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Cyclists' expectations when encountering automated vehicles: results of an international photo-based questionnaire

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ABSTRACT

In the future, cyclists will be sharing the roads with automated and traditional vehicles [1]. Interactions between cyclists and automated vehicles (AVs) may differ from interactions with traditional vehicles, because cyclists may hold incorrect expectations about how AVs will react to their presence, leading to confusing and risky situations.

The objective of this study was to assess the (self-reported) behaviour and expectations of cyclists when encountering an AV with different external features as compared to a traditional vehicle. This study builds on a smaller questionnaire conducted by Hagenzieker et al. [2].

607 participants from 15 countries completed an online questionnaire, in which they were shown 12 photos from a cyclist's point of view. Each photo involved a traditional vehicle or an AV recognisable by a specific feature (door sign or roof sign with the message 'self-driving'). Moreover, three descriptions of the capabilities of AVs (negative, neutral, positive) were provided in a between-subjects design. Participants had to report, for each photo, (1) how sure they were that the car had noticed them, (2) how sure they were that the car would stop, both on a scale from unsure to sure, and (3) what they would do on a scale from 'increase speed' to 'wait'. Personal characteristics (trust in automation and sensation seeking) were also measured.

The results showed that participants were more sure to be noticed by an AV with a door sign than by a traditional vehicle. They were also more sure that the car would stop when the vehicle was an AV. The type of AV description showed statistically significant interaction effects with vehicle type. Furthermore, results differed per country group. For example, European respondents were more sure to be noticed by the car than respondents from North America. Finally, trust and sensation seeking scores showed positive correlations with participants' answers to the three questions.

Keywords: cyclists, automated vehicles, intentions, expectations, road safety.

1 INTRODUCTION

1.1 Transition from traditional vehicles to automated vehicles – Implications for cyclists

It is expected that, for a long period, automated vehicles and traditional (manually driven) vehicles will be present on roads, and that both vehicle types will be sharing the urban road environment with vulnerable road users such as cyclists and pedestrians [1], [2]. It is important to ensure that the interactions between automated vehicles and vulnerable road users are safe, which may be challenging because vulnerable road users might be unfamiliar with automated vehicles and uncertain about their behaviour. So far, little is known about the interactions between vulnerable road users and automated vehicles. In the current study, we focus on the interactions between cyclists and automated vehicles in an urban environment from a cyclist's point of view.

1.2 Cycling as a transport mode

Cycling is an important mode of transport in many countries, in particular in urban areas. In Europe, an average of 12% of the population uses a bicycle 'at least once a day' [3]. However, this percentage varies per country. In the Netherlands, for example, 36% of the population uses a bicycle as the main transport mode [4]. Because of increasing congestion problems in cities, governmental policies to reduce pollutant emissions and benefits of cycling on health and the environment [5]-[9], more and more people are choosing the bicycle as their transport mode [5]. However, cycling safety is a concern because cyclists do not have physical protection while they share the roads with much heavier and high-speed motorised vehicles [10], [11]. Hence, it is important that the introduction of automated vehicles on the roads does not create new types of crashes, or more severe crashes, involving cyclists.

1.3 Studies on the interaction between automated vehicles and vulnerable road users

A large amount of research has been carried out on the topic of automated vehicles. Most of the studies focused on the automated driving technology (e.g. [12]), the vehicle drivers (e.g., [13]-[17]), and the acceptance of automated vehicles (e.g., [18]-[20]). Many vehicle manufacturers are developing technological systems, such as improved sensors and algorithms, with the objective to avoid collisions with non-motorized vehicles such as cyclists. Recently, a number of studies have focused on the behavioural aspects of the interaction between vulnerable road users and automated vehicles (for a literature study, see [21]), but only a few are concerned with the interaction between cyclists and automated vehicles from the cyclists' perspective (e.g. [2], [22]).

The analysis of the behaviour and decision-making of cyclists when interacting with automated vehicles is important, because cyclists might alter their behaviour when interacting with an automated vehicle (which itself may behave differently from a traditional vehicle). If cyclists are uncertain about the type of vehicle they are dealing with (automated or manually-driven vehicle), they could become hesitant. Another possibility is that cyclists might want to 'test' the behaviour of automated vehicles to see their response to a near collision situation.

The behaviour of road users is dependent on many factors, including prior experience, expectations, routine actions, road design, and traffic rules [23], [24]. An example of a formal traffic rule is giving right of way to road users that come from the right, except when a different traffic rule applies (e.g., traffic signs). However, formal traffic rules can sometimes be ambiguous, in which case road users might apply informal right-of-way traffic rules [25]. For example, road users might use non-verbal communication with other road users to assess their intentions and guarantee an appropriate interaction [26], [27]. Hand gestures, eye contact, nodding, and features related to the vehicle such as the vehicle's speed and position and the use of blinkers or brake lights are examples of non-verbal communication [27]-[29]. During the interaction between cyclists and drivers, non-verbal communication could contribute to a prediction of what the other road user will do [30], [31].

The non-verbal communication techniques that are used to interact with traditional vehicles might not be useful when an automated vehicle is involved, because drivers of automated vehicles are not always attentive. As a result, cyclists might have incorrect or unrealistic expectations of how an automated vehicle will behave.

1.4 Aim of the study

The main objective of this study was to assess the (self-reported) behaviour and expectations of cyclists when encountering an automated vehicle as compared to when encountering a traditional vehicle. This study builds on a small-scale study conducted in the Netherlands by Hagenzieker et al. [2], but with larger sample size and at an international level, thereby allowing for an assessment of individual differences (e.g., effects of between-subject factors and correlations).

