Impact of Autonomous Vehicles Accidents on the Public Attitude Towards This Emerging Technology

Kareem Othman

Abstract Over the last few years, autonomous vehicles (AVs) have attracted researchers from different disciplines. Despite the effort put into the understanding and development of AVs, little is known about the factors that affect the public attitude towards this emerging technology. On the other side, public attitude is the main factor for the success of emerging technologies. Additionally, over the last few years, AVs were involved in multiple accidents that negatively affect the public attitude towards AVs. This paper focuses on investigating the impact of AVs' accidents on the public attitude towards AVs for different groups with different demographic characteristics (age, gender, educational level, household, and income) in the USA by analyzing the opinions of 5880 respondents who participated in the online questionnaire survey. The results show that people become less positive towards AVs after accidents but with different magnitudes for respondents with different demographic characteristics. Additionally, the results shed light on the importance of educating the public about the benefits and state of technology of AVs.

Keywords Accident · Autonomous vehicles · Crashes · Public acceptance · Demographic characteristics

1 Introduction

Vehicle automation has always been one of the main areas that attracted researchers from different disciplines. In the 20s, the focus was on the use of radio waves in order to establish the vehicle-to-vehicle communication [1]. In the 40s, the focus was on the invention of the electromagnetic guidance system [2]. This was followed by the cooperation between the Bundeswehr University in Munich and Mercedes-Benz that resulted in the invention of the first system for autonomous vehicles (AVs) [3].

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This invention was one of the biggest milestones that have attracted researchers and manufacturers from all over the world to introduce AVs [4]. In general, the National Highway and Transportation Safety Administration has classified AVs functionalities into 5 levels starting with level 0, that refers to the case of no automation at all, to level 5 that refers to full automation. Level 0 automation means no automation at all that the driver is responsible for performing all the driving tasks. Level 1 automation refers to the driver assistance system feature that assists the driver in some functions. Level 2 refers to partial automation as some functions are automated, but the driver must keep control of the vehicle and be alerted to the surrounding environment. Level 3 refers to conditional automation which requires the driver to be alerted to take control of the vehicle at all times with notice. Level 4 refers to high automation which indicates that the vehicle is able to operate autonomously but the vehicle can also be manually controlled. Level 5 refers to full automation which means that the vehicle is able to operate or navigate in all environmental conditions safely [5].

Over the last few years, the development of AVs has witnessed tremendous focus from researchers and manufacturers at a multidisciplinary level that the traditional vehicle manufacturers are not taking the lead in this area [6]. For example, Google has launched its AVs program in 2009 to develop its first self-driving car by 2020 [7]. Uber is one of the leading companies, in the area of vehicle automation, that partnered with Volvo in 2014 to introduce the third generation of their AVs that was anticipated to be to be tested by 2020 [8]. Similarly, Apple has launched the "Titan" project that focuses on developing AVs in 2014 with the vision of introducing AVs by 2023 to 2025 [9]. Additionally, AVs have attracted startup companies and a large number of companies are established with the goal of developing AVs such as Zoox [10]. From the perspective of cities, multiple cities started legalizing AVs as a quick reaction to this rapid development in the technology [11, 12]. In general, previous studies have shown that AVs have the potential to offer multiple benefits (improve the level of mobility, comfort, and productivity) [13–16] and risks (increase the vehicle travel distance, and in turn increase the level of congestion and emissions) [17]. While the implications of AVs have been investigated in a large number of studies, the public attitude has been rarely investigated in the literature. However, the main issues facing new technologies are non-technological and AVs are not an exception. For example, the IEEE has reported that the public attitude and acceptance of AVs will be the main barrier to the adoption of AVs [18].

Over the last few years, multiple studies have investigated the public attitude towards AVs, such as the studies by Othman [19], Jing et al. [20], Hilgarter and Granig [21], Wang et al. [22], Butler et al. [23], and Ahmed et al. [24]. Previous studies mainly focus on investigating the public acceptance of AVs for different groups with different demographics such as the gender, age, and education. On the other side, these studies show different levels of acceptance of AVs at different countries and at different years. While the public attitude has been investigated in the literature, the factors affecting the public attitude towards AVs have been rarely discussed. For example, Šinko et al. [25] study showed that while the level of awareness of AVs increases over time, the public became more negative towards AVs as the level of interest in AVs was dropping from 40% in 2014 (as shown in the study by Schoettle and Sivak

[26]) to 10% in 2017. Similarly, the study by Panagiotopoulos and Dimitrakopoulos [27] shows similar results as people become more negative towards AVs. The only difference between the early studies that showed high levels of interest in AVs and the more recent studies that show lower levels of interest towards AVs is the incidents involving AVs. In 2022, Othman [28] managed to explain this decline in the level of interest and they concluded that these two surveys by Schoettle and Sivak [26] and Panagiotopoulos and Dimitrakopoulos [27] were accompanied by the first fatal accident involving an AV in July 2016 that contributed to this negative switch in the public attitude towards AVs. Thus, accidents involving AVs have a major effect on the public perception of this emerging technology. Additionally, the study by Othman [19] studied the relation between the public attitude towards AVs and the number of fatal accidents involving AVs over the years using the data between 2016 and 2019 in the USA. The analysis shows a clear relation between the number of fatal accidents involving AVs and the percentage of respondents worried about AVs as this percentage increases with the increase in the number of accidents as shown in Fig. 1. As a result, it is crucial to investigate the relation between accidents of AVs and the public attitude towards this emerging technology. While the public acceptance of AVs has been investigated in multiple studies in the literature, the impact of accidents involving AVs on the public attitude has never been investigated in detail. Thus, the main objective of this study is to understand and quantify the impact of accidents involving AVs on the level of trust, interest, and concern of the public towards AVs. Additionally, a detailed analysis was conducted for different groups with different demographics (such as the age, gender, education, income, and previous knowledge about the technology) in order to understand how the opinions of these groups are affected by these accidents.
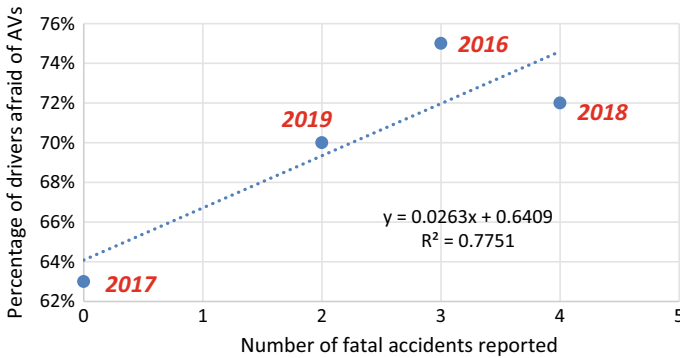
Fig. 1 The relation between the number of fatal accidents involving AVs and the percentage of people afraid of AVs in the USA. Adopted from [19]

