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ORIGINAL ARTICLE

Will I start an automated driving system? Report on the emotions, cognition, and intention of drivers who experienced real-world conditional automated driving

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Abstract
The automotive market today has seen the entry of Level-3 conditional automated driving vehicles equipped with an automated driving system that waits for the drivers to start it on the road. Before making a full assessment of the use of automated driving systems, drivers should be made to experience real-world conditional automated driving. A driver may have a mood change when driving a real-world automated vehicle. This emotion points to the mediation of motivation, which affects a driver's cognition and intention to start an automated driving system on the road. In this study, the emotion of experiencing autonomous driving, cognition, and satisfaction of the driving performance were introduced to construct an intention model to start an automated driving system. Online and off-line questionnaires were adopted, and the emotional response, cognition of automated driving, and intention of 133 drivers who experienced real-world conditional automated driving were determined. Driver experience was assessed in four scenarios as part of emotional tests: during manual driving, during conditional automated driving, during takeover under the influence of the warning system, and during takeover driving. The results of the questionnaire showed a significant positive correlation between emotion and cognition, satisfaction of autonomous driving performance, and the intent to start the automated driving system. Emotions play a mediating role between cognition, satisfaction, and intention to start automated driving. Drivers who experienced conditional automated driving appeared to exhibit a moderately high level of emotional response in terms of joy, interest, and surprise, whereas medium-level negative emotions included fear and anger. Drivers experienced some intensity of emotional changes during conditional automated driving and takeover driving. The emotional changes were uneven but encouraging support was reported. In addition, specific hypotheses relating the driving performance of the automated vehicles (in terms of programmed design of takeover and warning system of takeover) to the emotional dimensions were tested. A cluster analysis of the emotional response measures revealed five different emotional patterns when experiencing the real-world automated vehicle, among which the happy/satisfied group had higher intention to start an automated driving system on the road, followed by the emotional group, whereas the disgust group showed the lowest intention. The cluster analysis was supported by demographic and driving cognitive characteristics (age, education, and self-evaluation of the driving level and driving experience) of the five groups of drivers. Finally, the theoretical and practical significance of this study was expounded. The research results may provide some suggestions and hints for the government and enterprises to promote the development of automated driving.

Keywords Cognition · Emotions · Automated vehicles · Takeover · Cluster analysis · Intention

1 Introduction

In recent years, with technological progress, several automobile manufacturers have launched intelligent vehicles equipped with an automated driving system, which means that conditional automated driving characterized by human–machine co-driving is becoming a reality on real roads. This can help significantly improve the safety level of vehicles and alleviate driving fatigue in congested city

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environments. Although the starting up of an automated driving system is limited to specific scenes and is monitored in the background, the results of real-time automated driving are encouraging. The IHS, an American–British information provider, predicts the global penetration rate of Level-3 conditional automated driving vehicles to reach 15% by 2025 (China Association of Automobile Manufactures 2020a). This indicates that a large number of automated vehicles will be operational in the future. Many countries are actively promoting the development of automated driving in terms of policies and regulations, technological innovation, and infrastructure construction. In 2017, Germany became the first country to allow highly or fully autonomous vehicles to ply on their roads. The Japanese government lifted the relevant restrictions on L3 conditional automated driving vehicles plying on highways (China Association of Automobile Manufactures 2020b). The introduction of automation in vehicles represents a new era in the automotive industry (Du et al. 2020a). The question that needs to be addressed now is whether drivers are willing to start the automated driving system installed in such intelligent vehicles.

