Can automated vehicles make passengers happy?

by

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Abstract

This research delves into the transformative potential of self-driving vehicles by investigating their impact on passengers' happiness. As autonomous transportation technology rapidly evolves, understanding the user experience within these vehicles becomes essential. To investigate the happiness of the self-driving vehicles' passengers, which is defined as positive emotions and cognitive well-being during self-driving rides, real-traffic test rides were conducted among 31 participants, companied with two before-ride and after-ride surveys. The study employs a comprehensive approach, combining self-reported survey data and biometric measurements, which includes the participants' heart rate and the eye movement, to investigate passengers' happiness. The results present an overall positive emotions and positive attitudes towards the self-driving vehicle. Moreover, the findings present a notable shift in passengers' attitudes, with originally neutral sentiments transitioning to positive perceptions following the test ride. Participants exhibited various activities during the ride, enhanced comfort with the concept, and an improved satisfaction with self-driving technology. Remarkably, statistical trends suggest that self-driving vehicles hold the potential to alleviate stress and optimize time management, positively impacting passengers' overall well-being. Furthermore, biometric data of the participants presented participants' different physical reaction on different traffic scenarios and indicated the happiness and well-being of the participant. The research emphasizes the broad implications of self-driving technology on individual happiness, concerning both emotions and attitudes, extending beyond functional enhancements to encompass passenger happiness and societal integration.

Keywords: Self-driving vehicle, user experience, passengers' happiness.

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1 Introduction

1.1 Research Background

The fast development of autonomous vehicle technology has allowed us to witness the operation of self-driving vehicles on public roads, these vehicles are having high level of automation like level 4 or level 5. The leading big technology companies in the self-driving vehicle field, for instance Waymo, Tesla, Baidu, Cruise have developed such vehicles and put them into use on public roads available for the public (Sunny Betz, 2023; Tekedra Mawakana & Dmitri Dolgov, 2023). These vehicles radically change the task of driving, transforming the driver into a passenger who can engage in secondary activities, such as personal tasks or entertainments, contributing to a decrease in workload and an increase in relaxation. Meanwhile, automated vehicles could create a positive and relaxing atmosphere by playing music or adjusting the lightening, etc (Lekach, 2019). It is promising to assume that self-driving technology will soon become mature and ready to be widely used in the future.

Hence, the potential of these vehicles to contribute positively to the well-being of its passengers is enormous. However, it is still unclear whether the passengers will accept and be willing to use such new technology. Passengers must trust that these new vehicles will prioritize their safety and well-being, assuring them of a smooth and enjoyable journey before they are ready to try them. And research shows that the acceptance of automated vehicles decreases with the increase of autonomous level (Hewitt et al., 2019), users displayed significantly lower intention to use highly autonomous vehicles (Hewitt et al., 2019). Hence, even if automated vehicles could promise traffic efficiency and convenience, the acceptance of automated vehicles by passengers remains unclear.

Moreover, public acceptance of automated cars is subject to technology evolves, acceptance was gradually increasing as people became more familiar with the technology and its potential benefits. And researchers (Ettema et al., 2011; Koch et al., 2021; Singleton, 2019) argued that well-being is a higher-order need that users strive to fulfil when using automated vehicles, after the more basic-needs, such as trust, safety, efficiency, comfort, are fulfilled. The capability of automated vehicles to improve user's well-being could be an important factor that determines the extent to which users will accept this technology. Hence, the successful integration of new transportation technologies will not only depend on their technical progress but also on their ability to cater to the needs and desires of the passengers, fostering a sense of satisfaction and happiness during their travels.

Meanwhile, there have been growing calls for prioritizing the overall well-being and happiness of people instead of solely pursuing economic gains to. Improving the well-being and happiness of individuals can lead to increased productivity, stronger social connections, better physical and mental health, economic benefits, and improved education outcomes, ultimately fostering a thriving and prosperous society (Azar & Haddad, 2021). With the prevalence of depression and other mental health issues affecting a significant number of individuals (World Health Organization, 2021, 2022), there is anticipation on the potential of emerging technologies to provide innovative solutions. These technologies can offer personalized interventions to both physical and mental health, and empower individuals in self-management, thereby potentially relieving the burden on healthcare systems while improving the overall well-being of the general public. Self-driving vehicles, which free the user from the driving tasks and offer positive interventions, for instance providing personalized entertainment or adjusting in-vehicle atmosphere, have the potential to significantly enhance the happiness of the users. However, the potential of self-driving vehicles to improve the well-being of its passengers, has not been investigated yet and this is the gap which this research aims to address.

Research has shown commuting by car was considered stressful (Koch et al., 2021). And such stress is not only influencing the riding experience itself but may also affect traveler’s efficiency at work and even daily life quality (St-Louis et al., 2014). These means that vehicles serve as crucial instruments for sustaining passengers' positive moods during the ride, as they offer an opportunity, particularly self-driving vehicles, for users to engage in various activities such as reading, working, or leisure activities (Conceição et al., 2023). Self-driving vehicles may enhance the overall travel experience and potentially reducing stress and anxiety related to driving responsibilities, leading to improved happiness and a more enjoyable commuting experience (Singleton, 2019; Ye & Titheridge, 2019).

Hence, my thesis intends to investigate to what extent the use of self-driving vehicles impact the happiness of the passengers.

1.2 Problem Description

As stated previously, understanding whether the user accept and enjoy the autonomous vehicles are the prerequisites for the development and wide application of them. Previous research has discussed comfort, safety or the mental workload in the sense of improving the acceptance and trust of AVs to the general public (Hartwich et al., 2018; Luger-Bazinger et al., 2021; Moody et al., 2020; Niermann et al., 2021). Despite such growing interest in autonomous technology and its user experience, little is known about how the use of self-driving vehicles affects the happiness and overall well-being of its passengers, especially the fully automated vehicles' passengers. Assuming the eventual realization of self-driving vehicles, there is a need to shift research attention towards the happiness and well-being of the self-driving vehicles' passengers, in addition to their improvements on traffic safety and efficiency. Otherwise, the development of automated vehicle technology can only limitedly improve the acceptance of the public.

Moreover, how passengers' happiness can be defined, measured, and modelled is unclear. Research in this domain remains sparse, and implications of how self-driving cars can positively contribute to passengers' well-being are not yet fully understand. It is important to address this gap as it holds the key to enhancing the overall travel experience and ensuring that automated vehicles cater to the emotional needs and contentment of their passengers. Existing studies mainly use questionnaires to investigate individuals' attitudes and acceptance of automated vehicle (de Winter & Nordhoff, 2022; Nordhoff et al., 2020). Other studies used driving simulators to test individual responses and reaction in the automated vehicle' ride(Sahar et al., 2021).

However, current research rarely uses real traffic experiments to investigate individuals' experience with self-driving vehicles. Although the real-traffic ride is a powerful measure to give the individual an authentic experience, indeed, current technology can hardly provide an adequately safe and reliable self-driving vehicle for real traffic tests. Safety concerns, unpredictable road conditions, ethical problems and the need to ensure the well-being of passengers and other road users are the challenges associated with conducting large-scale real traffic experiments at the current stage.

Despite the current limitations, the pursuit of real traffic testing remains crucial. As technology progresses and regulatory frameworks evolve, conducting real traffic experiments will become essential in understanding how passengers truly interact with autonomous systems, gauging their comfort, trust, and overall satisfaction. When it comes to this research, a 'pretended' self-driving vehicle will be used, which is manually driven but provides the passenger a self-driven feeling. By using this test vehicle, we can 'persuade' the participants they are on a self-driving vehicle without putting them in dangerous situations as well as collecting valuable data about the reaction and evaluation of the participants towards the self-driving vehicle.

1.3 Research Objective

This research aims to investigate the happiness of the automated vehicles' passengers with real traffic experiment. The experiment will use both the self-reported measurement and biometric measurement to analyze passengers' happiness and the influence of the potential factors on happiness.

Understanding whether the passengers are happy with self-driving rides and what factors contribute to passengers' happiness, such as interventions, demographic factors or road type factors, etc. may provide valuable insights that enable policymakers, engineers, and designers to create future transportation solutions that do not only prioritize safety and efficiency but also foster a profound sense of joy and satisfaction among passengers during their journeys. Furthermore, the results of this research will reveal the connection between the self-driving ride experience and the happiness or satisfaction of the passengers, and since happier passengers may be more likely to choose automated vehicles over traditional modes of transportation (Hartwich et al., 2018), this research may give positive guidance to the adoption of this technology.

1.4 Research Questions

This research study aims to address the following research questions, which seek to investigate the happiness of the passengers in the self-driving vehicle and provide insights into the relationship between the real traffic ride and the passengers' experience.

Main research question: To what extent can automated vehicle, specifically self-driving vehicle help to improve the happiness of the passenger?

To answer the main research question, the following sub questions are formulated:

Sub research question:

(1) How to define the happiness of self-driving vehicle's passenger?

(2) How to measure the happiness of self-driving vehicle's passenger?

(3) What factors could influence the happiness of self-driving vehicle's passenger?

(4) To what extent can these factors influence the happiness of self-driving vehicle's passenger?

(5) To what extent can a ride in a self-driving car influence the happiness of the passengers?

The first two sub-questions are answered by doing the literature research, during which the passenger's happiness will be conceptualized. The third sub-question is answered with both the literature research and experiment result. The experiment includes a real-traffic test ride in the self-driving vehicle with one before-ride survey and another after-ride survey. After the experiment and data analysis, the rest two sub-questions can be answered. Finally, the research can answer the main research question, whether the self-driving vehicle can improve the passenger's happiness, and if yes, how much can it contribute to the passenger's happiness.

1.5 Research Scope

This study delves into a comprehensive exploration of passengers' happiness in self-driving vehicles, encompassing a range of dimensions within the user experience and well-being of individuals. The primary objective is to define and measure the happiness of self-driving vehicle's passengers. It also examines various potential factors that may influence passengers' happiness, as well as the extent these factors could affect happiness.

It's important to note that while this study tries to offer a comprehensive analysis, it does not encompass the investigation of acceptance of the self-driving vehicles. Although analyzing the happiness of self-driving vehicle passengers could somehow reveal the acceptance of passengers and the potential methods to improve the acceptance, this research limits the scope and analyzes the problem within the context of happiness and wellbeing.

In summary, the research scope of this study encompasses an examination of happiness and wellbeing of the passengers in self-driving vehicle. This exploration extends to various dimensions while adhering to the selected methodology and predefined boundaries.

1.6 Terminology and Definitions

To answer the research questions, some concepts and terminologies need to be explained first.

Self-driving vehicle and automated vehicle: An automated vehicle is a vehicle that can operate without direct human intervention. These vehicles can sense their environment, interpret data, make decisions, and control their movement, aiming to provide safe and efficient transportation while reducing the reliance on human drivers. In this research, self-driving vehicle refers to the fully automated vehicle, which is the automated vehicle in the highest level of automation (level 5). In this research, a ‘pretended’ fully automated vehicle will be used to collect the participants’ reaction during their ride, as well as provide a scenario where they can consider their evaluation towards the vehicle and the ride. In the literature review part, the term ‘automated vehicle(s)’ will be applied for a more general description of the research target. In the methodology and result analysis part, since the experiment was operated on the assumption that the vehicle is self-driven, the term self-driven vehicle will be used.

Passenger in the self-driving vehicle: In the context of fully-automated vehicle, the driver is no longer needed. Hence, all the users in the vehicles are the passengers. Hence this research focus on the passenger’s experience and happiness of the ride and towards the vehicle.

Happiness of the passenger: The happiness of the passenger in this research is defined broadly, it is construct with the emotional happiness and the positive evaluation towards the vehicle and their life. The well-being is included in the happiness in this research.

1.7 Thesis Outline

This thesis is structured to provide a cohesive and comprehensive analysis of happiness of self-driving vehicle’s passengers which follows the following outline:

1 Introduction: This chapter introduces the research background, highlighting the significance of passenger’s happiness analysis. It outlines the research problem, objectives, and the broader scope of the study.

2 Literature Review: In this chapter, a thorough exploration of existing literature is undertaken to establish the theoretical foundation. It synthesizes the happiness and well-being related topics, the measurement of participants physiological and psychological conditions, and the potential factors influencing participants' experiences in previous studies to generate the conceptual framework. The conceptual framework forms the basis for the methodology development and give answers to sub-research-questions.

3 Methodology: This chapter details the research approach, outlining the chosen methodology, experiment method, data collection methods, and data analysis techniques. It justifies the selected methodology and discusses its appropriateness for addressing the research questions.

4 Data collection: In this chapter, the collected data is presented, and primarily interpreted.

5 &6 Results and Discussion: Results are presented and interpreted. Findings are discussed in relation to the research questions and relevant literature. Visualization graphs and tables are utilized to enhance the presentation of results. Moreover, interpretation and discussion of the results are made building upon the findings. The implications of the findings are explored in relation to the research objectives and connections are drawn to existing literature.

7 Conclusion and Recommendations: The final chapter summarizes the study's key findings and their implications. It answers the research questions and discusses the study's contributions to the field. Based on the findings, recommendations for practice and future research are provided.

Reference and appendices: In this section, the bibliography will be added. Supplementary materials, such as the consent form, the full survey, additional data, and visualization charts, are included in the appendices.

2 Literature Review

2.1 Happiness of the Automated Vehicles' (AVs') Passengers

Happiness is often defined as a positive emotion or a pleasurable feeling, but it can also refer to a broader sense of satisfaction and fulfillment with one's life. The happiness of the people is a well-discussed topic in many areas. For example, in the field of sociology and economics, the happiness is often defined as the overall quality of life and healthy social relationships and social connectedness. Gross National Happiness (GNH) is a good index to measure the collective happiness and welfare of on a national scale ('Gross National Happiness', 2023). In the field of engineering and designing, happiness is often defined in terms of user satisfaction and positive experience of the products and systems. In the field of travelling, there is the Satisfaction with Travel Scale (STS) (Ettema et al., 2011), which includes both affective and cognitive components to measure the people's satisfaction with travel. The STS analysis the affective satisfaction of the traveler on two dimensions: the positive deactivation–negative activation (e.g., feeling time pressed or relaxed), positive activation–negative deactivation (e.g., feeling tired or alert). There is also discussion on the effect of the transport on mental well-being (Conceição et al., 2023), where the reviewed papers take into account various constructs related to mental health, including affective states (emotions and mood), well-being and satisfaction with life or travel, stress and mental workload, and mental health disorders.

But when it comes to the field of automated driving, the happiness of the automated vehicle user is limitedly discussed. Research focused on the automated vehicle acceptance (de Winter & Nordhoff, 2022; Dimitrakopoulos et al., 2021; Jing et al., 2020; Kaye et al., 2021) in the intention to increase its acceptance and usage, then further improve the technology utilization, traffic efficiency and safety. But the impact of automated vehicles on society can extend beyond this: as automated vehicles, along with other promising new technologies, continue to develop, they hold the transformative power to elevate people's overall well-being and potentially revolutionize entire societies (Azar & Haddad, 2021).

By investigating automated vehicles in enhancing happiness and passenger experience, researchers gave valuable insights that beyond its technical functionality. The advent of autonomous driving presents a unique opportunity to redefine transportation experiences, where passengers can reclaim time typically spent on driving and allocate it to more fulfilling and enjoyable activities (e.g., working, studying, eating) (Meyer et al., 2017; Singleton et al., 2020). In a future where AVs are seamlessly integrated into daily life, stress and frustration associated with commuting could significantly reduce, leading to improved mental well-being and overall satisfaction (Azar & Haddad, 2021; Dean et al., 2019). Moreover, the positive implications of automated vehicle extend to broader societal aspects: the potential for reduced traffic congestion, improved road safety, since automated vehicles could curtail human lapse (Dean et al., 2019), increased accessibility for individuals with mobility problems, these can contribute to a more inclusive and harmonious society (Yurtsever et al., 2020). Research also revealed that interventions like meditation and playing the music, which are the simple examples of what automated vehicle can provide, could improve the drivers' mental condition during the ride and their overall well-being (Koch et al., 2021; Magaña et al., 2020). With automation technology evolves and matures, it will even encourage innovative changes in urban planning and infrastructure, fostering more sustainable cities with enhanced livability in the future (Yurtsever et al., 2020).

Even though the potentials of the automated vehicle have been investigated and proposed by different researchers, the direct discussion between automated vehicle and the passenger's happiness is limited, whether these potentials can bring convenience and happiness to its user remains unknow. Referred from previous literatures (Conceição et al., 2023; Ettema et al., 2013), this research aims at investigating the happiness of automated vehicle passenger, where the happiness is constructed with passenger's mental state and the cognitive evaluation on the automated ride and the vehicle. It is unsure how much improvement, in the sense of happiness, can automated vehicle bring to the passengers after the ride.

Present research has demonstrated that individuals are more likely to persist in using a transport mode if they have had positive experiences while traveling on it (Ettema et al., 2016). Consequently, providing delightful and gratifying experience with automated vehicles to the public can undoubtably boost their popularity and lead to increased acceptance and adoption. Furthermore, by prioritizing passenger happiness and satisfaction as a core objective in the development of automated vehicle technology, we have the potential to shape a future where transportation go beyond its function of sending us to our destinations. Instead, it turns to enhance our overall quality of life, offering not just efficient mobility but also moments of relaxation, productivity, and enjoyment during our journeys.

As technology move forward, it becomes essential to prioritize the human-centric aspects of automated vehicle design. This ensures that every automated vehicle ride becomes a delightful and cherished journey of our daily lives.

2.2 The Measurement of Passengers' Happiness

The happiness of automated vehicle passengers is limitedly discussed, and direct measurements of passengers' happiness are currently not readily available. Nevertheless, existing scales and measurements related to user experience in various contexts can be referred, such as travel satisfaction, perceived utility of the technology, and ease of use (*Technology Acceptance Model (TAM)*, n.d.). By applying these established evaluation tools, we can gain valuable insights into passengers' happiness within the context of automated vehicles. By merging diverse user experience measurements and scales, researchers can gain insight on the relationship between automated vehicle technology and passengers' emotional well-being. As the understanding of passengers' happiness in this context matures, it will contribute significantly to enhancing the design, and acceptance of automated vehicles.

In general, the measurement can be classified into self-reported measurement and the biometric measurement. The self-reported measurement uses the survey and questionnaire to investigate the participant's feelings and attitudes. While the biometric measurement uses physiological or behavioral indicators, e.g., heart rate, eye movement to investigate the participant's physical reaction.

2.2.1 Self-reported Measurement

The self-reported measurement generally refers to the survey and interview, which is the most common method to measure ones' subjective feelings in automated vehicle related topics (Azad et al., 2019).

Surveys have proven to be particularly valuable in investigating various aspects of user experience in different contexts, including travelers' satisfaction with transportation systems and t (Ettema et al., 2011; Fan et al., 2021; St-Louis et al., 2014), users' acceptance on the AVs (de Winter & Nordhoff, 2022; Kaye et al., 2021; Nordhoff et al., 2020; Zhang et al., 2019), drivers' or passengers' perceived safety and comfort in AVs (Niermann et al., 2021; Nordhoff, Stapel, et al., 2021; Salonen, 2018).

Some research only uses the survey to get the participants' feelings towards a given technology, but some research asks the participants to do the survey after experiencing the technology, e.g. riding in a driverless shuttle, driving a partially automated vehicles or riding in a driving simulator etc. (Hartwich et al., 2018; Koch et al., 2021; Luger-Bazinger et al., 2021; Salonen, 2018). This approach allows researchers to obtain more nuanced and authentic insights, as it captures users' impressions immediately after interacting with the technology, yielding a wider understanding of their actual experiences and perceptions.

Besides the surveys and interviews, self-reported device is also applicable to measure the participants' subjective feelings, e.g., the grip measurement which enables the participant to press and report their self-reported stress level (Niermann et al., 2021; Sahar et al., 2021).

2.2.2 Biometric Measurement

In addition to self-reported measures, biometric or physical measurements are another valuable method commonly used to assess participants' subjective feelings. This approach provides a more objective and physiological perspective, offering specific data such as heart rate parameters, eye movement parameters, blood volume pulse, facial expressions etc.

- **Cardiovascular Measurement**

Combining cardiovascular parameters include the heart rate (HR), heart rate variation (HRV), which can provide valuable insights into people's cardiac function, autonomic nervous system activity, and cardiovascular health. The heart rate and heart rate variation can be applied to assess discomfort, stress level or other user experience related topics in automated driving. For instance, heart rate increased significantly when the participants were in discomfort (Beggiato et al., 2018). Heart signal (mainly the HRV) and skin conductivity can be applied to measure the drivers' stress level, and investigate the impact of different factors on the driving behavior and driving stress (Magaña et al., 2020). The heart rate can also be applied to predict aggressive driving styles, combining with vehicle dynamics parameters (Meseguer et al., 2018). Result showed slightly higher heart rate for the aggressive driving behavior and the quiet behavior. Moreover, the overall heart rate in the long term could be a good indicator for wellbeing, since it is negatively correlated with self-reported health and negatively associated with life satisfaction (Blanchflower & Bryson, 2021).

- **Eye movement Measurement**

Eye tracking is one of the promising measurements to investigate one's emotions and feelings (Lim et al., 2020). It collects user's visual focus and determine the point of gaze, gaze duration, blink and blink duration, pupil size etc. to pinpoint what is attracting the user's attention and observe their subconscious behaviors (Lim et al., 2020). This technique allows researchers to gain valuable insights into the user's visual attention and engagement, and provides objective data that complements self-reported measures, offering a more comprehensive analysis of user experience.

In general, people would blink less when visual information is more important to the him/her (Ranti et al., 2020), i.e., keep observing the situation and surroundings (Andrychowicz-Trojanowska, 2018; Reinolsmann et al., 2023). In the case of self-driving vehicle ride, a lower blink rate indicates a deeper concentration on the road and surroundings. Similarly, the higher fixation rate indicates a higher engagement and attention on the road during the ride. Longer eye fixation durations indicate difficulties in extracting information (Andrychowicz-Trojanowska, 2018). The fixation rate also increases with age and driving experiences, as experienced drivers showing greater sensitivity (Fancello et al., 2021; Underwood et al., 2003). Research also found that the gaze pattern of pedestrians changes with the decrease vehicle's distance: their gaze gradually shifts from the road or the surrounding environment to the vehicle when it was getting closer (Dey et al., 2019).

However, the happiness of the participants cannot be directly measured through these biometric measurements. Even the potential factors, e.g., the comfort, the perceived safety or the stress of the participants are not directly measured but derived from these measurements. The connection between the biometric data and the passengers’ happiness is still unknown.

By capturing these biometric data, researchers gain deeper insights into individuals' physiological responses and emotional states, complementing the subjective information obtained through surveys or interviews. Biometric measurements provide information about participants’ emotional and physiological reactions that might not be self-reported. Integrating both self-reported and biometric measures create a comprehensive and multi-dimensional approach to analyzing user experience, in this case the happiness of passengers. Nevertheless, it is essential to handle biometric data with strict privacy and security measure, and proper data protection are necessary to ensure that individuals' biometric data is safeguarded against unauthorized access or misuse.

2.3 Factors Influencing the Happiness of Automated Vehicle’s Passenger

There is a wealth of research proposing factors that relates to the individual feelings and well-being in the automated vehicle’s experience. The factors may not be directly related to the happiness, but to the automated vehicle’s comfort, the subjective safety, or the satisfaction etc. of the automated vehicle’s drivers or passengers.

The driving styles, i.e., whether driving defensively or aggressively, could influence the users' trust and perceived safety towards the AVs' experience (Ekman et al., 2019, 2019; Luger-Bazinger et al., 2021). Meanwhile, different driving scenarios would pose different level of discomfort to the passengers, for instance scenarios with high traffic density, close proximity to other road users, and requiring driving maneuvers would increase the passengers' discomfort (Niermann et al., 2021).

Moreover, traffic characteristic and the travel time are necessary explanations to the satisfaction and well-being of the AVs' users, where the traffic congestion and extended travel time would bring negative emotional feelings to the users (Conceição et al., 2023; St-Louis et al., 2014).

Research also proposed that the demographic factors, including the gender, age, ownership of cars have an impact on perceived AVs' safety and comfort, it is found that young males tends to feel safer on AVs and more optimistic to the application of the AVs (Moody et al., 2020; Nordhoff et al., 2020). The personal attitudes, such as the trust or preference to the new technology may also influence ones' feelings to the AVs' experience (Niermann et al., 2021; Sahar et al., 2021).

Additionally, the in-vehicle facilities or service also have large potentials on improving the drivers or the passenger's happiness and well-being. Entertainments, for instance music, movies or games, and meditations can make the passengers, in the context of fully automated vehicles, feeling relaxed and happy (Koch et al., 2021). In fact, the self-driving technology company, Waymo, has been allowing the passenger to stream music through the in-vehicle screens apart from some basic maps and ride progress, which could enrich the AVs' passengers activities and improve their riding experience (Lekach, 2019).

