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Impact of Accidents Involving Autonomous Vehicles on the Perceived Benefits and Concerns

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Abstract **-** Autonomous vehicles (AVs) or self-driving cars have the potential to offer a large number of benefits such as improving the mobility for people with limited modes of transportation and the reduction of the emissions, energy, travel time, and required fleet size to service the same population. Despite the enthusiastic speculation of AVs, little is known about the public attitude towards AVs and the factors that affect the public acceptance of this emerging technology. However, the public attitude is considered a main determinant for the success of any new technology. Over the last few years, AVs were involved in multiple accidents that attracted the media and news. While these accidents are expected to affect the public attitude and discourage people from adopting AVs, the impact of these accidents on the public attitude has been rarely discussed in the literature. Thus, this paper mainly focuses on understanding and quantifying the impact of AVs accidents on the general opinion, level of trust, level of concern in traveling in an AV, perceived benefits, and perceived concerns using an online questionnaire survey that was completed by 1987 respondents from the USA. The results show that AVs accidents negatively affected the public attitude towards AVs that the level of interest in owning an AV decreased by 25%. Additionally, these accidents have negatively affected the level of trust in AVs that most of the respondents will not allow their kids to travel in an AV by themselves.

Keywords**:** autonomous vehicles, accidents, safety, public attitude, questionnaire survey

1. Introduction

Over the last few years, automation of vehicles has attracted researchers from different disciplines starting from the vehicle-to-vehicle communication system in the 20s [1] to the invention of the first autonomous system in the 80s [2], which was a turning point for autonomous vehicles (AVs) technology as a large number of companies started competing for developing their AVs [3]. In general, the National Highway and Transportation Safety Administration has classified the automation of vehicles into 5 different levels. Level 0 refers to the case of no automation, while level 1 refers to the automation of one control feature such as the lane-keeping system. Level 2 refers to the automation of functions, while level 3 refers to partial automation as the vehicle can drive autonomously but the driver might be required to take control at any point with adequate warning, while level 4 refers to high automation as the vehicle can drive autonomously but the driver can take control of the vehicle. Finally, level 5 refers to the case of full automation as the vehicle can travel with no human control [4, 5]. Over the last few years, the market leaders have been heavily investing in their vehicle automation projects such as Google, Uber, and Apple [6]. Additionally, new startup companies are entering the market with the objective of developing AVs such as Zoox [7].

Over the last few years, AVs have been investigated with regard to their benefits, implications, technological development, and challenges. Previous studies show that AVs have the potential to improve the level of traffic safety by eliminating the human error, reducing the required fleet size to serve the same population, reducing the emissions and energy consumed, increasing coverage, and improving the accessibility for people with limited transportation [8]. On the other side, it is anticipated that AVs will increase the vehicle kilometres travelled as a result of the empty trips [9]. While the benefits, implications, and technological development have been extensively discussed in the literature, less attention has been devoted to the public acceptance of this new technology. However, it has been frequently reported in the literature that the public

attitude is one of the main barriers facing the wide spread of any emerging technology and AV technology is not an exception [10]. Additionally, it is crucial to understand the factors that influence the public attitude towards AVs. One of the main factors that is expected to influence the public attitude is the news about accidents involving AVs. One of the early studies highlighting this action is the study by Šinko et al. (2017) [11] which investigated the public attitude towards AVs by replicating Schoettle and Sivak (2014) survey [12]. The results show that while people become more familiar with AVs technology, they became more pessimistic towards AVs. Investigating the reason for this negative shift shows that the survey by Šinko et al. (2017) [11] was conducted during the first fatal accident involving an AV in 2016, which negatively affected the public opinion [8]. Additionally, the study by Othman (2021) [3] investigated the relation between the public fear of AVs and the number of fatal accidents over the years. The results show a direct relation between the two variables as the level of fear of AVs increases with the increase in the number of fatal accidents of AVs as shown in Figure 1. Thus, accidents involving AVs have a major impact on the level of fear of AVs and thus a detailed analysis of the impact of these accidents is needed. As a result, this study focuses on understanding and quantifying the impact of AVs accidents on the public attitude towards AVs. In other words, in this study, the general opinion, level of trust, and concern will be investigated before and after AVs accidents. Additionally, a detailed analysis of the impact of these accidents on the perceived benefits and concerns is conducted to understand the impact of these accidents on the different public attitude parameters.

