Should Self-Driving Cars Mimic Human Driving Behaviors?

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Abstract. Recent studies illustrate that people have negative attitudes towards utilizing autonomous systems due to lack of trust. Moreover, research shows a human-centered approach in autonomy is perceived as more trustworthy by users. In this paper, we scrutinize whether passengers expect self-driving cars (SDC) to mimic their personal driving behaviors or if they hold different expectations of how a SDC should drive. We developed a survey with 46 questions that asked 352 participants about their personal driving behaviors such as speed, lane changing, distance from a car in front, acceleration and deceleration, passing vehicles, etc. We further asked the same questions about their expectations of a SDC performing these tasks. Interestingly, we observed that most people prefer a SDC that drives like a *less aggressive version of their own driving behaviors*. Participants who reported they trust or somewhat trust AI, autonomous technologies, and SDCs expected a car with behaviors similar to their personal driving behaviors. We also found that the expectation of a SDC's level of attenuated aggressiveness witnessed among all other participants was *relative to their personal driving behavior aggressiveness*. For instance, male drivers showed to be more aggressive drivers than female drivers, and therefore, their expectations for a SDC was slightly more aggressive. These findings can be useful in developing certain profiles or settings for SDCs, and overall they can help in designing a SDC that is perceived as trustworthy by passengers.

Keywords: Self-driving cars' behavior; mimicking human-driving cars' behavior; trust in self-driving cars.

1 Introduction

Self-driving cars are quickly becoming a reality and will have significant consequences on our society. A substantial amount of research is being conducted to make vehicles that are fully autonomous, where humans are no longer needed for operation. AI and machine learning have been instrumental in the development of these advanced systems and continue to improve at a rapid rate. While the academia, tech community and researchers in the field of AI and autonomy eagerly work towards delivering a fully autonomous vehicle, there is evidence showing that the general public is apprehensive towards using such systems.

Recent studies show that people have negative attitudes towards utilizing autonomous platforms [9, 19]. A survey conducted by Continental AG found that 31% of respondents stated they were unnerved by the development of automated vehicles, and 54% claimed that they do not believe that such vehicles will function reliably[1]. In addition, researchers at the University of Michigan found that 46% of adult drivers preferred to retain full control while driving. Just under 16% of the 618 respondents said they would rather ride in a completely self-driving vehicle[2]. This hesitation to utilize SDCs is not unfounded [21, 22, 12]. In fact, Howard and Dai identified five challenges to the adoption of SDCs including: lack of a robust legal and regulatory framework, cost of technology and it's result on economic equality, control and trust, privacy, and safety [7]. Driving autonomous vehicles with adaptive and personalized features is a key technological challenge that can improve some of the aforementioned problems [4, 13, 14, 16].

1.1 Trust and Levels of Autonomy

Human trust in AI or autonomy is a major theme seen throughout the literature on autonomous system adoption [5, 2, 15, 1, 20, 18]. The focus of our paper is to explore this trust/distrust and determine if there is a relationship between a person's driving behaviors and their expectations of the driving behaviors of a SDC. A definition of trust is needed in order to investigate trust in relation to driving behaviors and expectations of SDCs. Lee and See [10] define trust as "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability." Another more detailed definition of trust is an entity that will act with benevolence, integrity, competence, and predictability [11]; *Benevolence* means the entity will act in the subjects interest rather than acting opportunistically; *Integrity* means the entity will fulfill what it promises to do; *Competence* means the entity has the ability, expertise, or authority to do the task at hand; and *Predictability* means the actions of the entity, whether good or bad, are consistent enough that they can be forecasted in a given situation. Based on this definition, in order for a person to trust a SDC, the passenger will expect the SDC to act in the best interest of its passenger and keep them safe, i.e., to perform autonomous driving tasks successfully, and to operate consistently so that the passenger can predict the SDC's actions in most driving situations. The SAE International standard J3016 defines six levels of autonomy as follows:

- Level-0 - No Automation: The human controls the system 100% of the time.
- Level-1 - Driver Assistance: The vehicle must have at least one advanced driver-assistance feature, e.g., adaptive cruise control or lane-keeping assist.
- Level-2 - Partial Automation: The vehicle has two or more advanced driver assistance systems that control speed and acceleration, steering, and braking.
- Level-3 - Conditional Automation: The vehicle is capable of taking over full control and can operate for selected parts of a journey. However, conditions must be ideal and human supervision is needed to take over in case of failures.