Hereby, the factors influencing the happiness of the AVs' passengers can be summarized in to following categories: the individual factors, the driving or traffic factors and the in-vehicle factors. However, the relation between the happiness and the individual perceptual factors are limitedly discussed. The perceptual factors, which includes the comfort, the perceived safety, and the mental workload, etc., are generally discussed separately in previous studies. In fact, these perceptual factors could be highly related to the happiness and well-being (Conceição et al., 2023; Fan et al., 2021), and the inter-relations between them deserve further attention.

2.4 Experiment Approach

To carry out experiment on the user experiences in the automated vehicles, different experiment approach can be applied: the visual scenario experiment, the driving simulator experiment, the VR scenario experiment, and the real-traffic experiment, etc.

The visual scenario experiment presents participants with simulated driving scenarios on a screen, including the photos or animations, which allows controlled and repeatable investigation of participant's reaction to specific situations (Lim et al., 2020). Comparably, the driving simulator experiment provides a more immersive experience, providing the participants with a more realistic driving condition. This approach enables researchers to observe participants' reactions in a context that closely resembles real driving, while maintaining a safe and controlled setting (Fancello et al., 2021; Hartwich et al., 2018; Reinolsmann et al., 2023; Schmidt et al., 2016; Zieger et al., 2023).

Moreover, the virtual reality (VR) scenario experiment takes even more immersion by placing participants in realistic and interactive virtual environment, which helps the researcher to gain deeper insights into users' emotional and behavioral reactions. VR experiments enable researchers to assess user responses in highly realistic and potentially challenging scenarios that closely resemble real driving experiences (Dey et al., 2019; Kaye et al., 2021; Tews et al., 2011). The VR experiment could be regarded as part of the simulator experiment, which the researchers can conduct the experiment in safe and controlled environment while providing critical and highly realistic scenario to the participants.

The real-traffic experiment involves studying users' experiences in actual driving conditions on public roads, which offers a direct observation of how participants interact with automated vehicles in real-world settings, providing valuable data on the riding experience, satisfaction and enjoyment, etc. (Nordhoff, Malmsten, et al., 2021; Reinolsmann et al., 2023; Sahar et al., 2021). However, real-traffic experiments have to consider the impact of external factors, for instance traffic conditions, weather conditions and other unexpected events on the experiment results, as these external factors are less controllable compared to simulated experiment environment.

Moreover, conducting a real-traffic experiment introduces safety concerns that demand careful consideration and control measures. The primary concern is to about the safety and well-being of participants, other road users, and the general public during the experiment (Reinolsmann et al., 2023). A thorough risk assessment, including carefully selecting appropriate test locations with controlled traffic conditions, is required to minimize potential risks. Furthermore, careful explanation to participants of the experiment and adequate supervision provided by trained safeguard are essential during the experiment if any safety concerns arise. The safety precautions not only protect the participants but also promised the credibility and reliability of the research findings.

Conducting real-traffic experiments in the context of automated vehicle research is a less applied method but are crucial in advancing understanding and development of automated vehicles (Azad et al., 2019). Firstly, real-traffic experiments offer researchers the opportunity to observe human-vehicle interactions in authentic, unscripted scenarios. Additionally, real-world conditions expose the vehicle to a wide range of driving situations, such as traffic congestion, adverse weather, and unexpected road events, which are challenging to replicate in controlled environments (Beggiato et al., 2018). Meanwhile, the real-traffic test can provide the participants a more immersive experience, which may comfort their concern on the new technology (Ekman et al., 2019). Specifically, a ride in a self-driving car may largely eliminate their uncertainty towards the vehicle and change their attitude towards this technology. Real-traffic experiments are instrumental in bridging the gap between laboratory research and real-world deployment, paving the way for safer, more efficient, and user-friendly automated vehicles on our roads.

2.5 Conceptual Framework

Based on the literatures, the conceptual framework of this research is developed as Figure 1 . The research is theoretically established on three aspects: the definition of happiness, the factors influencing happiness and the measurements of happiness.

Referred from the literatures, the happiness of the passenger is construct by two components: the affective component, which is the positive mental state and the cognitive component, which is positive cognitive evaluation.

The potential factors that could influence the happiness of passengers include the perceptual experiences, which includes the perceived comfort and safety, the workload, etc., individual factors, which include the gender differences, age differences and mental condition differences, etc., external conditions, which includes the traffic conditions, the road type and the weather conditions, etc., and in-vehicle facilities, which includes the entertainment and the environment controls.

The measurement of happiness generally includes the self-reported measurement and the biometric measurement. Self-reported survey functions the primary tool where the participant's emotional state, attitude towards the experience and their demographics can be collect. From the survey results, the happiness of passengers can be roughly seen. Biometric data, however, can collect the participants' physiological reaction, which is not self-reported, and can provide additional information of the participant's emotional conditions and feelings to the survey answers. Integrating both self-reported and biometric measures can create a comprehensive idea to understand the happiness of the passengers.

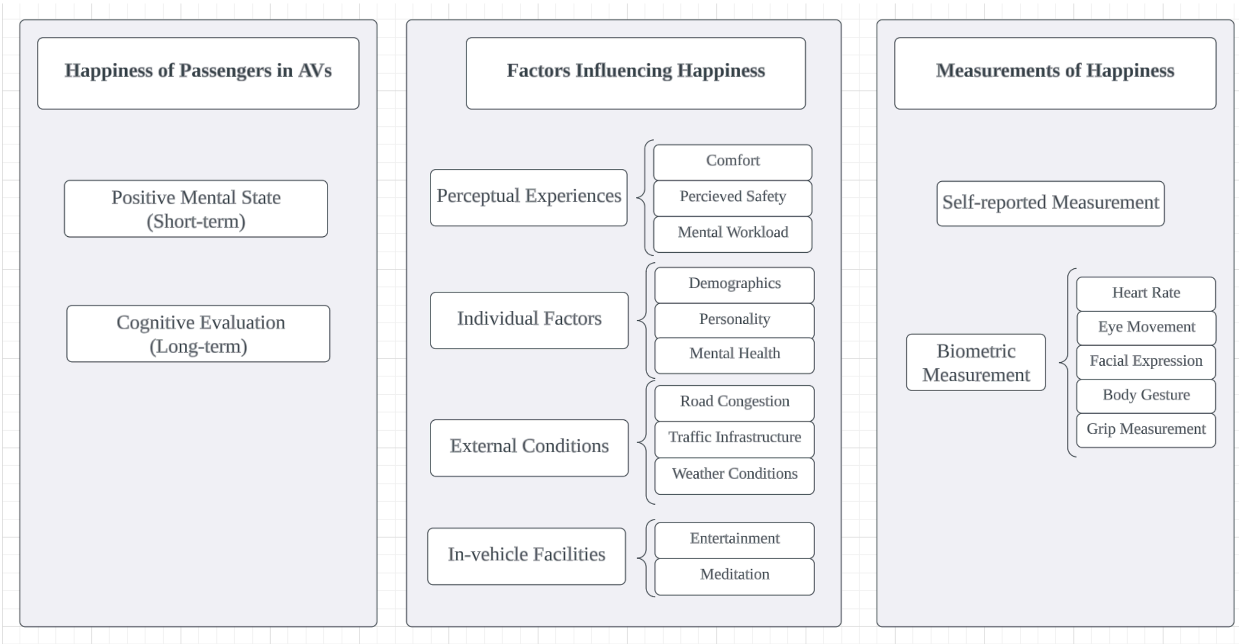


Figure 1 Conceptual Framework

3 Research Methodology

3.1 Research Framework

3.1.1 The Definition of the Happiness of the AVs' Passengers

This research would follow the construction summarized by Conceição et.al., where the happiness of the AVs' passenger could be constructed as the affective states, well-being and satisfaction with life or travel, stress and mental workload, and mental health disorders (Conceição et al., 2023). For the mental disorder, this research considers it as individual factors instead of constructs in this research.

Figure 2 presents the definition of the passengers' happiness in this research, where the happiness is constructed as positive mental state and positive cognitive evaluation towards the self-driving vehicles.

The mental state evaluation scale is derived from the Swedish Core Affect Scales (SCAS) (Västfjäll & Gärling, 2007), which used 6 pairs of bipolar to evaluate the mental state of the participants.

The cognitive evaluation specifically includes three parts: the satisfaction on trip/travel, the usefulness of technology and the willingness to use the technology. The satisfaction on trip/travel scale is derived from the Satisfaction with Travel Scale (STS) (Ettema et al., 2011), which used 3 pairs of bipolar to evaluate the user's cognitive evaluation towards the trip. The usefulness of technology scale, in this research is the usefulness of the self-driving vehicle is derived from the Technology Acceptance Model (TAM), where it represent whether an individual believes that a technology will help them to perform their tasks more effectively or efficiently . The willingness to use (the self-driving vehicle) scale is derived from the Autonomous Vehicle Acceptance Model (AVAM), where it represents whether an individual is willing to use a technology when available.

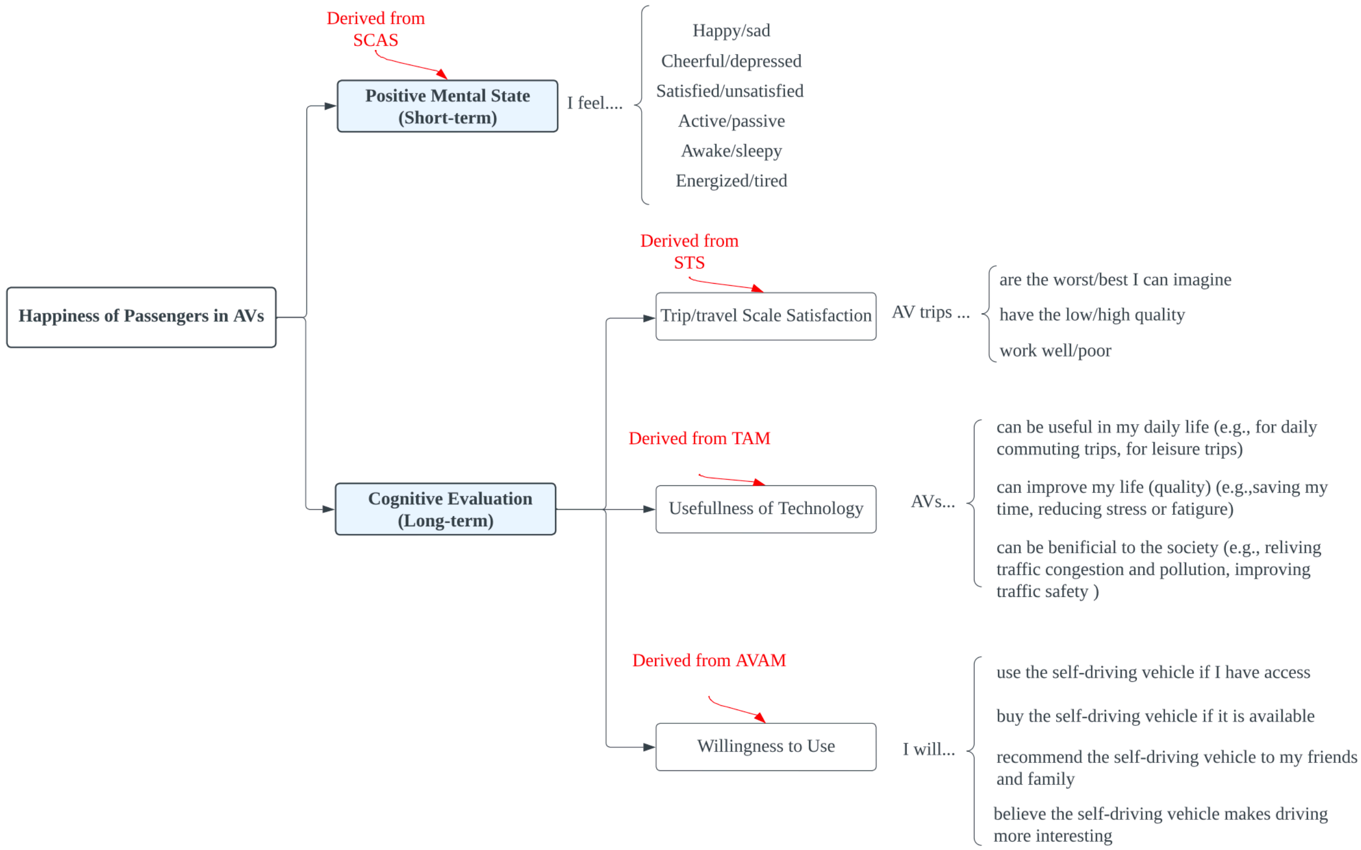


Figure 2 The Definition of Happiness in this Research

3.1.2 The Measurement and Predictor of Happiness

Based on the literatures, the measurement of the happiness mainly includes the self-reported measurement and the biometric measurement. The self-reported measurement uses the survey or interview to obtain the participants' mental feelings and user experiences, which could directly investigate the happiness and well-being of participants.

The biometric or physical measurements, however, cannot directly measure the happiness of the participants but act like indicators or predictors of happiness. In this experiment, the physiological reaction of participants was continuously collected, while participants could only report their happy or uncertain feelings before and after the ride, in other words subjective psychological state is not continuously collected during the ride. Hence, the relation between the self-reported measure and the biometric data is hard to make, and the biometric data cannot directly tell the happiness and well-being of the passengers. Instead, biometric responses of participants were mainly used as predictors to investigate what typical type of scenario could make the participants feeling negative, e.g., feeling stressed, insecure or overwhelmed, etc. The biometric data being collected in this study includes the heart rate and the eye movements (Figure 1).

In short, this study uses a comprehensive approach by gathering both self-reported and biometric data from participants. Participants will engage in two surveys—a before-ride survey and an after-ride survey—offering insights into their mental states and attitudes toward the test ride and self-driving vehicles. The heart rate and eye movement of participants will be monitored throughout the test ride. This research intends to use self-reported data to evaluate the happiness of the passengers and investigate the potential influences of a real self-driving ride would bring, while collecting biometric data to investigate the potential risky scenario which would bring negative feelings to the participants.

3.1.3 The Factors Influencing the AVs' Passengers' Happiness

Based on the literatures, the factors that could influence the happiness of AVs' passengers are summarized into four categories: perceptual experience, individual factors, external conditions, and in-vehicle facilities (Figure 1).

In the literature, the perceptual experience refers to the passengers' subjective feelings including the comfort, the perceived safety, the mental workload, and stress etc. While this research tends to regard these as the happiness itself but not influencing factors, i.e., when passenger feels uncomfortable and insecure, then they are experiencing reduced happiness. Perceptual experience is hard to measure directly, but with biometric measurement it can be indirectly measured.

The individual factors are more about the passengers' demographic or personality factors, including the gender differences, age differences, and the mental health differences. Participants for this study are mainly student hence age difference is hardly recognizable. And the percentage of participants with mental problems is too low to conduct statistical analysis. Therefore, only gender differences will be assessed in this study.

The external conditions refer to the factors out-of-vehicle, which includes the traffic conditions (e.g., traffic congestion, mixed traffic), the traffic infrastructure (e.g., different road sections, the road layout) and the weather conditions, etc. To control the complexity of the study, the traffic conditions and weather conditions should keep as constant as possible between different rides. Different road sections can be extracted from the test route, including the highway, the roundabout, the intersection, and the bridge, which the influence of the infrastructure differences can be investigated.

The in-vehicle factors refer to the entertainments for instance listening to music, watching movies, or playing games, and other relaxation services including taking meditation, enjoying food and beverages. The experiment in this research provided the participants with phone and snacks, to improve the activity variety during the ride.

The final research framework is developed as Figure 3 . Based on the definition of happiness—wherein it includes the union of a positive mental disposition and a favorable cognitive evaluation toward self-driving vehicles—this study launched a real-traffic test ride. In this experiment, comprehensive measurements of gathering both self-reported data and biometric data from participants were employed. These data points not only offer an insight of passenger experiences but also reveal the potential influences that shape the contours of passenger happiness.

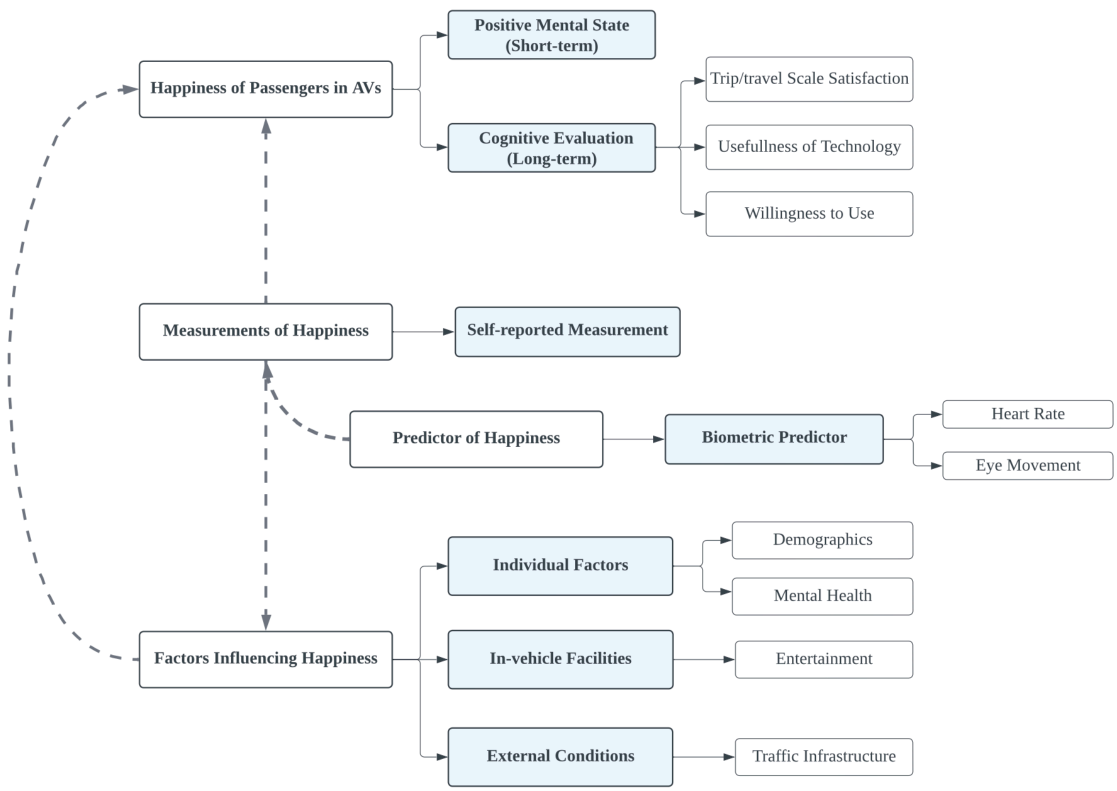


Figure 3 Research Framework

3.2 Experiment Design

3.2.1 Experiment Set-up

This research used the Nissan experiment vehicle (Figure 4) to conduct a real-traffic test ride, aside with two surveys before and after the test ride. The Nissan experiment vehicle was modified to give passenger at the back seat a feeling that the vehicle is self-driven, while the vehicle was actually human driven. The drivers recruited for this experiment were trained to drive the test vehicle in a cautious and stable driving style, which included slower turning and lane change, bigger distance with former vehicle, longer starting time at intersections, etc.

To present the self-driving scenario, three independent screens were installed inside the vehicle to display the real view outside the running Nissan vehicle, and the driver's compartment was separate from the passenger compartment with a physical barrier. The passengers were notified about the driving conditions, whether the vehicle was self-driving or human-driven, through the interactive screen in front of them.

Participants was allowed to communicate with the driver, which was introduced as ‘safeguard’, directly about the concerns and questions they want to. Our drivers were trained to answer the questions as formal but not reveal anything about the operation or algorithms of the vehicle and everything that would reveal that the vehicle is actually a human-drive. In case that the participants were feeling dizzying or sick during the ride, they could press emergency button on the back seat, then the driver would park the car as the nearest safe place and let the participants to take a rest. During the whole experiment procedure, not any participants were feeling uncomfortable and asked for a break during the test ride.

An Wi-Fi-connected phone with basic communication function and entertainments (e.g., games, video player and music player) was equipped on board, as well as some snacks and beverages. Participants can use these facilities at their will.

Figure 4 Experiment Vehicle

3.2.2 Route Selection

The 20-minutes test ride went through the city of Delft, starting from Café Labs, going through N470 highway, den Hoven, Zuidwal and Sint Sebastiaansbrug, then returning to the campus. The exact route is presented in Figure 5 . The car started with “manual mode” and switched to “autopilot” after turning in to the main road. When returning, it returned to “manual mode” after the roundabout on Schoemakerstraat.

This ride in the city of Delft covers different road types in order to investigate the traffic infrastructure impact on the passengers’ happiness. Meanwhile, the traffic conditions and weather conditions were kept consistent between different rides with different participants. In case the disparity, for instance the crowding level, the lightening conditions, would influences the participants experience and furthermore influencing the reliability and consistency of experimental data.

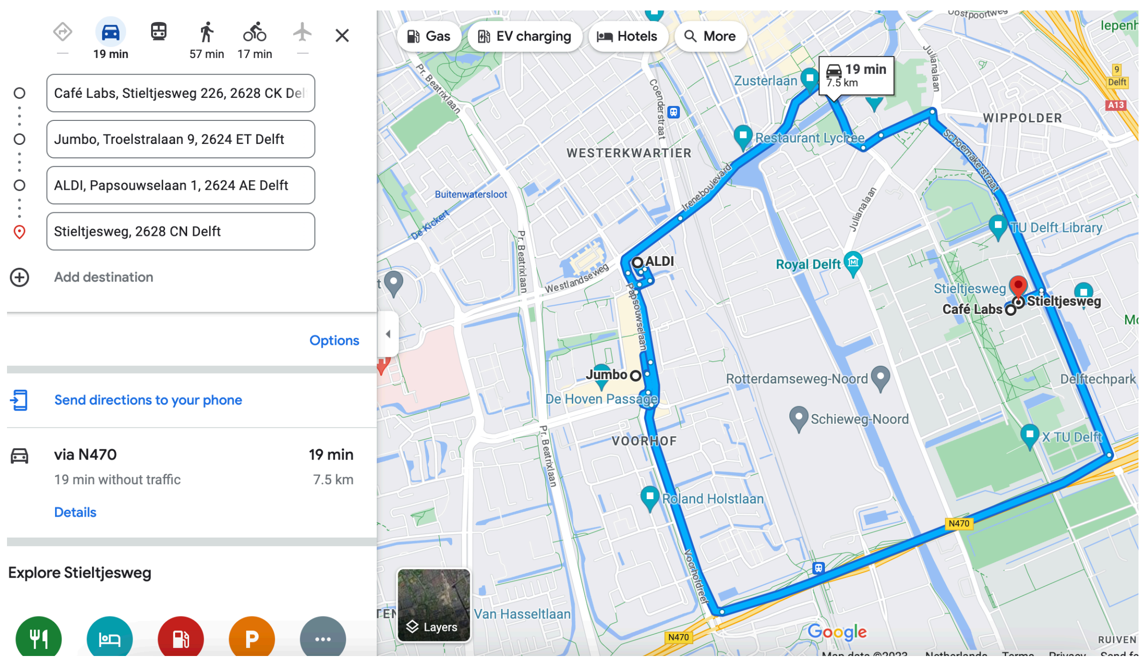


Figure 5 The Test Ride Route

3.2.3 Test Procedure

The experiment took place from May.12th to Jun.2nd at TU Delft campus. On the test day, each participant took a one-hour session. This session included one before-ride survey, a 20-minute ride and an after-ride survey. The test ride was done by the student driver in our “special” self-driving vehicle, which was actually human-driven. The drivers were trained to drive the vehicle like a robot during the self-driving mode i.e., Autopilot mode. We gave the participants the audio signal “Autopilot is on” and “Returned to manual mode” to indicate the driving mode of the vehicle. In case of emergency, for instance the bridge was open or there was a traffic jam, the driver would give the “Returned to manual mode” signal and keep driving.

During the test ride, the participants were not assigned any task, and they could do whatever they wanted. The participants need to wear eye-tracking glasses and a smart band when taking the ride. Since the eye tracker was recording all the ride long, if the participants used their own cellphones, then what was on their phone screen would be recorded by the eye tracker, which would become a privacy issue. Hence, they were provided with another well-equipped phone that they can use to browse the internet or play with during the ride.