2   Literature Review

In general, the studies that focus on analyzing the impacts of AVs' accidents are rare and these studies mainly analyze social media data in order to understand the public attitude towards AVs before and after an accident that involved an AV. Starting with the first study by Jefferson and McDonald [29] that used sentiment analysis of Twitter in order to understand how the public attitude towards AVs changes as a result of an AV accident. The study focused on analyzing tweets before and after the 10th of February 2019 accident that involved an AV. The authors collected and analyzed tweets three days before the accident, the day of the accident, and three days after the accident [30]. The analysis shows a major shift in the public attitude towards AVs. For example, the word "crash" did not appear prior to the accident; however, it became one of the most common words used on the day of the accident and three days prior. Additionally, the most common words prior to the accident were mainly about Amazon, startups, and investments. On the other side, the words "crash," "autopilot," and "vehicle" become the most common words used on the day of the accident and three days after the accident. Additionally, a sentiment analysis was conducted to measure the positivity and negativity of the tweets in order to understand the public attitude towards AVs. The sentiment analysis of the tweets shows a significant drop in the positive sentiment to almost half after the accident.

Penmetsa et al. [30] investigated the influence of two fatal accidents that occurred in March 2018. The first accident occurred on 18 March 2018 and it involved an Uber-operated Volvo vehicle with a self-driving system that collided with and killed a pedestrian who was crossing the street in Arizona [31, 32]. This accident was the first fatal accident involving a pedestrian. The second accident occurred on 23 March 2018, and it involved a Tesla Model X vehicle that speeded up and steered into a concrete barrier while it was operating on the autopilot mode [33, 34]. Penmetsa et al. [30] conducted a before-and-after sentiment analysis using the data collected 15 days before and 15 days after every incident. The analysis shows a significant change in the public attitude towards AVs. For example, the results show that the negative tweets about AVs or self-driving cars increased by 32%, jumping from 14 to 46%. Additionally, the average compound sentiment score witnessed a major decrease for the tweets involving Uber (−6%), Tesla (−6%), or self-driving cars (−11%). Thus, these results show a major impact of these two accidents on the public trust in AVs.

Finally, the study by Jing et al. [35] explored the impact of the NIO crash in August 2021 on the public attitude towards AVs in China. Unlike the previous two studies, this study collected and analyzed comments from Chinese mainstream social media platforms (Sina Weibo and TikTok) seven days before and seven days after the accident. In general, Sina Weibo and TikTok are the leading social media platforms in China that the report by Sina [36] revealed that Weibo had 530 million monthly active users, which represents one-third of the Chinese population. Similarly, TikTok has more than 680 million daily active users [37]. Results of the sentiment analysis show major changes in the positive and negative emotions before and after the accident as the negative sentiments witnessed 18% increase (from 29 to 47%), while the

positive sentiments witnessed 10% decrease (from 40 to 30%). Additionally, a day-by-day analysis of the comments shows that negative sentiment remains consistently negative at the same level for the entire seven days after the crash. Additionally, one of the key points highlighted by this study is that the sentiment score of the different brands of AVs is negatively affected by any accident involving an AVs in general even from a totally different brand. For example, in this study, the accident involved a NIO car; however, the sentiment analysis of Tesla shows a negative trend after the accident as the negative sentiment towards Tesla increased by 5% (from 43 to 43%), while the positive sentiment decreased by 9% (from 32 to 23%).

3   Research Gap and Study Objectives

Analyzing social media data is beneficial as it offers a large amount of data that helps in building conclusions. For example, Twitter holds over 300 million active accounts with more than 45%, and 30% of adults aged 18–24 years and 25–49 years use Twitter [29]. Thus, analyzing social media data provide a lot of insights about the impact of AVs accidents on the public attitude towards AVs. However, this analysis is subjected to multiple limitations and cannot really provide a detailed analysis for the different groups with different demographics. For example, the sentiment gathered from social media platforms might not accurately represent the general public. For example, more than one-third of Twitter users in the USA have a college degree and earn more than 75.000$ a year, which indicates that the US-based Twitter users have more education and higher income than the general average population in the USA [38]. Additionally, the 2021 report by Twitter shows that 62% of Twitter users are males [39]. Similarly, for the most leading social media platforms in China, around 80% of the users of both Sina Weibo and TikTok are adults who have an age of 30–40 years [37]. Thus, the results of analyzing social media data might be biased towards a specific group with specific demographics, which necessitates the need for a study that balance these demographics in the samples in order to have results that can generalize.