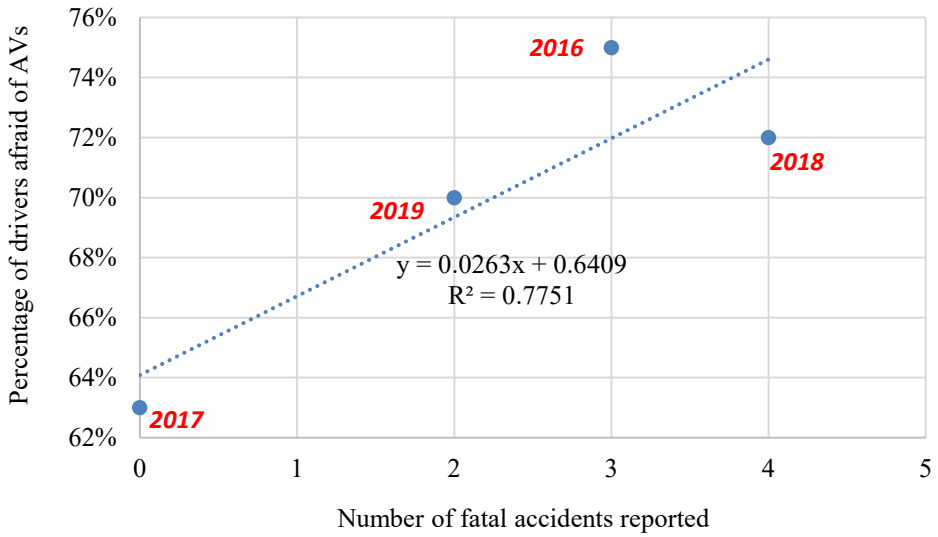

Fig. 1. The relation between the number of AVs fatal accidents and the percentage of drivers afraid of AVs [adopted from (3)]

2. Research Gap and Study Objectives

The impact of AVs accidents on the public attitude has been rarely discussed in the literature by analyzing the social media data and conducting a sentiment analysis of the public comments. For example, the study by Jefferson and McDonald (2019) [13] used Twitter data to understand the impact of the 10th of February 2019 accident that involved an AV on the public attitude by analyzing tweets before and after the accident. The sentiment analysis of the tweets discussing AVs shows a major reduction in the positive sentiment score to the half, while the negative sentiment score remained at the same level. These results show a major shift in the opinion of people with a positive attitude towards AVs moving from a positive to a neutral or a negative attitude. Secondly, the study by Penmetsa et al. (2021) [14] investigated the impact of two AVs fatal accidents, which occurred in March 2018, on the public attitude by analysing tweets. The first fatal accident occurred on the 18th of March 2018 in Arizona, USA and it involved an Uber-operated Volvo vehicle that hit and killed a pedestrian who was crossing the street [15, 16]. The second accident occurred on the 23rd of March 2018 that involved a Tesla X model that was operating on the autopilot mode when the vehicle speeded up and steered to hit the concrete barrier [17, 18]. These two accidents have attracted massive attention through multiple social media platforms such as Twitter. The study by Penmetsa et al. (2021) [14] conducted a before-and-after sentiment