An automated driving system includes two processes (Borojeni et al. 2017): (i) switching from manual driving to automated driving; (ii) switching from automated driving to manual driving. The entire process requires not only an accurate and complex automated driving system, but also the cooperation and adaptability of human drivers (Gold et al. 2015). According to research (Vanderhaegen 2021a; Schneemann et al. 2019), drivers who toggle the autopilot function option on and off may only be doing their fair share of work. In terms of the principle of shared control between humans and automated systems, conditional automated driving has an incomplete level of autonomy in that some tasks are reassigned to the driver. The driver and the automated vehicle complete their respective tasks and achieve their goals. However, conflicts may arise while sharing the control, resulting in the failure of cooperation. For example, the abuse of automation leads to inefficiency of drivers (Banks et al. 2018). In fact, early users activated the autopilot system on roads it had not been designed for, which unfortunately caused fatal collisions. Critics are beginning to question whether such intelligent systems pose a threat to humans (Neumann et al. 2016; Pearl 2017). On the other hand, drivers may feel that they are willing to hand over control of the vehicle. Part of the reason may be attributed to current marketing and deployment methods that enhance the stability of automated systems (Vanderhaegen and Carsten 2017). Nevertheless, a driver's initial experience with automated vehicles will have a far-reaching impact on widespread adoption and use (Robertson et al. 2017). It is of great significance (Vanderhaegen 2012) to discuss the acceptance and adaptation level of the automated driving system by drivers. Only when these systems are widely accepted and used can they provide potential benefits, improve the driving experience of drivers, and encourage greater acceptance.

People's decisions on the acceptance of an automated driving system depend primarily on perceptions of its benefits and risks (Liu et al. 2019a, b; Chikaraishi et al. 2020; Kohl et al. 2018). Cognition is an important factor influencing attitudes and decision-making toward emerging technologies. Cognition (Dixon et al.2020; Siegrist et al. 2000; Parnell et al. 2018) in psychology and cognitive science refers to all the processes whereby a person's sensory input is transformed, processed, retrieved, and used (Trevarthen 1977). It constructs the process of continuous creation of people's experience of the world. For example, autonomous driving faces technical, ethical, and legal challenges that may pose potential risks to users (personal injury, privacy leakage, and economic loss) (Zhang et al. 2021). These risk perceptions can have a significant impact on user attitude toward autonomous driving technology (Gardner,1989). Variables such as perceived value, trust, and worldview (Dixon et al. 2020; Schraagen et al. 2020; Schwarz et al. 2019) have also been introduced to explore and predict public perceptions of autonomous driving technology. However, a driver's intention to activate the automated driving system is not limited to cognitive factors, because the emotions generated by the driving environment stimuli seem to be universal (Rolls 1990). Moreover, driving an automated vehicle itself is not only a cognitive task, but also an emotional experience. Hence, in this research, investigations were performed specifically from the perspective of the changes in a driver's experience of autonomous driving. Further, how people's emotional changes while driving an autonomous vehicle affect their perception of the autonomous vehicle and their intention to initiate autonomous driving were examined.

The individual-level personal factors influencing people's cognition of automated driving technology are related to emotion (Raue et al. 2019). According to appraisal theories of emotion, emotion is considered an adaptive response to an external environment. Moreover, emotions arise from the subjective cognitive evaluation of external stimulus events. Once individuals perceive the external environment, they will evaluate this external stimulus information in a meaningful direction (Lee 2016). For example, people's emotion for vehicles comes from the degree of being excited or stimulated by a specific vehicle (Moon et al. 2017).

For drivers, starting an automated driving system is a new experience, which involves handing over the steering wheel to the machine and switching from the conventional role of a controller to a more monitoring role. Moreover, drivers need to takeover driving from the automated driving vehicle when necessary, which will test their nerves (Huang et al. 2020). In a broad sense, driving experience refers to the subjective consciousness of drivers as they interact with automated driving vehicles. It includes not only the conscious cognitive phenomena of driving automated vehicles, such as relevant thoughts, beliefs, and goals, but also the perception of sensory, emotional, and imaginal responses related to the driving behavior and features of the automated vehicles (Oliver and Westbrook 1993). Izard (1977) believes that emotion permeates the full range of experiential activities, which points to the mediation of motivation and seems to be the driving force for information processing and behavior (e.g., to avoid behavior, people tend to maintain or reach a positive emotional state) (Peters et al. 2006). Furthermore, emotion can be a powerful predictor of a person's behavior (Nass et al. 2005). Therefore, when exploring a driver's experience of automated driving vehicles, the role of emotion cannot be ignored. This may help expand our understanding of the relationship between personal emotional response and behavioral intention (Darley et al. 1992).

