After the intermezzo, the participants went through the same 30 photos, in a different randomised order, thus completing two series. Finally, the participants completed an online version of the three questionnaires on personal characteristics. At the end of the session, the experimenter explained the background of the study, and participants had the opportunity to ask questions or give feedback about the experiment. After the entire experiment was completed, the participants received a 10 euro gift coupon as a reward. The complete experiment took approximately 30 minutes.

2.8. Data-analysis

In order to analyse the questionnaire data, the scores for each condition were aggregated by taking the Mean. This implies that for the manipulation of car type, three variables were construed containing the mean scores of these three conditions (traditional manually driven cars, roof name plate, and sticker). For the first and second question, this mean is a value between 1 and 10. For the third question, the mean is a value between 1 and 5. For the questions about priority, angle of approach and car-type manipulation, six variables were created. All variables were assumed to be continuous and of an interval measurement level, although this is not strictly true.

Repeated-measures ANOVAs were conducted, treating car type manipulation (three levels: traditional/roof name plate/sticker), priority (two levels; car/cyclist) and approaching angle (two levels: parallel/from side road) as within-subject factors, and instruction as a between-subjects factor. The same procedure was used to analyse the eye-tracking data.

3. Results

For the analysis of the responses on the questions, the total number of participants was 35. Five participants failed to answer some of the three questions on one or two photos. The number of missing values is small and does not substantially influence the mean scores. The participants were all included in the analysis to prevent a reduction in statistical power. Of these 35 participants, nine had been wearing an eye-tracker during the experiment. Descriptive statistics showed that the answers on the questionnaire of these participants wearing an eye-tracker did not deviate from the other 26 participants. They were therefore analysed together.

During the intermezzo (i.e., after the first set of 30 photos) the respondents were asked whether they had noticed the self-driving cars on the photos. All participants answered affirmatively. ANOVA showed no main effect of series (1 or 2), nor were interactions with other factors statistically significant (see Section 4.1). Therefore, all results reported are based on data acquired in first and second series together; with only one exception that is reported below. An overview of the Means and Standard Deviations for all three questions is provided in Table 2, and an overview of the ANOVA results is shown in Table 3. These ANOVA results are, in fact, based on two experimental designs. In both designs, the between-subjects factor Instruction and the within-subjects factor Cartype was used. Additionally, in one design a second within-subjects factor Priority was used, and the other within-subjects factor Approach Angle in the other design. Also, in Table 3, we do not report the first-order interactions between Instruction and Priority and between Instruction and Approach Angle, nor the second order interactions of Instruction by Cartype by Priority and Instruction by Cartype by Approach Angle. First of all, we were not interested in these interactions. Moreover, these interactions were never significant.

3.1. Car type manipulations

A repeated-measures ANOVA showed no main effects of manipulation of Cartype for Questions 1, 2, and 3, $F(2, 66) = .096$, $p = .908$; $F(2, 66) = 2.401$, $p = .098$; $F(2, 66) = .576$, $p = .565$ (see Table 3). Although the means on Q2 were somewhat higher for the two 'automated car' conditions as compared to the traditional car (see Table 2), this effect was not statistically significant.

As mentioned earlier, no main effect of series (1 or 2) was found, nor were the interactions with this factor statistically significant, with the exception of the interaction between Series and Cartype for variable Q2, $F(2, 66) = 3.856$, $p = .026$: participants were more confident that the car with the rooftop sign would stop for them in the second series as compared to the first series (see Figure 2). In the second series means for rooftop and sticker conditions were higher than for the traditional car condition ($M = 6.8$, $SD = 2.3$ for rooftop; $M = 6.7$, $SD = 2.3$ for sticker; $M = 6.0$, $SD = 1.9$ for traditional car condition; see also Section 3).

So, the results show that there were generally no statistically significant differences in how cyclists evaluate whether they are being noticed (Q1), how the car would react to them (Q2), and how they intended to react themselves (Q3). However, participants were more confident in the second series of photos that 'automated' cars equipped with rooftop sign or sticker would stop for them as compared to a traditional car.

