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Cyclists' Acceptability of Connected Automated Vehicles

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Abstract

The technology of Connected Automated Vehicles (CAVs) has been developing rapidly over the last few decades and will transform the traffic environment by decreasing the number of traffic accidents, leading to less congestion, and saving fuel, amongst other things. To shift to CAVs, public acceptability is needed. Most research on acceptability of CAVs has been focused on potential users, while little research has been focused on other road users. In this study the effect of perceived environmental sustainability (PES) on cyclists' acceptability of CAVs and the moderating role of biospheric values were investigated. Increasing PES was expected to increase cyclists' acceptability of CAVs, and this effect was expected to be stronger when participants' biospheric values were stronger. Additionally, the study investigated whether perceived safety and trust in CAV technology increased when PES was increased. Data was collected using an online questionnaire filled in by students participating in a psychology course at the University of Groningen. Participants were shown pictures of CAVs in which PES was manipulated through changing the CAV's appearance by adding a sustainability logo, which was tested in a pilot test. Acceptability, perceived safety, and trust in CAVs were measured as dependent variables. Results indicated that PES did not have a significant effect on acceptability, even when considering biospheric values. PES did increase trust in CAVs, but not perceived safety. The results showed adding a sustainability logo was not enough to increase cyclists' acceptability, potentially because cyclists did not identify with the CAVs and interacted with them briefly.

Keywords: Connected autonomous vehicles, acceptability, perceived environmental sustainability, cyclists, perceived safety, trust in CAV technology

Cyclists' Acceptability of Connected Automated Vehicles

A world where Connected Automated Vehicles (CAVs), i.e., self-driving cars, are a daily mode of transport for people all over the world is nearby. Almost as early as the automotive industry emerged, the idea of autonomous vehicles existed (Schwarz et al., 2013). Successful demonstrations of autonomous vehicles in the 1980s increased government funding of research on the subject. Then, in the 1990s, the development of computing hardware led to an increased interest in autonomous vehicles (Kanade et al., 1986; Schwarz et al., 2013). Over the last few decades, the technology of autonomous vehicles has been developing rapidly. In 2010, after Google announced to be experimenting with CAVs, the idea of self-driving cars reached the general public as well (Sperling & Brown, 2018). The introduction of CAVs will transform the traffic environment because they partly or completely eliminate the participation of a human driver (Umar Zakir Abdul & Al-Turjman, 2021). The driver will assume the role of a passenger, and this will change the interaction from drivers and other road users to computer systems and other road users (Rouchitsas & Alm, 2019). Currently, five levels of automation are defined, level 1; driver assistance to level 5; full automation (Dirsehan & Can, 2020). Most current vehicles are equipped with technologies such as cruise control and automatic braking technology, which refers to level 1 and 2 automations (Sperling & Brown, 2018). Currently, the automotive industry has been implementing projects to test level 4 automation, which refers full automation on limited routes (Ahmed et al., 2022). The term 'connected' refers to the need for interaction between CAVs in order to enhance the driver experience, enable vehicle platooning and to intervene in emergencies (Umar Zakir Abdul & Al-Turjman, 2021).

Impacts and potential benefits of autonomous vehicles

Studying CAVs and their impact on the traffic environment is important. The implementation of connected automated vehicles on the road could lead to many positive changes in the environment (Hanappe et al., 2018; Schwarz et al., 2013; Wintersberger et al., 2019). A large proportion of accidents are a result of human error. According to Dirsehan and Can (2020) a driver's lack of attention is responsible for 94% of collisions. CAV technology can reduce the number of traffic accidents significantly. The implementation of CAVs will also lead to less congestion and more fuel savings because of shorter gaps between vehicles, higher and constant speeds, and smart-parking decisions. Furthermore, CAVs provide more personal freedom for older adults or adults with disabilities not able to drive or not comfortable driving. Additionally, the implementation can have a positive effect on land use,

because it can lead to a shift from private ownership to a shared ownership, which reduces the number of vehicles needed and the number of parking areas.