analysis to understand how the public attitude changes. The analysis shows a major negative shift in the public attitude after the accidents as the negative tweets about AVs had witnessed a 32% increase jumping from 14% to 46%. Additionally, the sentiment score for AVs had decreased by 11% for self-driving. While the previous studies provide multiple insights about the impact of AVs accidents on the public attitude, these studies suffer from multiple limitations that affect the results. Firstly, the analysis of social media data can show the overall impact on the public attitude without understanding the impact of these accidents on specific concerns or on how it affects the way the public perceives AVs benefits. Secondly, social media data might not represent the general public. For example, more than one-third of Twitter users in the USA have a college degree and earn more than 75,000K$, which shows that these users are more educated and have higher incomes when compared to the average person in the USA [19]. Thus, this analysis might be biased and representative of a specific group with specific demographic characteristics. Finally, previous studies highlighted that a significant number of tweets had shared a link from a newspaper website [20], which is hard to analyse and include in the sentiment analysis.

Thus, the previous limitations necessitate the need to further research in order to understand and quantify the impact of AVs accidents on the public attitude. Thus, in this paper, a detailed analysis will be conducted in order to quantify and understand the impact of AVs accidents on the general public using a questionnaire survey. Specifically, this study focuses on understanding the impact of AVs accidents on the public opinion, level of trust, and concerns about traveling in AVs. Additionally, the analysis goes into specifics to understand which concerns are affected and by how much after the accidents. Furthermore, the analysis shows AVs accidents affect the way the people perceive AVs benefits and by how much.

3. Methodology

A questionnaire survey was designed and conducted between February 2022 to June 2022 in order to assess the public opinion, level of trust, and concern towards AVs before and after accidents. Before sending the survey to the public, a pilot survey was conducted in order to make sure that the survey is accurate, understandable, descriptive, and fair. During this pilot survey, the survey was sent to three experts working on public surveys in the USA and it was also sent to 13 of the public participants. The results show a great level of satisfaction as all the experts and general declared that they had no difficulty reading, undereating, or replying to the survey. The survey consists of four sections. Section one gives the respondents some background about the survey and AVs in general. Section two focuses on quantifying the public attitude towards AVs and in this section the respondents were asked to rank their opinion, level of trust, concern in traveling in an AV, and level of interest in owning an AV on a Likert scale from 1 to 5. Additionally, the responses were asked to rank specific benefits and concerns about AVs on a Likert scale from 1 to 5. Section three focuses on quantifying the public attitude words AVs after accidents. At the beginning of this section, nine different accidents that involved AVs with different levels of severity and showing different multifunction were introduced to the public with some visuals and written descriptions about every accident as shown in Table I. Then, the respondents were asked to rank the same questions shown in section 2 once again but now after giving them details about AVs accidents. Finally, the final section focuses on collecting demographic information about the respondents such as the age, gender, and education.

The survey was then posted and sent to the public through SurveyMonkey from February to June 2022 and a total of 1987 complete responses were received from respondents from the USA. One of the main advantages of this approach, when compared with previous studies that analyse social media data, is the ability to gain information about the demographics of the respondents to make sure that the same is representative of the general public. The demographic characteristics summarized in table II show a great level of balance between the different groups and a high level of consistency with the February 2022 United States Census Bureau report [21] that present the demographic characteristic of the general public in the USA.

4. Results

In order to quantify the impact of these accidents on the public attitude, the average values or the relative importance index (RII) were calculated for every factor tested. The RII is calculated using equation (1).

$$RII_n = \frac{\sum_{i=1}^{5} iX_i}{1987} \tag{1}$$

Where: RII_n is the relative importance index for factor n; i is the rating given to each factor (ranging from 1 to 5); X_i is the number of respondents giving rating i for factor n; and 1987 is the total number of respondents.

Table 1: summary of the accidents presented to the participants of the survey.