Therefore, in this study, the focus is on content related to the emotions of drivers as they experience automated vehicles on roads, given that emotions probably affect people's cognition and are vital to the final decision or decision-making process (for example, McNeely et al. (2020) reported affection influences of customers experiencing adventure tourism). Currently, there are relatively few studies on drivers' real driving experience of automated vehicles, though recent studies have reported the emotional experience of drivers in an automated driving simulator.

Wintersberger et al. (2016) employed the facial expressions of passengers experiencing automated vehicles equipped with an automated driving system to estimate their emotional responses (in terms of pleasure and wake-up dimensions) to this experience. The results showed subtle mood changes, with little difference in expressions of passion, fidgety, and uneasiness.

Du et al. (2020b) conducted a driving simulation experiment on automated vehicles with 32 participants to study the effect of emotions on a driver's takeover performance. The participants exhibited different emotional states (sad, angry, happy, and calm) with different levels of emotional arousal. Positive emotions were conducive to the stable transitioning from automated driving to manual driving.

Techer et al. (2019a) reported the emotional reactions of drivers who needed to take over control from automated driving frequently when encountering interruptions while driving. Fifty subjects participated in a driving simulator experiment, following which they gave a semi-structured interview. The experimental results only slightly supported the previous hypothesis; nevertheless, certain clues pertaining to their emotional changes were obtained through the interview. Most of the participants expressed anxiety when taking over control from the machine. However, they avoided frustration by simply taking over.

Du (2020a) reported the psychological and physiological responses of drivers who were made to take over control from L3 conditional automated driving vehicles. Their emotional responses were recognized through facial expressions. The results of tests conducted on 109 people showed that drivers had more negative emotions (such as pressure) when taking over control, and their positive emotions were strengthened in the event of an emergency; the same applied to the negative emotions.

The current research reports on the emotional experience of drivers while taking over control from an automated driving vehicle. However, most emotional forms are limited to one-dimensional responsive emotions (such as positivity or negativity). The discrete emotion method allows to analyze the relationship between behavioral intention and each effect separately as opposed to a single correlation with a dimensional representation (e.g., the difference between interest and happiness cannot be detected in a single dimension). In addition, the sources of various emotions are still unknown. Westbrook (1987) found that they are related to the characteristics of experiencing a product itself or the performance of operation and usage. Sanghavi (2020) asked participants to report nine discrete emotions from past experiences; however, this was insufficient to explain the characteristics or operational performance of automated driving vehicles that could lead to specific emotional profiles.

Although only a few drivers have experienced automated driving vehicles in the real world at this stage, their experience driving these vehicles should be of concern. Most studies on drivers' emotions while driving automated vehicles have been based on driving simulations, with hardly any studies under actual road traffic conditions (Naujoks et al. 2019). Therefore, the effectiveness of the results is probably limited. To explore drivers' cognition and attitude toward an automated driving system, emotional changes over time and engagement between the drivers and the automated system need to be well understood (Omozik et al. 2019).

The motivation behind our study was to understand the emotional changes of early drivers who drove automated vehicles and their cognition and intention toward the actual use of an automated driving system. Studying the emotions and use intentions of these experience groups may yield views different from those of users after a formal promotion of automated vehicles. The results thus obtained may help develop the infrastructure, enable technological innovation (Moons et al. 2019), and enact relevant laws and regulations pertaining to the usage of automated vehicles.

The purpose of this study was twofold: (i) to mainly identify and describe the discrete emotional response patterns of drivers during conditional automated driving and takeover driving and (ii) to study the causal relationship between a discrete emotional response model and the cognition and goal of these drivers. Based on this knowledge, this study provides relevant information for understanding early drivers' cognition and emotion toward starting up an automated driving system on the road, including the motivation and obstacles related to this experience. Our study can serve as a basis for the successful introduction and implementation of conditional automated driving vehicles.