Acceptability of CAVs

To shift to CAVs, not only technological changes are needed, but societal changes as well. CAVs need to be adopted by society in order to achieve their potential (Dirsehan & Can, 2020). Sperling and Brown (2018) suggest autonomous vehicles could be dominating the road in one to three decades, but that this might be longer if public acceptability is lacking. Most research on the public's perception of CAVs has been focused on the acceptability of potential users, while little research has been focused on acceptability from the perspective of other road users (Hulse et al., 2018). In the Netherlands, the mode of transport most used after driving cars is cycling. People use their bicycle more than one fifth of the time they spend travelling (Statistics Netherlands, 2016). The interaction between cyclists and CAVs will be different from interactions with drivers of traditional cars. Cyclists partly depend on non-verbal communication with a driver. However, with CAVs this is impossible (Deb et al., 2018; Post et al., 2020). Research by Post et al. (2020) showed cycling frequency was related to lower perceived safety of CAVs and lower trust in CAV technology, indicating that cyclists' perceptions of CAVs differs from potential drivers. This study will on the acceptability of CAVs from the perspective of cyclists to fill gaps in our knowledge of the public's perception of CAVs. The term acceptability can have multiple meanings and is sometimes used interchangeably with acceptance in the literature. In the present study, acceptability of CAVs is defined as the prospective judgement of CAVs before experiencing CAVs in real-life (Post et al., 2019; Schade & Schlag, 2003).

Determinants of acceptability of CAVs

Research by Post et al. (2020) on the determinants of public acceptability of CAVs, shows acceptability was mainly predicted by perceived safety, perceived convenience, and perceived environmental sustainability (PES). Greater PES was related to greater acceptability of CAVs in potential users. People are motivated to adopt sustainable innovations because of their environmental attributes, even when controlling for symbolic and instrumental attributes (Noppers et al., 2014). The focus of the present study will be the influence of PES on acceptability. Even though cyclists do not experience direct benefits by green consumption of potential users, they might still be influenced by environmental attributes.

When investigating the potential influences of PES on cyclists' acceptability of CAVs, it may be useful to look at the role of values. Values are desirable goals that guide the

evaluation of behaviours and events (Schwartz, 1992). People have many values, which influence behaviour based on which value is considered relatively the most important. Biospheric values are values specifically related to protecting the environment and preventing pollution (de Groot & Steg, 2007). Post et al. (2020) found biospheric values moderated the effect of PES on acceptability of CAVs when the CAV is perceived to be environmentally sustainable. The present research takes biospheric into account as well, by investigating whether as cyclists' biospheric values are stronger, the positive effect of PES on acceptability strengthens.

In the present study we also investigated whether PES might trigger a halo effect, the tendency of not being able to evaluate separate aspects of an entity without being influenced by other aspects of an entity (Thorndike, 1920). In other words, a positive evaluation of one aspect, such as a greater PES, can unconsciously lead to more positive evaluations of other aspects, such as perceived safety and trustworthiness of CAVs (Nisbett & Wilson, 1977; Thorndike, 1920). Safety was found to have the highest priority of benefits people would like CAVs to deliver in a study by Lustgarten and Le Vine (2017). In a survey conducted in Texas a lack of trust in CAV technology was mentioned most frequently and safety concerns as second most frequently as a reason not to drive CAVs (Sener et al., 2019). The present study examines whether a more positive evaluation of CAV's environmental sustainability is related to greater perceived safety and greater trust in CAV technology, indicating a halo effect.

The present research investigates the effect of PES on acceptability, the moderating role of biospheric values, and whether PES increases perceived safety and greater trust in CAV technology. When interacting with CAVs, cyclists will most likely not be aware of the specifications of the CAV like a driver would be, as cyclists only perceive the appearance of the car. Research on traditional cars found that a car's appearance can elicit stereotypes, evoking beliefs about the characteristics of the car (Davies, 2009).