In the current study, respondents from different countries, recruited via crowdsourcing, completed an online questionnaire. Respondents were regular cyclists and had to assess vehicle-bicycle interactions shown in 12 photos taken from a cyclist's point of view. These 12 photos resulted from taking four photos and creating three different versions of each photo. The photos involved traditional and automated vehicles with one of two different features (door sign or roof sign with the message 'self-driving'). During the questionnaire, respondents had to assess, for each of the 12 photos, how sure they were that the vehicle had seen them, whether they thought that the vehicle would stop for them, and how they would react in that situation. Personal characteristics of the participants, trust in self-driving technology, trust in machines, and sensation seeking scores were also assessed.

Previous studies have shown that people have different trust levels towards automated vehicles [18], [19], [32]. To assess the possible effect of prior knowledge and expectations that cyclists have about automated vehicles, participants received information describing automated vehicles in either a positive, neutral, or negative way.

2 METHODS

2.1 Participants

Participants were recruited using the CrowdFlower service, and completed the questionnaire using SurveyMonkey. Participants had to fulfil the following inclusion criteria: (1) being 18 years or older, (2) having responded 'yes' to a question about whether they had read and understood the questionnaire introduction, (3) having a detectible IP address that allowed us to link the CrowdFlower and SurveyMonkey responses, (4) not using the same IP address more than once, and (5) not failing more than one of the test questions that were used to verify that participants were not clicking random answers to finish the questionnaire. A total of 607 people with a mean age of 38.77 years (*SD* = 12.55) completed the questionnaire, consisting of 319 women and 288 men from 15 Western countries where cycling is a relatively common mode of transport [33], see supplementary materials (Table S1).

2.2 Design

The study consisted of a combined between-subjects and within-subject design. The between-subjects factor was the information about self-driving vehicles given to the participants (three levels: negative, neutral, and positive). The vehicle type was the within-subject factor, with three different levels: (1) automated vehicle recognisable by a roof plate with the message 'self-driving', (2) automated vehicle recognisable with the message 'self-driving' on the hood and door of the vehicle, and (3) manually driven (traditional) vehicle without any addition.

2.3 Photos

Four photos were selected from the study by Hagenzieker et al. [2]. All photos were taken from the point of view of the cyclist in a Dutch traffic situation (Figure 1). These photos had been processed using Adobe Photoshop by adding the message 'self-driving' either on the hood and the door of the vehicle or on a roof plate.

The number of photos shown to participants was reduced with respect to [2], to reduce the questionnaire completion time and to prevent that participants would not finish the questionnaire. The photos involved different situations, depending on the approach angle and priority:

1. The vehicle drove in the same direction as the cyclist and aimed to turn right and cross the cyclist's path. The cyclist had priority because s/he was cycling straight ahead. This concerned three photos (Figure 1, P1–P3). This case was chosen because traffic situations in which the cyclists are on the vehicle's blind spot are typical accident scenarios. The size of these photos was 1200 x 800 pixels.
2. The vehicle approaches from the front (oncoming) and aims to turn left and cross the cycle path. The vehicle has priority because the cycle path contains 'shark teeth' yield lines as well as a yield traffic sign, and the cyclist therefore has to give right of way to the vehicle (Figure 1, P4). The size of these photos was 1200 x 594 pixels.

In summary, 12 photos were selected for this study: 9 photos focusing on a typical accident scenario (cyclist in the vehicle's blind spot) and 3 photos where the vehicle approached from the front. It is important to note that the photos were taken on hand-right driving roads and participants from left-hand driving countries might not be familiar with them. Therefore, a distinction between participants from right-hand driving and left-hand driving countries has been made in the results section.

P1: Roof sign (AV)

P1: Hood/door sign (AV)

P1: No sign

P2: Roof sign (AV)

P2: Hood/door sign (AV)