1 https://www.continental.com/en/press/initiatives-surveys/continental-mobility-studies/mobility-study-2013
2 https://news.umich.edu/vehicle-automation-most-drivers-still-want-to-retain-at-least-some-control/

- Level-4 - High Automation: The vehicle can complete an entire journey without human intervention. In rare situations, a human may need to intervene.
- Level-5 - Full Automation: A vehicle does not require any human intervention and can operate under all circumstances.

Trust is essential from levels 1 through 5 as the car starts to take over operational tasks. SDCs at level 2 and 3 are at transition levels between the driver having full control over all the car's functions to the car having full control over all the car's functions. Levels 2 and 3 is where we see the most interaction between the driver and the autonomous system in terms of operation. At these levels, the human driver is expected to make decisions with the system, interact with the system, and at times take over the system. The trust at these levels depends on communication and mutual understanding. Because of this, one hypothesis for the distrust in SDCs is that the user does not understand why the car is making certain decisions, and therefore the user cannot predict what the car will do in various driving situations [8]. If the user is expected to interact with the system but cannot anticipate the car's actions, it is likely that the user's trust will decrease. According to Butakov and Ioannou [4], "The closer the automated vehicle dynamics are with those of a manually driven vehicle, the more likely that the comfort level of the automated vehicle user will improve."

1.2 Our Motivation and Contribution

There are two approaches to tackle the aforementioned problem. First is to design a SDC that mimics real human driving behaviors, more specifically, mimicking the driving behaviors of the actual passenger [13]. Second is to control a SDC to be responsive to the driver's emotional state [14, 17, 16] or to control it based on the driver's expectations of the SDC's driving behaviors. A question we hope to answer in this research is: *Do users expect the SDC to exhibit their personal driving behaviors or do they hold different expectations of how a SDC should drive?* Once this question is answered, it will be imperative to design a system that can communicate with the user through a user-friendly interface.

Previous studies that have used surveys and questionnaires to collect empirical data on trust between humans and SDCs have focused more on the users overall feelings towards SDCs and their potential to use them [3, 7, 9]. In contrast, our survey asks the users to report their own driving behaviors in various situations, and then it asks similar questions in the scenario that they are in a SDC and not in control of driving. With this approach, we expect to find certain profiles of drivers and explore the possibilities of there being a difference between users' own driving behaviors and the expectations of driving behaviors of SDCs.

The rest of this paper is organized as follows. In Section 2, we review some remarks and important observations in existing literature. In Section 3, we discuss our research methodology. In Section 4, we present our technical results. Finally, in Section 5, we conclude the paper with remarks and future directions.

2 Remarks in Existing Literature

In a 2015 study, Butakov and Ioannou [4] assert that the two major determining factors in the successful adoption of SDCs are for them to be perceived as safe and comfortable. There are four conditions that ultimately need to be satisfied in order for humans to perceive the technology as safe and useful.

1. The SDC should always perform better than the human driver.
2. While the SDC safely and reliably operates within its limitations, the driver should have a clear understanding of what those limitations are.
3. The driver should know when the SDC is in control and what it will do.
4. The SDC's behavior should be predictable and acceptable to the passenger.

The researchers collected experimental data from a twenty seven years old human driver who made daily trips over the course of four months in a customized vehicle equipped with side-facing radars and front and rear facing LiDAR (Light Detection and Ranging). This experiment illustrated how the autopilot personalization feature can make autopilot behavior more transparent and intuitive to the driver. Overall the driver is able to detect the boundaries and behavior of the autonomous vehicle because the autopilot personalization is mimicking their own driving behaviors. One point to mention is that the researchers assumed the human subject in their study would prefer a more conservative personalization of his own driving behaviors when setting up the autopilot features. This assumption deserves a more in-depth analysis and raises the question of whether humans feel safer in a SDC that drives like them or drives like a more conservative version of themselves. This assumption is explored in more depth in our research, as explained in Section 4.

Goodrich and Boer [6] laid out the same four conditions for safety and usefulness as mentioned in Butakov and Ioannou's research. However, their motivations came from a case study on an automated car following systems whose fundamental design principle was to use the human operator as a template for automation. Through their case study, they demonstrate the need for a human-centered approach in the design of automation and they were able to support the following hypotheses. A human-centered approach:

1. Can improve the users detection of nonsupport situations.
2. Improves the user's evaluation of the system's performance.
3. Facilitates the development of a proper level of trust within the user.
4. Improves the ability for the user to take over control.
5. Enhances safety of the automation theoretically.