2 Literature review and assumptions

2.1 Research models and hypothesis

Based on the above analysis, a model framework is built, assuming that people have corresponding emotional changes (while switching between manual and automated driving) due to the external stimulation of experiencing autonomous vehicles. Automated driving represents a fundamental change in driving tasks (Raue et al. 2019), and people's emotion toward experiencing automated driving may affect their response to potential changes. In particular, this research considers the emotions evoked during the entire process of automated driving, rather than performing a deliberate analysis of its advantages and disadvantages, which will affect the extent of people's judgment on autonomous vehicles. This study assumes that people's perception of the benefits and risks of autonomous vehicles can help predict their intention to start the automated driving system. In addition, based on existing studies (Kohl et al. 2018; Liu et al.2019a, b; Chikaraishi et al. 2020) on perceived benefits and risks, the satisfaction of drivers is introduced in the characteristics of autonomous vehicles (such as the design of the takeover program, operating performance) as a predictive variable.

Therefore, this study developed an emotion–cognition–intention framework to study the intention of users to accept the automated driving system. Figure 1 shows the model. The hypothesis is as follows:

H1: emotion affects the driver's intention to start the automated driving system.

H2: cognition affects the driver's intention to start the automated driving system.

H3: emotion affects the driver's cognition of automated driving vehicles.

H4: satisfaction of autonomous driving's performance affects the driver's emotion in experiencing automated driving vehicles.

H5: the satisfaction of autonomous driving's performance affects the driver's intention to start the automated driving system.

2.2 Emotions of experiencing automated driving vehicles

The emotion evoked while driving can be defined as a reaction of the physiological expression and mental state through conscious and subjective experience (Turner 2009). Emotion

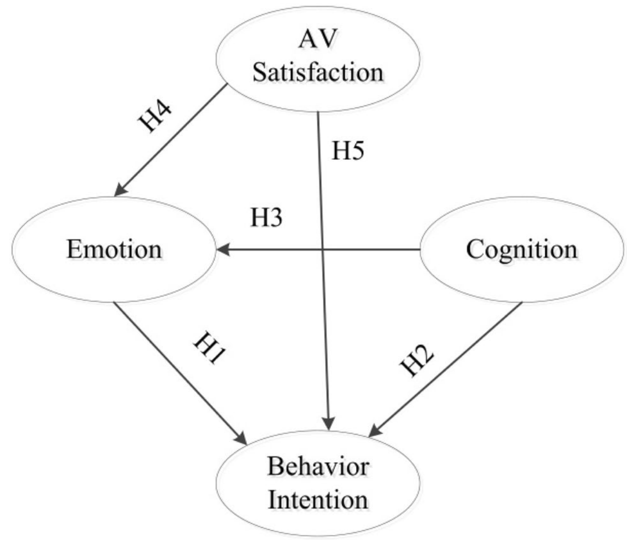

Fig. 1 Research model

theory (James 1884; Lange, 1885) states that when a person feels emotion, he/she first experiences physical reactions, such as increased heart rate. When this response is recognized, a person feels an emotion, which is called discrete emotion (Ekman 1992). From the perspective of discrete emotions, this study analyzes the emotions of drivers experiencing automated vehicles and their intention to start an automated driving system. The taxonomy of discrete emotions proposed by Izard (1977) was adopted. The measurement items of Izard's emotion assortment have been successfully applied to various fields; these are perhaps more suitable for an empirical study (Nezu et al. 2004). For example, Taarvig et al. (2016) used it to explain the emotional awareness of children with internalization problems, which benefited the prevention and treatment of mental illness in children. Westbrook and Oliver (1991) reported the discrete emotional status and satisfaction of automobile consumers. Kaleńska-Rodzaj (2020) studied the emotional state before and after a musical performance, and based on this, conducted an emotional regulation.

Izard's classification of the fundamental categories of emotional experience distinguishes ten types of discrete emotions: interest–excitement, enjoyment–joy, shame, anger, guilt, sadness, fear, surprise, disgust, and contempt. Complex emotional patterns are frequent. Multidimensional emotion measurement can be expected to reflect the unique emotion of drivers during the entire process of driving an automated vehicle.