Accident	Description
	May, 2018- Tesla, Utah, USA, Minor injury The driver was looking at her phone when the accident occurred. The autopilot mode was on when the vehicle speeded up and hit a fire truck. The driver thought that Tesla braking system would stop the car.
	May, 2018- Tesla, California, USA, Minor injury The car crashed into a parked police car. The driver was using the auto pilot mode when the vehicle steered to hit the police car. After the accident, Tesla stated that the drivers must remain their hands on the wheel. The car speeded up before hitting the parked police car.
	March, 2018- Tesla, California, USA, Fatal accident The vehicle speed up and steered into a concrete barrier. The National Transportation Safety Board (NTSB) stated that four seconds before the collision the car stopped following the path and three seconds before the accident it sped up towards the barrier.
	Feb, 2016- Google, California, USA, Property damage only To the date of this accident, 53 Google AVs were used for almost 2.25 million Km and were involved in 17 crashes, but never been considered faulty before. Google's car collided with a bus at an intersection. The accident highlighted the imperfections in the new technology, as it was one of the early accidents.
	Feb, 2016- Volvo, Arizona, USA , Pedestrian Fatal accident Uber self-driving vehicle with an operator hit a pedestrian who was crossing the street. The pedestrian was walking outside the crosswalk with a bicycle when the collision happened.
	March, 2019- Tesla, Florida, USA Fatal accident. The car crashed into a truck when the autopilot was on. The roof of the vehicle was sheared as a result of the accident causing the death of the driver who engaged the autopilot system 10 seconds before the accident and his hands weren't on the wheels.
	July, 2016- Tesla, Florida, USA , Fatal accident. First fatal AV accident. The car's sensor system failed to distinguish a wheel truck as the car attempted to drive at full speed under the truck. The accident represented a huge setbacks in the growth of the AVs technology. Tesla share were down by almost 1% on the accident day.
	August, 2019- Tesla, Russia, Minor injury The passengers were slightly injured but the car exploded after the accident. The driver engaged the drive assistant feature (not autopilot), and his hands were on the wheel when the car steered to crash a truck in the left lane. The driver stated that he didn't see the truck he crashed
	Jan, 2016- Tesla, Handan, China, Fatal accident Tesla reported that the damage made it impossible to know whether the autopilot system was on or not, however, in 2018 Tesla confirmed that the autopilot system was on. The car was moving in the left lane before steering to ram a truck (road sweeper).

Table 2: summary of the demographics of the respondents.

Demographic characteristics		**Percentage (%)**
Gender	Male	48%
	Female	52%
Age	18-29	24%
	30-44	28%
	45-60	26%
	>60	22%
Education	High School or lower	31%
	Bachelor	46%
	Master's degree	15%
	Higher than master's degree	8%

4.1 General opinion, level of truss, and level of concern about traveling in an AV:

This section focuses on understanding the impact of AVs accidents on the general opinion, level of trust, concern in in traveling on AVs, and the level of interest in owning an AV as summarized in Figure 2. The analysis shows that the public public attitude is negatively affected by these accidents. For the general opinion towards AVs, the respondents were asked asked to rank their opinion on a scale from 1 to 5 where 5 refers to very positive and 1 refers to very negative. The results show that the average general opinion towards AVs moves from an average value of 3.25 before introducing the accidents to 2.92 after (10.12% decrease) as shown in Figure 2. For the level of trust in AVs, the respondents were asked whether to rank their level of agreement with the following question "Self-driving cars can improve the level of safety when compared to human-driven vehicles?" on a scale from 1 to 5 where 5 refers to strongly agree and 1 refers to strongly disagree. The results reveal that the average level of trust in AVs moves from 3.35 to 2.9 (13.33% decrease) as shown in Figure 2. Then, the respondents were asked to rank their level of concern about traveling in an AV on a scale from 1 to 5 where 5 refers to very concerned and 1 refers to not concerned at all. The results show that the average level of concern moves from 3.46 to 3.88 (12.18% increase) as shown in Figure 2. Finally, the respondents were asked to rank their level of interest in owning an AV on a scale from 1 to 5 where 5 refers to very interested and 1 refers to not interested at all. The results show a major impact of the accidents on the level of interest in owning an AV as the average value moved from 2.95 to 2.22 with 25% reduction in the average level of interest in owning an AV. While these results are consistent with previous studies that analysed social media data showing a reduction in the level of interest in AVs after accidents, this study provides more insights about the impact of these accidents on the level of interest, trust, and concern towards AVs.