Based on the literature presented here, cyclists are expected to be more accepting of CAVs if they perceive them as more environmentally sustainable. In the present study it is hypothesised that acceptability of cyclists will be positively correlated to PES. In other words, we expect cyclists' acceptability of CAV will be higher when PES is higher (H1). Furthermore, it is hypothesised that the effect of PES on acceptability is stronger for people with strong biospheric values (H2). Lastly, greater PES is expected to trigger a halo effect, leading to greater perceived safety (H3a) and greater trust in CAV technology (H3b).

The next section describes the methodology used to test the hypotheses, in which the methods used to measure the variables will be described and the data collection and analysis will be explained. The following section contains the results of the study. In the last section the results and their relevance will be evaluated, and the future implications will be discussed.

Method

Participants

A power analysis was used to determine that the minimum number of participants needed to achieve a power of $\beta = .8$, with $\alpha = .05$ was 114. In total, 127 students from the University of Groningen participated in this study. The online recruitment system SONA was used, which allows students to sign up for studies as part of their psychology course work and receive course credits for participating. The study was conducted as an online survey using the online survey software Qualtrics. Twelve participants were excluded before analysing the data. Ten participants did not complete the survey and two participants were removed because they reported answering the questions from the perspective of a pedestrian instead of a cyclist. The final data set included 79 women (68.7%), 33 men (28.7%), 1 non-binary/third gender (0.9%) and 2 participants (1.7%) who preferred not to report their gender. The ages of participants ran up from 18 to 28 years ($M = 20.3$, $SD = 1.9$). The research was approved by the Ethics Committee of Psychology of Groningen.

Procedure

Participants first received information about the content and duration of the study and were asked to give informed consent. In the first part of the survey, participants were asked to answer questions measuring biospheric, egoistic, hedonic, and altruistic values. Next, descriptions of a traditional car and a CAV were given, after which they were presented with images of traffic situations in random order. Each image represented one of the four conditions: a traditional car with sustainability logo, a traditional car without logo, a CAV with sustainability logo and a CAV without logo. Each image was accompanied by a short description of the scenario, e.g., “You are riding your bike and you see a connected automated vehicle (self-driving car)/traditional car coming from the right. Please look at the picture and answer the following questions.” After each image participants completed a questionnaire measuring PES, acceptability, perceived safety, and trust in CAV technology (Post et al., 2020). During the last part of the survey participants were asked whether they answered the questions from the point of view of a cyclist, how many times they ride a bike on average, whether they have a valid driver’s licence, gender, age, and country of residence. Comments could be left at the end of the survey.

Manipulation

To determine if CAVs that are seen as more sustainable are also rated more positively on acceptability among cyclists, PES was manipulated. PES was increased by changing the car's appearance by adding a sustainability logo on the side of the car. Several logo designs intended to increase PES were tested in a pilot study (N = 46) to test the effectiveness of the manipulations. The results showed that all the designs were effective in significantly increasing PES. The design with the largest effect was used in the main study. Please see the Appendix for the images used in the survey.

Measures

Values

Biospheric, egoistic, hedonic, and altruistic values were measured by asking participants to rate how important they rated a list of values as guiding principles in life (Steg et al., 2012). In this research we focused only on biospheric values. The guiding principles of biospheric values were: "respecting the earth", "unity with nature", "protecting the environment" and "preventing pollution". A short explanation was provided with each value, e.g., "protecting the environment: preserving nature". Four items were used to measure biospheric values on a 9-point Likert-scale from -1 (the value is opposed to the principles that guide you) to 7 (value is of supreme importance as a guiding principle in your life). Internal reliability of the scale was high (α = .920).

Perceived environmental sustainability

To assess PES, participants were asked to indicate the extent to which they agreed or disagreed with two statements on a 7-point Likert-scale from 1 (completely disagree) to 7 (completely agree). The statements used were: "I think this car is environmentally friendly", "I think this car reduces carbon emissions and pollution caused by car traffic" and "I think this car emits few particulates and greenhouse gases". Internal reliability of the scale was high in the condition with logo (α = .932) and without logo (α = .909).