3.2.4 Collected Data

In the experiment, the survey data was collected using the online survey platform Qualtrics. For the eye tracker, Pupil Invisible eye tracker was selected as it is in the form of ordinary glasses, which can be worn directly with naked eyes or on the participants' original glasses. It is relatively portable and versatile. Otherwise, glasses-wearing participants need to take off their glasses in order to wear an eye tracker, which will affect their experience and visual perception during the ride. The heart rate data was collected by an Apple watch, this was not the best choice, but the original heart tracker was broken in the last minute before the experiment, and this watch is the best available option. The Apple watch collected the heart rate of the participants with in-constant intervals, for instance two or three data points will be collected within 10 mins.

The collected data and the collecting devices were presented in Table 1 .

Table 1 The Collected Data and its Device

Data	Data type	Collecting devices
Survey data	Demographics, mental state, cognitive evaluation towards self-	Qualtrics surveys

	driving, activities during the ride, etc.	
Eye movement data	Gaze behavior, blink behavior, fixations etc.	Pupil Invisible eye tracker
Heart rate data	Average heart rate	Apple watch

3.2.5 Survey Development

In total, the participants had to take two surveys, one before the ride and another after the ride. The two surveys are almost the same except that the first survey includes the consent form and participant's demographics, and the after survey includes the evaluation on the functionality of the self-driving vehicle. The survey components and example questions are presented in Table 1 , this table does not include all the survey questions and the full survey can be accessed in the Appendix.

The survey was basically developed based on the happiness definition, as presented in the research framework Figure 3 . The terms and questions were adapted from the original version to fit the self-driving vehicle context.

Table 2 Survey Questions Examples

Survey	**Question**		**Question Type**
Before-ride survey	Demographics	What is your age?	Multiple Choice
		What is your gender?	
		What is your level of education?	
		How are your current mental health conditions?	
		…	
Before and after-ride survey	Mental state	How happy are you now?	Slider
		How sad are you now?	
		How sleepy are you now?	
		How dissatisfied are you now?	
		…	
		How much are you agree with:	

<table>
<tr><td rowspan="5">Before- and After ride survey</td><td rowspan="5">Cognitive evaluations on self-driving vehicles</td><td rowspan="5"></td><td>The ride in a self-driving vehicle would be satisfying.</td><td rowspan="5">6-scale Likert</td></tr>
<tr><td>Using the self-driving vehicle would be fun.</td></tr>
<tr><td>The self-driving vehicle would improve my life quality.</td></tr>
<tr><td>The self-driving vehicle would improve riding experience.</td></tr>
<tr><td>…</td></tr>
<tr><td rowspan="2">After-ride survey</td><td rowspan="2">Riding experience</td><td colspan="2">What did you do during your ride?</td><td>Multiple Choice</td></tr>
<tr><td colspan="2">Please rate the level of autonomy you perceived during your ride.</td><td>Slider</td></tr>
</table>

3.2.6 Participants and Recruitment

Participants were mainly recruited within TU Delft campus, i.e., students in TU Delft. The recruitment was done mostly online, a Calendly invite link (Figure 4) was shared into student groups through WhatsApp, Instagram, LinkedIn, WeChat. This research also recruited the participants with the help of student associations. Moreover, a poster was put up on the faculty and library news board (Figure 6).

In total 31 participants were recruited, with 15 male participants and 16 female participants. The demographics and the knowledge level of autonomous driving is presented in Table 3 and Table 4 .The participant pool reflects a range of educational backgrounds, with 11 bachelor students, 18 master students, 1 PhD student. Furthermore, participants display varying levels of familiarity with autonomous driving technology, with the majority of the participants reported themselves as slightly or moderately knowledgeable about autonomous driving.

Table 3 Distribution of Gender and Education State

Gender	Count	Current Education State	Count
Male	15	Bachelor	11
Female	16	Master	18
Non-binary	0	PhD	1
		Non-above	1

Table 4 Distribution of Knowledge Level on the Autonomous Driving

Knowledge on the Autonomous Driving	Count
Not knowledgeable at all	2
Slightly knowledgeable	13
Moderately knowledgeable	10
Very knowledgeable	5
Extremely knowledgeable	1

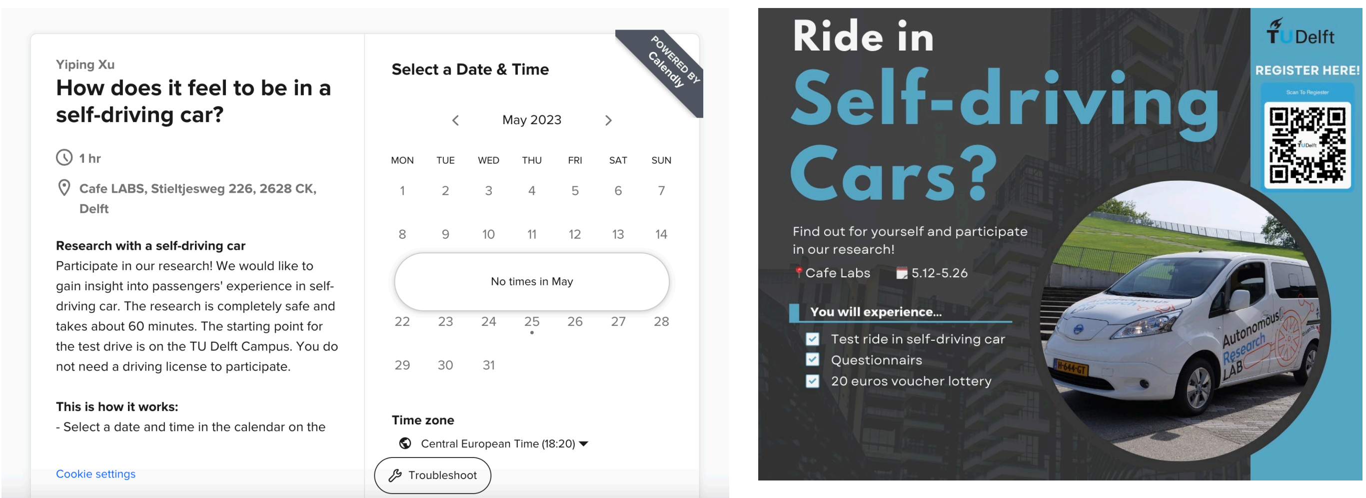


Figure 6 The Calendly Invite Page (All Slots Booked) and the Poster

3.2.7 Ethical Issues

The studies involve human participants, and the ethics concerns were reviewed and approved by the TU Delft Human Research Ethics Committee (HREC). The risks and privacy concerns were indicated in the consent form, which participants had to sign the consent form in order to participate in this study.

4 Data Collection and Analysis

In this section, the collected data from the experiment will be presented. The collected data includes the survey data and the biometric data. Before heading into the data results, the data analysis method and the classification of the road type will be introduced.

4.1 Collected Data Type

4.1.1 The Survey Data

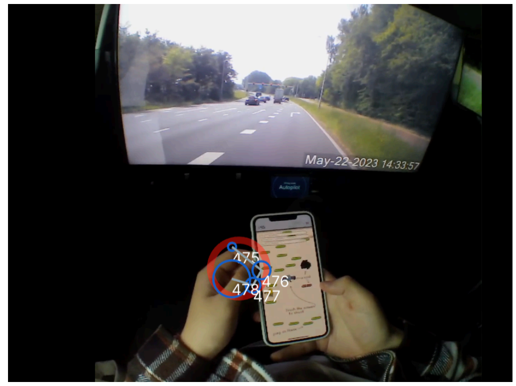
The survey data were collected and stored on Qualtrics, which includes the participants ’mental state and cognitive evaluation towards the self-driving vehicle before and after the test ride. In total, 31 participants response were collected.

The survey data will be visualized using box plots, for instance the distribution of the participants’ mental states before and after the ride. Moreover, the statistical analysis will be employed to understand if the participants’ mental conditions and attitude towards the self-driving vehicle is significantly different before and after the test ride. In the following section, the analysis and results of the survey data will be further presented.

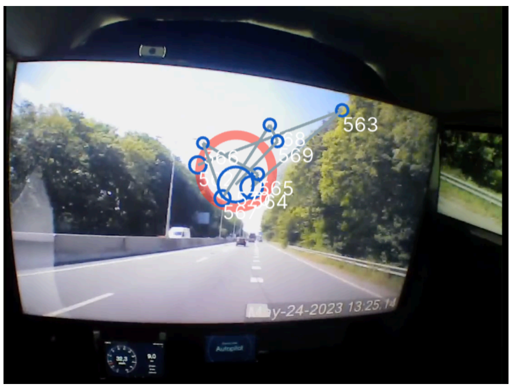
4.1.2 The eye movement data

The eye movement data was uploaded to the cloud storage, where through the online tools, the fixation and blink behavior analysis can be done. The original data, presented in Figure 7 , shows the participants’ attention distribution. The small blue circles are the fixation points of the participants connected with their glance trajectories. The big red circle is the gaze point of the participants. In later analysis, the fixation and blink behavior will be used to investigate the physiological reaction differences between different road sections, which may further tell the potential scenarios that would raise the stress or insecurity of the participants.

(a) Attention on the other cars



(b) Attention on the phone (entertainment)



(c) Attention on the scenery

(d) Attention on the road

Figure 7 Eye Tracker Data Indicating the Participants' Focus

4.1.3 Heart rate data

The heart rate was collected by the Apple watch but imported manually. The data had no fixed collection interval, for instance within a 20 mins ride, only 5-6 heart beats per min were collected. This means that the heart rate is inconsistent and cannot be analyzed simultaneously with the other types of biometric data. Instead, the abnormal heart rate situation will be investigated individually, which may reveal potential triggers of participants' negative feelings.

4.2 Classification of Traffic Infrastructure

In the following section, analysis on the influence of different road sections will be developed, where the test route needs to be classified into several sections. The test route contains different road sections including highway, city road, bridges, and different types of intersections, and four different types were classified: the highway, the roundabout, the road with signalized intersection and bridge, presented in Figure 8 .

(a) Highway

(b) Roundabout

(c) Road with signalized intersection

(d) Bridge

Figure 8 Road Section Classification

5 Results of Self-reported Measurement

In this section, the results from the before-ride and after-ride survey will be presented, which includes the participants' during ride activities, their emotional state, their cognitive evaluation towards the self-driving vehicle and the ride.

5.1 Passengers' Activities During the Ride

Figure 9 presented the engaged activities the participants reported after the test ride, which indicates that every participant enjoyed the scenery outside the vehicle, and more than half of the participants daydreamed during their ride. This suggests that although it is likely the first time they are on the self-driving vehicle, they can have a sense of ease and relaxation beside just observing the operation of the vehicle.

Meanwhile, participants also did a diverse range of activities beyond passively sitting during the ride. Some seized the time to taking short naps and recharge their energy levels. Others use the time to have some snacks or engage with their smartphones, embracing the newfound personal time given by the self-driving vehicle.

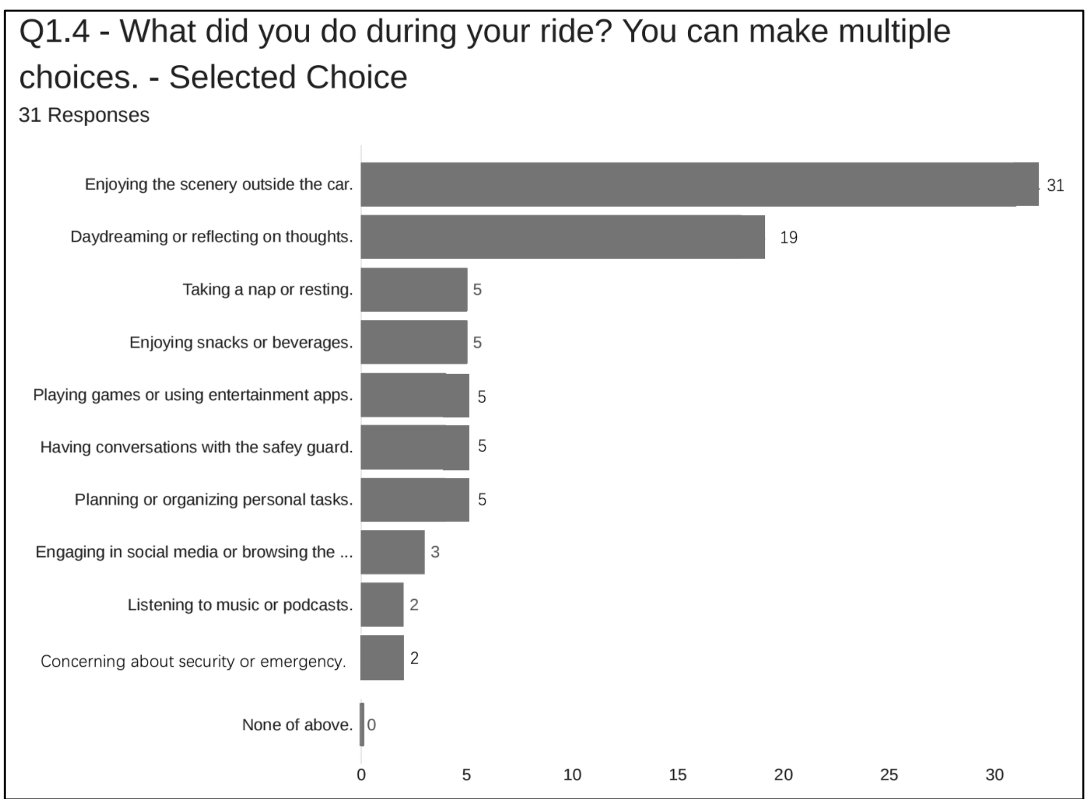


Figure 9 Activity Distribution of the Participants

Table 5 presents the number of activities the participants did during the test ride, where only 12.90% of the participants merely looking the scenery outside without doing other activities. More than half (51.61%) of the participants did three or more different activities during the test ride. The results indicate that the participants not only tried various activities, but also did multiple activities during the ride. Interestingly, as presented in Table 6 , for the five participants who reported to have a nap during the ride, they all whether used the phone for entertainment or personal tasks, or they enjoyed the snacks or beverages. Yet, for the five participants who reported to have talked with the safeguard, only one participant indicated doing other entertaining activities. This could be the reason that talking to the safeguard taking up too much time and the test ride is only 20 minutes. While this could also because those who talked to the safeguard are somehow uncertain and anxious about the self-driving vehicle, and they are less likely to relax themselves on the entertaining activities.

Although the time-spent distribution of the participation is unknown, the results show positive sign that participants are willing to actively using their time on the self-driving vehicle rather than just focusing on the driving task or on the road.

Table 5 Number of Activities Distribution

Number of Activity	Counts	Percentage
1	4	12.90%
2	11	35.48%
3	9	29.03%
4	6	19.35%
5	1	3.23%

Table 6 The Joint Activity of Participants

Activity	Daydream	Use phone	Enjoy snacks	Have nap	Talk to safeguard	Concern safety
Count	19	15	5	5	5	2

Daydream		9	3	3	1	0
Use phone	9		2	4	0	1
Enjoy snacks	3	2		1	1	0
Have nap	3	4	1		0	0
Talk to safeguard	1	0	0	0		1
Concern safety	0	1	0	0	1	

In Figure 9 , five participants reported to have talked with the safeguard during the ride. The presence of a reachable staff member onboard appears to enhance the perceived safety and overall experience of passengers in the autonomous vehicle. Previous research has corroborated this preference for having a staff member available (Azad et al., 2019; Davis, 1989), as it increases a sense of reassurance, thereby mitigating the fear or anxiety associated with self-driving vehicles. Meanwhile, there are also two participants reported that they were concerning about the safety and emergency of the vehicle. These concerns highlight the need for continued efforts in increasing public confidence in autonomous technology and improving the safety measures.

The various activities the participants reported demonstrate the potential of autonomous vehicles to give precious additional free time on their passengers. Self-driving technology liberates users from the pressure to focus on driving tasks or on the road, allowing them to assign this time to activities that benefit their comfort and well-being. This could indicate a transformative shift in how we perceive and utilize our ride, where the ride itself could become a productive part of our daily lives.

5.2 The Happiness of the Passengers

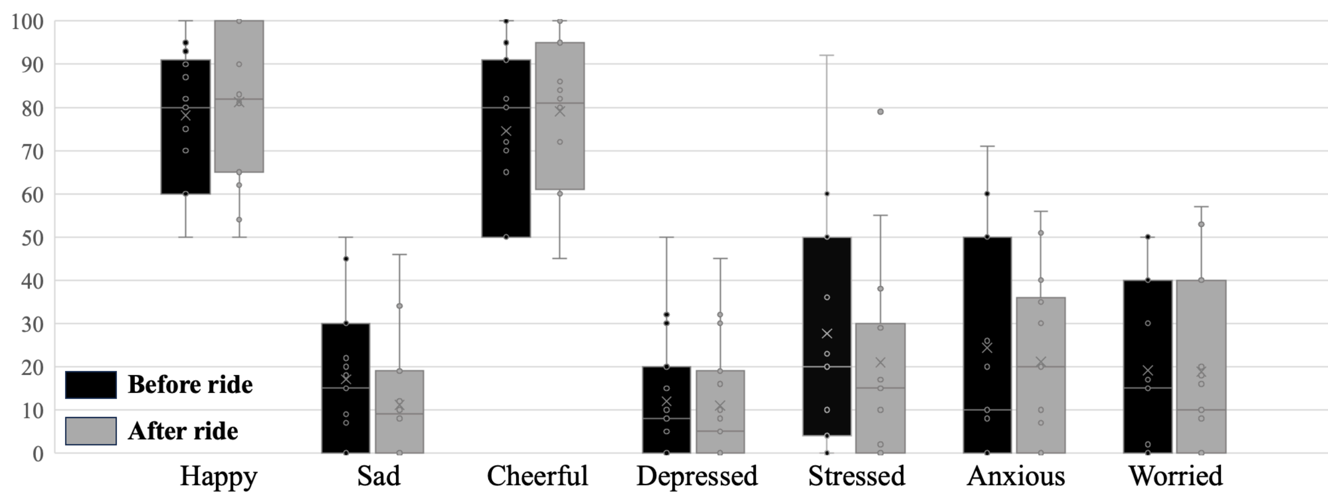
In this section, the survey response will be analyzed, presenting the happiness of the passengers from two directions: the emotional happiness and the genitive happiness.

5.2.1 Emotional Happiness

In the before-ride and after-ride survey, 14 variables are applied to assess participants’ emotional states. 0presents the box plot of the variables before and after the test ride. The results show that the participants were overall feeling positive, for instance they rated ‘happy’ and ‘relaxed’ higher than 70 averagely for both before and after the ride, rated ‘sad’ lower than 20 averagely, and rated ‘depressed’ lower than 10 averagely etc.

Moreover, 0presented the different degree of dispersion of the variables. Emotions such as ‘happy’, ‘sad’, ‘relaxed’ and ‘depressed’ and ‘dissatisfied’ have smaller dispersion, suggesting that participants' responses were more concentrated and aligned. While variables like ‘stressed’, ‘tired’, ‘anxious’ and ‘sleepy’ have comparably bigger dispersion, indicating greater variability in how participants perceived and experienced.

The tendency is that clearer variables, which have well-defined characteristics and are easily recognizable, tend to evoke more consistent responses across participants. On the other hand, ambiguous emotions may elicit varied interpretations and responses due to their subjective nature and individual perceptions. Individual differences could also be an explanation for such difference, as people are reporting different stress levels based on their personality, recent experience or living habits.



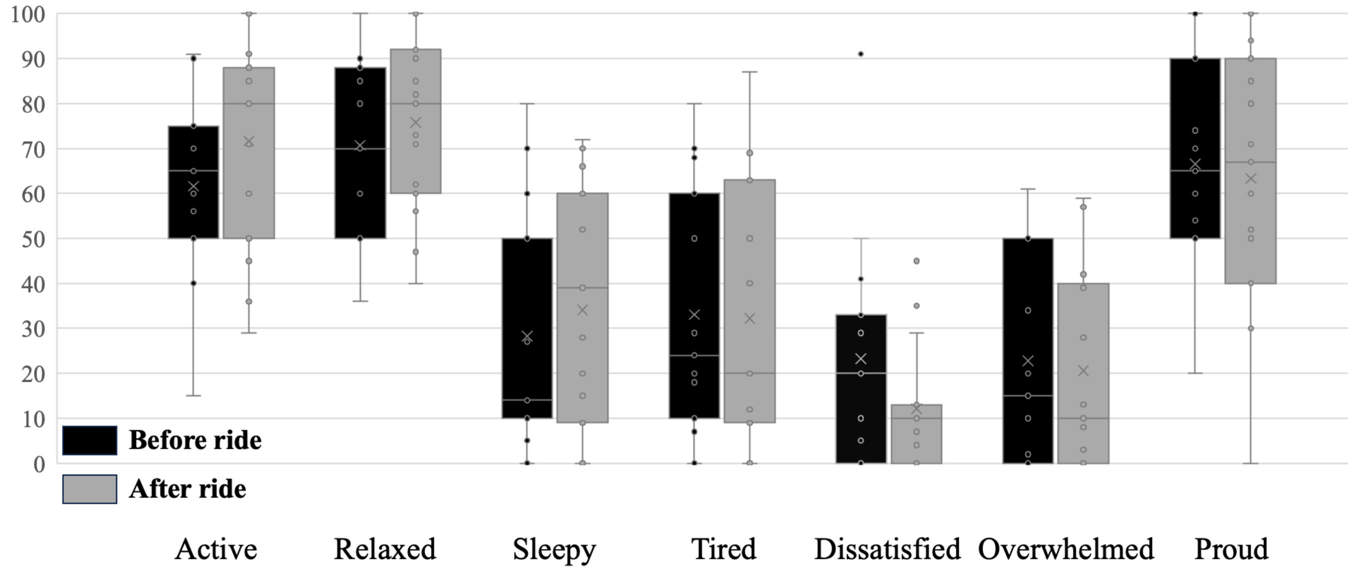


Figure 10 The Box Plot for the Emotional Variables Before and After the Ride

Based on 0, the difference between the before-ride emotions and after-ride emotions can already be observable. To know whether the changes are significant or not, a paired t-test was carried out for the 14 emotions and the results are presented in Table 7 . In Table 7 the emotions are colored if they are significantly different after the test ride (significance level = 0.05), and the red color indicates a significant increase, the green color indicates a significant decrease.

Results shows that the emotion ‘happy’, ‘cheerful’, ‘relaxed’ and ‘proud’ are significantly improved, indicating that participants are feeling more positively after the ride. Emotions ‘sad’, ‘depressed’, ‘stressed’, ‘anxious’, ‘worried’, ‘overwhelmed’ are significantly mitigated after the ride, indicating a less stressful and nervous condition for the participants. Surprisingly, the emotion ‘stressed’ have a big drop of 18.71 averagely. Instead of regarding that the 20-minute self-driving journey reduced the stress that participants had built up in their daily lives, such a significant stress drop may have been more about the stress of taking a self-driving experience, and after the experience, participants were less uneasy and less stressed about riding in a self-driving car.

Meanwhile, a big increase in the emotion 'proud' have a notable increase of 10.39 averagely, which give out a promising tendency that the participants would feeling prouder of a self-driving vehicle after having real experience in this technology.

Table 7 The Significance Test Results for Emotional Variables

Emotions	Differences	H1: There is a significant difference in before and after (Test stat/P-values)	H1: There is a significant higher value after the ride (Test stat/P-values)	H1: There is a significant lower value after the ride (Test stat/P-values)
Happy	4.61	2.63/0.01*	2.63/0.00**	2.63/0.50
Sad	-5.97	-3.07/0.00**	-3.07/0.50	-3.07/0.00**
Cheerful	6.84	2.73/0.01*	2.73/0.00**	2.73/0.50
Depressed	-5.58	-3.47/0.00**	-3.47/0.50	-3.47/0.00**
Dissatisfied	2.65	0.75/0.46	0.75/0.12	0.75/0.38
Active	1.16	0.37/0.72	0.37/0.18	0.37/0.32
Relaxed	6.39	2.54/0.02*	2.54/0.00**	2.54/0.50
Sleepy	2.32	0.58/0.57	0.58/0.14	0.58/0.36
Stressed	-18.71	-3.87/0.00**	-3.87/0.50	-3.87/0.00**
Tired	0.32	0.07/0.95	0.07/0.24	0.07/0.26
Anxious	-5.52	-1.75/0.09	-1.75/0.48	-1.75/0.02*
Worried	-7.52	-3.42/0.00**	-3.42/0.50	-3.42/0.00**
Overwhelmed	-6.00	-2.77/0.01*	-2.77/0.50	-2.77/0.00**
Proud	10.39	2.48/0.02*	2.48/0.00**	2.48/0.50

*In the table, *indicates p-value smaller than 0.05, **indicates p-value smaller than 0.01.*

- **Summary of the Emotional Happiness Evaluation**

The survey results offer an insight into the participants' emotional experiences during the self-driving ride, revealing an overall sense of happiness and contentment. The self-ride journey seemed to have a positive impact on participants' well-being, elevating their happiness levels compared to before ride. This finding certified the transformative potential of self-driving vehicle in enhancing passengers' emotional states and overall happiness. For instance, one of the self-driving ride's potentials is alleviating participants' stress, as the autonomous vehicle would take up the driving tasks and alleviate the user's pressure associated with driving. This newfound freedom and relaxation could have a positive effect on their emotional. By prioritizing user well-being and happiness, self-driving technology has the capacity to not only revolutionize the concept of transportation but also positively impact individuals' daily lives.