P2: No sign

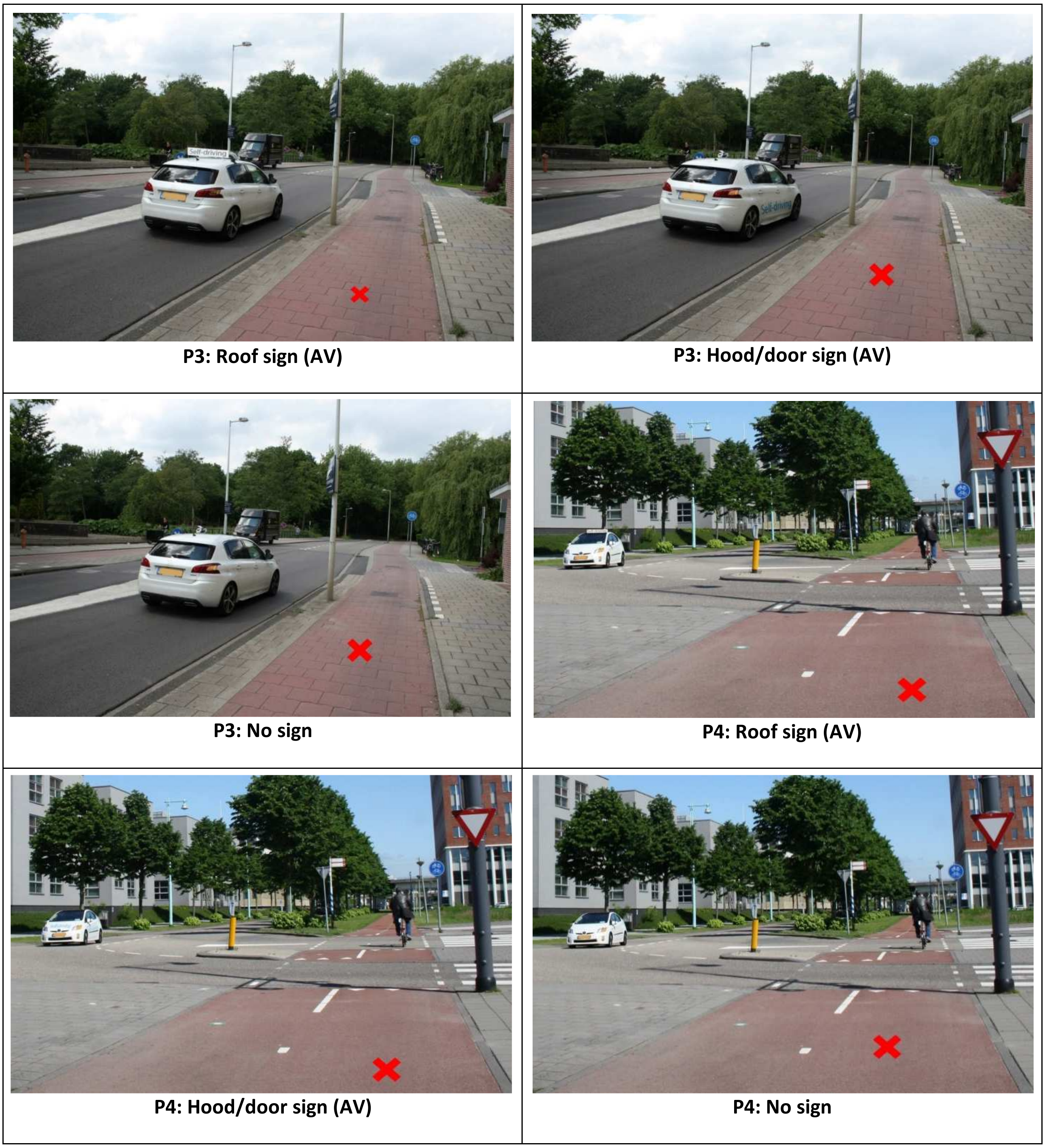

Figure 1. Photos shown to participants in the questionnaire. The red cross on the road marks the position of the cyclist.

2.4 Conducting the questionnaire

The questionnaire was implemented online using SurveyMonkey. The recruitment was done via CrowdFlower (https://www.crowdflower.com), from where participants were linked to the questionnaire in SurveyMonkey (https://www.surveymonkey.com).

First, participants were provided with the name of the study, the expected length of the questionnaire (10 minutes), the name of the research institutions involved in the study, and contact information in case of questions. Participants had to indicate by means of a yes/no question whether they had read and understood this information. Then, participants were redirected to SurveyMonkey, where they could start the questionnaire. At the beginning of the questionnaire, participants answered several questions regarding their background (e.g., age, gender, cycling frequency, bicycle ownership, and type of bicycle). After that, a brief description of the study and the instructions for the questionnaire were detailed (see supplementary materials).

Next, information about self-driving vehicles was given to the participants. The information contained similar numbers of words and the same elements. The only difference was that the information that was provided described the features of a self-driving vehicle either negatively, neutral or positively (see supplementary materials). The three types of information were randomly assigned to participants.

Thereafter, a practice photo was presented, followed by the 12 photos (Figure 1) presented in random order. The intended manoeuvre of the vehicle was described below the photo: "the car wants to turn right" or "the car wants to turn left". The position of the cyclist (participant) was indicated with a red cross on the photo. Below each photo, four questions were asked:

1. How sure are you that the car has noticed you?
2. How sure are you that the car will stop if you continue cycling?
3. What would you do as a cyclist in this situation?
4. What colour is the car?

Questions 1 and 2 had to be answered using a 10-point Likert scale ranging from 1 (unsure) to 10 (sure). For Question 3, participants were provided with the following five possible answers:

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

In Question 4, participants had to indicate the colour of the vehicle in the photo, choosing an answer from five given colours. This question was added to verify whether the participants were answering the questions seriously instead of quickly clicking answers to finish the questionnaire. If participants failed at responding to this test question more than once, they were excluded from the dataset.

At the end of the questionnaire, participants answered two questions:

- So far you've seen photos that included self-driving cars. This was noticeable by their appearance. Did you notice the self-driving cars? (Yes/No)
- Which of the above options would you prefer to see when encountering a self-driving car? (Two photos were shown as an example of the available options, and they had to select one of two answers: "Photo 1: a sticker on side and hood of the car" or "Photo 2: a name plate on the roof").

After this, participants completed three brief questionnaires assessing their sensation seeking, trust in machines, and trust in self-driving technology. To assess the sensation seeking, the Brief

Sensation Seeking Scale (BSS-8) questionnaire was used [34]. Respondents had to indicate their agreement level with statements such as “I would like to explore strange places” or “I like wild parties”. A five-point Likert scale was used ranging from “strongly disagree” to “strongly agree”.