Acceptability

Acceptability was assessed by the extent to which participants agreed or disagreed with three statements on a 7-point Likert-scale from 1 (completely disagree) to 7 (completely agree). These statements were: "I would cross the road in front of this car", "I would have no concerns cycling as usual if this car would be on the road", and "The prospect of interacting with this car as a cyclist appeals to me." However, after inspecting the data, an issue appeared with the first statement leading to the decision to delete this item. Comments revealed that the question "I would cross the road in front of this car" could be interpreted as questioning

which road user had priority to cross the road instead of measuring acceptability. Internal reliability of the scale including this statement was low in both the condition with logo (α = .658) and without logo (α = .614). After deleting the first statement internal reliability was increased in both the condition with logo (α = .808) and the condition without logo (α = .736).

Perceived safety

To assess perceived safety, participants were asked to indicate the extent to which they agreed or disagreed with three statements on a 7-point Likert-scale from 1 (completely disagree) to 7 (completely agree). The statements were: “I think this car is safe”, “I think this car poses minimal risk to its driver and passengers” and “I think this car poses minimal risk to other road users”. Internal reliability of the scale was high in the condition with logo (α = .902) and without logo (α = .928).

Trust in CAVs

Lastly, in the CAV condition, trust in CAVs was measured by asking participants to indicate the extent to which they agreed or disagreed with three statements on a 7-point Likert-scale from 1 (completely disagree) to 7 (completely agree). The statements were: “I trust this car to behave as intended”, “I trust that this car correctly detects other road users” and “I trust the computer systems of this car cannot get hacked”. Internal reliability of the scale in the condition with logo (α = .797) and without logo (α = .817) were both moderately high.

Statistical analyses

Paired samples t-tests were used to test the difference between the scores in the condition with logo and the condition without logo of PES, acceptability, perceived safety of CAVs and trust in CAVs. To examine whether there was an interaction between the with and without logo conditions and biospheric values, a linear regression was used. We used an alpha level of .05 for all statistical tests and analysed the data using SPSS version 27.0.

Results

Manipulation of PES

A paired samples t-test comparing acceptability in the condition with logo (high PES) and without logo (low PES) was used to test whether the manipulation of PES was effective. Results revealed a significant difference between the condition of a CAV with logo (M = 4.82, SD = 1.34) and the condition without logo (M = 4.28, SD = 1.40); $t(114) = 4.18$, $p <$ .001 The results suggest that PES was effectively manipulated. Cyclists perceived CAVs as more sustainable when a sustainability logo was added to the vehicle.

Acceptability

Hypothesis 1: A higher level of PES increases acceptability of CAVs from the perspective of cyclists.

A paired samples t-test was conducted to compare the effect of a CAV without a logo and a CAV with a logo on cyclists' acceptability. No significant difference was found between the scores of acceptability of CAVs with logo (M = 4.23, SD = 1.54) and without a logo (M = 4.08, SD = 1.48); $t(114) = 1.76$, $p = .081$. These results suggest that a sustainability logo does not increase acceptability of CAVs of cyclists, rejecting the hypothesis.

Biospheric values

Hypothesis 2: The effect of PES on acceptability of CAVs is stronger for cyclists with high biospheric values.

An interaction analysis using linear regression was used to detect an interaction effect with acceptability as dependent variable and logo and biospheric values as predictor variables. The centered scores of biospheric values were used. Results showed no significant interaction effect ($F(3,226 = .78$, $p = .506$) with an R^2 of .01. Contrary to the hypothesis, biospheric values did not increase the effect of the effect of PES in de condition with and without logo on cyclists' acceptability.

Table 1

Interaction analysis: acceptability, logo and biospheric values

Effect	Estimate	*SE*	95% CI		*p*
			LL	*UL*	
Intercept	4.226	.141	3.948	4.504	< .001
Logo	-.144	.200	-.537	.249	.472
Biospheric (centered)	-.008	.092	-.189	.173	.933
Interaction	-.116	.130	-.372	.140	.373

Note. Dependent Variable: acceptability. A CAV without logo is used as the reference category.