5.2.2 Cognitive Happiness

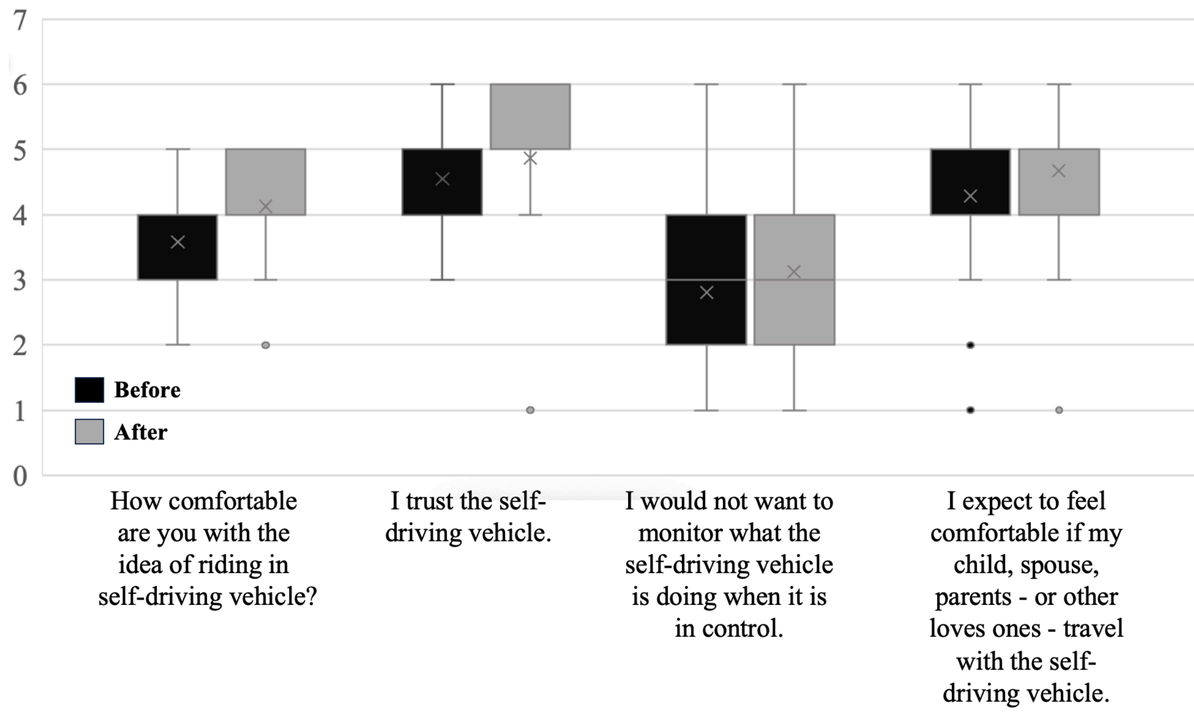
The cognitive happiness was evaluated by 33 questions in the before-ride and after-ride survey. For each question the participants need to respond to what extent they were agree or disagree with the statement, e.g., to what extent do you agree with the statement 'I trust the self-driving vehicle'.

The questions can be classified into four parts: (1) overall evaluation towards the self-driving vehicle, (2) trip/travel scale satisfaction, (3) functioning of technology, (4) usefulness of technology and (5) willingness to use. For each part, the bar chat for the survey responses and the statistical analysis results will be presented.

- **Overall Evaluation Towards the Self-driving Vehicle and Ride**

The overall evaluation section includes 4 questions in both the before-ride and after-ride survey and the response for each question are presented in Figure 11 . From Q3.7 and Q3.8 we can see the participants who were originally feeling neutral were turning to feel positive towards the self-driving ride. And the percentage of hoping to monitor the self-driving vehicle dropped after the test ride.

To better understand the extent of the change the test ride brought the participants, the Wilcoxon signed-rank test and the results are presented in Table 8 . The results shows that the test ride in the self-driving car significantly improved the acceptance of the participants in the sense that they are more comfortable with the idea of riding in a self-driving vehicle. Even though not all scales are significant, but a tendency of improvement can be witnessed.



**Y-axis indicate the level of agreement to the statement, from 0-strongly disagree to 6-strongly agree.*

Figure 11 Results of Overall Evaluation Section (Before & After)

Table 8 Significance Test Results for Overall Evaluation Section

Question	Differences	H1: There is a significant difference in before and after (Test stat/P-values)	H1: There is a significant positive response after the ride. (Test stat/P-values)	H1: There is a significant negative response after the ride. (Test stat/P-values)
How comfortable are you with the idea of riding in self-driving vehicle?	0.55	30.00/0.02*	30.00/0.01*	30.00/0.99
I trust the self-driving vehicle.	0.32	38.00/0.20	38.00/0.10	38.00/0.90
I would not want to monitor what the self-	0.32	90.50/0.23	90.50/0.12	90.50/0.88

driving vehicle is doing when it is in control.				
I expect to feel comfortable if my child, spouse, parents - or other loves ones - travel with the self-driving vehicle.	0.39	63.00/0.10	63.00/0.05	63.00/0.95

*In the table, *indicates p-value smaller than 0.05, **indicates p-value smaller than 0.01.*

- **Trip/Travel Scale Satisfaction (Similar scales can be removed)**

The trip/travel scale satisfaction is about participants expectation or satisfaction towards the self-driving ride. This part includes 8 questions in both before-ride and after-ride survey, and the response results are presented in Figure 12 . Results show that after the test ride, more participants were feeling more agree and positive to the self-driving vehicle. About two-thirds of the participants somewhat or strongly agreed to the statement that the self-driving vehicle is satisfying and have high standard. Participants were also more complied with the idea that the self-driving vehicle is fun and functions well.

Table 9 presents the statistic test results of this section. Results shows a significant higher agreement in the satisfaction of the ride, the functioning of the vehicle, and the overall evaluation.

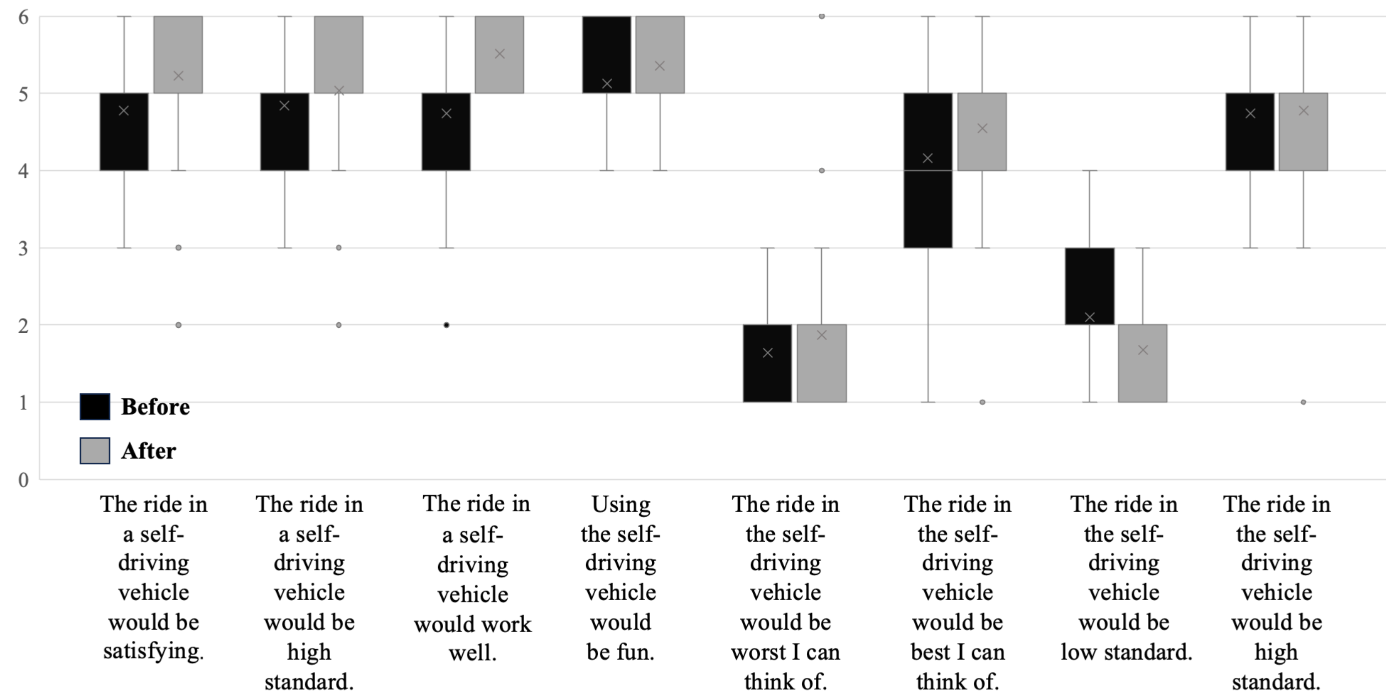


Figure 12 Results of Trip/travel Satisfaction Section

Table 9 Significance Test Results for Trip/travel Satisfaction Section

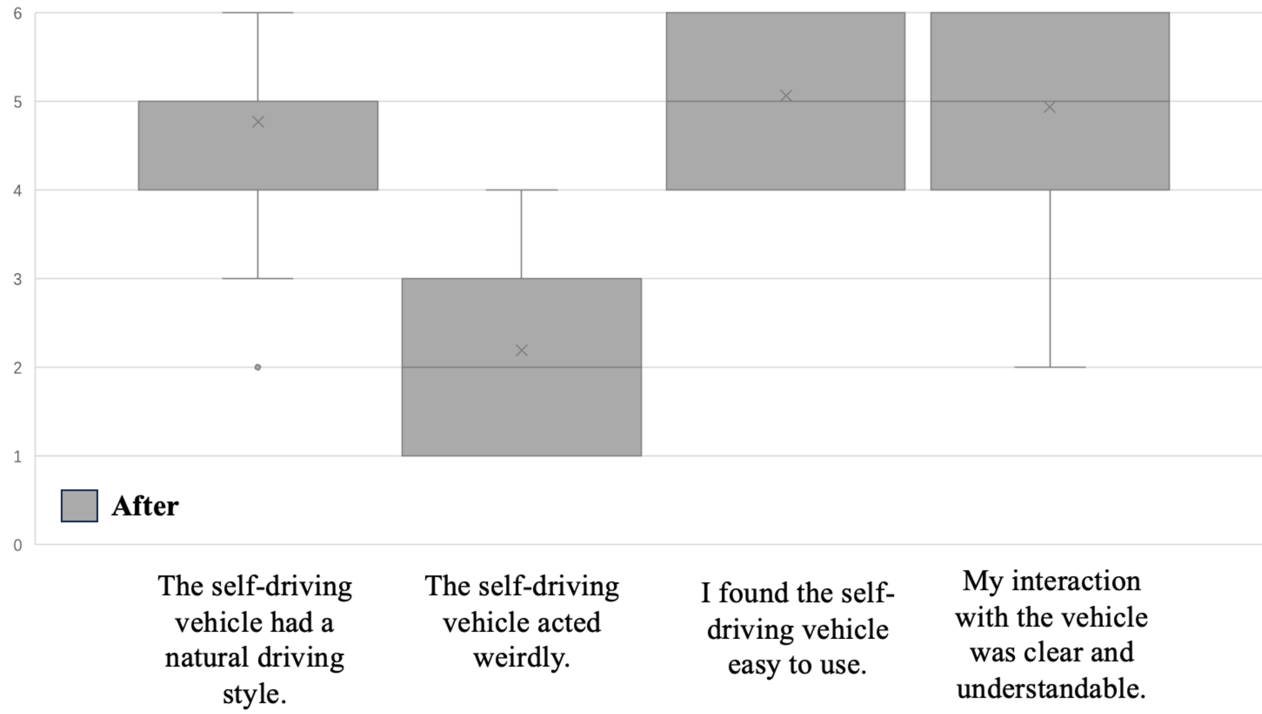
Question	Differences	H1: There is a significant difference in before and after. (Test stat/P-values)	H1: There is a significant positive response after the ride. (Test stat/P-values)	H1: There is a significant negative response after the ride. (Test stat/P-values)
The ride in a self-driving vehicle would be satisfying.	0.45	88.00/0.07	88.00/0.03*	88.00/0.97
The ride in a self-driving vehicle would be high standard.	0.19	99.00/0.35	99.00/0.18	99.00/0.82
The ride in a self-driving vehicle would work well.	0.77	27.00/0.00**	27.00/0.00**	27.00/1.00

Using the self-driving vehicle would be fun.	0.23	50.50/0.19	50.50/0.10	50.50/0.90
The ride in the self-driving vehicle would be worst I can think of.	0.23	52.00/0.38	52.00/0.19	52.00/0.81
The ride in the self-driving vehicle would be best I can think of.	0.39	45.00/0.06	45.00/0.03*	45.00/0.97
The ride in the self-driving vehicle would be low standard.	-0.42	65.00/0.03*	188.00/0.98	188.00/0.02*
The ride in the self-driving vehicle would be high standard.	0.03	93.50/0.65	93.50/0.33	93.50/0.67

*In the table, *indicates p-value smaller than 0.05, **indicates p-value smaller than 0.01.*

- **Functional Satisfaction**

The functional satisfaction section is about the driving style and usage evaluation of the self-driving vehicle. This part includes 4 questions in the after-ride survey exclusively, and the responses are presented in Figure 13 . Participants responses showed that the majority of them agree that the self-driving vehicle drove naturally, and the vehicle was easy to use. Although the test vehicle of this research is actually human-driven, and the participants' evaluation on the vehicle or the driving style is not on the self-driving technology but on the test vehicle, this result functions as firm support that participants were trusting this test vehicle was self-driven and guarantee the collected data could reflecting the participants' experience with a self-driving vehicle.

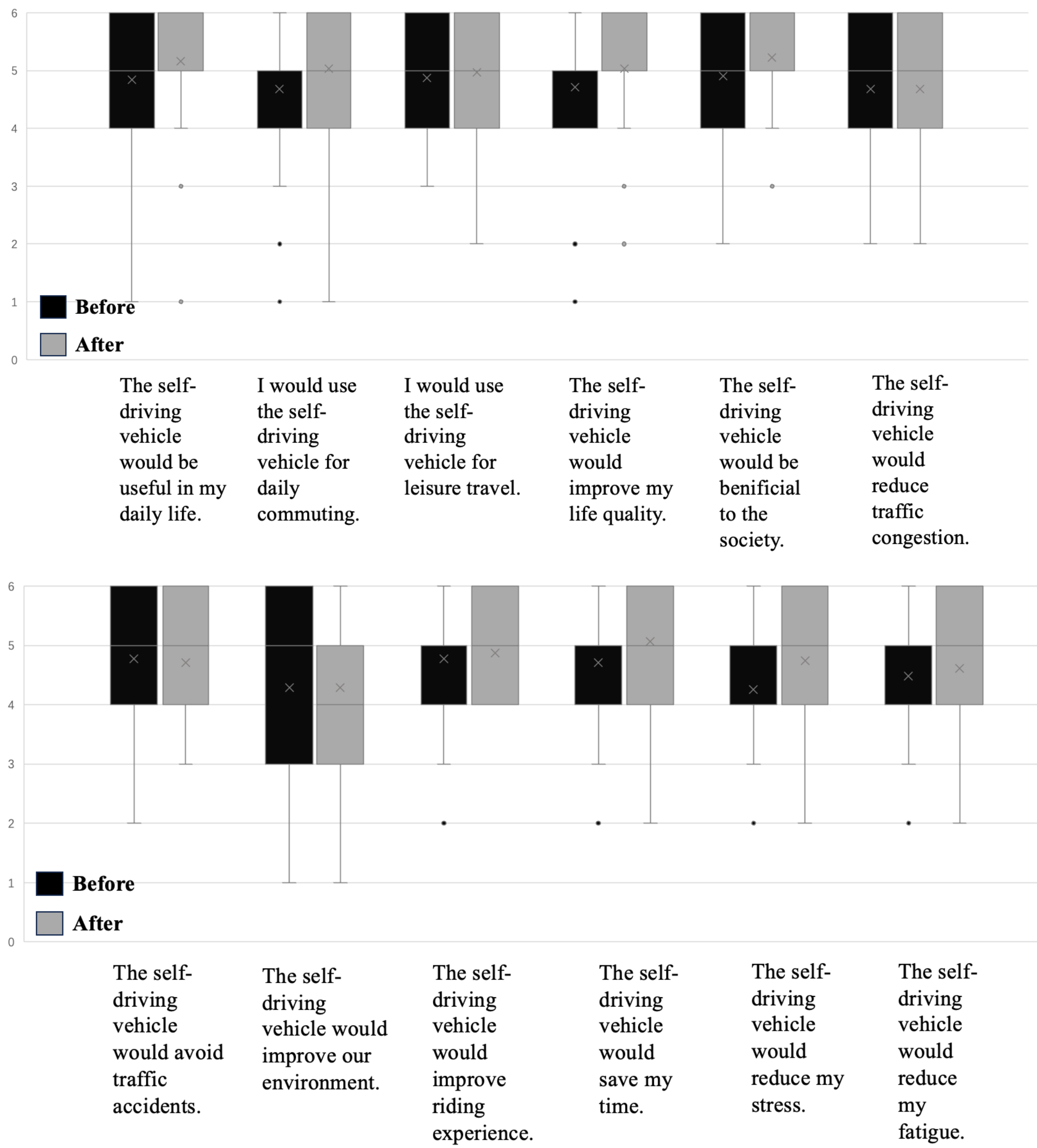


**Y-axis indicate the level of agreement to the statement, from 0-strongly disagree to 6-strongly agree.*

Figure 13 Results of Functional Satisfaction Section

- **Usefulness of Technology**

Usefulness of technology is about the extent the self-driving vehicle will help the user to perform their tasks more effectively or efficiently, which includes 12 questions in both before-ride and after-ride surveys. The survey responses are presented in Figure 14 and the statistical tests for the 12 questions are presented in Table 10 . Figure 14 indicates a high agreement on that the self-driving vehicle will be useful in daily life in whether commuting or leisure travel, and this improved agreement is also supported by the statistic results. The participants are tending to believe the self-driving vehicle are beneficial to the society and such agreement also statistically improved after the test ride. But the response on specific matters is more ambiguous, for instance the responses for whether the self-driving vehicle can improve traffic efficiency or improving the environment were distributed more in a dispersed way. On the other hands, the results also revealed a general acknowledgment on the potential of the self-driving vehicle in improving the traffic safety but a skeptical opinion on its ability in improving the traffic or the environment, or other abilities. Moreover, the results show that, statistically, more participants are tending to believe that the self-driving vehicle can reduce their stress, as well as saving their time.



**Y-axis indicate the level of agreement to the statement, from 0-strongly disagree to 6-strongly agree.*

Figure 14 Results of Usefulness of Technology Section

Table 10 Significance Test Results for Usefulness of Technology Section

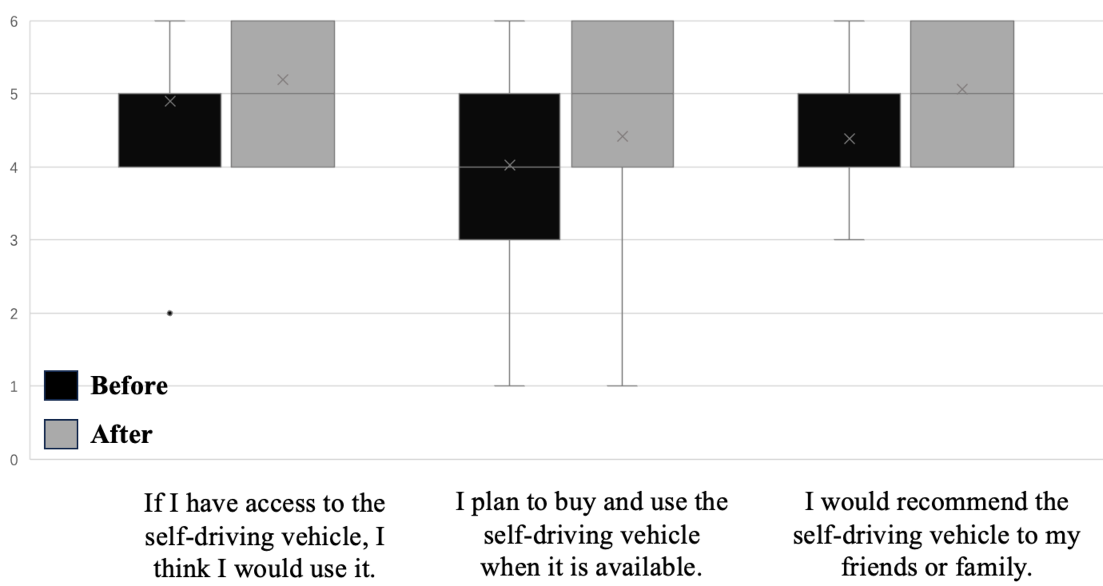
Question	Differences	H1: There is a significant difference in before and after. (Test stat/P-values)	H1: There is a significant positive response after the ride. (Test stat/P-values)	H1: There is a significant negative response after the ride. (Test stat/P-values)
The self-driving vehicle would be useful in my daily life.	0.32	46.50/0.07	46.50/0.04	46.50/0.96
I would use the self-driving vehicle for daily commuting.	0.35	51.00/0.06	51.00/0.03	51.00/0.97
I would use the self-driving vehicle for leisure travel.	0.10	74.00/0.60	74.00/0.30	74.00/0.70
The self-driving vehicle would improve my life quality.	0.32	47.50/0.03*	47.50/0.02	47.50/0.98
The self-driving vehicle would be beneficial to the society.	0.32	40.00/0.14	40.00/0.07	40.00/0.93
The self-driving vehicle would reduce traffic congestion.	0.00	70.50/0.77	70.50/0.38	70.50/0.62
The self-driving vehicle would avoid traffic accidents.	-0.06	77.50/0.71	93.50/0.64	93.55/0.36
The self-driving vehicle would improve our environment.	0.00	59.50/0.98	59.50/0.49	59.50/0.51
The self-driving vehicle would improve riding experience.	0.10	60.00/0.65	60.00/0.33	60.00/0.67
The self-driving vehicle would save my time.	0.35	30.00/0.03*	30.00/0.02	30.00/0.98

The self-driving vehicle would reduce my stress.	0.48	11.00/0.01*	11.00/0.00	11.00/1.00
The self-driving vehicle would reduce my fatigue.	0.13	45.50/0.39	45.50/0.19	45.50/0.81

*In the table, *indicates p-value smaller than 0.05, **indicates p-value smaller than 0.01.*

- **Willingness to Use**

The willingness to use part measures the participant's intention to use the technology in the future, which includes 3 questions in both before-ride and after-ride survey. The survey response and the statistic test are presented in Figure 15 and Table 11 . Overall, the results indicate positive and wiliness to use the self-driving vehicle if available, for all questions only less than one-third of participants disagree to use this technology. Moreover, the statistic test shows a significant improved agreement in the willingness to buy and use the self-driving vehicle as well as the willingness to recommend the self-driving vehicle to family and friends.



**Y-axis indicate the level of agreement to the statement, from 0-strongly disagree to 6-strongly agree.*

Figure 15 Results of Willingness to Use Section

Table 11 Significance Test Results for Willingness to Use Section

Question	Differences	H1: There is a significant difference in before and after. (Test stat/P-values)	H1: There is a significant positive response after the ride. (Test stat/P-values)	H1: There is a significant negative response after the ride. (Test stat/P-values)
If I have access to the self-driving vehicle, I think I would use it.	0.29	51.00/0.12	51.00/0.06	51.00/0.94
I plan to buy and use the self-driving vehicle when it is available.	0.39	47.00/0.08	47.00/0.04*	47.00/0.96
I would recommend the self-driving vehicle to my friends or family.	0.68	21.00/0.00**	21.00/0.00**	21.00/1.00

*In the table, *indicates p-value smaller than 0.05, **indicates p-value smaller than 0.01.*

- **Summary of the Cognitive Happiness Evaluation**

The results present an obvious shift in participants' attitudes toward self-driving vehicles. Originally neutral sentiments transformed into positive perceptions towards the self-driving vehicle after the test ride. The test ride indicated an enhancement in participants' acceptance of self-driving vehicles, an improved comfort with the concept of riding in such vehicles. This newfound comfort translated into improved satisfaction with self-driving technology, as evidenced by participant responses.