4.2 Change in the perceived benefits

While the previous section mainly focused on understanding the general impact of AVs on the public attitude and perception of AVs, this section gets into the details and analyzes the impact of AVs accidents on the public perception of the different benefits of AVs. In this question, the respondents were asked to rank their level of agreement with some four main benefits of AVs on a scale from 1 to 5 where 5 refers to strongly agree and 1 refers to strongly disagree. While it is expected that AVs can deliver multiple benefits, this section mainly focuses on the benefits related to the accidents presented to the respondents so that these accidents can affect the public perception of these benefits. Specifically, the respondents were asked about their level of agreement with the ability of AVs in reducing the number of accidents, reducing the severity of accidents, increasing the level of comfort, and reducing the anxiety before and after introducing the accidents. The results show that these accidents had negatively affected the public perception of the different benefits as shown in Figure 3 (a). Additionally, the results show that the increase in the level of comfort is the main benefit that is affected by the accidents as the average rank value moved from 3.68 to 3.25 (11.8% reduction). These results show the impact of AVs on the level of trust in AVs but in an indirect way. This reduction shows the impact of AVs accidents on the level of trust in AVs in an indirect way. The analysis suggests that these accidents will reduce the level of trust in AVs that the public will have to keep monitoring the vehicle at all times to avoid any malfunction or wrong decision, which in turn reduces the level of comfort or does not significantly increase the level of comfort while traveling in an AV. Additionally, the results show a high level of consistency between the reduction in the level of trust and the reduction in the level of comfort after accidents as the two values declined by 13.3% and 12%, which confirms the previous relation between the level of trust and level of comfort in AVs.

For the remaining benefits, the analysis shows that the different benefits move from an average value indicating some level of agreement to a neutral or a disagreement opinion as the average values higher than 3 indicate some level of agreement, an average value of 3 indicates a neutral condition, and an average value less than 3 indicates some sort of disagreement. For the reduction in the number of accidents and the severity of crashes, the two benefits moved from agreement average values of 3.25 and 3.24 (>3) before the accidents to neutral opinions with average values of 2.97 and 3.03 (≈ 3) after the accidents. Finally, the analysis shows that the responses were neutral about the ability of AVs in reducing the anxiety before introducing the accidents with an average value of 2.97 (≈ 3); however, this value moved to the disagreement direction after introducing the accidents with an average value of 2.78 (<3).

4.3 Change in the concerns

The previous section mainly focuses on quantifying the impact of AVs accidents on the public perception of the of AVs. This section focuses on understanding the impact of AVs accidents on the public perception of the concerns to AVs. In this question, the respondents were asked to rank their level of concern about different aspects of safety-issues of AVs on a Likert scale from 1 to 5 where 5 refers to highly concerned and 1 refers to not concerned at all. While AVs can be associated with different concerns, this section focuses on studying the concerns related to the accidents presented or that might be affected by these accidents. Specifically, the respondents were asked to rank their level of concern about the vehicular or system failure, the ability of the vehicle to operate safely in all conditions, letting their child travel in an AV by themselves, financial or legal liability in case of an accident, traveling in an AV with no driver, interacting with non-self-driving cars, and interacting with pedestrians and cyclists. The respondents were asked to complete this question twice once before introducing the accident and the second one after introducing the accidents. The results show that the levels of concern increase for all the aspects after introducing the accidents as shown in Figure 3 (b). Additionally, the results show that the level of concern of the respondents regarding allowing the vehicle to travel in an AV by themselves is the main concern affected after introducing the accidents moving from an average value of 3.89 to 4.34 (11.6% increase). The previous analysis shows the impact of AVs on the level of trust in AVs but in an indirect way as the analysis suggests that these accidents will reduce the level of trust of the respondents in AVs that they will not let their kids travel alone in an AV. Moreover, the analysis shows a high level of consistency between the level of trust in AVs and the level of concern in allowing their kids to travel alone in an AV as the two values declined by 13.3% and 11.6% after introducing the accidents, which confirm the previous relation between the level of trust in AVs and the concern in letting the kids travel alone in an AV.