They conclude that advanced vehicle system design can benefit from in-depth analysis of driver behavior by constructing a control system that can be perceptible to the human driver. It's worth mentioning that our research is an attempt to get a better understanding of driving behavior and driver's expectations of SDCs in a variety of driving scenarios. Ultimately, this can be used to construct driving models for SDCs.

Finally, in a recent study [20] Shahrdar et. al. designed and implemented a VR-based self-driving car simulator using a realistic driving scenarios captured by 360-degree camera. They recorded the fluctuations of passengers' trust levels through various trust building and trust damaging driving scenarios. The simulation ran for approximately ten minutes and the users were asked to report their levels of trust through the VR simulation in increments of two minutes. Prior to the simulation, participants were also asked sixteen demographic and psychological questions through an anonymous questionnaire. The authors showed that trust levels of human subjects were directly correlated to the driving style of the SDC. They also found that certain demographic attributes such as gender, cultural background, and current attitude toward autonomous driving technology had an effect on the way people trusted the simulated SDC. They later repeated this experiment by using both subjective and objective data collections [16]. We therefore intend to take Shahrdar's et. al. research a step further by asking detailed questions about driving behaviors and expectations of SDC driving behavior. Would the subjects in this research have had a higher trust level if the SDC simulation matched the driving style of the subject? If the subject's performance expectations of a SDC were known before and reflected in the simulation, would this also increase the level of trust in the human subject? Could a simulation model that is trustworthy be constructed based on the demographics of the subject? These are questions we intend to expand upon in this paper.

3 Research Methodology

We surveyed 352 participants that were recruited on social media platforms, PollPool.com, and through e-mails sent out to students and faculty.

3.1 Survey Procedure and Instruments

Participants were told that the purpose of the survey was to gain a better understanding of driving behaviors among the population and how these driving behaviors can be modeled by SDCs. In addition, they were told the survey was completely anonymous, voluntary, and that it would take fifteen minutes to complete. Participants were not offered compensation for responding.

This survey was created in Google Forms and consisted of 46 fixed-response and forced-choice questions. The 46 questions were broken down into three categories: (a) Demographic questions, (b) Personal driving behavior questions, and (c) Questions involving SDCs. With the demographic questions, we collected the following information: age, gender, ethnicity, education, employment status, income, and marital status. The personal driving behavior questions focused on various behaviors such as *speed, lane changing, breaking, acceleration, deceleration, passing other vehicles, signaling, lane preference, and parking.* These behaviors were asked in regards to 4 driving situations such as highway and non-highway roads, driving in a less than perfect weather condition, and driving at night. The final section of the survey was focused on SDC-related questions.

First, the participants were asked about their trust levels to utilize AI or fully autonomous technologies on a fuzzy set of trust states, i.e., *distrust, somewhat distrust, neutral, somewhat trust, trust.* Next, the participants were asked what are their trust levels to utilize a SDC when this technology becomes available using the same fuzzy set of trust states. The rest of the SDC questions were similar to the personal driving behavior questions but from the perspective of the subject traveling in a SDC.

3.2 Quantitative Measurement

In order to examine driving behaviors and the expected driving behaviors of a SDC, we generated a score for each one. These two scores were normalized between 0 and 1 and represented the aggressiveness of the driver or the car. To generate this score, we assigned a numerical value to each answer of each question. The answer was assigned a 0 if the response represented a behavior of a *cautions/conservative* driver, a 0.5 if the response represented a behavior of a *moderate driver*, and 1 if the response represented a behavior of an *aggressive driver*. Table 1 illustrates an example of how each question was coded.

Question: Which best describes your behavior most of the time in terms of speed while driving on: THE HIGHWAY	**Aggressiveness Score**
I typically drive under the speed limit (more than 5 mph UNDER the speed limit)	0
I typically drive the speed limit (with plus or minus 5mph)	0.5
I typically drive over the speed limit (more than 5 mph OVER the speed limit)	1

Table 1. Example of Individual Question Coding.

Once each question was coded using this approach, we summed the answers in each group, i.e., personal driving behaviors and expected driving behaviors of SDCs, and then divided the result by the total number of questions used in each group. To insure that the questions from each section were the same, we combined the numerical values from the highway and non-highway equivalent questions and took the average. After making this adjustment, there were 6 questions used to calculate the *Driving Behavior Aggressiveness* score (DBA) and 6 questions used to calculate the *Self-Driving Car Aggressiveness* score (SDCA). For instance, if participants had a DBA score of roughly 0.9, they would be considered aggressive drivers. Likewise, if participants had a SDCA score of 0, they would be considered conservative drivers or conservative passengers of SDCs.