Secondly, the previous studies that used sentiment analysis concluded that there are several deficiencies in the application of topic modeling and sentiment analysis in the AV crash domain [29, 30]. First, the analysis shows that there is a mismatch between the sentiment assigned to words in a traditional sentiment dictionary and the likely sentiment of words in the AV domain [30], which necessitate the need to develop a domain-specific sentiment dictionary for AV domain. Second, the study by Jefferson and McDonald [29] mentioned that a notable number of tweets adopted the concept of blaming the vehicle and that the vehicle got confused. This frequent repetition of the words "blame" and "confused" suggests that Twitter users may be drawn to discussions of crashes involving compelling and concise narratives. The emergence of these terms highlighted a limitation in the keyword search, which suggests the need for a more advanced search method. Finally, the analysis shows

that most of the tweets are linked a website from newspapers [40], which is hard to analyze and include in the sentiment analysis.

Thus, this paper mainly focuses on investigating the change in the public attitude as a result of AVs' accidents in detail for different groups with different demographics in the USA. The main objectives of this study are:

- Understand the impact of AVs' accidents on the public trust, interest, and concern towards AVs.
- Understand how these accidents change the opinions of people in different age groups.
- Understand how these accidents change the opinions of males and females towards AVs.
- Understand how the opinions of people with different educational levels change after the accidents.
- Understand how these accidents affect the opinions of the people with different levels of income.

4 Methodology

This public survey was designed in order to assess the public attitude, trust, interest, and concern towards AVs before and after accidents that involve AVs. Before sending the main survey to the public, a pilot survey was conducted in order to make sure that the questions included in the survey are fair, accurate, descriptive, comprehensive, and understandable to the public. Thus, the survey was initially sent to five professors (from multiple universities across Canada and the USA) who mainly lead research in the domain of public surveys, and 20 participants from the general public in the USA. The assessment of the survey shows a great level of satisfaction from both the professors and the public participants as all the 25 respondents declared that they had no difficulty reading or understanding the questions. The survey consisted of three sections. The first section of the survey was an introductory page that provide the respondents with a brief overview about AVs and the purpose of the survey. The second section focuses on collecting the general opinion about AVs. In this section, the respondents were asked to rank their level of interest, trust, and concern about AVs on a Likert scale from 1 to 5. At beginning of the third section of the survey, nine different accidents with different levels of severity (minor, major, fatal) were introduced to the respondents with some images that visually shows the impact of the accident as summarized in Fig. 2. The main idea for choosing these different accidents was to introduce the different malfunctions that might occur and cause accidents from AVs starting from issues in the vision, issues in controlling speed (the vehicle speed up instead of slowing down in some cases causing an accident), and directions, to issues with the batteries that might cause explosion of the vehicle. The main objective of introducing these accidents is to try to put all the presidents on the same level of information regarding AVs accidents and the possible issues. After introducing these accidents, the respondents were asked to rank their level of interest,

Fig. 2 Details about the accidents introduced to the respondents during the survey (red text for fatal accidents and orange text for minor injury accidents)

trust, and concern regarding AVs once again on a Likert scale from 1 to 5. Finally, the last section of the survey focuses on collecting the demographic information of the respondents.

The survey was then posted online on SurveyMonkey platform between February to June 2022 and a total of 5880 responses were collected from respondents from the USA. The demographic characteristics of the sample used in this paper are summarized in Table 1. The table shows a good representation of the different groups in the sample, which is essential for this study to understand the impact of accidents of AVs on the different age groups. The gender ratio was balanced as 48% of the respondents were males and the remaining 52% were females. Similarly, the different age groups are well represented in the survey sample as the different groups are almost equally represented in the sample. For the educational levels attained, most of the respondents either have a high school degree or lower, or have a bachelor's degree, while 22% of the respondents have a master's degree or a higher. While the sample seems to underrepresent respondents with higher degrees of education, it is actually very representative of the educational attainment data published by the United States Census Bureau in February 2022 [41]. The Census Bureau report shows that 36.8% of the US population has a high school degree or less, compared to 32.8% of the respondents who highlighted that they have a high school degree or lower. Similarly, the Census Bureau report shows that 48.9% of the US population have bachelor's degrees, and 14.4% have master's degrees, compared to 45% and 16% of the survey respondents. A similar trend can be observed for the yearly household income, the different percentages are very similar to the real income distribution in the USA as shown in the Census Bureau report in 2021 [42]. The Census Bureau report shows that 18.1%, 19.7%, 28.7%, and 23.3% of the US population has a yearly annual

Table 1 Demographic information of the respondents participated in the survey

| Demographic characteristics		Frequency (N)	Percentage (%)
Gender	Male	2805	47.70
	Female	3075	52.30
Age	18–29	1315	22.36
	30–44	1814	30.85
	45–60	1345	22.87
	>60	1406	23.91
Education	High school or lower	1930	32.82
	Bachelor	2648	45.03
	Master's degree	943	16.04
	Higher than master's degree	359	6.11
Household income ($/year)	<25,000	1204	20.48
	25,000–50,000	1237	21.04
	50,000–100,000	2067	35.15
	100,000–200,000	1186	20.17
	>200,000	186	3.16

household income of 25K$, 25–50K$, 50–100K$, and 100–200K$, compared to 20.48%, 21.04%, 35.15%, and 20.17% from the survey respondents.

5 Results

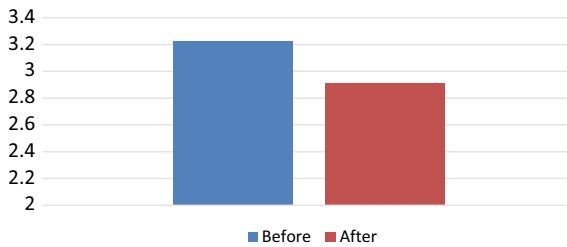## 5.1 Impact of AVs' Accidents on the Public Attitude Towards AVs