In this study, the entire process of driving an automated vehicle can be divided into four stages in which discrete emotions may be stimulated: (1) preparation before the automated vehicle takes over the driving, wherein a positive emotion of deciding to let the vehicle take over may promote a high takeover performance (Zhang et al. 2019), (2) during conditional automated driving (e.g., tension due to high degree of attention, worry, and fear of possible traffic accidents,) (3) preparation for the drivers to take over from the automated vehicles (the excitement brought by the warning signal from the automated vehicle), (4) during takeover driving (e.g., distress or anger due to a not-so-smooth takeover).

2.2.1 Joy

The feeling is usually of happiness and freedom as the drivers engage in nondriving-related tasks during takeover time. These two subjective states show the connotation of happiness. To the extent that drivers perceive much meaning in the automated vehicles, the drivers may feel a pleasant sense of enjoyment and relaxation (Zurawik et al. 2019). A related source of happiness is that which is accompanied by a sense of "pride" in daring to try automated driving, resulting in the feeling of belonging.

2.2.2 Interest

First, motorists realize that the driving experience in an autopilot mode is different from that of conventional manual driving. Second, the appreciation of the new technological properties and quality of automated driving may arouse people's interest (Fagnant et al. 2015), including the novel features of autonomous vehicles.

2.2.3 Shame

People expect things to happen in an ideal state; however, they may end up with a completely unexpected idea (Rosaldo 1983). Therefore, it may cause a sense of shame when they are aware of the heavy burden due to the fear of failure during a takeover. Izard (1977) points out that the cause of shame is the fear that an individual's impulsive behavior may lead to actual or potential loss of self-boundary.

2.2.4 Anger

Studies on anger have shown that anger response is incited easily in the event of an improper behavior (Robins and Novaco 1993). Specifically, operations that hinder normal driving or unsuccessful takeover may cause anger response, particularly when the drivers are required to take over frequently during traffic interruptions. Drivers may feel a strong emotional change because of increased burden (e.g., traffic violations, driving errors, and road rage (Techer et al. 2019b)).

2.2.5 Guilt

Guilt is defined as a negative emotion when the behavior violates the norms or personal goals (Becheur 2019). A driver's guilt related to driving an automated vehicle often comes from the distraction before and after taking over control, which may lead to traffic rule violations (e.g., sending text messages while driving or paying no attention to controlled driving (Lajunen and Summala 1995)). Another aspect of guilt is when people do not believe that their driving experience is fully "competent" for automated vehicles, which may indicate that it is not an ideal time to achieve personal goals. These forms of guilt are due to deliberate personal behavior that violates social or internal norms (Wang 2014).

2.2.6 Fear

Taylor (2002) pointed out that there is a strong uneasiness and fear about a vehicle being out of control. Drivers must have the ability to operate their own vehicles and be good at coping with the driving environment; otherwise, they may have some anxiety or even fear of the driving task. Based on previous safety education, drivers may also be afraid of the deep impression of traffic accidents due to the distraction caused by nondriving tasks (Gauld et al. 2014) (e.g., making phone calls and sending text messages while driving). In an automated vehicle plying under unknown road traffic conditions without the driver's control, the drivers may worry and feel anxious.

2.2.7 Depression/sadness

When an individual's purposeful behavior is hindered, it may lead to depression (Brown and Farber 1951). For example, drivers may feel frustrated with driving an automated vehicle under very low driving speeds set at the beginning; the drivers may try to save time and have the impulse to take over the vehicle (Techer et al. 2019b). Sadness, in particular, could occur when it makes people wonder if hindrance is unnecessary trouble. Depression has also been noted as a gap in expectation that, for example, might occur when an automated vehicle plies on urban roads, wherein the drivers expect the vehicle to effectively predict pedestrian traffic behavior, but eventually the vehicle may fail to implement countermeasures (Techer et al. 2019a).