Perceived safety

Hypothesis 3a: A higher level of PES triggers a halo effect, increasing cyclists' perceived safety of CAVs.

A paired samples t-test was conducted to compare cyclists' perceived safety of CAVs in the condition with logo and without logo. There was no significant difference between

perceived safety of CAVs in the condition with logo (M = 4.62, SD = 1.29) and without logo (M = 4.49, SD = 1.39); t(114) = 1.74, p = .085. Contrary to the hypothesis, perceived safety did not differ significantly between the conditions.

Trust in CAV technology

Hypothesis 3b: A higher level of PES triggers a halo effect, increasing cyclists' trust in CAV technology.

A paired samples t-test was conducted to compare cyclists' trust in CAV technology of CAVs with logo and without logo. The results revealed a significant, but small difference between trust in CAV technology with logo (M = 4.28, SD = 1.34) and without logo (M = 4.14, SD = 1.32); t(114) = 2.07, p = .041, d = .193. Consistent with the hypothesis, participants reported more trust in CAV technology when presented with a CAV with a logo than when presented without a logo.

Discussion

The purpose of this study was to investigate the influence of PES on cyclists' acceptability of CAVs, the moderating role of biospheric values and how perceived safety and greater trust in CAV technology are related to PES. Contrary to expectations, PES did not seem to influence acceptability. The results suggest PES does not increase cyclists' acceptability and that biospheric values do not moderate the relationship between PES and cyclists' acceptability. The results demonstrate no correlation between PES and perceived safety for cyclists. The data do suggest a positive relationship between PES and trust in CAV technology.

Acceptability and biospheric values

To investigate whether PES influences cyclists' acceptability, cyclists' acceptability of CAVs with logo and CAVs without logo was compared. In line with research by Davies (2009), a car's appearance can elicit beliefs about the characteristics of the car, the results of the present study revealed that a sustainability logo significantly increased PES. Contrary to our expectations, the results did not support the hypothesis that higher PES subsequently increases cyclists' acceptability of CAVs. Cyclists rated CAVs with a sustainability logo as slightly more acceptable than without a sustainability logo, but this difference was not significant. These findings do not correspond with previous literature indicating PES predicted acceptability in potential users (Post et al., 2020) and with research on electric cars demonstrating environmental attributes increased interest in sustainable innovations (Noppers et al., 2014).

The results also did not show a significant effect of PES on acceptability when taking biospheric values into account. Having stronger biospheric values was predicted to enhance the effect of PES on acceptability. Even though this did apply to potential users (Post et al., 2020), the results of this study did not show the same effect for cyclists.

To date, acceptability of CAVs from the perspective of other road users, and specifically cyclists, has received little attention. These results reveal new insights into acceptability of CAVs from a cyclist's point of view. Cyclists rate CAVs not as more acceptable when they perceive the vehicle as more sustainable. Cyclist and potential users may thus differ in what they care about regarding aspects of CAVs.

Status signal

These findings might be explained by the influence of sustainable innovations on self-identity. Noppers et al. (2014) suggest people are more likely to be interested in sustainable innovation because of positive symbolic attributes. These symbolic attributes represent features of a product that can positively reflect one's identity to oneself and others when using the product. Symbolic attributes were important predictors of adoption of electric cars and of interest in local sustainable energy. According to Noppers et al. (2014) the more people expect adopting an innovation will enhance a positive self-identity and their social status, the more likely they are to adopt the innovations. This could explain why PES does increase acceptability of potential users, because CAVs have the potential to signal their environment conscious identity or status to others and themselves. Additionally, this might explain why PES does not increase cyclists' acceptability. While driving a CAV might signal something about the driver, this might not be the case for cyclists who briefly interact with CAVs and whose self-identity and social status are not changed.