This part focuses on understanding how the public attitude towards AVs changes for all respondents after introducing the accidents. Figures 3, 4, and 5 show the average level of interest, trust, and concern about AVs before and after introducing the accidents. The results show major changes in the public attitude towards the negative direction after introducing the accidents. The general opinion about AVs became more negative towards AVs after introducing the accidents. On a scale from 1 to 5 where 1 indicates that the respondent has a very negative opinion about AVs and 5 indicates that the respondent has a very positive opinion about AVs, the average opinion of all respondents moves in the negative direction after the accident jumping from 3.2 before introducing the accidents to 2.9 after the accidents as shown in Fig. 3. Additionally, there is a major reduction in the level of trust in AVs as the level of trust decreases from an average value of 3.22–2.86 after introduction the accidents as shown in Fig. 4. Finally, the level of concern regarding AVs increased
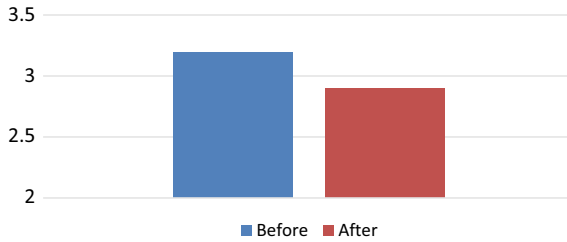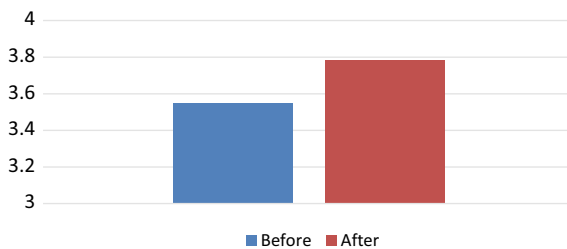
Fig. 3 Average level of interest for all respondents before and after introducing the accidents (where 5 indicates "very positive opinion" and 1 indicates "very negative opinion"). Before = before introducing the accidents, After = after introducing the accidents

after introducing the accidents from an average value of 3.55–3.78 as shown in Fig. 5. The results presented in this subsection are consistent with the results introduced in previous studies that analyzed social media data [29–33] as all these studies concluded that the public attitude becomes more pessimistic towards AVs after an accident.

Fig. 4 Average level of trust for all respondents in AVs before and after introducing the accidents (where 5 indicates "strongly agree" and 1 indicates "strongly disagree"). Before = before introducing the accidents, After = after introducing the accidents


Fig. 5 Average level of concern for all respondents about AVs before and after introducing the accidents (where 5 indicates "highly concerned" and 1 indicates "not concerned at all"). Before = before introducing the accidents, After = after introducing the accidents
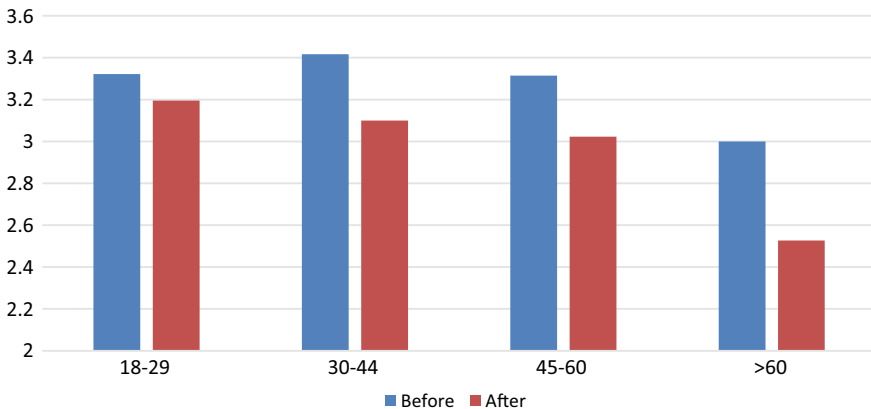
5.2 Perception of AVs for Different Age Groups Before and After AVs Accidents

Previous studies that investigated the public attitude towards AVs highlighted that the public acceptance of AVs changes according to the age of the respondents. In general, a large number of studies concluded that there is an inverse relationship between the age of the respondent and the level of interest in AVs [43–47]. In this subsection, the public attitude of the different age groups will be investigated before and after introducing the accidents. Figures 6, 7, and 8 show the opinion, level of trust, and concern of the different age groups in AVs. In general, the public attitude towards AVs became more negative after introducing the accidents for the different age groups. Before introducing the accidents, the general opinion about AVs for the respondents who have 18–29 years old was at an average value of 3.43 and increased to 3.5 for respondents who have 30–44, then, it declined to 3 and 2.75 for respondents at the 45–60 and > 60 age groups as shown in Fig. 6. On the other side, after introducing the accidents, the general opinion had a different pattern as respondents became more pessimistic towards AVs with the increase in the age. Figure 6 shows that, after introducing the accidents, the general opinions have an average value of 3.28, 3.1, 2.87, and 2.39 for respondents in the 18–29, 30–44, 45–60, and > 60 age groups. For the level of trust in AVs, the before and after cases have two different patterns very similar to the two patterns observed in the general opinion about AVs. Before introducing the accidents, the level of trust for the 18–29 years group was at an average value of 3.32 and increased to 3.42 for the 30–40 years group and then declined to 3.31 and 3 for the 45–60 and > 60 groups as shown in Fig. 7. On the other side, after introducing the accidents, the level of trust in AVs has an inverse relation with the age as the average level of trust is 3.2, 3.1, 3.02, and 2.53 for respondents in the 18–29, 30–44, 45–60, and > 60 age groups. Additionally, it can be seen that the elder group (>60) is not only the group with the lowest level of interest in AVs before introducing the accidents, but also the group with the most significant decrease in the level of interest and trust after introducing the accidents as their average opinion moves from 2.75 to 2.36 (15% decrease) and the average level of trust moves from 3 to 2.53 (16% decrease).