3.2. Instruction

Two groups of participants received different instructions. The more positively framed instruction A was given to 19 participants (11 men and eight women), the neutral instruction B was given to 16 participants (seven men and nine women). A repeated-measures ANOVA with two instruction levels (between-subjects) and three car type levels (within-subjects) showed a significant interaction between Cartype and Instruction for Q1, $F(2, 66) = 3.961$, $p = .024$. Participants were more confident that they had been noticed (Q1) by the automated cars than by traditional cars when presented with the more positively framed instruction A than instruction B. The reverse was found for instruction B: participants presented with the more neutral phrased instruction B were more confident that they had been noticed by traditional cars than by automated cars (see Table 2 and Figure 3).

Table 2. Means and standard deviations for Q1: 'How sure are you that the car noticed you?' Q2: 'How sure are you that the car will stop if you continue cycling?' and Q3: 'What would you do as a cyclist in this situation?' for each of the three car conditions: traditional, roof name plate and sticker. The last column indicates whether the (interaction) effect was significant (*, **) or not (*ns*).

	CarType	Traditional	Roof plate	Sticker	Sig.
	Condition	*M (SD)*	*M (SD)*	*M (SD)*	
Question 1	Overall	7.0 (1.5)	7.0 (1.9)	7.0 (1.9)	*ns*
	Instruction A	7.0 (1.7)	7.5 (2.0)	7.4 (2.0)	*
	Instruction B	7.1 (1.0)	6.4 (1.7)	6.6 (1.6)	
	Series 1	7.1 (1.5)	6.9 (2.0)	7.0 (1.9)	*ns*
	Series 2	7.0 (1.6)	7.1 (2.0)	7.1 (2.1)	
	Priority cyclist	6.7 (1.5)	7.0 (2.1)	7.0 (2.0)	**
	No priority cyclist	7.4 (1.6)	7.0 (2.0)	7.1 (2.0)	
	Crosswise approach	7.4 (1.6)	7.1 (1.9)	7.1 (2.0)	**
	Parallel approach	6.7 (1.6)	6.9 (2.1)	7.0 (2.0)	
Question 2	Overall	6.0 (1.7)	6.6 (2.2)	6.6 (2.1)	*ns*
	Instruction A	6.2 (1.7)	7.0 (2.0)	7.1 (2.1)	*ns*
	Instruction B	5.8 (1.6)	6.0 (2.2)	6.1 (2.1)	
	Series 1	6.1 (1.8)	6.4 (2.2)	6.6 (2.1)	*
	Series 2	6.0 (1.9)	6.8 (2.3)	6.7 (2.3)	
	Priority cyclist	6.8 (1.5)	7.2 (2.1)	7.2 (2.0)	*ns*
	No priority cyclist	5.3 (2.4)	6.0 (2.6)	6.1 (2.6)	
	Crosswise approach	6.2 (1.7)	6.6 (2.1)	6.7 (2.1)	*
	Parallel approach	5.9 (1.8)	6.5 (2.4)	6.6 (2.3)	
Question 3	Overall	3.1 (0.5)	3.2 (0.6)	3.2 (0.5)	*ns*
	Instruction A	3.0 (0.4)	2.1 (0.5)	3.1 (0.5)	*ns*
	Instruction B	3.3 (0.5)	3.2 (0.6)	3.3 (0.6)	
	Series 1	3.2 (0.6)	3.2 (0.6)	3.2 (0.6)	*ns*
	Series 2	3.1 (0.5)	3.2 (0.7)	3.2 (0.7)	
	Priority cyclist	3.8 (0.5)	3.8 (0.5)	3.9 (0.5)	*ns*
	No priority cyclist	2.4 (0.8)	2.5 (0.9)	2.5 (0.8)	
	Crosswise approach	3.0 (0.5)	3.1 (0.6)	3.1 (0.5)	*ns*
	Parallel approach	3.3 (0.6)	3.2 (0.7)	3.3 (0.7)	

*$p < .05$, **$p < .01$.