4 Technical Analyses and Results

We compared the DBA scores against SDCA scores for various categories. We found that overall, most people prefer a SDC that is less aggressive than their personal driving behavior. We highlight specific categories that we compared. We report significant results found within these categories with $p-value<0.05$.

4.1 Trust and Driving Aggressiveness

The first significant comparison we found was between all DBA scores and all SDCA scores with $p-value = 0.000$ calculated using the Mann-Whitney U Test. The summary statistics of these two groups are shown in Table 2. This illustrates that the personal driving behaviors significantly differ from the expectations of a SDC's driving behaviors.

Score	**Median**	**Mean**	**Standard Deviation**	**Min**	**Max**
DBA Scores	0.492	0.482	0.147	0.083	0.925
SDCA Scores	0.417	0.381	0.191	0.000	1.000

Table 2. Summary Statistics for DBA scores and SDCA Scores.

The two histograms illustrated in Figure 1 and 2 show that while the DBA scores have a normal distribution, the SDCA scores were skewed to the left. Based on the summary statistics, the participants from our sample preferred a SDC that was less aggressive than their personal driving behaviors. This may also indicate that people do not trust SDCs compared to the trust that they have in their own driving. In other words, it confirms the apprehension of trust towards self-driving cars as stated earlier.

Fig. 1. Distribution of DBA Scores.

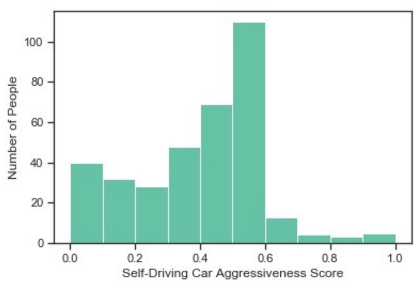

Fig. 2. Distribution of SDCA Scores.

4.2 Gender and Driving Aggressiveness

When comparing Female DBA scores to Female SDCA scores, we found a significant difference between the two scores with $p - value = 0.000$ calculated using the Mann-Whitney U Test. Similarly, we also found a significant difference between male DBA scores and male SDCA scores with $p - value = 0.036$ calculated using the Mann- Whitney U Test. We can conclude that both male and female drivers have expectations of self-driving cars that differ from their personal driving behaviors.

We then compared the DBA scores of female drivers to the DBA scores of male drivers and found a significant difference, i.e., $p - value = 0.004$. Table 3 displays the summary statistics of male and female drivers. From this table, we can see that the average male DBA score and SDCA score are higher than the equivalent scores of an average female driver. We can see that male drivers tend to be more aggressive drivers than female drivers, and therefore, their expectations for a SDC is slightly more aggressive.

Score	**Median**	**Mean**	**Standard Deviation**	**Min**	**Max**
Female DBA Scores	0.475	0.470	0.136	0.083	0.808
Female SDCA Scores	0.333	0.336	0.173	0.000	0.750
Male DBA Scores	0.508	0.497	0.158	0.083	0.925
Male SDCA Scores	0.417	0.439	0.198	0.000	1.000

Table 3. Summary Statistics for Gender DBA scores and SDCA Scores.

To conclude, female drivers are less aggressive drivers than male drivers and while both male and female drivers prefer a SDC that is less aggressive than their personal driving behaviors, a female expects an SDC to be less aggressive than the equivalent male expectations of a SDC, as shown in Figure 3.

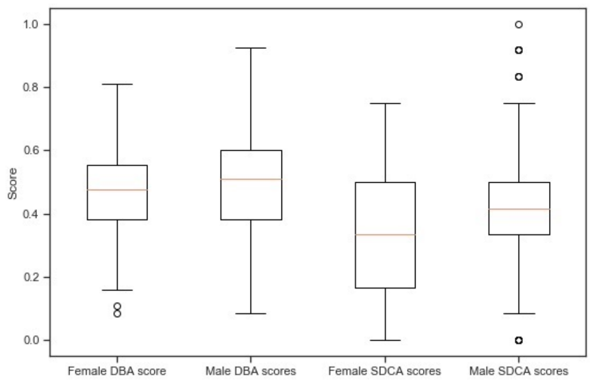

Fig. 3. Boxplot of Gender DBA Scores and SDCA Scores.

4.3 Trust Levels and Driving Aggressiveness

Next, we examine the results from the following questions and separate the results into three trust groups, as shown in the pie charts in Figures 4 and 5.