For the level of concern about AVs, the results show that there is a direct relationship between the age of the respondents and the level of concern towards AVs for the two cases before and after the accidents as shown in Fig. 8. Before introducing the accidents, the average levels of concerns were 3.2, 3.54, 3.53, and 3.86 for respondents in the 18–29, 30–44, 45–60, and > 60 age groups. On the other side, the levels of concerns increase after introducing the accidents to 3.45, 3.74, 3.74, and 4.17 for respondents in the 18–29, 30–44, 45–60, and > 60 age groups. Additionally, the elder group does not (>60) only has the highest level of concerns regarding AVs before and after introducing the accidents, but also has the highest increase in the level of concerns from 3.86 to 4.17 (8% increase).
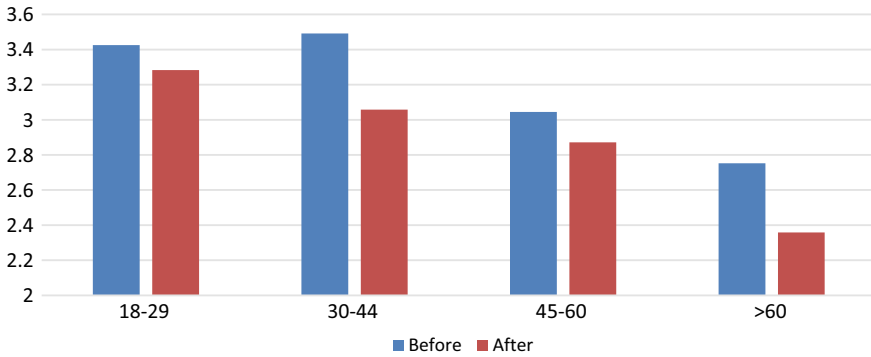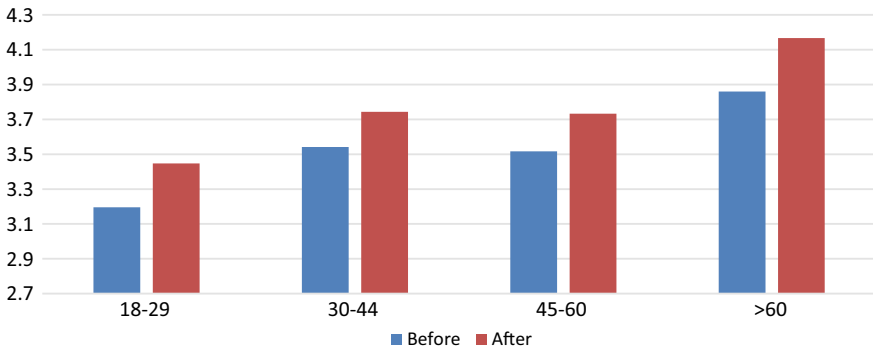
Fig. 6 Average level of interest for the different age groups before and after introducing the accidents (where 5 indicates "very positive opinion" and 1 indicates "very negative opinion"). Before = before introducing the accidents, After = after introducing the accidents

Fig. 7 Average level of trust in AVs for the different age groups before and after introducing the accidents (where 5 indicates "strongly agree" and 1 indicates "strongly disagree"). Before = before introducing the accidents, After = after introducing the accidents

5.3   *Impact of AVs' Accidents on the Public Attitude of Males and Females*

In general, previous studies that investigated the public attitude towards AVs highlighted that the public attitude towards AVs changes according to the gender of the respondents. In general, males are more optimistic towards AVs than females as concluded in a large number of studies [43–45, 47–51]. This subsection focuses on quantifying the impact of AVs' accidents on the opinion, level of trust, and concerns of males and females towards AVs. Figures 9, 10, and 11 summarize the opinion,
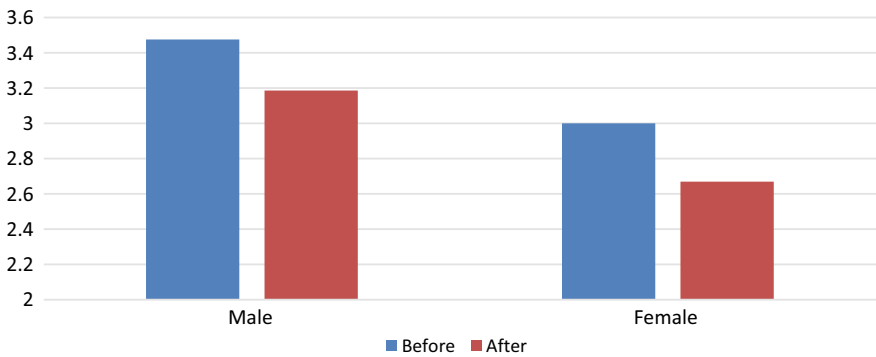
Fig. 8 Average level of concern about AVs for the different age groups before and after introducing the accidents (where 5 indicates "highly concerned" and 1 indicates "not concerned at all"). Before = before introducing the accidents, After = after introducing the accidents