3.3. Priority

To assess the effect of right of way for either the cyclist or the cars, the photos were divided into two equally sized sets. The first set of photos contained situations in which the cyclist had right of way, the second set contained photos where the car had right of way.

The repeated-measures ANOVA with two priority types and three car types (both within-subjects) only showed a significant interaction between Cartype and Priority for Q1, $F(2, 66) = 7.106$, $p = .002$. When the car had priority participants were more confident to be noticed when confronted with traditional cars ($M = 7.4$, $SD = 1.6$) than when confronted with 'automated' cars ($M = 7.0$, $SD = 2.0$; and $M = 7.1$, $SD = 2.0$). When the cyclist had priority the respective means showed an opposite pattern: participants were somewhat more confident to be noticed by the automated cars ($M = 7.0$, $SD = 2.1$; and $M = 7.0$, $SD = 2.0$) than by the traditional cars ($M = 6.7$, $SD = 1.5$; see Table 3 and Figure 4). There were also significant main effects (i.e., regardless of car type) of Priority for Q2, $F(1, 33) = 162.186$, $p < .001$, and Q3, $F(1, 33) = 195.184$, $p < .001$.

Table 3. Overview of results of the repeated-measures ANOVA analysis for car type manipulation (Cartype), and for the interactions between Cartype and Instruction, Cartype and Priority, and Cartype and Approach Angle (see text for explanation).

Analysis	Question	Sum of Sq.	*df*	Mean Sq.	*F*	Sig.
Cartype	Q1	0.707	2	0.353	0.096	0.908
	Q2	25.340	2	23.535	2.401	0.098
	Q3	0.133	2	0.066	0.576	0.565
Cartype * Instruction	Q1	29.124	2	14.562	3.961	0.024
	Q2	9.501	2	4.751	0.900	0.411
	Q3	0.217	2	0.109	0.943	0.395
Cartype * Priority	Q1	9.650	2	4.825	7.106	0.002
	Q2	2.040	2	1.020	1.108	0.336
	Q3	0.071	2	0.036	0.400	0.672
Cartype * Approach Angle	Q1	5.559	2	2.780	5.055	0.009
	Q2	2.201	2	1.100	3.032	0.055
	Q3	0.234	2	0.117	1.016	0.368

3.4. Approach angle

To assess the effect of the approach angle of cars, again photos were divided into two groups. The first group contained photos where the cars were driving parallel either behind or in front of (oncoming) the cyclist, the second group contained photos in which the cars approached the cyclist perpendicularly (from either left or right). For each car manipulation, the set contained five photos per approach angle type.

A significant interaction between Cartype and Approach Angle was found for Q1, $F(2, 66) = 5.055$, $p = .009$, and this interaction approached significance for Q2, $F(2, 66) = 3.032$, $p = .055$ (see Table 3). When the car approached from the left or right the participants/cyclists tended to be more confident to be noticed in case of the traditional car ($M = 7.4$, $SD = 1.6$) as compared to both 'automated' cars ($M = 7.1$, $SD = 1.9$; and $M = 7.1$, $SD = 2.0$, respectively). When the car approached in parallel direction this pattern was reversed, and participants were more confident to be noticed by both automated car types ($M = 6.9$, $SD = 2.1$; and $M = 7.0$, $SD = 2.0$, for roof name plate and sticker, respectively) than by the traditional car ($M = 6.7$, $SD = 1.6$; see Table 2).

There were also main effects of Approach Angle for Q1 and Q3. Cyclists were more confident to be noticed (Q1, $F(1, 33) = 6.820$, $p = .013$), regardless of car type, when the car approached them from the left of right as compared to when the car approached from the front or behind. Cyclists were also more inclined to slow down (Q3, $F(1, 33) = 5.699$, $p = .023$) with a car approaching from the left or right as compared to the parallel direction.