Perceived safety and trust in CAV technology

Next, the present study investigated whether higher PES was related to greater perceived safety and greater trust in CAV technology. It was predicted that a positive evaluation of a CAV's sustainability would trigger a halo effect, which would lead to more positive evaluations of perceived safety and trust in CAV technology (Nisbett & Wilson, 1977). This prediction was not supported for perceived safety. Cyclists did not perceive CAVs as safer when they perceived CAVs as more sustainable. On the other hand, PES did have a small effect on cyclists' trust in CAV technology. They had greater trust in the vehicle when the CAV was perceived as more sustainable, indicating a halo-effect was triggered. The results imply that changing the appearance of a CAV by adding a sustainability logo may benefit cyclists' trust in CAV technology but not their perceived safety.

According to Chernev and Blair (2021) perceived sustainability of a product is likely to produce a halo effect when consumers perceive the product's company as a moral agent and when moral concerns are salient in the consumer's mind. Associating the product's company with sustainability rather than the product itself strengthens the halo effect. In the present study no information was provided about any organisations or companies associated with the CAV or the logo. Additionally, cyclist exposure to cars may be too short to be aware of the specifications or the brand of the car. Longer exposure or deeper processing may be needed for the halo effect to occur and might explain why PES did not increase perceived safety.

Limitations

Certain limitations should be taken into consideration when evaluating the results of the study. An alternative explanation why PES did not significantly increase acceptability and perceived safety could be that the manipulation of PES was not sufficient. Although PES was significantly higher in the condition with the logo, the difference between the scores was only 0.5 point on a 7-point scale. A manipulation that would result in a larger difference in PES might reveal a significant result of the effect of PES on acceptability. In the present study a new sustainability logo was created which was not connected to an existing organisation. A stronger manipulation might be reached by collaborating with an organisation, such as a government department or an environmental organisation. According to focus groups in a study by Kester et al. (2019), acknowledgement of government support schemes may normalise CAVs and increase trust in CAVs.

Another limitation concerns the generalizability of the results. Firstly, participants were recruited through a first-year psychology course and their average age was 20 years. Some studies suggest there may be differences in attitudes about CAVs between age groups (Post et al., 2019). As an example, Gold et al. (2015) found older participants rated CAVs more positively and safer than younger people, while a review by Becker and Axhausen (2017) showed younger people were more open to CAVs. Moreover, the study was conducted in the Netherlands, where cycling is one of the main modes of travel (Statistics Netherlands, 2016). In countries where cycling is less common instead of developing a safe cycling infrastructure, cyclists are expected to ensure their own safety with equipment, such as helmets, to be 'respected' by other traffic. According to Zuev et al. (2021), these infrastructures and norms can make cyclists feel ignored and endangered. The results of this study might not pertain to other parts where cycling is less prevalent, because of the differences regarding cyclists' feelings of safety.

Implications

Despite these limitations, these results suggest several potential theoretical and practical implications. To implement CAVs on the road, acceptability of the public is needed. Firstly, the results indicate that increasing the perceived sustainability by adding a sustainability logo to a CAV does not increase cyclists' acceptability of CAVs. While PES may influence potential users because it can signal status and identity, this study suggests this does not apply to cyclists. This also underlines the importance of not only studying potential users, but to also focus on other road users when investigating acceptability of CAVs.

PES does have a positive effect on trust in CAV technology. Participants reported more trust in CAV technology when they were presented as sustainable with a sustainability logo. For future research, it would be interesting to examine whether PES increases acceptability and perceived safety when the CAV's company is presented as a moral agent. For example, by adding a sustainability logo with a message representing the moral goals of the company, or by using advertisements to portray the company as a moral agent.

The present research enhances the understanding of cyclists' acceptability of CAVs. Although further research is needed to draw conclusions, the results indicate that presenting a CAV as sustainable by adding a sustainability logo does not increase cyclists' acceptability and perceived safety, but does increase trust in CAV technology.

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Appendix

Image used in survey of CAV with sustainability logo

Image used in survey of CAV without sustainability logo

Image used in survey of traditional car with sustainability logo

Image used in survey of traditional car without sustainability logo