level of trust, and concern of male and female respondents before and after introducing the accidents. Additionally, introducing the accidents had a significant impact on the attitude of female respondents when compared to the change in the attitude of male respondents. In general, male respondents are more optimistic towards AVs than female respondents before and after introducing the accidents. Before introducing the accidents, male respondents had an average positive opinion of 3.39 which is higher than the 3.23 for the average aver opinion of female responses as shown in Fig. 9. Then, after introducing the accidents, the opinions of male and female respondents reached an average value of 3.23 and 2.7. For the level of trust, male respondents had an average level of trust of 3.48 before introducing the accidents and female respondents had an average level of trust of 3 as shown in Fig. 10. Then, this level of trust declined, after introducing the accidents, to 3.19 and 2.67 for male and female respondents. Finally, the level of concern increased for both male and female respondents after the accidents moving from 3.33 to 3.58 for male respondents and from 3.76 to 4.06 for female respondents as shown in Fig. 11. While the previous results show that female respondents are always less optimistic towards AVs than male respondents, it also shows that the impact of these accidents on the opinion of female respondents is more significant than on the opinions of male respondents. The positive opinion of female respondents moves from 3.03 before introducing the accidents to 2.7 after introducing the accidents (11% decrease), while the female respondents' level of trust moves from 3 to 2.67 (11% decrease). Similarly, the level of concerns about AVs moved from 3.75 to 4.06 (8.5% increase) for female respondents.
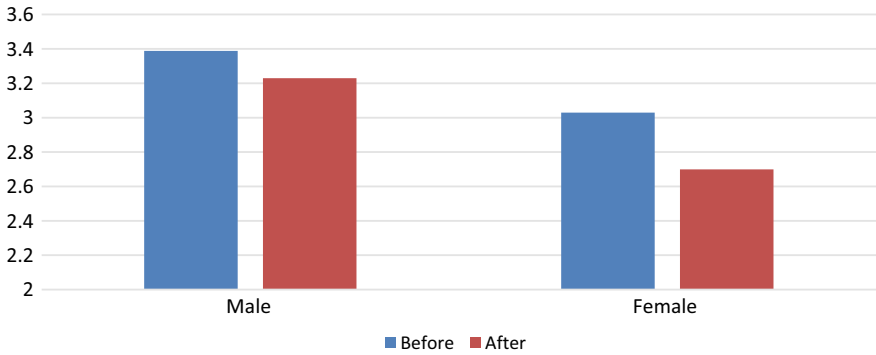
Fig. 9 Average level of interest for males and females before and after introducing the accidents (where 5 indicates "very positive opinion" and 1 indicates "very negative opinion"). Before = before introducing the accidents, After = after introducing the accidents

Fig. 10 Average level of trust in AVs for males and females before and after introducing the accidents (where 5 indicates "strongly agree" and 1 indicates "strongly disagree"). Before = before introducing the accidents, After = after introducing the accidents
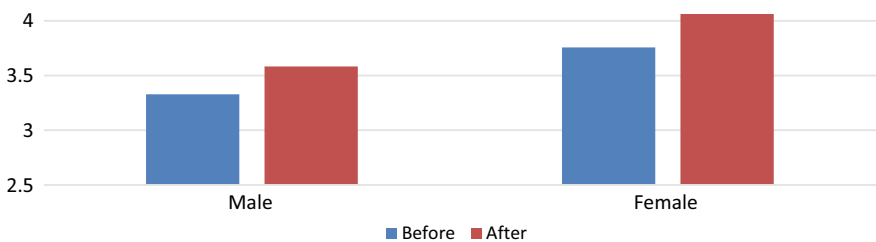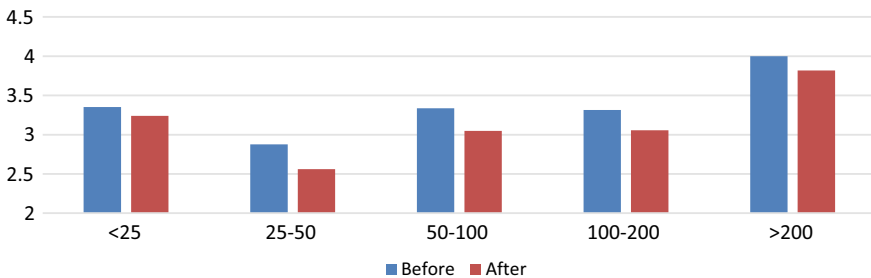

Fig. 11 Average level of concern about AVs for males and females before and after introducing the accidents (where 5 indicates "highly concerned" and 1 indicates "not concerned at all"). Before = before introducing the accidents, After = after introducing the accidents

5.4   Impact of AVs' Accidents on Respondents with Different Household Incomes

Analyzing the level of acceptance of AVs technology based on the level of income has been rarely discussed in the literature. However, plenty of studies managed to analyze the public acceptance of AVs for respondents with different household income levels in different countries [52, 53]. Thus, in this subsection, the public attitude towards AVs before and after introducing the accidents for respondents with different household income levels was investigated. Figures 12, 13, and 14 show the opinion, level of trust, and concerns towards AVs for respondents within a specific household income level. The figures show that the level of interest and trust in AVs decreased after introducing the accident for the different respondents within the different household income levels. Additionally, both the general opinion and level of trust in AVs have the same pattern before and after introducing the accidents and in general respondents within the 25–50K$ are the least optimistic and have the lowest level of trust in AVs before and after introducing the accidents. On the other side, respondents who have a household income of more than 200K$ are the most optimistic towards AVs and show the highest level of trust towards AVs before and after introducing the accidents. Comparing these results with the results of the survey by Lee et al. [54] in the USA shows a high level of consistency in the results of the two surveys as the results of the two surveys have similar patterns. Lee et al. [54] study shows that the level of interest in AVs has a parabolic with the different household income levels, which is consistent with the results presented in Figs. 12 and 13.

For the level of concern regarding AVs, respondents show similar results as the relation between the level of concern and household income takes an inverse parabolic shape before and after introducing the accidents which is the opposite of the relations shown in Figs. 12 and 13 for the level of trust and interest in AVs. Additionally, respondents within the 25–50K$ household income have the highest level of concerns regarding AVs (peak point) before and after introducing the accidents with an average