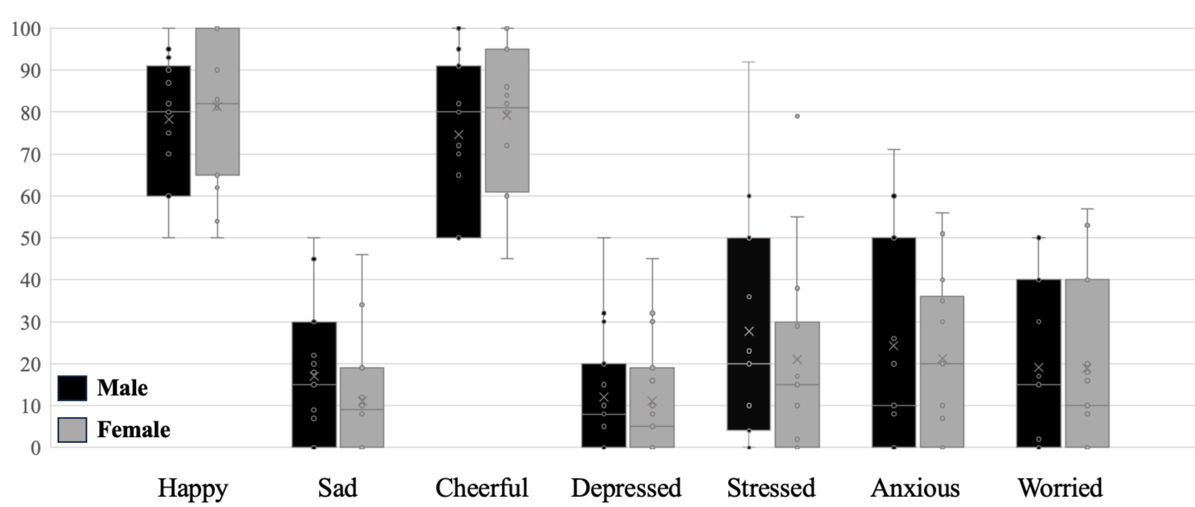
Moreover, the response among participants indicated the natural driving behavior of the self-driving vehicle and agreement on its user-friendly interface. The majority of the participants expressed agreement regarding the vehicle's utility in daily life, both for commuting and leisure travel. Intriguingly, statistical trends revealed an increasing belief among participants that self-driving vehicles can alleviate stress and save their time. This positive shift in perception reflects the potential of self-driving technology to positively impact passengers' well-being.

Meanwhile, the results demonstrated a willingness among participants to embrace self-driving technology, which is supported by a strengthened willingness to purchase and use elf-driving vehicles, as well as the intention to recommend these vehicles to friends and family.

Therefore, these findings emphasize the potential of self-driving technology, not only in enhancing traffic conditions but also in reshaping individual attitudes and perceptions toward self-driving vehicles.

5.3 The Influence of Demographic Factors

This section will investigate the influence of gender on the happiness, through analyzing the mental state differences after the test ride. Participants only responded with two genders, whether male or female, hence this study only looked into the difference between two genders. The box plots for the 14 emotional variables after the ride of the different genders are presented in Figure 16 . Surprisingly, for almost every positive emotion, for instance happy, cheerful, active, relaxed, female participants' responses were higher than male participants. And for negative emotions, for instance sad, depressed, stressed, anxious etc., the female participants' responses were lower than the male participants. This indicated that female participants tended to have more positive mental conditions and more satisfied with the self-driving ride.



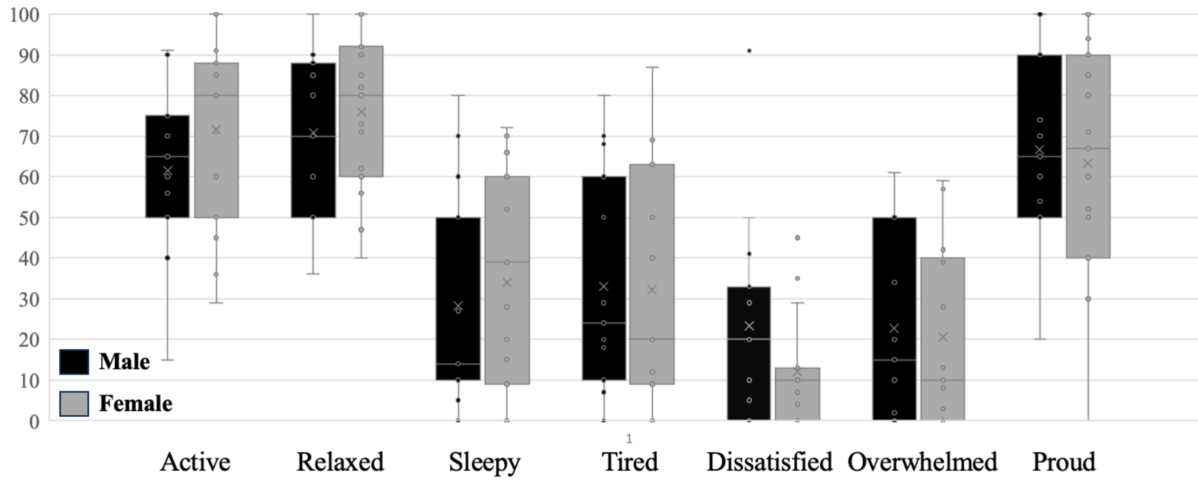


Figure 16 Box Plots of Mental State Variables for Different Genders (After Ride)

To understand whether the differences between two genders are significant, a paired t-test were made, and the results were presented in Table 12 . Results shows that the response of feeling dissatisfied was significantly higher for the male participants, and male participants were slightly significant sadder than the female participants. Meanwhile, female participants were more active than the male participants after the ride. This corresponds with former argument that female participants were more positive and satisfied with the self-driving ride.

Table 12 Significance Test Result for Gender Differences

Emotions	Average Difference	H1: There is a significant difference in the variable before and after.	H1: There is a significant higher value for male.	H1: There is a significant higher value for female.
Happy	-3.07	-0.52/0.61	-0.52/0.35	-0.52/0.15
Sad	5.93	0.97/0.35	0.97/0.09*	0.97/0.41
Cheerful	-4.60	-0.74/0.47	-0.74/0.38	-0.74/0.12
Depressed	1.00	0.18/0.86	0.18/0.22	0.18/0.28
Dissatisfied	11.20	1.79/0.10*	1.79/0.02**	1.79/0.48
Active	-10.07	-1.15/0.27	-1.15/0.43	-1.15/0.07*

Relaxed	-5.13	-0.67/0.52	-0.67/0.37	-0.67/0.13
Sleepy	-5.80	-0.72/0.49	-0.72/0.38	-0.72/0.12
Stressed	6.67	0.61/0.55	0.61/0.14	0.61/0.36
Tired	0.87	0.08/0.94	0.08/0.23	0.08/0.27
Anxious	3.20	0.34/0.74	0.34/0.18	0.34/0.32
Worried	0.27	0.03/0.97	0.03/0.24	0.03/0.26
Overwhelmed	2.27	0.25/0.81	0.25/0.20	0.25/0.30
Proud	3.27	0.37/0.72	0.37/0.18	0.37/0.32

*In this table, *indicates p-value smaller than 0.1, **indicates p-value smaller than 0.05.*

In summary, female participants were generally reporting higher positive emotions than male participants after the test ride. The statistic test showed that male participants were significantly feeling less satisfied and sadder after the ride.

6 Results of Biometric Measurement

In this section, the biometric reaction of the participants during the self-driving ride will be presented and analyzed. Firstly, the eye movement data will be analyzed, including the fixation and blink behavior. The eye movement will be used to analyze the influence of different road infrastructures on the physical and psychological experience of participants. Then specific cases that participants were experiencing abnormal heart rate will be looked at. With the findings from previous literatures on the relation between biometric reaction, i.e., eye movement and heart rate, the potential psychological conditions of participants will be proposed.

6.1 Eye Movement

The eye movement data can directly reflect the participants attention focus during the whole ride. However, in this experiment the view of the participants was not fixed, the focus of the participants cannot be analyzed statistically but only individually. Hence, this research mainly uses the fixation behavior and blink behavior to reflect the feeling and mental state of the participants indirectly.

Meanwhile, since the eye movement data is the only type of data that can cover the whole ride, it was applied to analyze the influence of different road types. Four road types are classified: the highway, the roundabout, the road with signalized intersection and the bridge. In the following section, the eye movement difference between different road sections will be presented and analyzed.

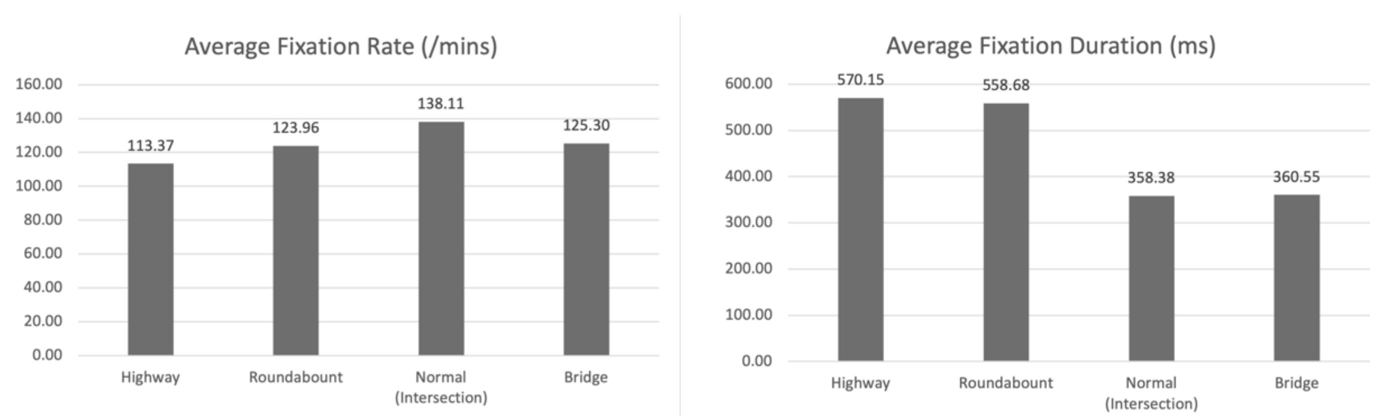
6.2.1 The Influence of Traffic Infrastructure Factors – Fixation Behavior

Fixation is one’s ability to process relevant parts of visual information and the point of interest (Pollmann & Schneider, 2022). High fixation rate indicates a frequent switch from one point to another, which means that the participant's attention is constantly shifting, possibly indicating higher mental load and higher engagement on the road (Lim et al., 2020; Rayner, 1995). This pattern might suggest a certain level of discomfort or unease, potentially reflecting a degree difficulty in processing the information. Low fixation duration indicates short periods of focus on specific points, which might suggest a quick scanning and processing of the information (Andrychowicz-Trojanowska, 2018). While longer eye fixation durations indicate difficulties in extracting information (Andrychowicz-Trojanowska, 2018).

The fixations of the four road sections were counted and the average fixation rate and fixation duration are presented in Figure 17 . The result indicates that the road with signalized intersection have the highest fixation rate and lowest fixation duration, followed by the bridge section. While the highway section has the lowest fixation rate and highest fixation durations.

The low fixation duration on the road with signalized intersection and the bridges indicates that these road types are relatively common and familiar to the participants which requires less time to process each new visual information. While for the road with signalized intersection, it has the highest fixation rate which indicates its highest amount of information that requires participant’s attention. Therefore, the road with signalized intersection has the most processing workload, even each attraction requires only a quick glance.

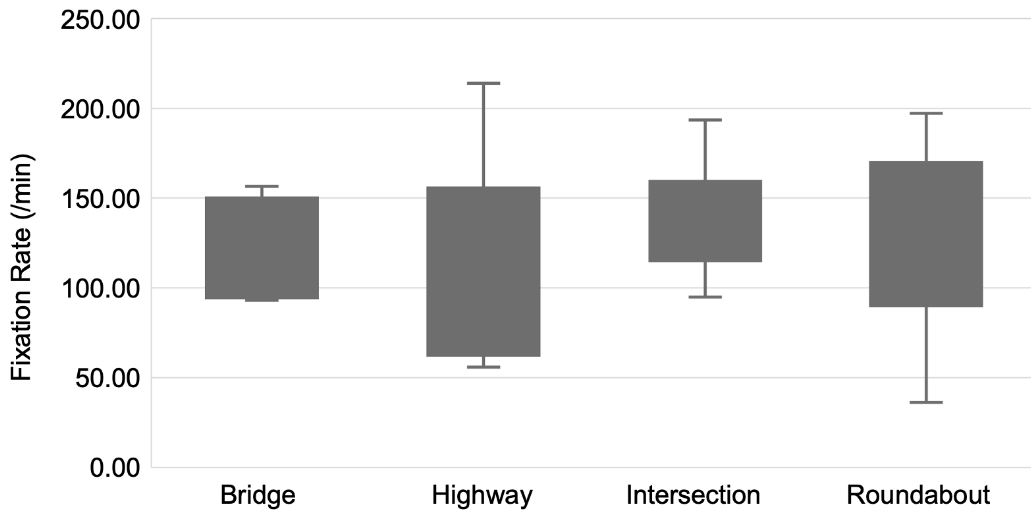
On the other hands, the lowest fixation rate and the longest fixation duration indicates that on the highway less extra information needs to be processed. But for each information that requires attention, it took longer for the participants to process.



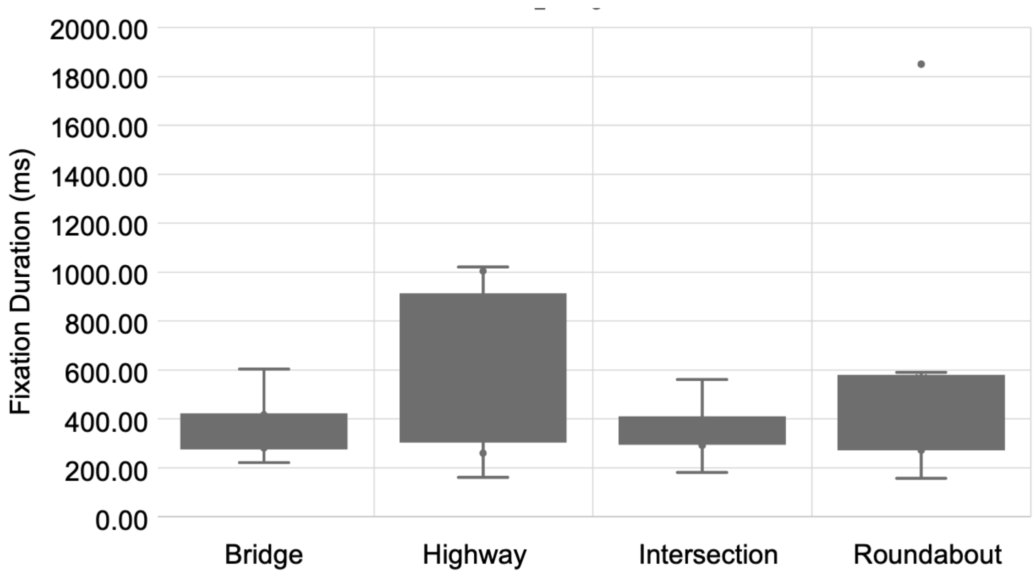
(a) Histogram of Fixation Rate (b) Histogram of Fixation Duration

Figure 17 Average Fixation on Different Road Sections

Figure 18 present the distribution of the fixation rate and fixation duration, where the variability of the highway and the roundabout are higher than the road with signalized intersection and the bridge. This shows that on roads with relatively few information such as highways and bridges, the individual differences of participants are more obvious. Some participants may feel cautious and stay tuned all the way which results in higher fixation rate, while others may feel the ride on the highway relatively bored and simple and turned less engaged with the driving which results in lower fixation rate.



(a) Fixation Rate Distribution on Different Road Sections



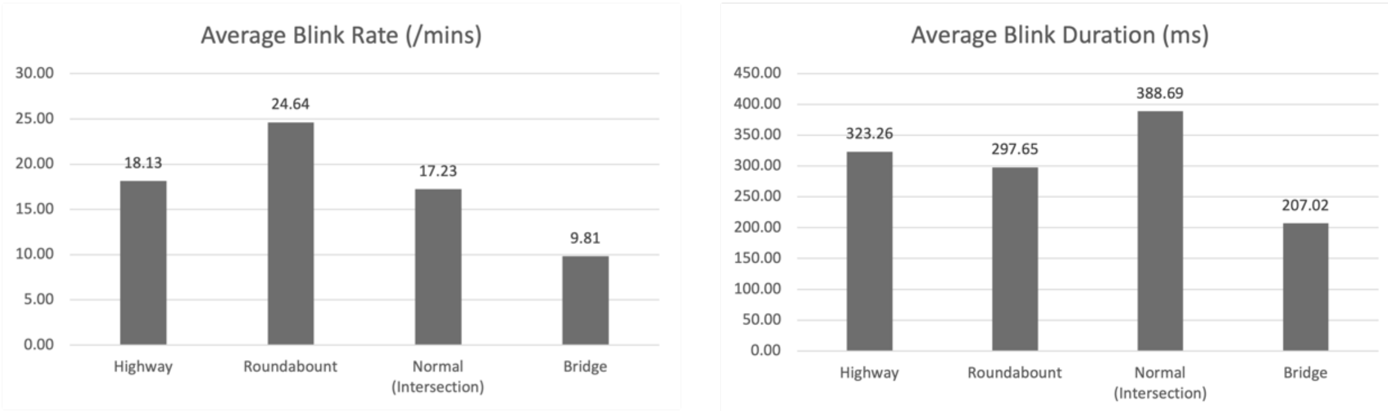
(b) Fixation Duration Distribution on Different Road Sections

Figure 18 Box Plot for the Fixation on Different Road Sections

6.2.1 The Influence of Traffic Infrastructure Factors – Blink Behavior

Blinking is the rapid closing and opening of the eyelids, and on average, a person blinks about 15 to 20 times per minute (Abusharha, 2017; Bentivoglio et al., 1997). Blinking rate is in relation to one's engagement, workload, stress levels and other physiological or psychological conditions. In general, the lower blink rate indicates a higher engagement, as people need more time to process the visual information between two continued blinks (Ranti et al., 2020). Quicker blinks, i.e., blinks with a shorter duration of the eyelid covering the eyeball, can indicate higher engagement, or a moment of intense focus (Ranti et al., 2020). When an individual blinks more rapidly, it may suggest heavier processing work on visual information. On the contrary, the slower blink shows a reduced engagement or relaxation, sometimes it is also a signal of fatigue. The blink frequency is also related to the activity the individual is doing, for instance having conversation with others have higher blink frequency (more than 25 blinks/min) than doing nothing but rest (around 17 blinks/min), and higher than reading (lower than 5 blinks/min) (Bentivoglio et al., 1997).

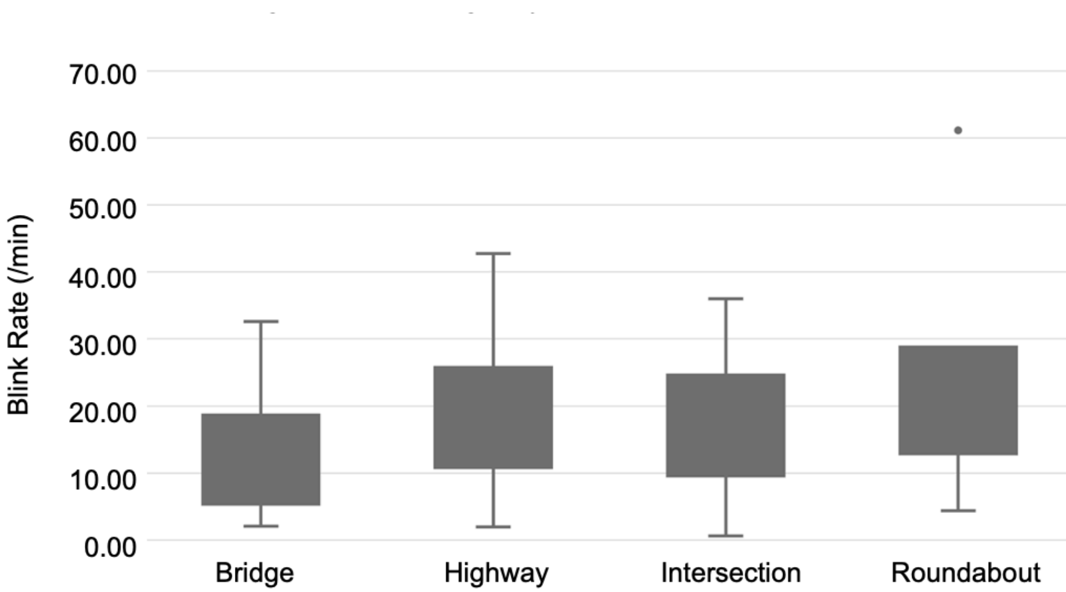
Figure 19 presents the counted average blink rate and blink duration on different road sections. The average blink rate on the roundabout the blink rate is relatively higher and on the bridge is relatively lower, as indicated Figure 19 (a). And in Figure 19 (b), it is shown that the blink duration on the roundabout and the bridge are relatively lower than the highway and the road with signalized intersection. Particularly on the roundabout, the high blink rate indicates a rapid visual focus switch, potentially due to the complex traffic dynamics. Contrary to what was discussed earlier about lower blink rate indicate higher engagement, the high blink rate and the quick blinking on the roundabout might imply that the participants are focused but less concentrated on single attraction, and they have heavier visual information to process, which correspond with the higher fixation duration discussed in the previous paragraph. The less frequently and faster blinking behavior on the bridges is easier to explain: this indicates the state of increased cognitive load, mental engagement, and potential stress.



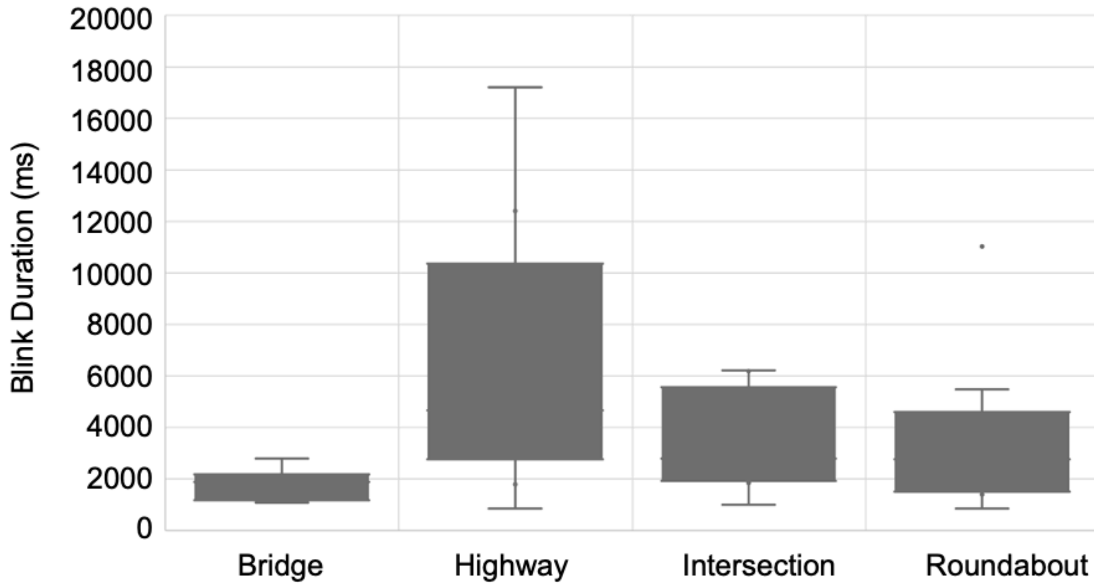
(a) Histogram of Blink Rate (b) Histogram of Blink Duration

Figure 19 Average Blink on Different Road Sections

Figure 20 presents the distribution of the blink rate and blink duration, which indicates that the blink behavior on highway has the highest variance among different road sections. This result corresponds with the fixation result, which means that on the highway the participants' behavior varies from individual to individual.



(a) Blink Rate Distribution on Different Road Sections



(b) Blink Duration Distribution on Different Road Sections

Figure 20 Box Plot for Blink on Different Road Sections

- **Summary of the Eye Movement Analysis**

In summary, the difference of psychological conditions, including attention and engagement, stress level, etc., is observable among different road sections.