The trust in machines questionnaire was adapted from [35] as explained by [2]. Using a five-point Likert scale ranging from “strongly agree” to “strongly disagree”, participants showed their level of agreement with the following four statements (1) “I usually trust machines until there is a reason not to”, (2) “For the most part, I distrust machines”, (3) “In general, I would rely on a machine to assist me”, and (4) “My tendency to trust machines is high”. The trust-in-machines score was calculated as the mean of these four items, with the scoring for the second item reversed.

The trust in self-driving technology was adapted from [36]. Respondents indicated their level of agreement on a five-point scale from “strongly disagree” to “strongly agree” for six statements: (1) “Generally speaking, I have trust in self-driving cars”, (2) “I trust the self-driving car to overtake in a safe way”, (3) “I trust the self-driving car to avoid obstacles in a safe way”, (4) “I trust the self-driving car to maintain a safe distance to the vehicle ahead”, (5) I trust the self-driving car to keep the same lane”, and (6) “I trust the self-driving car to react safely to cyclists”. The trust in self-driving technology score was calculated as the mean of these six items.

At the end of the questionnaire, participants were thanked and were shown a debriefing text, which explained that participants had been provided with a positive or negative explanation of the capabilities of self-driving vehicles.

2.5 Configuration of CrowdFlower

Participation in the questionnaire was intentionally restricted to 15 countries where cycling is an important mode of transport (Table S1). It was not allowed to answer the questionnaire more than once from the same CrowdFlower worker ID. The respondents of the questionnaire received a compensation of $0.25. The total cost of the questionnaire was $210. The study was approved by TU Delft Human Research Ethics Committee (nr. 216) and by the Ethical Committee Research SWOV (nr. S17.05).

2.6 Data analysis

Only the results for the photos P1, P2, and P3 were taken into account because these three photos are similar (Figure 1). P4 was a different scenario in which the cyclist did not have right of way, and for which there turned out to be visibility problems (i.e., the sign with the message ‘self-driving’ was not clearly readable). Data analyses were performed on the mean scores of P1–P3.

To analyse the effects of sign type, information, and country group, repeated measures ANOVAs were conducted. These parametric tests were performed because the average of three photos was taken and because there were no evident floor or ceiling effects on the data. Pairwise comparisons were performed using a Bonferroni correction, which implies that the *p* values were multiplied by 3, as there were three possible pairs of conditions.

Pearson correlation coefficients were used to examine the associations between the different variables. In the case of binary data (e.g., gender), the Pearson correlation coefficient is equivalent to the point-biserial correlation coefficient.

3 RESULTS

Data were filtered before obtaining the final data set. Four respondents indicated that they were younger than 18 years, 1 reported 'no' to a question about whether the instructions were read and understood, 20 had the same IP address, 45 had an IP that could not be linked between CrowdFlower and SurveyMonkey, and 35 failed more than 1 of the 13 test questions concerning the colour of the vehicle. The final data set consisted of 607 respondents.

The expected questionnaire duration was 10 minutes. Participants' median completion time of the SurveyMonkey questionnaire was 10 minutes (10th percentile = 6 minutes, 90th percentile = 21 minutes).

Table 1 shows the means and standard deviations for Questions 1, 2, and 3 per vehicle type, type of information about self-driving vehicles, and country group. The three country groups were selected based on differences in the road environment and cycling culture between European countries, North American countries, and left-hand driving countries.

Table 1. Means and standard deviations (SD) for Questions 1, 2, and 3 per vehicle type, type of information about self-driving vehicles, and country group for P1–P3.

	Vehicle type	AV with roof plate		AV with door sign		Traditional vehicle	
	Condition	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Question 1 How sure are you that the car has noticed you? *[1 = Unsure, 10 = Sure]*	Overall	4.90	2.66	4.97	2.68	4.75	2.55
	Information 1: negative (n = 216)	4.58	2.66	4.72	2.71	4.88	2.69
	Information 2: neutral (n = 184)	5.13	2.54	5.19	2.59	4.73	2.53
	Information 3: positive (n = 207)	5.03	2.74	5.03	2.72	4.65	2.42
	Country group 1: Europe (n = 230)	5.29	2.55	5.43	2.59	5.06	2.39
	Country group 2: left-hand driving countries (UK + AUS) (n = 85)	4.74	2.70	4.82	2.72	4.46	2.59
	Country group 3: USA + CAN (n = 292)	4.64	2.70	4.65	2.70	4.60	2.64
Question 2 How sure are you that the car will stop if you continue cycling? *[1 = Unsure, 10 = Sure]*	Overall	4.50	2.52	4.48	2.52	4.24	2.33
	Information 1: negative (n = 216)	4.19	2.45	4.21	2.42	4.32	2.41
	Information 2: neutral (n = 184)	4.76	2.49	4.69	2.57	4.15	2.36
	Information 3: positive (n = 207)	4.60	2.60	4.58	2.57	4.23	2.24
	Country group 1: Europe (n = 230)	4.99	2.45	5.01	2.43	4.76	2.21
	Country group 2: left-hand driving countries (UK + AUS) (n = 85)	4.26	2.52	4.28	2.55	3.86	2.41

	Country group 3: USA + CAN (n = 292)	4.18	2.52	4.13	2.53	3.93	2.34
Question 3 What would you do as a cyclist in this situation? *[1 = I would get off the bike and wait until the car has passed, 5 = I would increase my cycling speed so that I can pass in front of the car]*	Overall	2.92	0.81	2.92	0.84	2.87	0.80
	Information 1: negative (n = 216)	2.89	0.78	2.85	0.79	2.87	0.76
	Information 2: neutral (n = 184)	2.92	0.85	2.97	0.91	2.85	0.85
	Information 3: positive (n = 207)	2.94	0.82	2.94	0.83	2.90	0.79
	Country group 1: Europe (n = 230)	3.14	0.79	3.13	0.83	3.13	0.78
	Country group 2: left-hand driving countries (UK + AUS) (n = 85)	2.75	0.73	2.78	0.79	2.69	0.70
	Country group 3: USA + CAN (n = 292)	2.79	0.81	2.79	0.84	2.73	0.79

3.1 Effect of Vehicle Type

A repeated measures ANOVA was conducted to analyse differences in the answers to questionnaire questions as a function of vehicle type: AV with a roof plate, AV with a door sign, and a traditional vehicle. Vehicle type was considered a within-subject factor.