Fig. 12 Average level of interest for respondents with different household income before and after introducing the accidents (where 5 indicates "very positive opinion" and 1 indicates "very negative opinion"). Before = before introducing the accidents, After = after introducing the accidents
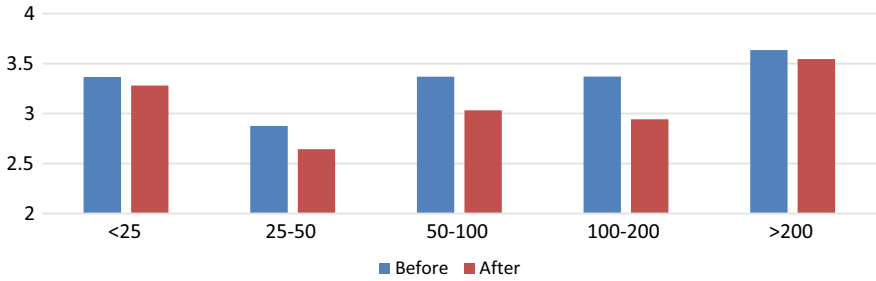
Fig. 13 Average level of trust in AVs for respondents with different household income before and after introducing the accidents (where 5 indicates "strongly agree" and 1 indicates "strongly disagree"). Before = before introducing the accidents, After = after introducing the accidents
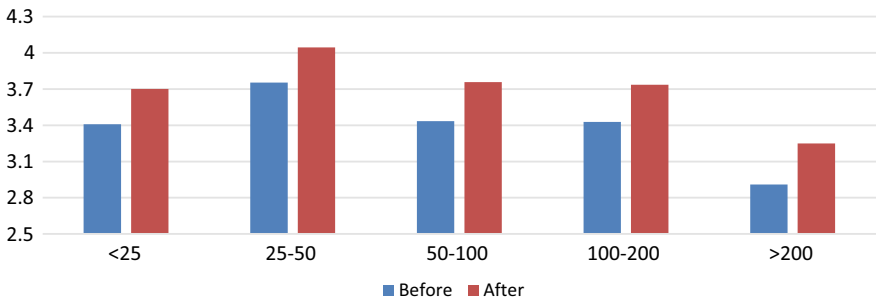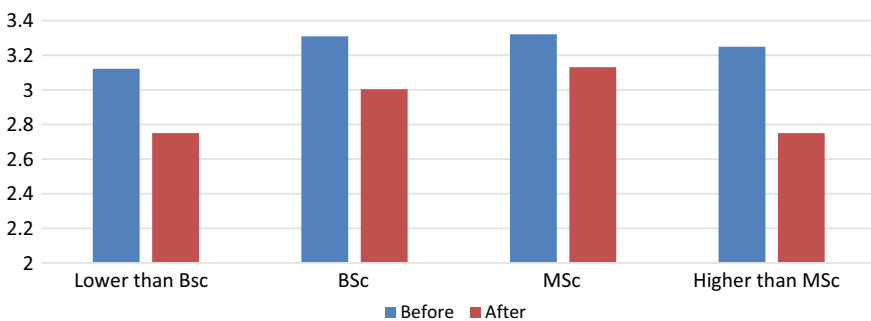

Fig. 14 Average level of concern about AVs for respondents with different household income before and after introducing the accidents (where 5 indicates "highly concerned" and 1 indicates "not concerned at all"). Before = before introducing the accidents, After = after introducing the accidents

concern level of 3.75 and 4.04 before and after introducing the accidents. On the other hand, respondents with the highest level of household income, which is > 200K\$, are the least concerned about AVs before and after introducing the accidents with an average level of concern of 2.9 and 3.25 before and after introducing the accidents. Additionally, Fig. 14 shows that the level of concern regarding AVs increases for the different levels of household incomes after introducing the accidents.

## 5.5 *Impact of AVs' Accidents on Respondents with Different Educational Levels*

Over the last few years, multiple studies investigated the attitude of people with different education levels towards AVs. In general, the results of previous studies show that people with different educational levels perceive the benefits and drawbacks of AVs differently [43, 50, 55]. The general trend observed is that people with higher

educational levels are more optimistic towards AVs, which was concluded in the studies by Piao et al. [43] and Lee et al. [54]. Thus, this subsection focuses on investigating the public attitude of the respondents within the different educational levels before and after introducing the accidents. Figures 15, 16, and 17 show the opinion, level of trust, and concern about AVs of the respondents with different educational levels before and after introducing the accidents. For the general opinion towards AVs before introducing the accidents, respondents with higher educational levels show higher positive opinion, except for respondents with an educational level that is higher than a master's degree who show a minor lower level of positive opinion towards AVs than respondents as shown in Fig. 15. After introducing the accidents, the general opinion towards AVs became less positive for the four groups; however, the positive opinion towards AVs had the same pattern as before introducing the accidents as respondents with higher educational levels showed higher positive attitude towards AVs, except for respondents with an educational level that is higher than a master's degree who showed a major decrease in their positive opinion towards AVs from 3.25 before the accidents to 2.75 after introducing the accidents (15.4% decrease) to make their opinion towards AVs similar to the opinion of the respondents with an educational level that is lower than a bachelor's degree after introducing the accident. For the level of trust of AVs before introducing the accidents, Fig. 16 shows that respondents with higher educational levels have higher levels of trust towards AVs, except for respondents who have an educational level that is higher than a master's degree. On the other side, after introducing the accidents, the different respondents with different educational levels show similar levels of trust towards AVs ranging from a maximum value of 2.94 for respondents with a master's degree to a minimum value of 2.8 for respondents with a bachelor's degree. Comparing these results with the results of the study by Lee et al. [54] in the USA shows that the two studies show a high level of agreement as the two studies show similar patterns for the relations between the educational levels and the level of interest towards AVs.
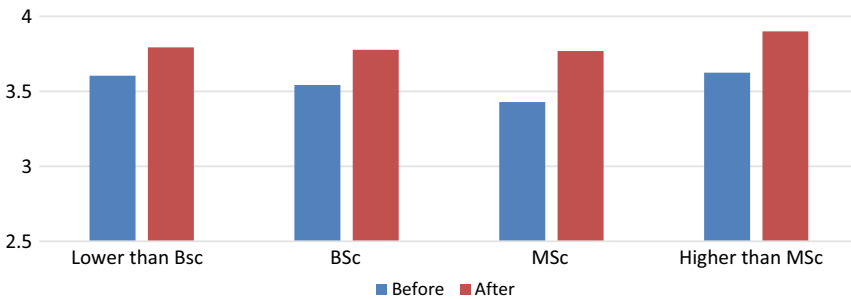