3.5. Personal characteristics

We found no differences on responses on the sensation seeking scale for gender, group, cycling speed, age related to the scores of the first, second,

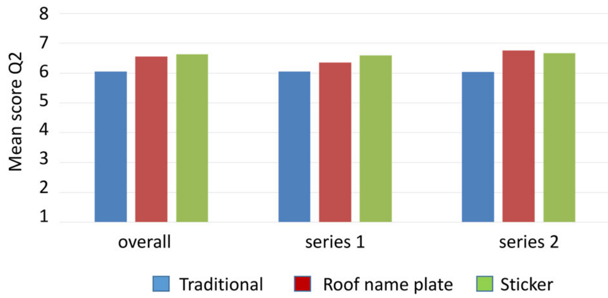

Figure 2. Overall mean scores of Cartype for Q2 'How sure are you that the car will stop if you continue cycling?', as well as means for Series 1 and 2 (range 1–10, the higher the score, the more confidence).

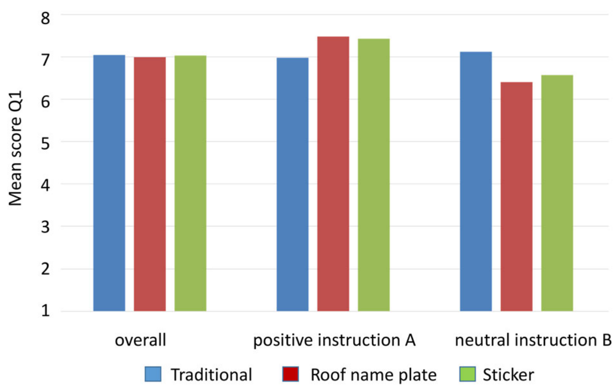

Figure 3. Overall mean scores of Cartype for Q1 'How sure are you that the car noticed you?' as well as means for the positive (A) and neutral (B) instruction (range 1–10, the higher the score, the more confidence).

and third question. We did find that the trust in technology and trust in automation questionnaires correlated positively: $r = .401$, $p = .017$ ($n = 35$).

3.6. Gender and preference

Participants were asked which of the two manipulations they would prefer as an indication of self-driving if those cars would become a common sight. No significant preferences were found for one or the other: 20 preferred the roof name plate, 15 the sticker.

4. Results eye-tracking data

For the analysis of the eye-tracking data, the total number of participants included was nine. The Means and Standard Deviations are presented in Table 4. The results of the ANOVAs are presented in Table 5. These ANOVA are based, as explained earlier (see Section 3), on two experimental designs. Also, in Table 5, we do not report the first-order interactions

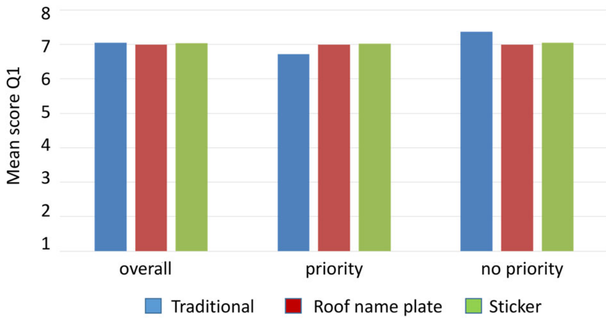

Figure 4. Overall mean scores of Cartype for Q1'How sure are you that the car noticed you?' as well as means for Priority for cyclists or no Priority for cyclists (range 1–10, the higher the score, the more confident).

Table 4. Means and Standard Deviations for average total time fixated at the cars (in seconds) at the cars. The last column indicates whether the (interaction) effect was significant (*) or not (*ns*).