The results showed significant differences in all three questions: Q1: $F(2, 1212) = 6.369$, $p = 0.002$, $\eta_p^2 = 0.010$; Q2: $F(2, 1212) = 12.969$, $p < 0.001$, $\eta_p^2 = 0.021$; Q3: $F(2, 1212) = 3.225$, $p = 0.040$, $\eta_p^2 = 0.005$.

Pairwise comparisons were carried out to assess the effect of the vehicle type. Results showed that participants were more sure to be noticed by the car when encountering an automated vehicle with the message ‘self-driving’ on the door than when encountering a traditional vehicle ($p = 0.007$), whereas there was no statistically significant difference between the traditional vehicle and the automated vehicle with the roof plate ($p = 0.105$) (Q1). Furthermore, participants were also more sure that the car would stop for them if they continued cycling when encountering an automated vehicle (either with a sign on the door [$p < 0.001$] or a roof plate [$p < 0.001$]) than when interacting with a traditional vehicle (Q2). No statistically significant differences between the three vehicle types were found for the question “What would you do as a cyclist in this situation?” (Q3).

3.2 Effect of Positive/Neutral/Negative Information of Automated Vehicles

As explained above, three types of information about automated vehicles were distributed among participants. 216 participants received the negative information, 184 the neutral information, and 207 the positive information.

A repeated-measures ANOVA was conducted to analyse interactions between vehicle type and type of information about self-driving vehicles. Vehicle type was considered a within-subject factor with three levels (AV with a roof plate, AV with a door sign, traditional vehicle) and type of information about self-driving vehicles a between-subject factor, also with three levels (negative, neutral, positive).

There were no statistically significant main between-subjects effects of information group for any of the three questions. However, the results showed significant vehicle type x information interaction effects for Questions 1–3: Q1: $F(4, 1208) = 8.701$, $p < 0.001$, $\eta_p^2 = 0.028$; Q2: $F(4, 1208) = 8.614$, $p < 0.001$, $\eta_p^2 = 0.028$; Q3: $F(4, 1208) = 2.864$, $p = 0.022$, $\eta_p^2 = 0.009$.

Figure 2 shows the mean score per vehicle type and information about self-driving vehicles for Questions 1, 2, and 3. It can be seen that, for Questions 1 and 2, for negative information group, the mean score for the traditional vehicle was *higher* (i.e., participants were surer to be noticed by the traditional car and that the traditional car would stop) than for the two automated vehicle conditions. Conversely, for the neutral and positive information groups, the mean score for the traditional vehicle was *lower* (i.e., participants were less sure to be noticed by the traditional car and that the traditional car would stop) than for the two automated vehicle conditions.

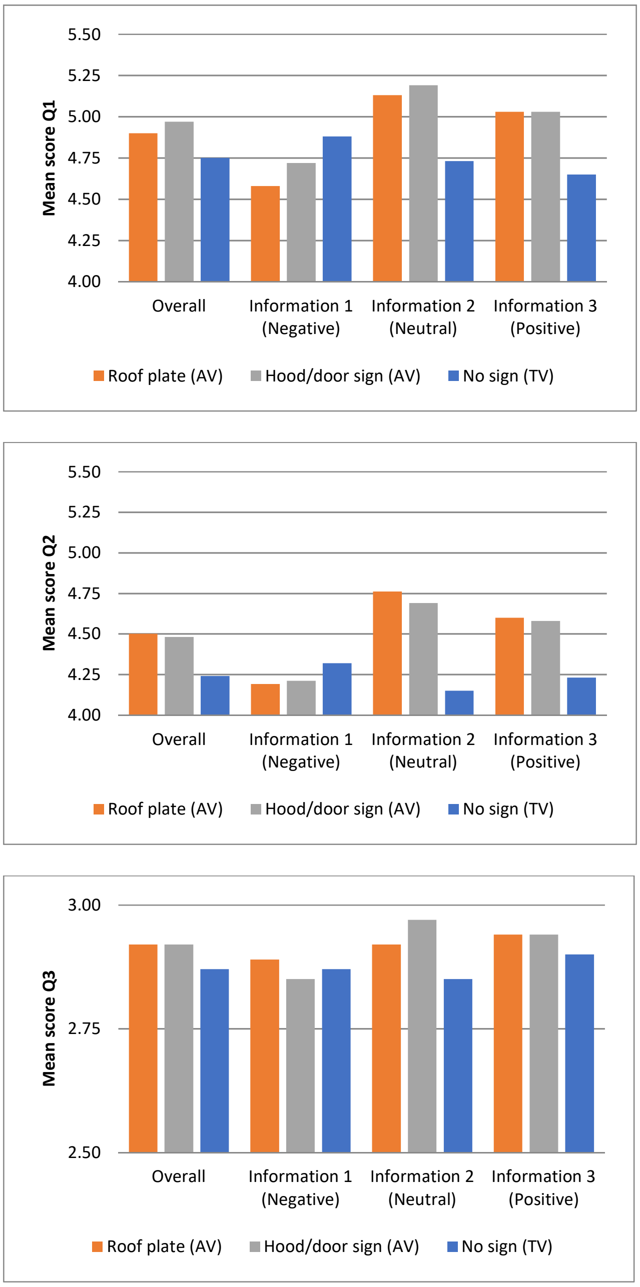

Figure 2. Mean scores for Q1, Q2, and Q3 per vehicle type and information type.