- What is your trust level to utilize AI or fully autonomous technologies?
- What is your trust level to utilize a SDC when it becomes available?

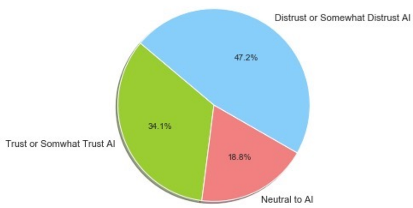

Fig. 4. Trust Levels to Utilize AI/Autonomy.

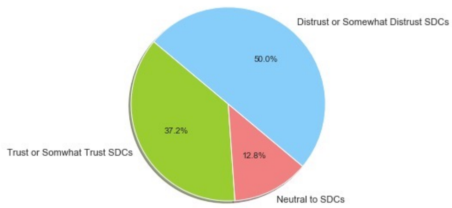

Fig. 5. Trust Levels to Utilize SDCs.

Trust. We compared the DBA scores against the SDCA scores for people that reported trust or somewhat trust towards utilizing artificial intelligence or fully autonomous technologies. We did not witness a significant difference between the two scores for this group. Likewise, we did not witness a significant difference between DBA scores and SDCA scores of people who said they trust or somewhat trust towards utilizing a SDC when this technology becomes available. We can conclude that people who report they trust or somewhat trust utilizing AI, autonomous technologies, and SDCs would want a SDC that exhibits the same driving behaviors as their own. The results are shown in Figures 6, 7, 8 and 9.

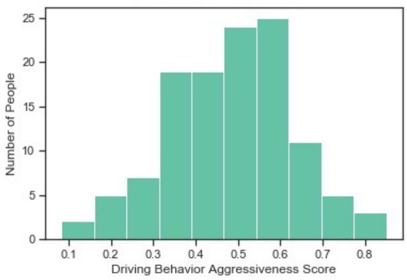

Fig. 6. DBA Scores of People Trusting AI.

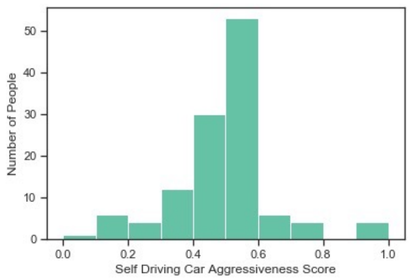

Fig. 7. SDCA Scores of People Trusting AI.

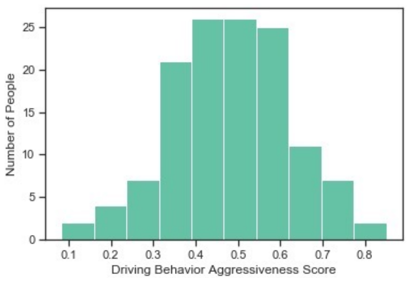

Fig. 8. DBA Scores of People Trusting SDCs.

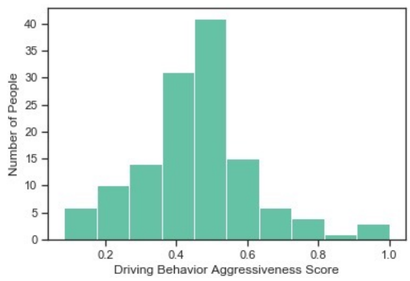

Fig. 9. SDCA Scores of People Trusting SDCs.

Distrust. In contrast, we compared the DBA scores against the SDCA scores for people that reported distrust or somewhat distrust towards utilizing AI or fully autonomous technologies. In this case, we did witness a significant difference, i.e., $p - value = 0.000$ calculated using the Mann-Whitney U Test, between the DBA scores and SDCA scores of this group. Similarly, we found a significant difference, i.e., $p - value = 0.000$ calculated using the Mann-Whitney U Test, between the two scores for people who reported distrust or somewhat distrust towards utilizing SDCs. From this, we can conclude that people who report distrust or somewhat distrust towards AI, autonomous technologies, and SDCs are less trusting of these technologies, and therefore, they would expect an SDC that is less aggressive than their personal driving behaviors. The results are shown in Figures 10, 11, 12 and 13.

Fig. 10. DBA Scores of People Distrusting AI.

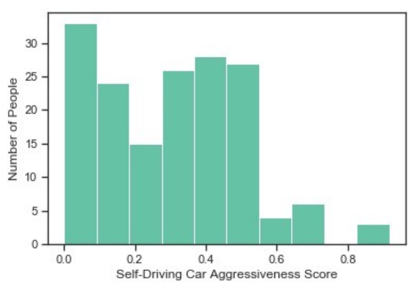

Fig. 11. SDCA Scores of People Distrusting AI.