CarType	Traditional	Roof name plate	Sticker	Sig.
Condition	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	
Overall	1.5 (0.6)	1.6 (0.7)	1.7 (0.8)	*ns*
Instruction A	1.8 (0.6)	2.1 (0.5)	2.0 (0.7)	*ns*
Instruction B	1.2 (0.5)	1.0 (0.5)	1.4 (0.8)	
Series 1	1.6 (0.6)	1.8 (0.7)	2.1 (0.7)	*
Series 2	1.5 (0.7)	1.5 (0.9)	1.4 (0.9)	
Priority cyclist	1.6 (0.6)	1.9 (0.9)	2.0 (0.9)	*ns*
No priority cyclist	1.5 (0.7)	1.4 (0.8)	1.5 (0.9)	
Crosswise approach	1.6 (0.7)	1.6 (0.9)	1.9 (0.9)	*ns*
Parallel approach	1.4 (0.6)	1.6 (0.7)	1.6 (0.7)	

*$p < .05$.

between Instruction and Priority and between Instruction and Approach Angle, nor the second order interactions of Instruction by Cartype by Priority and Instruction by Cartype by Approach Angle for the same reasons as explained in Section 3.

4.1. Car type manipulation

A repeated-measure ANOVA showed no main effects of Cartype, $F(2, 14) = 2.063$, $p = .164$, and Series, $F(1, 7) = 3.556$, $p = .101$, but a significant interaction was found between Car Type and Series, $F(2, 14) = 5.718$, $p = .015$ (see Table 5). Inspection of the means (Table 4) shows that participants particularly looked longer at the AOIs of the automated car manipulations during the first photo series as compared to the second series (Figure 5). Post hoc tests using the Bonferroni correction revealed a significant reduction in the time spent looking at the sticker condition ($p < .05$).

4.2. Instruction, priority and approach angle

Repeated-measures ANOVAs of fixation time with either Instruction (as a between-subjects factor with two levels), Priority (as within-subjects factor

Table 5. Overview of results of the repeated-measures ANOVA analysis of fixation time for car type manipulation (Cartype), and for the interactions between Cartype and Instruction, Cartype and Priority, Cartype and Approach Angle, and Cartype and Series.

Analysis	Sum of Sq.	*df*	Mean sq.	*F*	Sig.
Cartype	0.818	2	0.409	2.063	0.164
Cartype * Instruction	1.143	2	0.572	2.882	0.090
Cartype * Priority	0.784	2	0.392	1.395	0.280
Cartype * Approach Angle	0.525	2	0.262	1.544	0.248
Cartype * Series	2.049	2	1.024	5.718	0.015

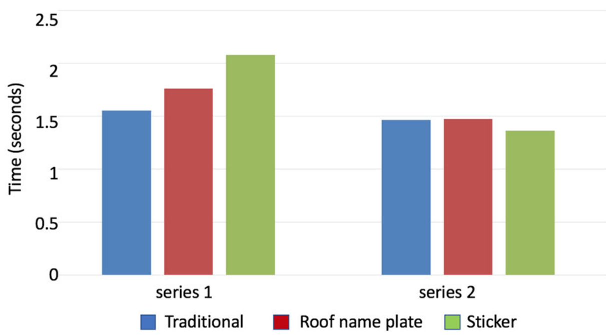

Figure 5. Total average time spent looking at the three car manipulations for series 1 and 2.

with two levels), or Approach Angle (as a within-subjects factor with two levels) and Cartype (as within-subjects factor with three levels) did not reveal any significant interaction effects (see Table 5).

5. Discussion

In this study, we explored cyclists' expectations when presented with photos of automated and traditional cars in a variety of situations. Cyclists could have incorrect or over-reliant expectations of automated driven cars, for instance about whether they had been noticed by an automated car, or whether the automated car would stop for them. As a result, cyclists might behave differently than when interacting with traditional cars, which in turn could create unsafe situations.