3.3 Country group

Repeated measures ANOVAs were conducted to assess the association between the participants' country (group) and their answers to the questionnaire depending on vehicle type. Because of the differences in road environments in European and American countries and in countries where vehicles drive on the left side of the road, three country groups were created: (1) European right-hand driving countries (*n* = 230), (2) left-hand driving countries (United Kingdom and Australia) (*n* = 85), and (3) Canada and the United States (*n* = 292). These groups were considered as three levels of a between-subjects factor, and vehicle type was considered a within-subject factor.

Results showed no statistically significant interactions between vehicle type and country group for the three questions: Q1: $F(4, 1208) = 1.740$, $p = 0.139$, $\eta_p^2 = 0.006$; Q2: $F(4, 1208) = 0.459$, $p = 0.766$, $\eta_p^2 = 0.002$; Q3: $F(4, 1208) = 0.736$, $p = 0.568$, $\eta_p^2 = 0.002$.

However, statistically significant main between-subjects effects of country group were observed for the three questions: Q1: $F(2,604) = 4.605$, $p = 0.010$, $\eta_p^2 = 0.015$; Q2: $F(2,604) = 9.329$, $p < 0.001$, $\eta_p^2 = 0.030$; Q3: $F(2,604) = 17.698$, $p < 0.001$, $\eta_p^2 = 0.055$.

Post-hoc tests showed that European participants were more sure to be noticed by the car (regardless of vehicle type) than participants from USA and Canada ($p = 0.011$) (Q1). Moreover, European participants were surer that the car would stop for them if they continued cycling (regardless of vehicle type) than participants from left-hand driving countries (UK and AUS) ($p = 0.021$) and participants from the USA and CAN ($p < 0.001$) (Q2). Furthermore, results showed that participants from left-hand driving countries (UK and AUS) and from the USA and CAN would be more cautious than European participants ($p < 0.001$) when encountering a vehicle (Q3).

3.4 Correlation analysis

Pearson correlation coefficients were computed to assess relationships between the variables considered in the study. The results are shown in Table 2. Negative correlations are shown in dark grey and positive correlations in light grey.

Table 2. Pearson correlation matrix among study variables

		Mean	1	2	3	4	5	6	7	8	9	10	11	12
1	Gender (1=female, 2=male)	1.47												
2	Age	38.77	-.119											
3	Cycling frequency (1=never, 5=5-7 days a week)	2.88	.229	-.081										
4	Own bike (1=no, 2=yes)	1.85	.139	-.047	.560									
5	Q1: Mean of P1-P3 (1=unsure, 10=sure)	4.87	.077	-.101	.117	.090								
6	Q2: Mean of P1-P3 (1=unsure, 10=sure)	4.41	.075	-.149	.134	.093	.856							
7	Q3: Mean of P1-P3 (1=get off bike, 5=increase speed)	2.90	.065	-.139	.121	.101	.475	.556						
8	Trust AV (1=strongly disagree, 5=strongly agree)	3.21	.180	-.173	.116	.060	.343	.427	.261					
9	Trust machines (1=strongly disagree, 5=strongly agree)	1,88	.060	-.103	.020	.012	.211	.268	.144	.567				
10	Sensation seeking (1=strongly disagree, 5=strongly agree)	2,82	.137	-.324	.235	.162	.157	.191	.145	.256	.164			
11	Noticed AV (1=no, 2=yes)	1,88	-.044	.025	.000	.026	.111	.071	.045	-.041	.032	-.033		
12	Information about self-driving vehicles (1=negative, 2=neutral, 3=positive)	1,99	-.054	-.028	-.052	-.029	.030	.042	.031	.028	.006	-.052	.012	
13	Sign preference (1=door & hood, 2=roof)	1,79	-.030	.138	-.055	-.024	-.046	-.096	-.090	-.102	-.042	-.086	-.013	.030

Absolute correlations of magnitude 0.08 or greater are statistically significant at p<0.05; Absolute correlations of magnitude 0.11 or greater are statistically significant at p<0.01; Absolute correlations of magnitude 0.13 or greater are statistically significant at p<0.001

Small negative correlations were found between participants' age and the following variables: cycling frequency, the mean score for Q1–Q3, trust in self-driving technology, and trust in machines. In other words, younger the participant, the more often s/he cycles and the more often s/he is sure that the vehicle has noticed them and would stop for them. Younger participants also reported less cautious behaviour (i.e., increased cycling speed), and they trusted self-driving technology and machines more than older participants. Moreover, a moderate negative correlation was found between age and sensation seeking, which means that older participants showed higher sensation seeking scores than younger participants.

Males had a higher cycling frequency (moderate correlation), higher bicycle ownership, higher trust in self-driving technology, and higher sensation seeking score (small correlations) than females.