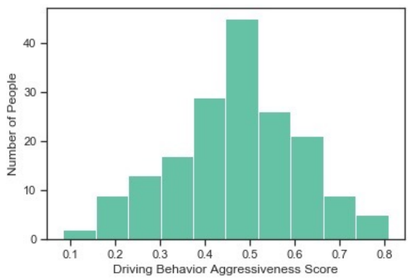

Fig. 12. DBA Scores of People Distrusting SDCs.

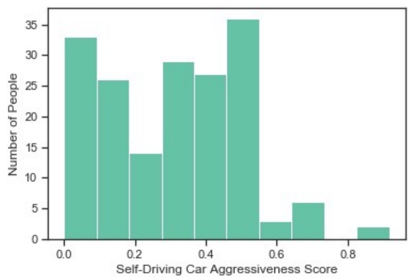

Fig. 13. SDCA Scores of People Distrusting SDCs.

Neutral. As a final comparison, we looked at the DBA scores against the SDCA scores for people who reported being neutral towards AI and autonomous technologies and found that the results confirmed the overall trend in our sample of people expecting a less aggressive SDC. We report a significant difference with $p - value = 0.00003$ calculated using the Mann-Whitney U Test. We also found a significant difference between these two scores for people who reported that they are neutral towards utilizing SDCs with $p - value = 0.0006$ calculate using the Mann-Whitney U Test. In summary, people who are neutral towards AI, autonomous technologies, and SDCs still prefer a SDC that is less aggressive than their personal driving behaviors.

5 Conclusion And Future Directions

Our technical results provide prominent insights into the driving behaviors and the expectations of drivers when it comes to SDCs. We sought to answer the question: Do passengers expect a SDC to exhibit their personal driving behaviors or do they hold different expectations of how a SDC should drive? When looking at the aggressiveness level of personal driving behaviors compared to the expected aggressiveness level of a SDC through the lens of gender, age, race/ethnicity, income and education, most people expect a SDC that is less aggressive than their personal driving behaviors. In other words, a SDC that drives in a way that is more conservative than their personal driving behaviors could be deemed more trustworthy. The SDC's level of aggressiveness is relative to each particular driver's DBA. Therefore, if the driver has a DBA score of 0.5, then an SDC should have an SCDA score that is lower, for instance, 0.4. When looking at male and female DBA and SDCA scores, we observed that female drivers would expect a less aggressive SDC compared to male drivers since female drivers were less aggressive drivers to begin with. This is an example of how the aggressiveness of the SDC is relative to each driver's driving behavior.

We found that current attitudes towards artificial intelligence, autonomous technologies, and SDCs had an effect on their expectations of a SDC. The one group that stood out were those that trust or somewhat trust towards utilizing

AI, autonomous technologies, and SDCs. Their DBA scores and SCDA scores were not significantly different. We therefore concluded that these participants would expect a SDC that drives the same as their personal driving behaviors. The participants that reported distrust or somewhat distrust towards utilizing AI, autonomous technologies, and SDCs prefer a SDC that is less aggressive compared to their personal driving behaviors. This same sentiment was found among the participants that reported being neutral towards AI, autonomous technologies, and SDCs.

The results of our research are in agreement with the results of [18, 20] where the author found that gender and the current attitude toward autonomous driving technology had an effect on the way people trusted a SDC simulator. Our results also confirmed the assumption made by [4] that explored a human-centered approach. Overall, we can conclude that since the DBA scores were significantly different from the SDCA scores on the same driving tasks, and since the summary statistics showed that the average DBA scores were always greater than the SCDA scores, most people prefer a SDC that drives like a more conservative version of themselves. Only those who claimed they trust or somewhat trust SDCs or AI would want a car that matched their personal driving behavior. These results can be considered by engineers, computer scientist, and researchers to design a SDC or SDC simulator that is deemed trustworthy by the user.

The next steps are to create a driving simulator based on our results as well as the calculated DBA score and SDCA score. The simulation would include three different driving profiles for each type of drivers, i.e., conservative/cautious, moderate, and aggressive, and the profile would be set according to the DBA score. The experiment would measure trust levels before and after the simulation. In addition, an appended survey, which asks questions as why the participants trust or distrust these technologies and prior exposures to these technologies, is essential in understanding where this trust or distrust is originating from.

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