The findings of the photo experiment generally point at a conservative, rather cautious disposition of the participants toward automated driven cars, in the sense that they do not expect to be noted by an automated driven car 'better' as opposed to a manually driven car. The results show that there were few statistically significant differences in how cyclists evaluate whether they are being noticed, how the car would react to them, and how they intended to react themselves. Nevertheless, some effects reached or approached statistical significance, and the results generally indicate that cyclists tended to have more confidence in traditional than automated cars. Particularly participants tended to be more confident to be noticed when interacting with a traditional car than with the two 'automated' cars. However, when we look at the different priority situations the participants were presented with, the results show that when the cyclist had priority over the car the participants were relatively more confident of being noticed by the cars indicated being automated cars (either by a roof name plate or sticker) as compared to the traditional car. This pattern was reversed for those situations in which the cyclist had no priority over the car: then the participants were more confident to be noticed by the traditional car. No differences were found between traditional and 'automated' cars in how sure they were that the car would stop for them. However, the results also suggest that experience with the appearance of automated cars plays a role. Participants were more confident that automated cars with a rooftop sign or a sticker would stop for them in the second series of photos than in the first series. Also, the more positively phrased instruction with regard to automated driven cars seems to counteract the cautious tendency in response patterns somewhat: participants who were presented with this instruction tended to be more confident they had been noticed than those who had been given the more neutral description.

Our findings are in line with results of the very few previous studies that investigated how non-motorised road users would react to automated driven cars. In a field test and questionnaire study Malmsten Lundgren et al. (2017) investigated pedestrian decisions to cross a street. Subjective evaluations of 13 participants showed that all of them would decide to cross the street when they got eye contact with the driver of the approaching car. When the driver was reading a newspaper or when there was no driver visible in the car their willingness to cross was reduced, and only five participants would cross in those cases. Blau (2015) conducted a stated-preference study in which cyclists (and pedestrians) indicated their preferred facility in various scenarios with and without the presence of driverless vehicles and on street types of varying motorised traffic volumes and speeds. Street type had a very strong influence on cyclists' preferences for more separated facilities as traffic volume and speed increased. The presence of driverless vehicles markedly increased these preferences. Both studies thus also show a cautious attitude of cyclist and pedestrians toward automated driven cars.

The results of the eye-tracking data showed that participants generally looked longer at the cars during the first series than during the second series, and particularly longer at the automated cars as compared to the traditional car during the first photo series. One possibility that might explain the difference in fixation times between the two series is that a fixation made while interacting with a type of car participants have experience with (i.e., the traditional one), is more effective. Thus, a shorter time looking at a traditional car would provide the cyclists with the information needed, whereas longer times on the automated vehicles' roof name plates or stickers were needed to process and acquire the same information (Chapman & Underwood, 1998; Crundall et al., 2012). The fact that the differences in looking times levelled out in the second series could indicate that participants accumulated enough experience with the appearance of the automated cars, which allowed them to process these as fast as the traditional cars during the second series. Interestingly, these differences in looking times between first and second series are not reflected in the response patterns on the three questions, except for Q2: here also 'experience' might explain why participants were more confident that the 'automated' cars would stop for them than traditional cars, whereas the reverse was found in the first series.

As mentioned, most of our results did not reach statistical significance and therefore must be treated with caution. Nevertheless, the results shed some light on what cyclists expect when interacting with automated cars in urban environments, in the presence of manually driven as well as various levels of automated vehicles. Such mixed traffic environments are envisaged to be realistic for many years to come (Hagenzieker, 2015; Shladover, 2016).

Finally, some limitations of the present study must be mentioned. First, we conducted a relatively small scale study using 35 participants, all relatively young and working or studying at Delft University of Technology. The results obtained might be mostly typical of this particular group of participants. Future studies involving more participants and using a more varied sample (age, background) must be performed to see whether results also apply more generally. Although we have assumed that the participants had no experience with automated car interaction, we cannot be absolutely sure whether this was indeed the case. On the other hand, this lack in experience of interacting with automated cars can of course also have affected the results as found in this study. Future studies must further study the influence of (real-life) experience on how cyclists interact with automated cars. Furthermore, the study used static photos representing traffic situations that were thought of relevance and could therefore not convey any information on speeds driven by the cars in these situations. Earlier studies on how non-motorised road users would react to automated driven cars indicated that speed was an important cue for pedestrian decisions to cross a street (Malmsten Lundgren et al., 2017) as well as preferred cycle facilities (Blau, 2015). Although our results show that even static photos induce certain expectations, in future studies dynamic situations should also be used to investigate whether these lead to similar results.

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