On the highway there was less new visual information, but participants were relatively unfamiliar with this information. Interestingly, even though the participants took longer to process and understand this unfamiliar information, their blink rate was relatively slow, which indicates that the participants were feeling calm and less alerted on the highway.

On the roundabout the participants were unfamiliar with the situation and were faced with multiple attractions, thus required longer processing time, i.e., longer fixation duration. And the high blink rate suggests a state of being distracted but alert on the roundabout, or even the feeling fatigue.

More visual workload appeared on the road with signalized intersection, but these attractions were those the participants are familiar with, thus resulted in shorter fixation rate. Meanwhile, the slower blinking behavior further indicates the participants are familiar with the situation and feel relaxed or durable during the ride.

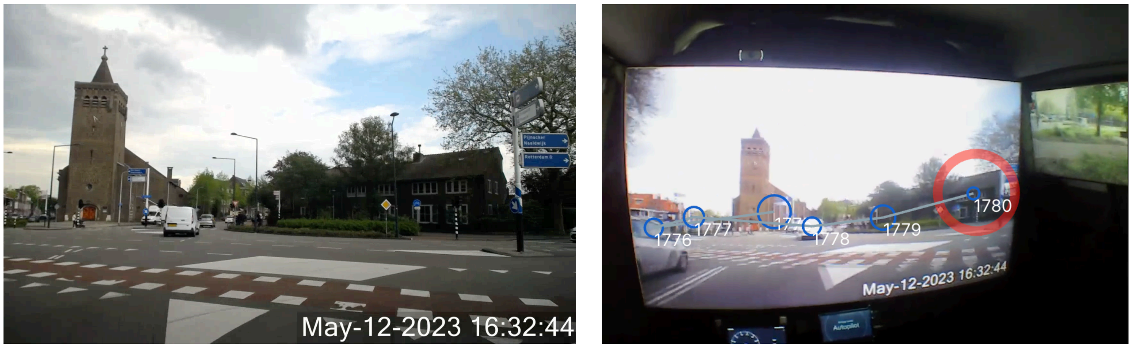
The high fixation rate and short fixation duration on the bridge section indicates that each visual element receives minimal processing time but much new visual information, which requires rapid reaction. Furthermore, the quick blinking behavior suggests higher mental engagement, which further indicates a state of increased stress and cognitive demand as participants handle the dynamic situation of the bridge.

6.1 Heart Rate

Due to the sensor limitations, only discrete heart rate data was collected, and in this section, specific abnormal heart rate cases will be investigated combined with the eye movement. Generally, the participants' heart rate was stable, but four participants were experiencing exceptionally high heart rate in four different scenarios, which will be presented and analyzed individually as follow.

Researches showed that 90th percentile heart rate is lower than 100 in individuals aged from 18 to 45 years old (Avram et al., 2019), and the American Heart Association defines the normal sinus HR as between 60 and 100 bpm (Mason et al., 2007). Therefore, the exceptionally high heart rate is defined as heart rate higher than 100 bpm.

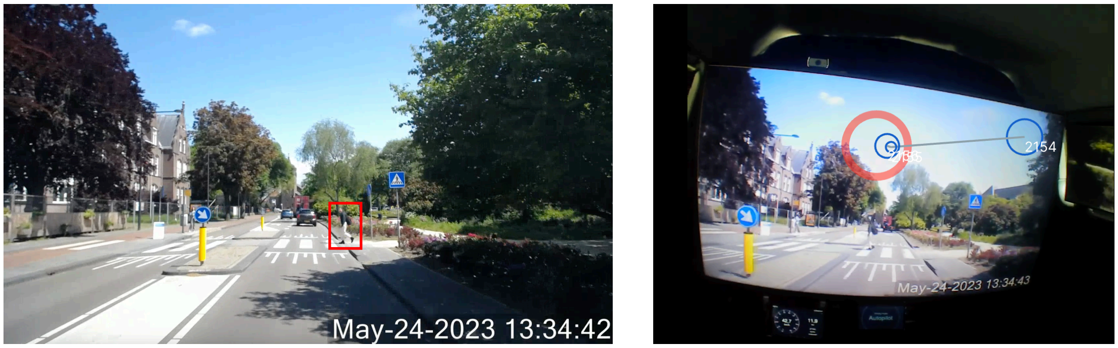
The first exceptionally high heart rate case appeared at a five-way intersection where the test vehicle was making a sharp right turn. Figure 21 presents the road view and the eye movement of the participants, where the blue circles are the fixations connected by the glance trajectory line, and the red circle is the gaze point. Figure 21 (b) presents that the participant's fixation move continuously from the left side of the screen to the right side of the screen, and the gaze point fell on the building across the road. This is a big intersection with multiple directions of traffic flow, even making a right turn not necessarily conflicting with other directions, could still potentially make some participant nervous and resulting in higher heart rate. Though the vehicle dynamics information is not available, the sharp turning might be sensed as aggressive driving behavior which gave the participants a feeling of being unsafe. Plus, the limited view of the screen inside the vehicle might block the sight on the right which added more insecure feeling to the participant.



(a) View in the Driving Recorder (b) View in the Eye Tracker

Figure 21 Scenario 1: Sharp Turn at a five-way Intersection

The second scenario appeared when a pedestrian is crossing the road. Figure 22 presents the road view and the eye movement of the participants, where a pedestrian was coming out on the right side of the road. Figure 22 (b) shows that the fixation points of the participant was higher above the road, while after checking the face camera video it was found that this was because of the height differences between the slipping glasses and the eyeballs. The slipping of the eye tracking glasses happened to some of the participants, but this research did not require statistically analyzing a fixed vision or participants attention point, the slipping did not affect the analysis. Assuming that the actual fixation points are lowered to the road, the participant were focusing and observing the sudden-appeared pedestrian. In this case, the participant would feel uncertain about whether the self-driving vehicle would act properly without run into conflict or traffic accidents. However, this was not the only participant who ran into a pedestrian crossing the road, but the only one whose heart rate increased abnormally. The possible explanations for this could be the driving behavior of the test vehicle. The machine-like driving style which the test vehicle driver adopted could be somehow not understandable to the participant and adding his/her uncertainty.



(a) View in the Driving Recorder (b) View in the Eye Tracker

Figure 22 Scenario 2: Pedestrian Crossing the Road

The third scenario appeared when the test vehicle was riding near a truck. Figure 23 presents the road view and the eye movement of the participants. Figure 23 (b) indicates that the participants kept focusing on the front truck, which shows the attention and even concern of the participant following the truck. It is assumed that the big size and moving speed of the truck is likely to give some participants a feeling of pressure and insecurity. Moreover, it is possible that the driving behavior of the test vehicle may add the insecurity and stress of the participants, for instance it might not perform different enough from the usual driving scenarios, keep the speed slow enough nor keep the distance big enough.

(a) View in the Driving Recorder (b) View in the Eye Tracker

Figure 23 Scenario 3: Following/riding with the Big Truck

Figure 24 presents the last abnormal heart rate scenario, where the test vehicle was passing the bridge. Figure 24 (b) shows that the participant was turning the sight from right to the front, following the right turning behavior of the test vehicle. The fixation point fell out of the screen, which potentially indicated that the participants is expecting to check the right-side view of vehicle but failed to do so due to the screen limit. This unexpected failure could add the insecurity of the participants.

(a) View in the Driving Recorder

(b) View in the Eye Tracker

Figure 24 Scenario 4: Going Through the Bridge

- **Summary of Exceptionally High Heart Rate Case Analysis**

In summary, though the abnormal heart rate appeared at comparatively low rate, the participants felt unsafe and stress in cases including the unexpected sight block due to the test vehicle screen limit, the obstacles on the road (pedestrians, trucks, and other traffic users), and potentially the improper driving behavior of the test vehicle.

7 Summary of the Results and Discussion

This research aims to investigate the happiness of the self-driving vehicle passengers, trying to figure out the emotional conditions and their cognitive evaluation towards the self-driving vehicle. In this research, a real-traffic test rides were carried out to give the participants the experience in the self-driving vehicle. During the experiment, two surveys before and after the test ride were employed to collect the participants emotional state and cognitive evaluation of the self-driving vehicles. The biometric reaction including the heart rate and eye movement of the participants were also collected to provide insight into the physiological reaction and psychological condition. The following section will summarize the research findings and discuss them with previous studies.

- **Emotional conditions**

The survey results revealed an overall sense of emotionally happy and content feelings among the participants. Results showed that the self-ride journey had a positive impact on participants' emotions, elevating their happiness levels compared to their state before ride. This finding certified potential of self-driving vehicle in enhancing passengers' emotional states and overall happiness, which somehow corresponded with former studies that people's opinions and attitudes change positively when they experience riding in an AV (Luger-Bazinger et al., 2021; Moody et al., 2020; *The Road Ahead*, n.d.). Specifically, the repeated experience with the self-driving vehicle (shuttle bus) improved the familiarity and perceived safety of the passengers (Luger-Bazinger et al., 2021)

One of the self-driving ride's potentials is providing the passengers with additional free time to spend on other activities which correspond with studies by (Meyer et al., 2017; Singleton et al., 2020), as the autonomous vehicle would take up the driving tasks. Moreover, participants responses showed that they engaged in multiple activities during the test ride, specifically more than half of participants did more than three activities. This newfound freedom could have a positive effect on their emotions.

- **Cognitive evaluation**

The survey results revealed a shift in participants' attitude towards self-driving vehicles. Following the test ride, initially neutral perspectives transformed into favorable perceptions, signifying an increased acceptance and comfort with this emerging technology. This newfound ease directly translated into heightened contentment with self-driving capabilities, evident from participant responses corresponded with former studies that experience with self-driving vehicle increase the positive attitudes towards this technology (Chee et al., 2020; *The Road Ahead*, n.d.).

Furthermore, participants widely agreed on the self-driving vehicle's natural driving behavior and user-friendly interface, even in previous studies, participants assert that the self-driving vehicle not necessarily need to use same driving style as a human driver (Luger-Bazinger et al., 2021). This tendency was reinforced by a consensus on the vehicle's practicality for daily commutes and leisure travel, substantiated through rigorous statistical analysis.

An intriguing observation was that participants increasingly believed that self-driving vehicles could alleviate stress and optimize time management. This perceptual shift aligns with prior research, indicating the potential of self-driving technology to positively impact passengers' overall well-being through improving traffic congestion, reducing human lapse or enhancing livability (Dean et al., 2019; Koch et al., 2021; Yurtsever et al., 2020).

Moreover, participants displayed a certain willingness to embrace self-driving technology, evident in their heightened readiness to acquire and use self-driving vehicles. This inclination extended to intentions of recommending these vehicles to others, emphasizing the ripple effect of positive perceptions. This results in line with former studies that individuals are likely to exhibit a greater willingness to pay for self-driving service after experiencing it (Chee et al., 2020).

- **Findings from Biometric data**

Besides the surveys, the experiment also collected the biometric data of the participants, including the heart rate data and the eye movement data.

In this study, participants' eye behaviors were analyzed in different driving scenarios. Results showed that on the highway, where there was less new visual information but unfamiliarity, participants took longer to process the information, yet their slow blink rate indicated a sense of calmness. In the roundabout, participants faced unfamiliarity and multiple attractions, leading to longer fixation durations and a high blink rate, suggesting distraction and possible fatigue. At signalized intersections, there was a higher visual workload, but since participants were familiar with the situation, fixation durations were shorter. Slower blinking behavior indicated relaxation during the ride. On the bridge, participants had minimal processing time for abundant new visual information, leading to quick blinking and high fixation rates, implying increased stress and cognitive demand in handling the dynamic bridge situation.

By analyzing abnormal heart rate patterns, it was observed that even though instances of abnormal heart rates occurred relatively infrequently, participants experienced feelings of insecurity and stress in situations such as unexpected visual obstructions caused by limitations in the test vehicle's screen, encountering road obstacles (like pedestrians, trucks, and other traffic), and potentially witnessing improper driving behavior by the test vehicle.

8 Conclusion and Recommendation

This research targets at evaluating the passenger's happiness with the self-diving technology and the actual experience of a self-driving ride. To achieve this, a 'pretended' self-driving car was employed in a real-traffic experiment.

Throughout the experiment, a range of biometric data was collected from the participants, which included the heart rate data and the eye movement data, providing rich physiological insights. Meanwhile, surveys were distributed to capture the participants' self-reported mental states and their cognitive evaluations of the self-driving vehicle. This approach, which combines objective biometric measurements with subjective self-assessments, enables a more holistic understanding of the complex relation between technology, emotional states, and cognitive perceptions in the context of self-driving technology.

The survey data were analyzed and to delve into both the passengers' mental and cognitive happiness, revealing a gratifyingly positive outcome. The biometric data was processed with a focus on understanding instances that could potentially cause stress and the underlying factors contributing to these physiological abnormalities. This two-faced approach allows us to not only grasp the passengers' emotional and cognitive state but also reveal intricate connections between their experiences, physiological responses, and external stimulants.

7.1 Answer to the Research Questions

In this section, the research questions will be answered, and firstly the sub-questions will be answered as follow:

Sub-question 1: How to define the happiness of self-driving vehicle's passenger?

The happiness of the self-driving vehicle's passenger can be defined as having both positive mental state during and after the ride and positive cognitive evaluation towards the self-driving vehicle. The positive mental state includes the feeling of happy, relaxed, cheerful, proud etc. The cognitive evaluation includes the trip/travel scale satisfaction, functional satisfaction, perceived usefulness of technology and willingness to use the technology.

Sub-question 2: How to measure the happiness of self-driving vehicle's passenger?

The measurement applied in this research includes the self-reported measurement, (surveys) and the biometric measurement (heart rate data and eye movement data).

The surveys collected the participants instant mental state and long-term cognitive evaluation towards the self-driving vehicle. To be specific, the survey revealed the participants' acceptance to the technology, trust in the self-driving vehicle, willingness to use the technology, and riding experience, etc. Meanwhile, participants' responses from the before-ride survey and after-ride survey revealed the impact of the test ride on the participants emotions and attitudes towards the self-driving vehicles, therefore the impact on the happiness of passengers.

The biometric data revealed the physiological reaction of the participants, and based on further analysis the data can reveal the mental state of the participants. Specifically, the abnormal heart rate can tell what kind of scenario would make the participants stressed or anxious and with further analysis, the causes for these negative feelings can be proposed. For the eye movement data, the different fixation and blinking behavior can tell the different mental state of the participants. Then it can be used to analysis the participants' mental conditions difference when riding on different road sections.

Sub-question 3: What factors could influence the happiness of self-driving vehicle's passenger?

Based on the literature search, the factors influencing the happiness of the passengers include perceptual experience, individual factors, external conditions, and in-vehicle facilities. The perceptual experience is the comfort, the perceived safety and mental workload etc., of the participants. The individual factors include the gender differences, age differences, personalities, and mental health etc. The external conditions include traffic conditions, road infrastructure, weather conditions etc. The in-vehicle facilities include the inner-environment of the vehicle, the entertainment, and the meditation etc.

Sub-question 4: To what extent can these factors influence the happiness of self-driving vehicle's passenger?

This research only looked at the influence of gender differences, and road infrastructure difference on the happiness of the passengers.

- **Gender Differences**

Results shows that female participants tend to feel more emotionally positive and more satisfied with the self-driving ride, while male participants are less happy and more dissatisfied with the ride. Though statistic results show rare significant differences between two genders for most of the given emotions, the results still indicate a significantly higher dissatisfaction of the self-driving ride among the male participants.

- **Road Infrastructure Influences**

The impact of different infrastructures on the happiness was evaluated by the eye movement data. Results show that a mental condition difference exist on different road sections. Specifically, road with signalized intersection has high visual workload but the participants were familiar with the road condition based on the shorter fixation rate and slower blinking behavior, hence the participants were somehow calm and peaceful. On the highway there was less new visual information, though participants were relatively unfamiliar with this information, they were calm and less alerted on the highway. The roundabout section contains more unfamiliar visual information to the participants, hence resulted in distraction of the participants. The bridge section includes too much new visual information indicated by the high fixation rate and quick blink behavior, and participants may experience increased stress and cognitive demand.

Sub-question 4: To what extent can a ride in a self-driving car influence the happiness of the passengers?

Based on the survey results, both the participants' mental state and the cognitive evaluation towards the self-driving vehicle turned more positive after the test ride in a self-driving vehicle.

Specifically, participants were significantly feeling happier, more cheerful, more relaxed, and prouder after the test ride. They were also feeling less stressed, depressed, anxious, and worried after the test ride. This decrease of negative emotions may not only be about their mental health but also about their attitude towards the self-driving vehicle, i.e., they were feeling less anxious and worried towards the self-driving technology not only towards their life. Moreover, the participants were significantly feeling more comfortable and satisfied with self-driving vehicle, and they have higher perceived usefulness and willingness to use towards the self-driving technology.

Answers to the sub questions can give a final answer to the main research question: **To what extent can automated vehicle, specifically self-driving vehicle help to improve the happiness of the passenger?**

Self-driving vehicle undoubtedly has such ability to improve the happiness of the passenger. From the survey response, a positive attitude towards the self-driving car can be seen, and passengers tend to believe the self-driving vehicle can be useful and beneficial to their life. Such preference is even more obvious after they took a real ride in the self-driving vehicle. Passengers' mental conditions can also get improved after a self-driving vehicle ride, they are specifically feeling happier, more cheerful, prouder, less stressed, and less anxious.

Furthermore, the self-driving vehicle allows passengers to engage in a variety of activities beyond the mere act of travel. These activities may include taking a nap, having some food, arranging personal tasks, listening to music or podcast etc. This variety emphasizes the self-driving vehicle's potential to improve the sense of leisure and utility for passengers. By affording passengers the spare moments which would otherwise be spent on driving tasks, self-driving vehicles not only facilitate physical transportation but also contribute to an overall enhanced quality of life.

Biometric data collected from the experiment acted as the passengers' happiness predictors. This research did not provide a method to predict the happiness level of participants using the biometric data but used the data to analyze influence of different traffic scenarios. The heart rate and the eye movement of participants provided further information about how the participants were feeling and what they were experiencing during the self-driving vehicle test ride. The results showed that overall, the participants experienced stable and calm rides, while some specific scenarios for instance encountering pedestrians or big trucks might influence the physical reaction of the participants, hence indicating a decreased happiness level of the participants.

7.2 Scientific Contributions

This study makes several significant contributions to the field of autonomous driving, specifically the user experiences of the self-driving vehicle. It advances the understanding of passengers' happiness by defining the happiness and measuring it through the survey, facilitated with the biometric data to understand the phycological reactions and psychological experiences. With the focus on the happiness and wellbeing of the passengers in the self-driving vehicles, this research not only tried to understand or improve the acceptance of the self-driving vehicle but more importantly demonstrate what are the potentials of these vehicles on the happiness of the passengers.

Moreover, this research employs a novel approach to conduct user experience research in the field of self-driving vehicles where self-driving vehicle is hardly available. A transformed normal vehicle was used to make a real-traffic experiment, proving the participants with authentic and safe self-driving experiences. Thereby collecting valuable biometric and self-reported data from the participants on a real self-driving ride.

In addition to its academic implications, this research has practical applications for road infrastructure design, self-driving vehicle design, and autonomous driving related regulation development. Understanding the factors that contribute to passenger happiness can guide road infrastructure design: research found that passengers concerned about the travel time when taking a self-driving vehicle, such preference for less congested trip can influence the planning of road networks. Moreover, obstacles such as big trucks and sudden appeared pedestrians would arouse the stress of the passengers, the self-driving vehicle can be designed more cautious at these sudden obstacles on the road, for instance keeping larger distance and lower speed. Research findings can help shaping regulations for self-driving vehicles as policymakers can use these data to establish guidelines that prioritize passenger well-being and safety. This includes setting standards for vehicle comfort, safety features, and the permissible level of automation for certain types of journeys. The physiological reaction of the participants indicated potential stress-causing obstacles or scenarios, which would be applicable to practical design.

In summary, the scientific contributions of this study encompass the academic knowledge on the passengers' happiness and its practical application. These findings, methodologies, and implications collectively contribute to the advancement of knowledge in the happiness and wellbeing of the self-driving vehicle users and unleash the potential of autonomous vehicles in advancing the happiness of its users.

8.3 Research Limitations and Recommendations for Future Research

7.3.1 Experiment Design

Though the transformation of a normal vehicle into 'pretended' self-driving is novel, the happiness is collected only before and after the ride and rarely self-reported information about the participants was obtained during the ride. Recommendations for future studies are to have more segment within the ride where the participants can give instant response during the ride. Hereby the self-reported data can be analyzed in relation to the self-reported data, where combined measurement of happiness can be made. Furthermore, more specific analysis about the factors influencing the happiness can be done, for instance what kind of road or situation would make participants stressed, or sleepy, or alert, etc.

7.3.2 Data Analysis

One limitation is that this study failed to link the biometric to the self-reported data in the sense of evaluating the passengers' happiness. Since the survey data is only available before and after the ride, only the collective value, for instance mean and variance of the biometric data is comparable to the survey response. If participants' responses are available during the ride as mentioned previously, for instance collecting their self-reported emotions during the test ride. then the link between biometric and self-reported can be analyzed.

In this study, the biometric data, due to the data collection limitation, was not linked to the survey data, hence no direct connection between the biometric behavior and the passengers' happiness could be drawn. The biometric data could only act as predictors or indicators of passenger' happiness. Further studies could convert the biometric data into comparable format with the survey data, for instance average blink or fixation rate for each participant, then comparison and analysis could be done to investigate the relationship between the biometric data and the happiness of the passenger. Moreover, the analysis of biometric data did not encompass statistical tests to confirm the significance of the results.

7.3.3 Research Participants

This research mainly recruited the student participants, which strategically selected individuals with comparable ages and a similar knowledge level of self-driving technology. And those who came to the experiment were somehow feeling comfortable or interested with the self-driving technology, as these volunteers were inherently more inclined to explore the self-driving car experience. However, acknowledging the inherent limitations, it's important to note the potential for a bias towards positive outcomes. To mitigate this, future study should broaden the participant pool to encompass individuals with varying perspectives, including those who hold reservations or skepticism towards this technology. This approach would provide a more comprehensive insights, enriching the findings by encompassing a wider array of reactions and sentiments.

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Appendix

A. Surveys

A.1 Before Test Ride Survey

Section 1: Basic Information (9)

Q3.2 What is your age?

-Under 18
-18-21
-22-25
-26-29
-30-33
-34-37
- Above 37
-Prefer not to disclose

Q3.3 What is your gender?

-Male
-Female
-Non-binary/third gender
-Prefer not to disclose

Q3.4 What is your education completion?

-Middle professional
-MAVO/VWO/HAVO (high school)
-Higher vocational education (HBO)
-Bachelor
-Master
-PhD or higher
-Other

-Prefer not to disclose

Q3.5 How would you rate your level of knowledge about automated vehicles?

-Not knowledgeable at all (1)

-Slightly knowledgeable (2)

-Moderately knowledgeable (3)

-Very knowledgeable (4)

-Extremely knowledgeable (5)

Q3.6 During the last 30 days, about how often did you feel …(Select the case that matches your situation the most)

	Never	Sometimes	About half the time	Most of the time	Always
… depressed?					
… so depressed that nothing could cheer you up?					
… hopeless?					
… restless or fidgety?					
… so restless that you could not sit still					
… you feel tired out for no good reason?					
… you feel that everything was an effort?					
… you feel worthless?					
… you feel nervous? … you feel ashamed?					
… you feel guilty?					
… You feel anxious?					

Q3.7 How comfortable are you with the idea of riding in self-driving vehicle?

-Extremely uncomfortable

-Somewhat uncomfortable

-Neutral

-Somewhat comfortable

-Extremely comfortable

Q3.8 I trust the self-driving vehicle.

-Strongly disagree

-Somewhat disagree

-Slightly disagree

-Slightly agree

-Somewhat agree

-Strongly agree

Q3.9 I would not want to monitor what the self-driving vehicle is doing when it is in control.

-Strongly disagree

-Somewhat disagree

-Slightly disagree

-Slightly agree

-Somewhat agree

-Strongly agree

Q3.10 I expect to feel comfortable if my child, spouse, parents – or other loves ones – travel with the self-driving vehicle.