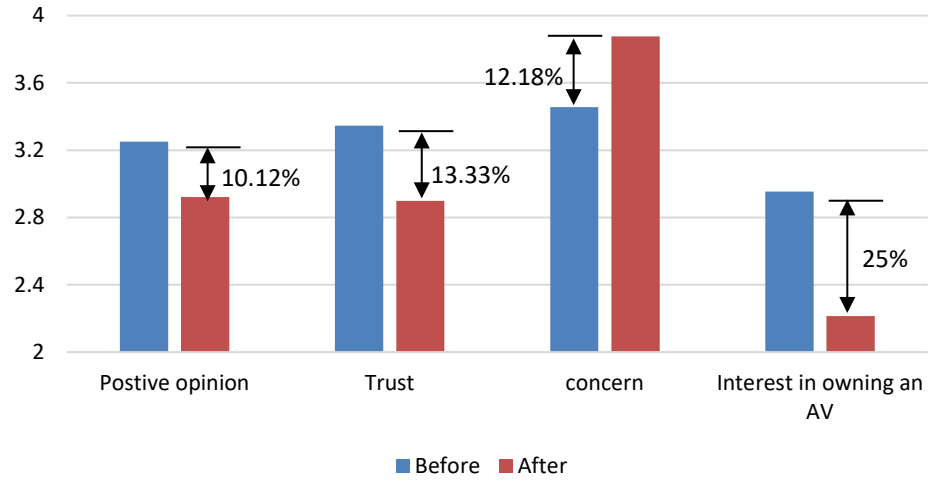

Fig 2. Change in the average attitude parameters towards AVs before and after the accidents (5 indicates very positive and 1 indicates very negative)

Before introducing the accidents. The levels of concern regarding the different aspects of AVs were already high with average values that are higher than 3 with the concern regarding allowing the kids to travel alone in an AV as the top concern followed by the ability of the vehicle to operate safely in all conditions and the financial and legal liability in the case of accidents with average values of 3.89, 3.73, and 3.71. On the other side, the levels of concern for all the aspects increased after introducing the accidents that all the average levels of concern for all the aspects studied reached a value that is around 3.9 except for allowing the kids to travel alone in an AV that witnessed a major shift in the negative direction and reached an average value of 4.34 indicating a high level of concern about this aspect as mentioned earlier.

5. Conclusion

This study focuses on understanding the impact of AVs accidents on the public attitude towards AVs. In this study, an an online questionnaire survey was conducted to understand the general opinion, level of trust, and concerns regarding traveling in an AV before and after AVs accidents. Additionally, a detailed analysis was conducted to understand the impact of these accidents on the public perception of the different benefits and concerns associated with AVs. A total of 1987 complete were collected from respondents in the USA with balanced demographic characteristics that represent the general population of the USA. This study offers multiple insights about the impact of AVs on the public perception of AVs as follows:

- While the public attitude towards AVs moves in the negative direction after introducing the accidents for all the aspects, the level of interest in owning an AV is one of the major aspects that is affected by these accidents as the average level of interest in owning an AV has witnessed a decrease of 25% moving from an average of 2.9 (neutral ≈ 3) to an average value of 2.2 indicating that the opinions of the majority of the respondents moved from the neutral state to a negative opinion about owning an AV.
- The analysis shows that the level of trust in AVs has decreased by 13% after introducing the accidents moving from an average value of 3.35 (positive attitude >3) to 2.89 (negative attitude <3).
- Similarly, the average level of concern has witnessed 12.2% increase after introducing the accidents moving from an Avera value of 3.46 (>3) to 3.9 (high level of concern> 3 and ≈ 4).
- Analysing the impact of AVs on the public perception of the different benefits offered by AVs shows that, in general, the public perception of the different benefits of AVs declined after introducing the accidents.
- Finally, the respondents had high levels of concern regarding the different aspects of AVs before introducing the accidents. On the other hand, after introducing the accidents, these concerns became higher with average values of 3.9 except for the concern about allowing the respondents' kids to travel alone in an AV which had an average value of 4.34 indicating a high level of concern and low level of trust in AVs.

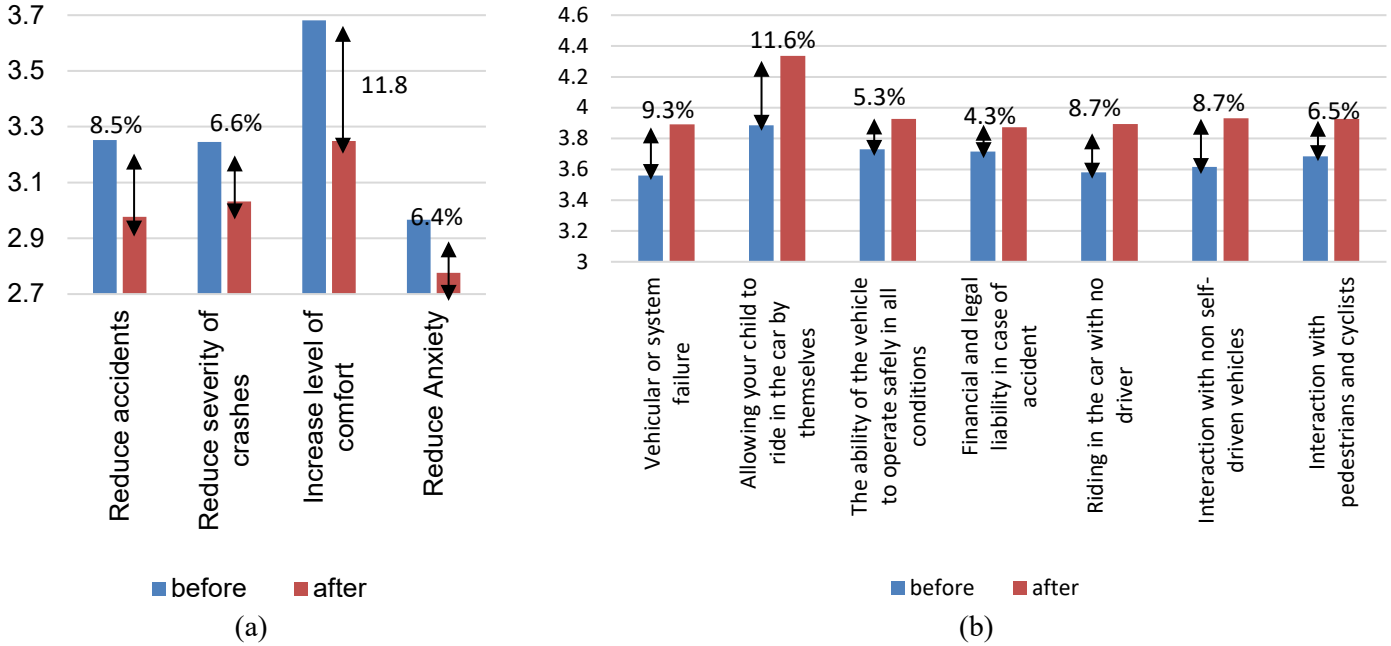

Fig 3. Changes in the public perception of the different (a) benefits, and (b) concerns of AVs before and after accidents

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