Table 3 also shows that participants with higher trust in self-driving technology or higher sensation seeking score preferred the door sign, and that participants with lower trust in self-driving technology or lower sensation seeking had a preference for the roof sign. These correlations, however, were small.

Answers to the three questionnaire questions (Q1, Q2, Q3) were positively correlated with cycling frequency and bicycle ownership. That is, participants who cycled more often and participants who owned a bicycle reported to be surer that they were noticed (Q1), to be surer that the car would stop for them (Q2), and to choose higher cycling speed (Q3). Moreover, there was a positive correlation between the answers to the three questions and trust in self-driving technology, trust in machines, and sensation seeking. In other words, participants who reported higher trust in self-driving technology, a higher trust in machines, or a higher sensation seeking answered the questions with a higher score, showing more confidence in AVs.

Sensation seeking correlated positively with trust in self-driving technology and trust in machines. Furthermore, a strong correlation between trust in self-driving technology and trust in machines was found.

4 DISCUSSION

This study built on a previous small-scale photo-based study conducted by Hagenzieker et al. [2] in the Netherlands, with the aim to assess self-reported behaviour of cyclists when encountering an automated vehicle and a traditional vehicle. The automated vehicles were recognisable by the message 'self-driving' on a door sign or a roof plate. An international online questionnaire was administered among 607 participants from 15 countries. Interaction situations were presented to the respondents in the form of photos taken from the perspective of the cyclist.

Results showed that the respondents reported being more sure to be noticed by a car when encountering an automated vehicle with the message 'self-driving' on the door than when encountering a traditional vehicle. This finding can be explained by the fact that, in the photos analysed (P1–P3), the cyclist was located in the blind spot (from the car driver's perspective). Participants may have assumed that automated vehicles have less difficulty to detect them than human drivers because automated vehicles are equipped with sensors and cameras. Results also showed that participants were more sure that the car would stop for them if they continued cycling when encountering an automated vehicle (either with a door sign or with a roof sign) than when encountering a traditional vehicle. The effects, although statistically significant, were small.

Three different types of information were provided, which differed regarding their explanation of the characteristics of an automated vehicle and phrased in a negative, neutral, or positive way. The results showed statistically significant interactions with the type of vehicle. More specifically, negative information led to relatively low sureness scores for the automated vehicles. In contrast, neutral and positive information led to relatively *high* sureness scores for the automated vehicle in Questions 1 (car would notice the participant/cyclist) and 2 (car would stop). These results may have relevance to media companies and public information programmes, as we showed that the type of information given to cyclists regarding self-driving technology affects cyclists' feelings of certainty and reported behaviour.

During the data analysis, respondents were classified into three different groups depending on their country: 1) European right-hand-driving countries, 2) Left-hand driving countries (UK and AUS), 3) Canada and the United States. There were no significant interactions between the vehicle type and the country group in the answers to the questionnaire, indicating that participants from different country groups appraised automated versus traditional vehicles in a similar manner. However, there were differences between the mean scores of the country groups (i.e., regardless of vehicle type). More specifically, in comparison with the two other country groups, European participants were more sure to be noticed by the car, more sure that the car would stop for them, and reported less cautious behaviour. Cycling frequency and bicycle ownership were higher among European respondents. This could be one of the reasons for the differences in reported behaviour: Because Europeans cycle more often than respondents from the other two groups, they might be more confident and more inclined to take risks. Another reason could be that the photos were taken in a European country, so European respondents may be more confident with the road environment and more confident that drivers would take cyclists into account as compared to participants from countries with other types of drivers.

The majority of respondents reported preferring the sign on the roof of the vehicle, which may be because the roof sign is more clearly visible than the door sign. Respondents with higher levels of trust in self-driving technology or higher sensation seeking were more likely to prefer the door sign. A possible explanation for this finding is that respondents with a lower sensation seeking score prefer clarity to avoid risks and uncertainty.

Respondents with higher trust in self-driving technology and with higher trust in machines tended to be more sure that the car had noticed them and would stop for them, and behaved less cautiously (e.g., 'continue cycling at the same speed'). The same pattern was found for participants with high sensation seeking scores. Participants with higher trust in self-driving technology may rely on the sensors and the technology of the vehicle to detect them and stop before hitting them, leading to less cautious behaviour. Participants with a high sensation seeking score may make riskier decisions regardless of AV capabilities. The level of sensation seeking also correlated negatively with age, meaning that older participants have a lower sensation seeking scale. This is in line with previous research [37].

The present study was based on a previous study by Hagenzieker et al. [2]. A comparison of the results of both studies is provided in the supplementary materials (Table S2). It is important to consider that there are some differences between both studies. Hagenzieker et al. [2] used ten photos, whereas the present analyses used three photos. Moreover, only Dutch participants (n = 35) participated in the study of [2], while in the present study, 18 out of 607 participants were Dutch. The information about AVs that was provided to participants and the experimental procedure (individual test with experimenter vs. online study) also slightly differed from the previous study.