-Strongly disagree

-Somewhat disagree

-Slightly disagree

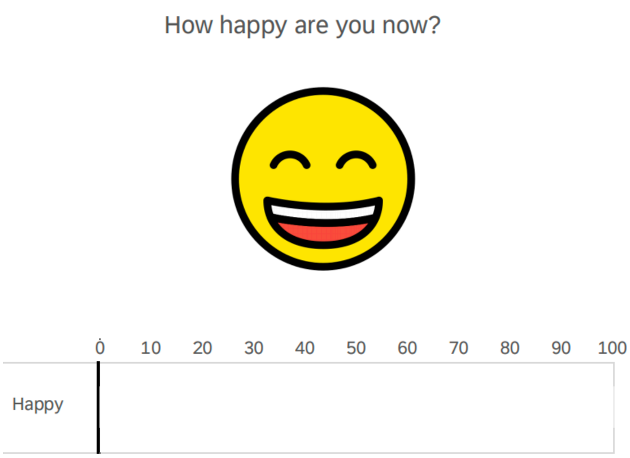
-Slightly agree

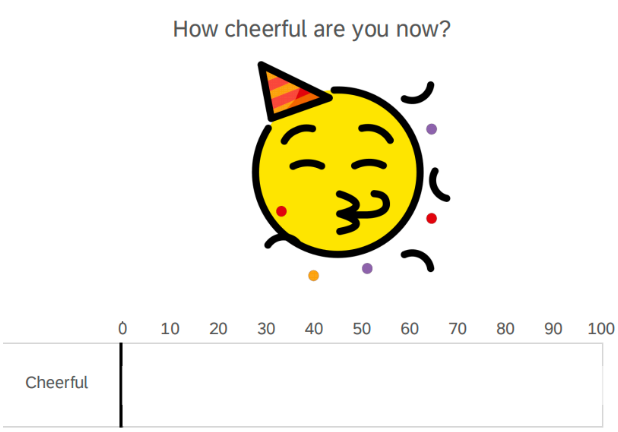
-Somewhat agree

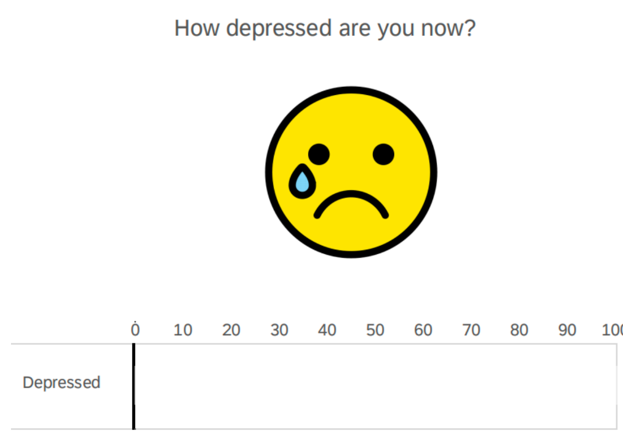
-Strongly agree

Section 2: Mental State (14)

Use the slider to indicate the current feelings based on given emotions (from 0 to 100).







How dissatisfied are you now?

0 10 20 30 40 50 60 70 80 90 100

Dissatisfied

How active are you now?

0 10 20 30 40 50 60 70 80 90 100

Active

How relaxed are you now?

0 10 20 30 40 50 60 70 80 90 100

Relaxed

How sleepy are you now?

0 10 20 30 40 50 60 70 80 90 100

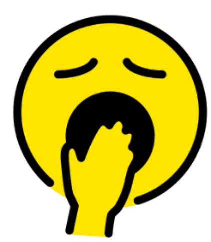
Sleepy

How stressed are you now?

0 10 20 30 40 50 60 70 80 90 100

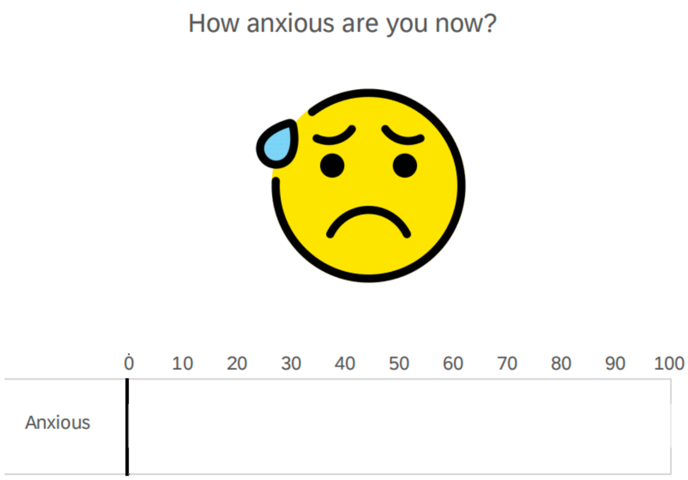
Stressed

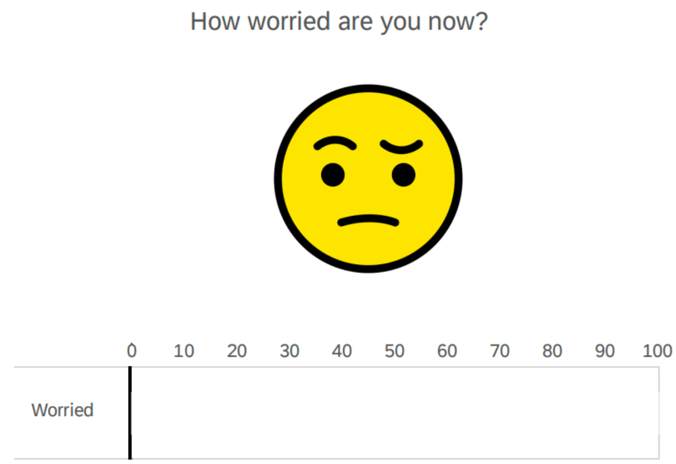
How tired are you now?

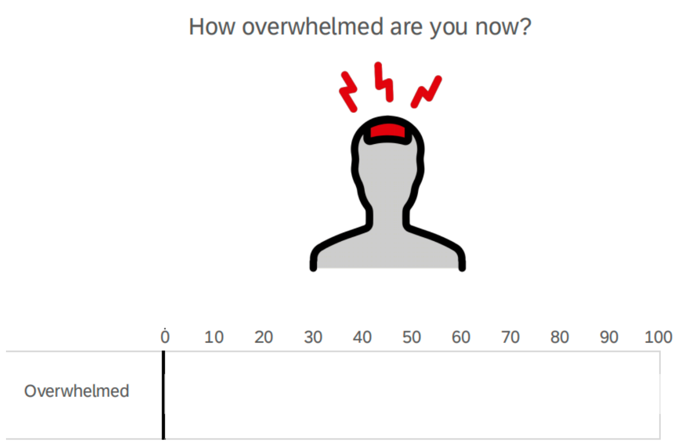


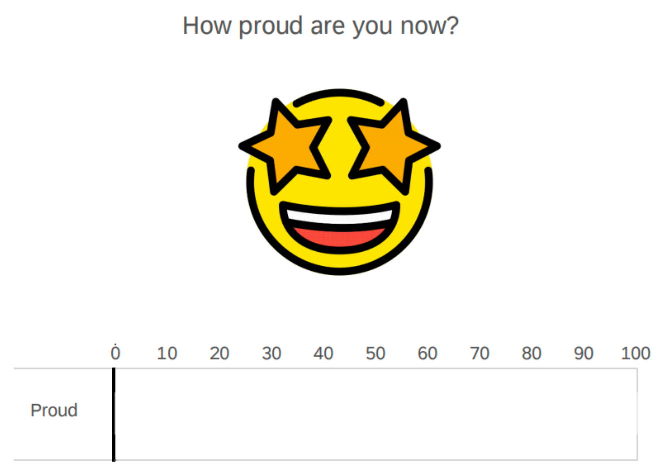
0 10 20 30 40 50 60 70 80 90 100

Tired









Section 3: Cognitive evaluation (ride) (2)

Q5.2 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q5.2_1 The ride in a self-driving vehicle would be satisfying.

Q5.2_2 The ride in a self-driving vehicle would be high standard.

Q5.2_3 The ride in a self-driving vehicle would work well.

Q5.3 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q5.3_1 Using the self-driving vehicle would be fun.

Q5.3_2 The ride in the self-driving vehicle would be worst I can think of.

Q5.3_3 The ride in the self-driving vehicle would be best I can think of.

Q5.3_4 The ride in the self-driving vehicle would be low standard.

Q5.3_5 The ride in the self-driving vehicle would be high standard.

Section 4: Cognitive evaluation (vehicle) (4)

Q6.2 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q6.2_1 The self-driving vehicle would be useful in my daily life.

Q6.2_2 I would use the self-driving vehicle for daily commuting.

Q6.2_3 I would use the self-driving vehicle for leisure travel.

Q6.3 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q6.3_1The self-driving vehicle would improve my life quality.

Q6.3_2 The self-driving vehicle would be beneficial to the society.

Q6.3_3 The self-driving vehicle would reduce traffic congestion.

Q6.3_4 The self-driving vehicle would avoid traffic accidents.

Q6.3_5 The self-driving vehicle would improve our environment.

Q6.4 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q6.4_1 The self-driving vehicle would improve riding experience.

Q6.4_2 The self-driving vehicle would save my time.

Q6.4_3 The self-driving vehicle would reduce my stress.

Q6.4_4 The self-driving vehicle would reduce my fatigue.

Q6.5 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q6.5_1 If I have access to the self-driving vehicle, I think I would use it.

Q6.5_2 I plan to buy and use the self-driving vehicle when it is available.

Q6.5_3 I would recommend the self-driving vehicle to my friends or family.

A.2 After Test Ride Survey

Q1.4 What did you do during your ride? You can make multiple choices.

- Enjoying the scenery outside the car.
- Daydreaming or reflecting on thoughts.
- Taking a nap or resting.
- Planning or organizing personal tasks.
- Enjoying snacks or beverages.
- Listening to music or podcasts.
- Having conversations with the safety guard.
- Engaging in social media or browsing the internet.
- Playing games or using entertainment apps.
- None of above.
- Other (Please indicate)

Q1.5 How comfortable are you with the idea of riding in self-driving vehicle?

- Extremely uncomfortable
- Somewhat uncomfortable
- Neutral
- Somewhat comfortable
- Extremely comfortable

Q1.6 I trust the self-driving vehicle.

-Strongly disagree

-Somewhat disagree

-Slightly disagree

-Slightly agree

-Somewhat agree

-Strongly agree

Q1.7 I would not want to monitor what the self-driving vehicle is doing when it is in control.

-Strongly disagree
-Somewhat disagree
-Slightly disagree
-Slightly agree
-Somewhat agree
-Strongly agree

Q1.8 I expect to feel comfortable if my child, spouse, parents – or other loves ones – travel with the self-driving vehicle.

-Strongly disagree
-Somewhat disagree
-Slightly disagree
-Slightly agree
-Somewhat agree
-Strongly agree

Section 2: Mental State (14)

Use the slider to indicate the current feelings based on given emotions (from 0 to 100)

How happy are you now?

0 10 20 30 40 50 60 70 80 90 100

Happy

How sad are you now?

0 10 20 30 40 50 60 70 80 90 100

Sad

How cheerful are you now?

0 10 20 30 40 50 60 70 80 90 100

Cheerful

How depressed are you now?

0 10 20 30 40 50 60 70 80 90 100

Depressed

How dissatisfied are you now?

0 10 20 30 40 50 60 70 80 90 100

Dissatisfied

How active are you now?

0 10 20 30 40 50 60 70 80 90 100

Active

How relaxed are you now?

0 10 20 30 40 50 60 70 80 90 100

Relaxed

How sleepy are you now?

0 10 20 30 40 50 60 70 80 90 100

Sleepy

How stressed are you now?

0 10 20 30 40 50 60 70 80 90 100

Stressed

How tired are you now?

0 10 20 30 40 50 60 70 80 90 100

Tired

How anxious are you now?

0 10 20 30 40 50 60 70 80 90 100

Anxious

How worried are you now?

0 10 20 30 40 50 60 70 80 90 100

Worried

How overwhelmed are you now?

0 10 20 30 40 50 60 70 80 90 100

Overwhelmed

How proud are you now?

0 10 20 30 40 50 60 70 80 90 100

Proud

Section 3: Cognitive evaluation (ride) (2)

Q3.2 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q3.2_1 The ride in a self-driving vehicle was satisfying.

Q3.2_2 The ride in a self-driving vehicle was high standard.

Q3.2_3 The ride in a self-driving vehicle worked well.

Q3.3 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q3.3_1 Using the self-driving vehicle was fun.

Q3.3_2 The ride in the self-driving vehicle was worst I can think of.

Q3.3_3 The ride in the self-driving vehicle was best I can think of.

Q3.3_4 The ride in the self-driving vehicle was low standard.

Q3.3_5 The ride in the self-driving vehicle was high standard.

Q3.4 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q3.4_1 The self-driving vehicle had a natural driving style.

Q3.4_2 The self-driving vehicle acted weirdly.

Q3.5 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q3.5_1 I found the self-driving vehicle easy to use.

Q3.5_2 My interaction with the vehicle was clear and understandable.

Section 4: Cognitive evaluation (vehicle) (4)

Q4.2 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q4.2_1 The self-driving vehicle will be useful in my daily life.

Q4.2_2 I will use the self-driving vehicle for daily commuting.

Q4.2_3 I will use the self-driving vehicle for leisure travel.

Q4.3 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q4.3_1The self-driving vehicle will improve my life quality.

Q4.3_2 The self-driving vehicle will be beneficial to the society.

Q4.3_3 The self-driving vehicle will reduce traffic congestion.

Q4.3_4 The self-driving vehicle will avoid traffic accidents.

Q4.3_5 The self-driving vehicle will improve our environment.

Q4.4 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q4.4_1 The self-driving vehicle will improve riding experience.

Q4.4_2 The self-driving vehicle will save my time.

Q4.4_3 The self-driving vehicle will reduce my stress.

Q4.4_4 The self-driving vehicle will reduce my fatigue.

Q4.5 To what extent do you agree with the following statements? (Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

Q4.5_1 If I have access to the self-driving vehicle, I think I will use it.

Q4.5_2 I plan to buy and use the self-driving vehicle when it is available.

Q4.5_3 I will recommend the self-driving vehicle to my friends or family.

B. Inform & Consent Form

Welcome to our study.

I hope you are as excited as we are because today you have the chance to **take a ride in a self-driving vehicle**, and we want to investigate your experience during the ride. You can see the vehicle in the image below. It is an electric bus.

You as passenger will sit in the backseat. You can simply enter the vehicle and enjoy the ride. The whole experiment includes three-part:

1 – consent to your participation and take a pre-ride survey (15 mins),

2 – take one test ride in a self-driving vehicle (20 mins)

3 – fill in the post-ride survey (10 mins).

Before you start to fill in the first survey, we kindly request you to read the participant information sheet on the next page and tick the box that you understand the study procedure and information described and agree to participate.

If you have any questions or remarks, please contact Yiping Xu
Thank you in advance for your cooperation!

This study is done by Delft University of Technology.

Data Collection, Storage, Confidentiality and Analysis

We will collect the following data:

- Heart rate using a smartwatch;
- Eye movement using Pupil Lab glasses;
- Video recordings of your face to register facial expression responses;
- General demographic information you provide us by filling in the first survey

*Note that you are free to leave parts of the survey unanswered if you do not wish to answer certain questions.

Data collected in this study will be stored and handled confidentially. The data that could be traced back to you will be converted to untraceable data whereafter the traceable data will be destroyed.

Video recordings of your face will be converted to facial landmarks (‘action units’), which are not personally identifiable. After the video with facial landmarks and heart rate measures will be linked to the responses in the surveys, the final dataset will be anonymized, leaving no traces leading to the re-identification of participants. This will be done one week after the end of the study (i.e., raw data will be stored until June 2023). Afterwards, the recordings and in-between links will be destroyed.

The video and heart rate data will be stored and encrypted on a hard drive. The hard drive is kept in a locked cabinet at the Department of Transport & Planning at TU Delft when not in use. At the end of the study, the video and heart rate data, and responses from the surveys will be transferred to the project storage drive in TU Delft. It is a classical TU Delft password-protect environment. Only the main researcher (Yiping Xu, Sina Nordhoff) will have access to the raw data. After all the data is combined in a final dataset and the raw data is destroyed, the final dataset will be further stored on the project storage drive.

Non-Disclosure of Test Ride Experience

You should keep all the information shared with you during the test ride day confidential and should not discuss or share this information with anyone other than with the study team until December 2023.

Compensation for Participation

You have a chance to win one of five Bol.com vouchers with a value of 20 euros each.

Participation, Withdrawal, and Your Data

- Your participation in this study is completely voluntary.
- You may withdraw at any point during the study without providing a reason. - You may refuse to answer any questions that you do not wish to answer.
- There is no penalty if you choose to withdraw from the study. You have the right to receive a copy of your data.
- You have the right to request that your data is partly or completely removed from the dataset. Your data will then be destroyed and not used in the analysis and not included in the final results.
- Please note that no personally identifiable data will be included in the results in any case.
- Please note that at most a week after the end of the study (i.e., June 2023) no identifiable data remains in the data set, meaning that we cannot identify which belongs to you.

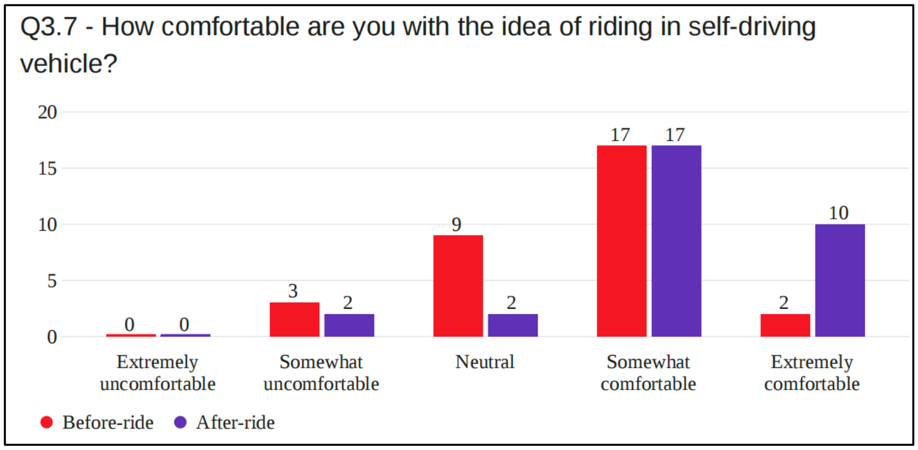
By clicking "Proceed", you agree to aforementioned, and you will start to fill in the first survey

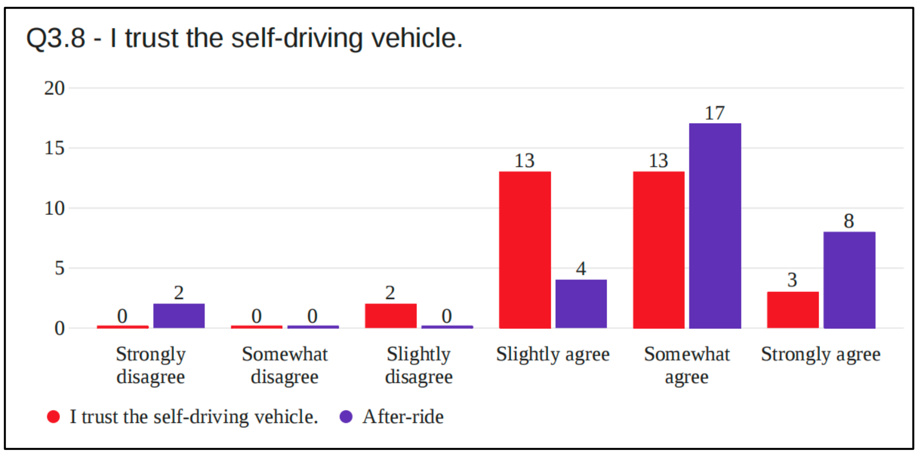
-Proceed.

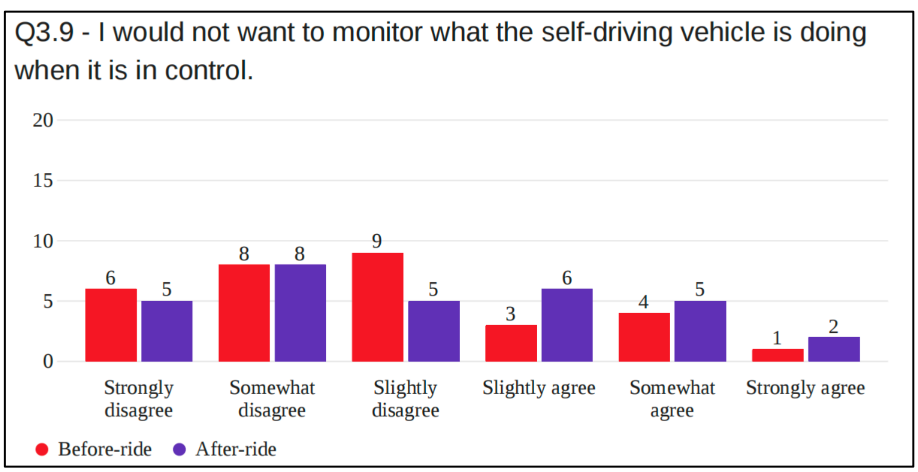
-No, I will not take part in this experiment.

C. Other Plots and Figures

In this part, the plots of the survey responses that did not presented in the previous contexts are listed as follow.