Fig. 15 Average level of interest for respondents with different educational levels before and after introducing the accidents (where 5 indicates "very positive opinion" and 1 indicates "very negative opinion"). Before = before introducing the accidents, After = after introducing the accidents
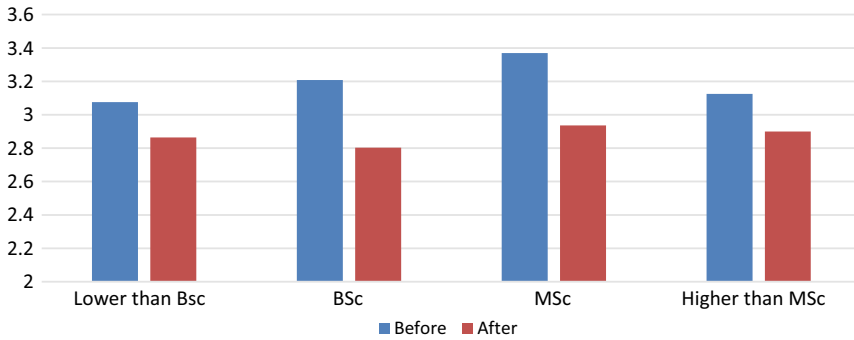
Fig. 16 Average level of trust in AVs for respondents with different educational levels before and after introducing the accidents (where 5 indicates "strongly agree" and 1 indicates "strongly disagree"). Before = before introducing the accidents, After = after introducing the accidents

Fig. 17 Average level of concern about AVs for respondents with different educational levels before and after introducing the accidents (where 5 indicates "highly concerned" and 1 indicates "not concerned at all"). Before = before introducing the accidents, After = after introducing the accidents

Finally, for the levels of concern towards AVs before introducing the accidents, the results show that respondents with higher educational levels have lower levels of concern towards AVs except for the respondents with a degree higher than a master's degree who showed a higher level of concern that is similar to the respondents with a degree lower than a bachelor's degree as shown in Fig. 17. On the other hand, after introducing the accidents to the respondents, the levels of concern increased for all respondents across the different educational levels that the respondents with different educational levels showed similar levels of concern, except for respondents with a degree higher than a master's degree who had higher levels of concern. Specifically, the average levels of concern regarding AVs after introducing the accidents were 3.79, 3.78, 3.3.77, and 3.9 for respondents with a degree lower than a bachelor's degree, respondents with bachelor's degrees, respondents with master's degrees, and respondents with a degree higher than a master's degree.

6   Conclusion

This study focuses on investigating the impact of accidents involving AVs on the public attitude towards this emerging technology for the different groups with different demographic characteristics. Thus, a questionnaire survey was conducted, and a total of 5880 complete responses were collected from respondents with different demographic characteristics in the USA. During the survey, the respondents were asked to rank their interest, level of trust, and concern about AVs on a Likert scale from 1 to 5; then, multiple accidents that involved AVs were introduced to the respondent and they were asked to rank their level of interest, trust, and concern about AVs once again. Then, the responses were analyzed based on the different demographic characteristics of the survey respondents (age, gender, educational level, household income, prior knowledge about AVs, and prior knowledge about AVs' accidents) before and after the accidents. This study offers multiple insights about the impact of AVs' accidents on the public attitude towards this emerging technology as follows:

- In general, the public attitude towards AVs became more negative after introducing the accidents as the respondents showed lower levels of interest and trust in AVs with higher levels of concern about the technology after introducing the accidents.
- Analyzing the responses based on the age of the respondents showed that younger respondents are more optimistic towards AVs before and after introducing the accidents. In other words, there are inverse relations between the age of the respondents from the one side and the level of interest and trust in AVs from the other side. On the other side, there is a direct relation between the level of concern about AVs and the age of the responses for the two cases before and after introducing the accidents. Additionally, the negative shift in the respondents' opinion increases with the increase in the age of the respondents.
- Analyzing the responses based on the gender shows that male respondents are more optimistic towards AVs than female respondents before and after introducing the accidents. Additionally, after introducing the accidents, the negative shift in the opinion of female respondents was much larger than the negative shift in the opinion of male respondents.
- Analyzing the responses based on the household income of the respondents shows that the relations between the level of interest, trust, and concern and the household income take a parabolic shape before and after introducing the accidents. The results show that respondents who have a household income of 25–50K$ are the most pessimistic towards AVs, while respondents with a household income > 200K$ have the highest level of interest towards AVs. Additionally, the negative shift in the opinion of the respondents in the 25–50K$ household income group is the largest when compared with the other groups.
- Analyzing the data based on the educational levels shows that respondents with higher educational levels are more in AVs technology before introducing the accidents, except for respondents who hold a degree higher than a master's degree. On the other side, after introducing the accidents, a similar pattern can be observed for the general opinion of the responses with different educational levels, but the

levels of trust and concern towards AVs became similar for the different groups except for the respondents with a degree higher than a master's degree who showed slightly higher levels of concern regarding the technology.

- The results show that respondents with prior knowledge about AVs are more optimistic about this emerging technology for both cases before and after introducing the accidents. Additionally, after introducing the accidents, the negative shift in the attitude decreases with the increase in the level of prior knowledge of the respondents about AVs. This analysis sheds light on the importance of educating the public about AVs and their benefits in order to achieve the highest level of acceptance of this emerging technology.

7   Limitations and Recommendations for Future Studies

While this study gives insights into the impact of accidents of AVs on the public attitude, this study has its limitations. This study focuses on the opinion of respondents from the USA, so further studies are needed to understand the impact of AVs accidents using the same approach in other countries. Additionally, the public awareness about AVs and in turn the public attitude are expected to change over time. Thus, it is recommended to replicate the survey regularly in order to understand how the change in the level of awareness is correlated with the public attitude.

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