2.2.8 Surprise

The emotional experience of feeling surprised comes from the fact that the occurrence of the event is inconsistent with the expected and standard script (Rubin and Berntsen 2003). The results of uncertainty inspire a sense of surprise. Therefore, surprise can occur in positive or negative events

(Noordewier et al. 2016). Thus, the surprise response can be invoked in the four stages of driving an automated vehicle: the surprise of "discovering" a one-click button for conveniently starting the automated driving system, the surprise of low risk of road traffic when the vehicle takes over driving, the surprise of taking over when hearing the warning system (effective and timely prompt), and the surprise of stable driving.

2.2.9 Disgust/contempt

Disgust and contempt typically occur along with anger; however, in Izard's (1977) emotion assortment, disgust and contempt are listed separately. The possible reason is that they are manifested as punishment or aggression in response to the offending entity (Hutcherson and Gross 2011). For example, drivers of automated vehicles might take the initiative to cancel the automated driving system for their aversion toward the automated driving function. Therefore, the two types of discrete emotional reactions can also be due to the unsatisfactory performance of the automated vehicle (not as good as human driving) or serious performance failure.

2.3 Emotions of experience and use intentions

In appraisal theories of emotion (Moors et al. 2013), the stimulating environment can trigger an individual emotional response, and an activated emotion can induce specific behaviors. That is, some behaviors of drivers after experiencing automated driving may be an emotional response to the stimulation of autonomous vehicles or the driving process. Research on emotion shows that positive emotion accompanied by pleasant feelings has a start-up and expansion effect on cognition (Guo and Wang 2007). It can not only promote individuals to maintain active contact with the external environment, but also make individuals to exhibit positive sharing behavior. For example, pleasure will increase their intention to drive autonomous vehicle. On the contrary, negative emotions lead to maladaptive cognition and action (Izard 2011). An online survey has shown that anxiety reduces a participant's intention to drive an autonomous vehicle (Liu et al. 2019a, b). Liu et al. (2008) determined the importance of emotion in customers and verified that emotional satisfaction is an accurate predictor of future behavioral intention. Therefore, it is supposed that emotions of experience have an important impact on the intention of drivers to start an automated driving system (H1).

2.4 Cognition and use of intention

The cognition of automated driving refers to the process whereby people acquire knowledge, views, and experience about the autonomous vehicle during their use, such as risk assessment of the takeover process, the trust in automated driving, and the perception of failure or collision. Although it can be criticized as a lack of technical education, misinformation from media, and even irrational ideas (Gardner 1989), people still oppose a new technology, such as nuclear energy and genetic engineering. In fact, it seems that there is no "empirical" prediction. Some studies have found that people doubt whether an autonomous vehicle can outperform human drivers (Dixon et al. 2020). People are unwilling to take risks to try new technologies but prefer to use existing products (Zhang et al. 2021), which may be the intention barrier caused by risk cognition. On the other hand, the public's view of the benefits often comes from their perception of the technology in relation to the environment and the government's support for various industries (Linnenbrink and Pintrich 2004). It is related to the processing and understanding of new information and knowledge. Some studies (Rogers 2010; Venkatesh et al. 2003) also pointed out that more favorable views of a technology is typically related to technology adoption. Drivers who experienced simulated vehicles believe that trust in autonomous driving can benefit from activities other than driving, which may help improve the acceptance of autonomous vehicles (Naujoks et al. 2017). Previous studies (Alexandre et al. 2018) have shown that cognition of emerging technologies is related to behavioral intention. That is, a low perceived risk and a high perceived safety are direct predictors of greater public acceptance (Liu et al. 2019a, b). Therefore, it is hypothesized that cognition of experiencing autonomous driving has an important impact on behavioral intention (H2).