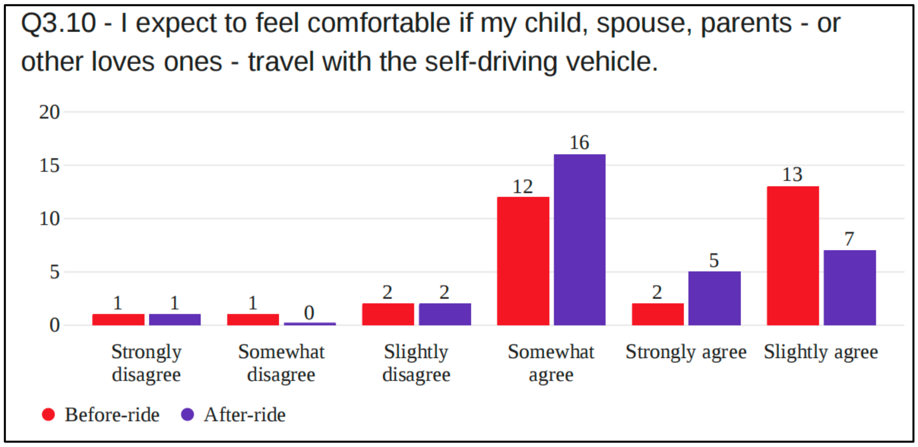
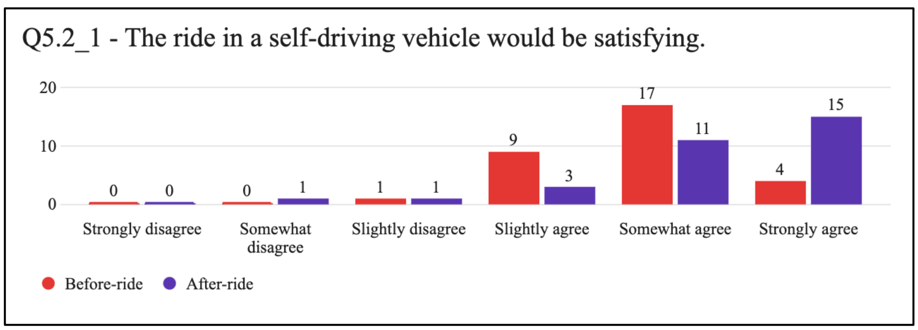
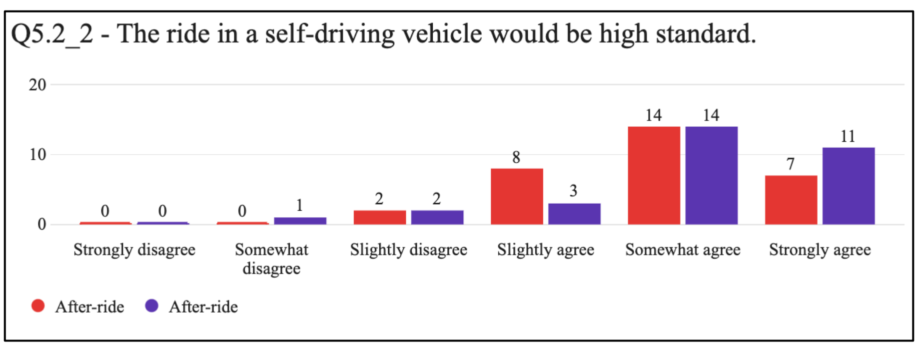
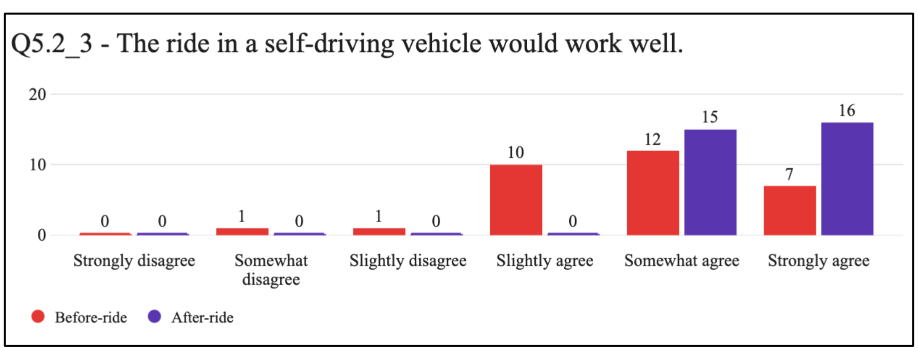
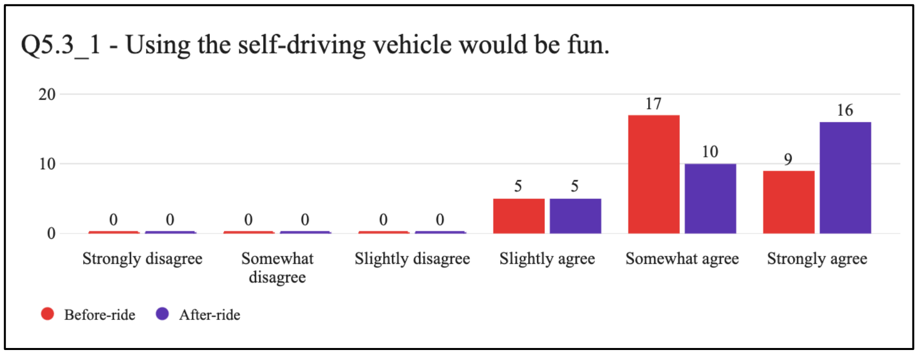


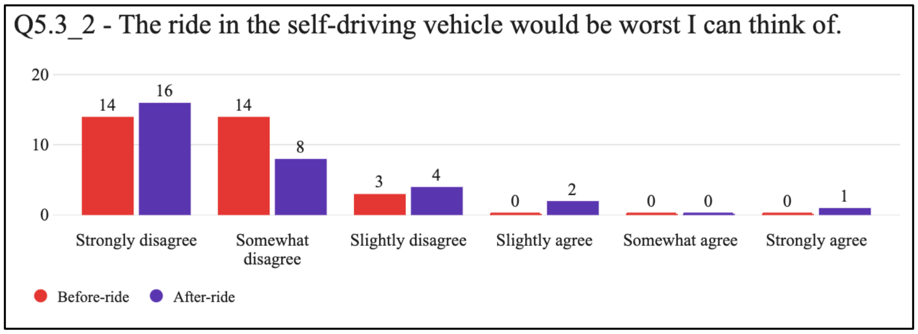
Figure 25 Survey Response – Overall Evaluation

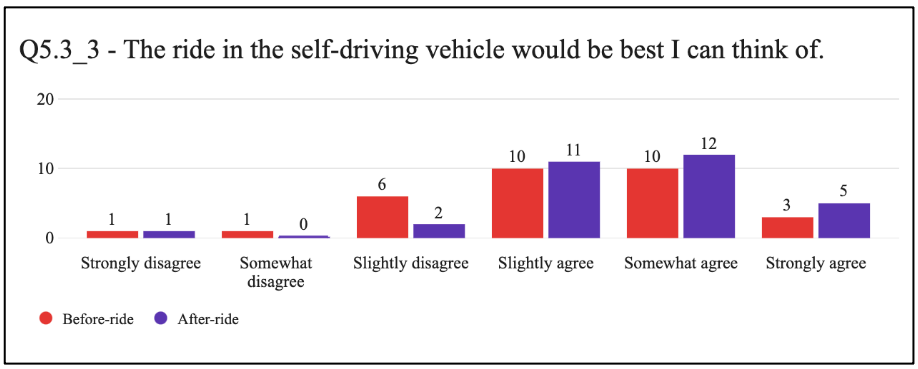


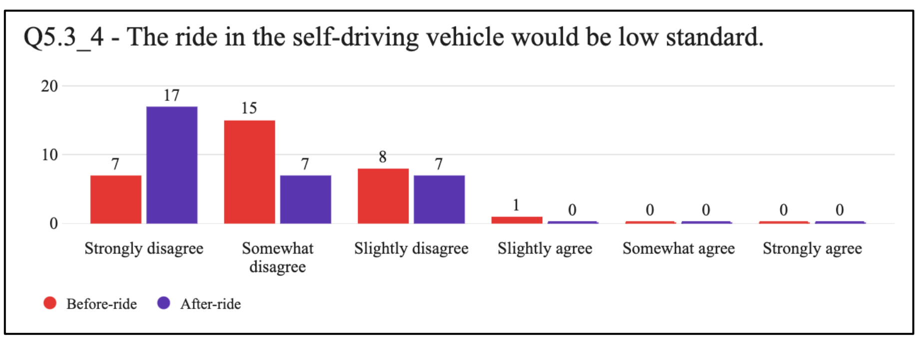





Q5.3_1 - Using the self-driving vehicle would be fun.
20
10
0
0 0 0 0 0 0 5 5 17 10 9 16
Strongly disagree
Somewhat disagree
Slightly disagree
Slightly agree
Somewhat agree
Strongly agree
Before-ride
After-ride


Q5.3_2 - The ride in the self-driving vehicle would be worst I can think of.
20
10
0
14 16 14 8 3 4 0 2 0 0 0 1
Strongly disagree
Somewhat disagree
Slightly disagree
Slightly agree
Somewhat agree
Strongly agree
Before-ride
After-ride


Q5.3_3 - The ride in the self-driving vehicle would be best I can think of.
20
10
0
1 1 1 0 6 2 10 11 10 12 3 5
Strongly disagree
Somewhat disagree
Slightly disagree
Slightly agree
Somewhat agree
Strongly agree
Before-ride
After-ride


Q5.3_4 - The ride in the self-driving vehicle would be low standard.
20
10
0
7 17 15 7 8 7 1 0 0 0 0 0
Strongly disagree
Somewhat disagree
Slightly disagree
Slightly agree
Somewhat agree
Strongly agree
Before-ride
After-ride

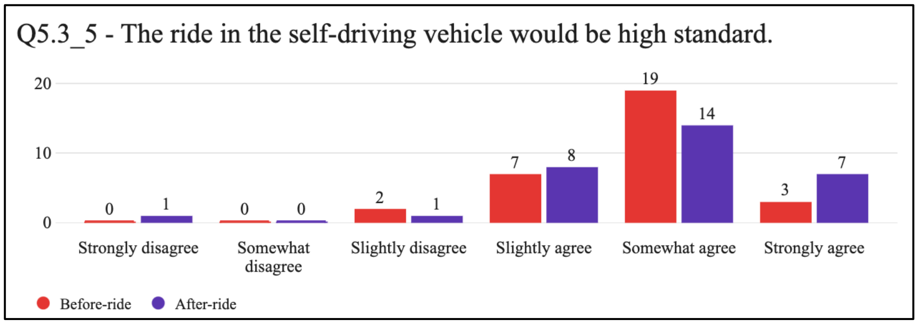
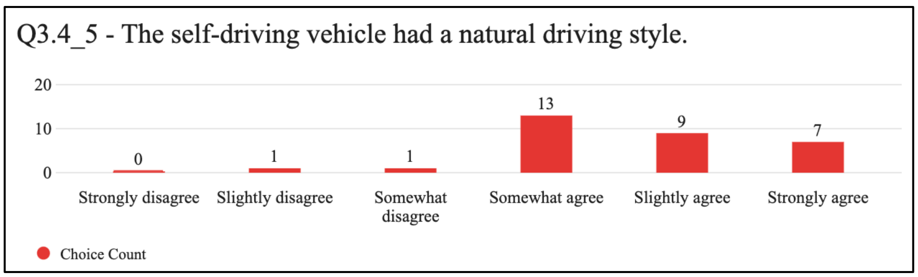
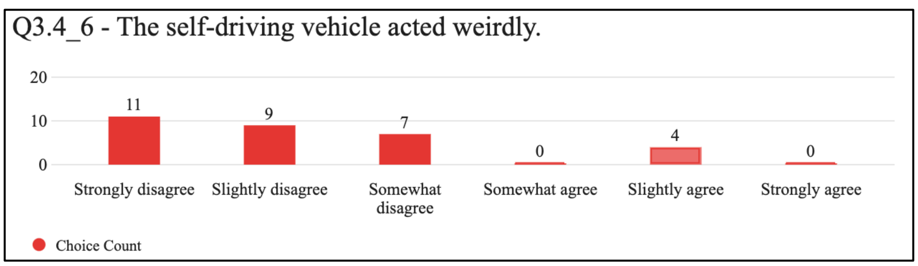
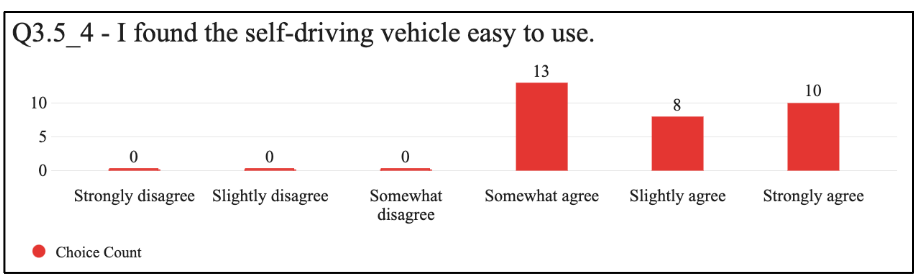


Figure 26 Survey Response – Trip/travel Scale Satisfaction







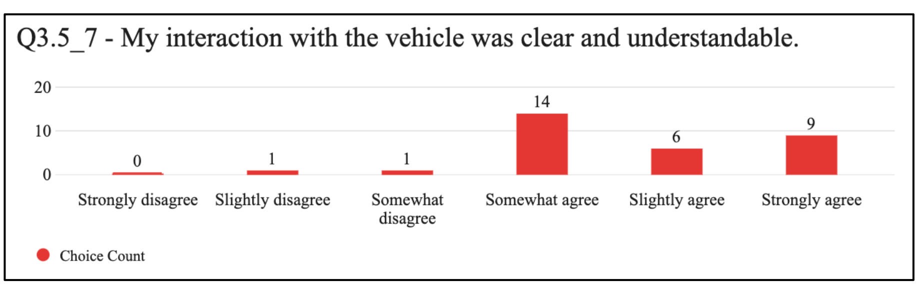
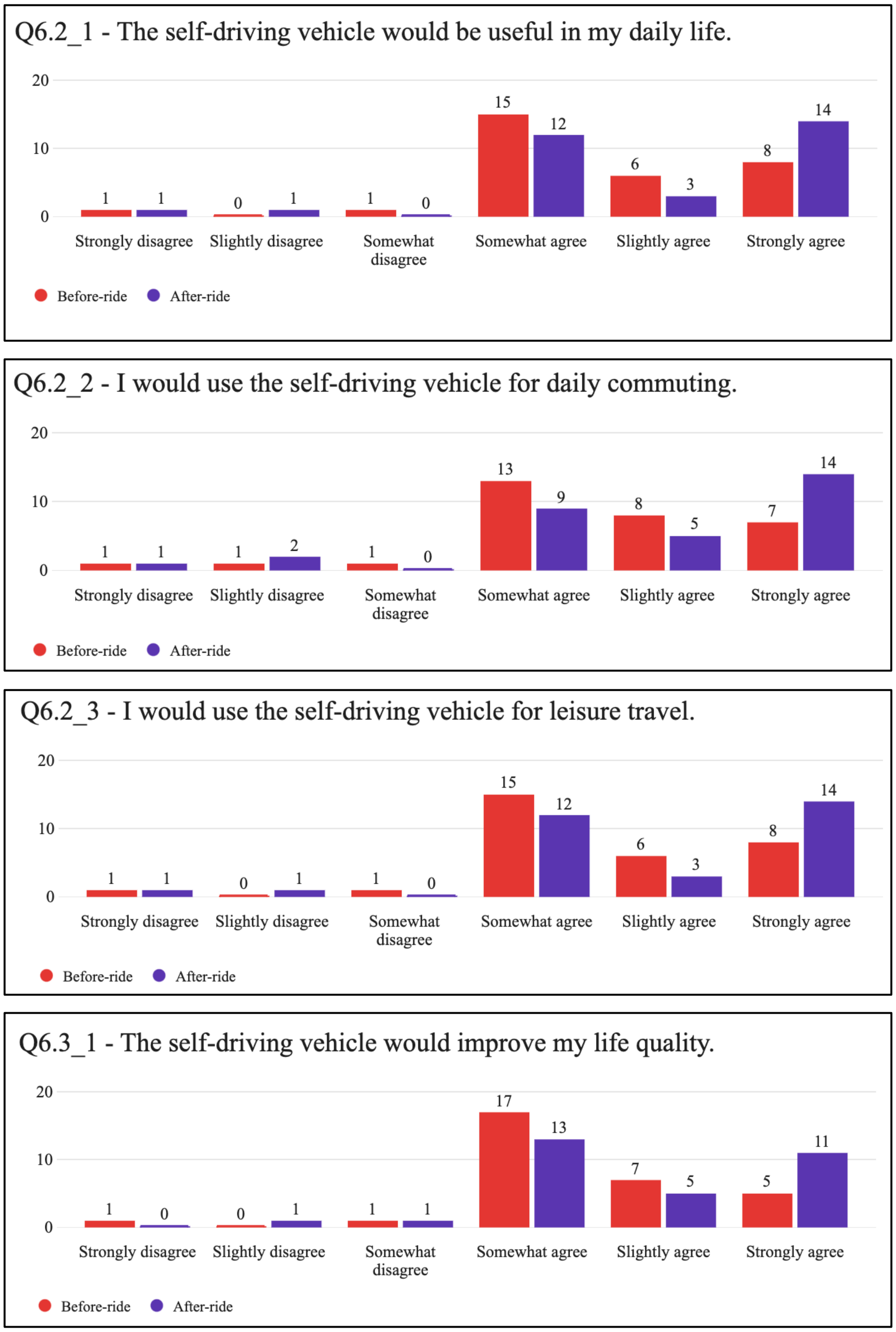
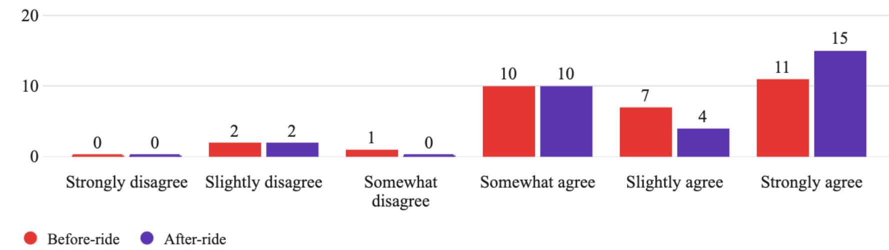


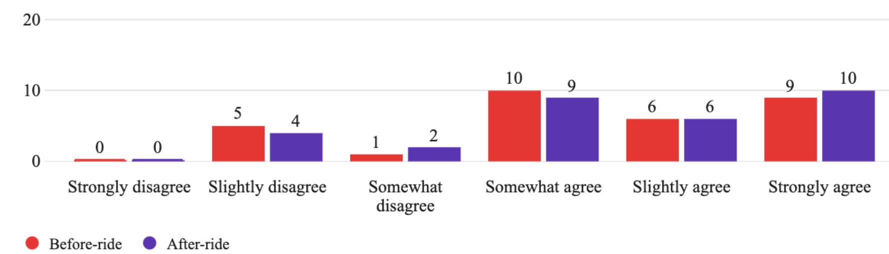
Figure 27 Survey Response – Functional Satisfaction



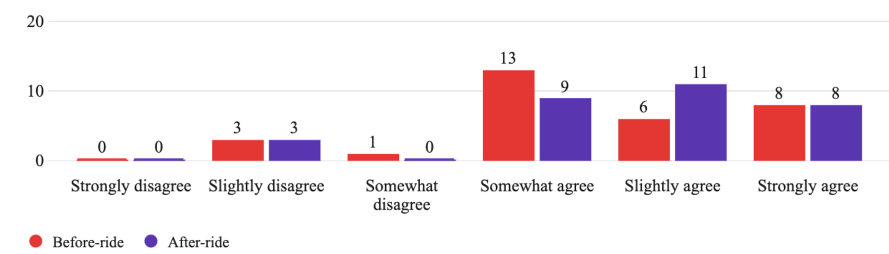
Q6.3_2 - The self-driving vehicle would be benificial to the society.



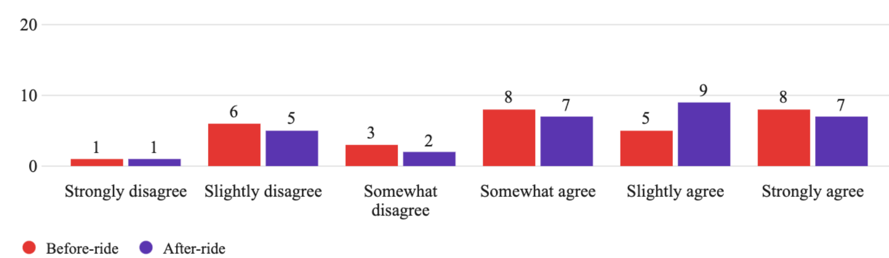
Q6.3_3 - The self-driving vehicle would reduce traffic congestion.



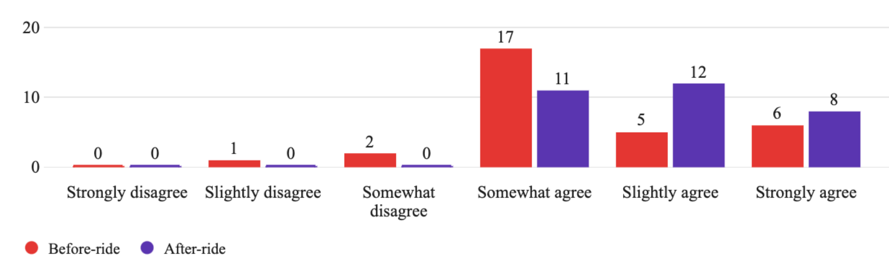
Q6.3_4 - The self-driving vehicle would avoid traffic accidents.



Q6.3_5 - The self-driving vehicle would improve our environment.



Q6.4_1 - The self-driving vehicle would improve riding experience.



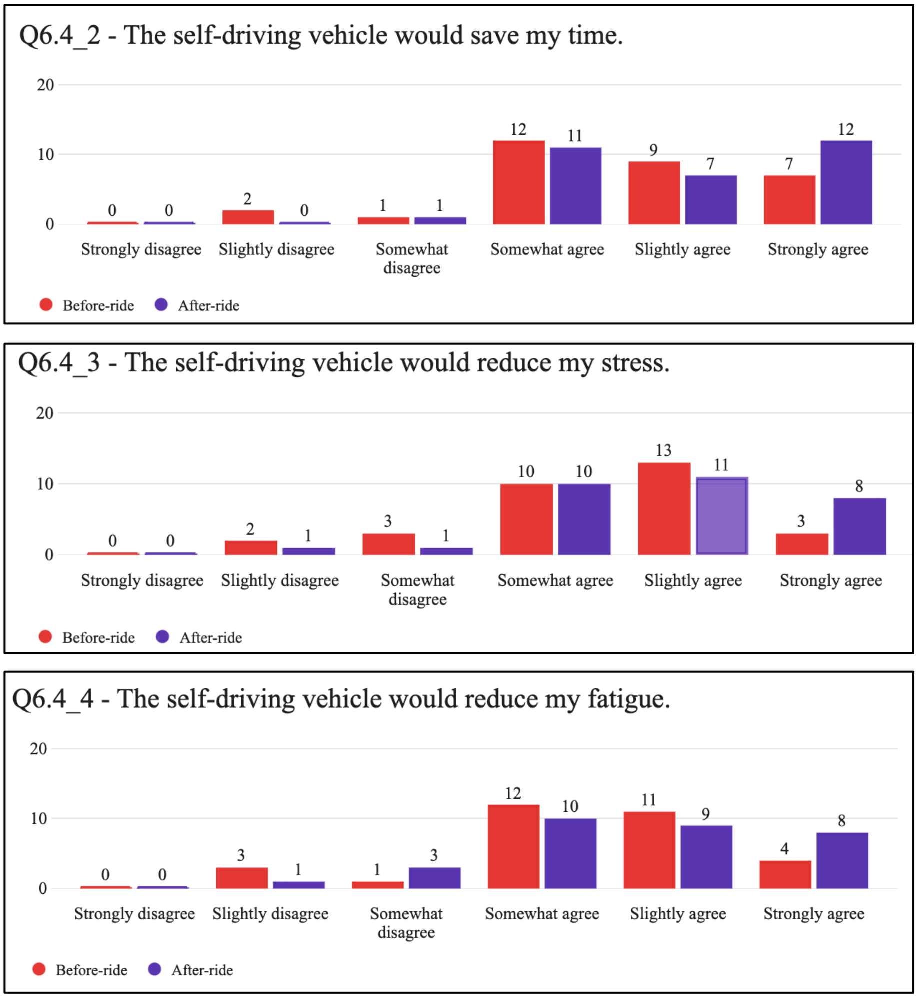
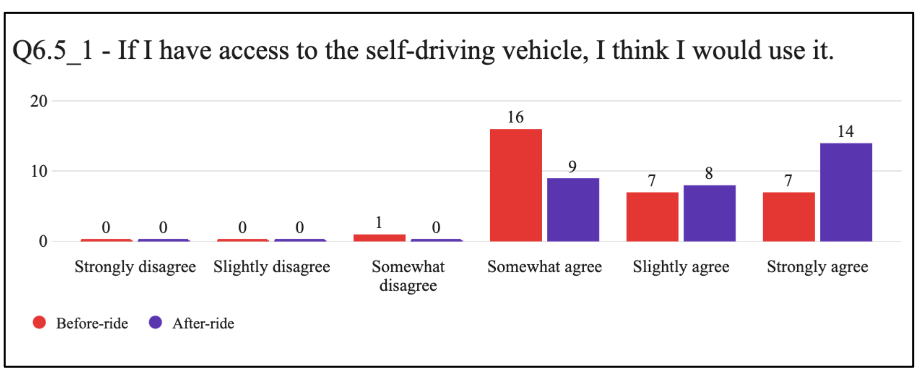


Figure 28 Survey Response – Usefulness of Technology



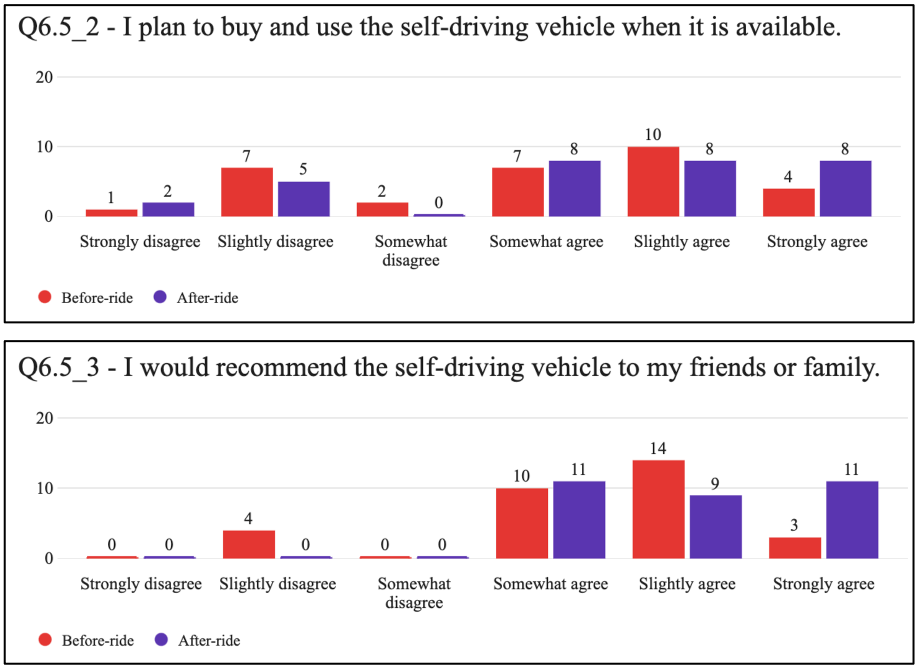


Figure 29 Survey Response -Willingness to Use