It is important to mention that our study has certain limitations. Static photos were used in the questionnaire, so the kinematic cues of the vehicle and the bicycle were not available to participants. Previous studies focusing on the interaction between vulnerable road users (pedestrians) and automated vehicles have identified vehicle speed and distance to the vehicle as main factors considered when deciding to cross a road [38], [39]. Moreover, participants' answers might differ from those they would give when encountering the vehicles in real life because physical risk is not experienced via a questionnaire. Future research could focus on dynamic situations (e.g., moving animations) and experiments in real-life. Moreover, it would be interesting to test different types of scenarios, as in the current study only one situation was tested (i.e., cyclist in the blind spot, where human drivers might have difficulty seeing the pedestrian as compared to the detection capabilities of an automated vehicle). The fact that we did not have access to the thought processes of respondents is another limitation because they may have assumed that a vehicle without signs was also an automated vehicle. Finally, the fact that the photos in the questionnaire were taken in the Netherlands can be considered a limitation. Future studies can focus on traffic situations from a larger variety of countries.

5 ACKNOWLEDGMENTS

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SUPLEMENTARY MATERIALS

Table S1. Country distribution among participants

Country of respondent	*N*
Australia (AUS)	8
Austria (AUT)	8
Belgium (BEL)	8
Canada (CAN)	83
Switzerland (CHE)	2
Germany (DEU)	53
Denmark (DNK)	3
Finland (FIN)	5
France (FRA)	29
United Kingdom (GBR)	77
Italy (ITA)	95
The Netherlands (NLD)	18
Norway (NOR)	3
Sweden (SWE)	6
United States (USA)	209
Total	**607**

Instructions given to participants

About this research

The Dutch Institute for Road Safety (SWOV) aims to investigate how cyclists react in traffic situations involving cars. In this experiment you will be shown photographs of traffic situations seen from the perspective of a cyclist. The photos will contain, in no particular order, conventional cars and self-driving cars. By 'conventional cars' we mean cars that are seen on the road today. By 'self-driving cars' we mean cars that are fitted with sensors, computers, and communication systems that take over all driving tasks from the driver: once the driver inputs the desired destination, the self-driving car performs all the tasks that a driver would normally do such as steering, accelerating and braking, maintaining distance, and overtaking.

About the task

In this survey you will see 12 photos. Each photo that you will see depicts a traffic situation from the perspective of a cyclist. On the photos you will see a cross which marks where you, the cyclist, are currently located. After each photo you will be asked four questions about the traffic situation in the photo.

As soon as you have answered the questions, you can click on the 'Next' button to proceed to the next photograph. You will first see an example photograph with questions. And then the survey starts.

Different types of information regarding AVs given to participants

- Negative information:

About self-driving cars

Experts strongly question whether self-driving cars could reduce road accidents, because there have already been several serious accidents involving self-driving cars. While the idea is that 360-degree sensors in the self-driving car will be scanning its surroundings, it cannot be ensured that the car responds when necessary, for example to give priority to other road users, to stop at red traffic lights, or to give way to pedestrians crossing the road. Furthermore, while self-driving cars are programmed to follow all applicable traffic rules, it is unlikely that self-driving cars will be able to take into account the unpredictable behaviour of other road users.

- Neutral information:

About self-driving cars

Experts suggest that self-driving cars may reduce road accidents, because self-driving cars can be expected to make fewer errors and violations than human drivers. The 360-degree sensors in the self-driving car are expected to be able to scan most of its surroundings to allow the car to respond when necessary, for example to give priority to other road users, to stop at red traffic lights, or to give way to pedestrians crossing the road. Furthermore, self-driving cars are programmed to follow all applicable traffic rules and may be able to take into account the unpredictable behaviour of other road users.

- Positive information:

About self-driving cars

Experts are convinced that self-driving cars will prevent road accidents, because self-driving cars never make errors or violations, contrary to human drivers. The 360-degree sensors in the self-driving car will be constantly scanning the surroundings to ensure that the car always responds when necessary, for example to give priority to other road users, to stop at red traffic lights, or to give way to pedestrians crossing the road. Furthermore, self-driving cars are programmed to always follow all applicable traffic rules and to take into account the unpredictable behaviour of other road users in a way that far exceeds the capabilities of human drivers.

Table S2. Comparison between results of Hagenzieker et al. [2] and results from the present study

	Study by Hagenzieker et al. [2] (*N* = 35 of which 17 women and 18 mean, Mean age = 29.2 years)	Present study (*N* = 607 of which 319 women and 288 men, Mean age = 38.8 years)
Statistically significant effects of vehicle type for Q1, Q2, and Q3	- **No**	- **Only for Q1 and Q2:** - Q1: Higher scores when encountering AVs with a door sign compared to when encountering a traditional vehicle. - Q2: Higher scores when encountering AVs with a door sign compared to when encountering a traditional vehicle.
Statistically significant effects of type of information about self-driving vehicles for Q1, Q2, and Q3	- **Only for Q1:** - Positive information about AVs received: Higher scores when encountering AVs compared to when encountering a traditional vehicle. - Neutral information about AVs received: higher scores when encountering a traditional vehicle compared to when encountering an AV.	- **For Q1–Q3:** - Q1: Positive and neutral information about AVs received: Higher scores when encountering AVs compared to when encountering a traditional vehicle. - Q2: Positive and neutral information about AVS received: Higher scores when encountering AVs compared to when encountering a traditional vehicle.
Correlation between trust in self-driving technology and trust in machines	- $r = 0.41$	- $r = 0.57$
Statistically significant differences on sensation seeking score regarding different personal characteristics (e.g. age, gender)	- No (no significant correlation between sensation seeking and age [$r = 0.32$] or gender [$r = -0.09$])	- Yes (e.g. correlations between sensation seeking and age [$r = -0.32$] / gender [$r = 0.14$])
Preferred sign	- Roof sign (57%)	- Roof sign (79%)