2.5 Emotion and cognition

According to the appraisal theories of emotion, people's emotional evaluation shapes their cognition of the risk and benefits of a new technology, because its impact can be used as a "psychological shortcut" relative to the evolution of professional knowledge to scientifically evaluate the risks and benefits of a technology. People rely on positive or negative emotions to judge their perceived benefits and risks (Visschers and Siegrist 2018). For example, when people feel good about a technology, they tend to think that its risk is low; if they feel bad, they may think the risk is high (Liu et al. 2019a, b). When drivers compared all levels of automation (from manual to automatic), participants compared the evaluation and found that manual driving was the most pleasant (Kyriakidis et al. 2015). People's feelings about autonomy and control of new technologies (Raue et al. 2021) may be important when determining whether to adopt or not. In addition, when people lack expertise in specific areas, they may be more inclined to use emotion as a common source to comment on both benefits and risks (Sokolowska and Sleboda 2015). Therefore, the emotion of experiencing an automated driving vehicle should have an important impact on a driver's cognition of the automated driving system (H3), which requires further research.

2.6 Satisfaction of automated driving performance, emotion, and use of intention

Previous studies (Lai and Chen 2011) have shown that product satisfaction plays an important role in user's decision-making and using products to achieve expected goals. For example, Schraagen et al. (2020) discussed the satisfaction of the information interface in autonomous vehicles and found that a good design helps drivers better understand the system and finally establish an appropriate level of trust with automated driving vehicles. In the research by Xu et al. (2021), users showed a positive attitude toward the functional quality, service quality, charging operation, and other product attributes of electric vehicles. For autonomous vehicles, their degree of intelligence, satisfaction with the design of the takeover program, and warning system of the automated vehicle should also have an important impact on their intention to start the automated driving system (H5).

This paper discusses the relationship between the driver's satisfaction with automated driving performance and the emotional response patterns generated while taking over driving (H4). Satisfaction is a type of evaluation and judgment after use or experience. Studies on emotional meaning and knowledge (Plutchik 1980; Russell 1979) have shown that the state of (high) satisfaction does have a clear emotional connotation. To further understand the emotion in automated driving, it can be reasonably assumed that the driver's evaluation and judgment of automated driving performance will evoke specific types of emotions during the experience. Based on the ten emotional responses discussed above, some specific relationships between satisfaction and emotion can be assumed.

First, the positive effects of joy and interest should occur with beliefs about a product's attribution and the experience result expected or desired by the users. Happiness is usually considered to occur when achieving one's goal. In our case, these two emotional responses are related to the experience and the functional characteristics of the automated vehicle. (Li et al. 2019) While experiencing an automated driving system, drivers' beliefs about the extent to which the automated vehicle provides reliable and stable automated driving service (H6), including smooth lane changing and turning, may be expected to activate feelings of joy and interest. For example, people may find that the automated driving system is useful and prompt as they start it frequently (Kim and Doerzaph 2020), and they have a strong sense of comfort and pleasure as they engage in nondriving tasks. With a higher level of automation, people's intention to experience tasks of driving automated vehicles was found to increase (Zeeb et al. 2017).

The automated vehicle liberates the drivers' hands, which allows the drivers to relax in the vehicle and be distracted. However, in the past, distraction implies a higher driving risk in the case of manual driving. If disturbed by the past memory cognition of driving experience, a sense of shame should occur in the drivers (H7). Shame is a type of emotion based on socialization whose occurrence seems to depend on the violation of group norms (Izard 1977). In this case, although automated driving is started under supervision, people will always doubt whether the automated driving system can be started so that they can perform activities unrelated to driving.

In an automated driving system, it is possible that the design of the drivers' takeover request mode is unreasonable or that there is no timely reminder for the warning system of takeover (Naujoks et al. 2014), which may lead to the failure of taking over and cause worry and hostility. Previous studies support the relationship between experiential activity failure and anger (Harmon-Jones 2004). Therefore, there is a link between beliefs about poorly designed procedures of taking over the automated vehicle, unreliable takeover warnings, and anger (H8)/disgust (H9).

These design defects may also lead to an emotional reaction of fear, which means anxiety about possible traffic risks. Izard (1977) believes that fear reflects an individual's cognition of helplessness or powerlessness in the face of imminent danger, in which the individual is threatened or injured. This anxiety eventually becomes a psychological fear rather than a technical obstacle (Noel et al. 2019). Therefore, a driver's uncertainty about an automated driving system must be directly related to the feeling of fear in the driving experience (H10).

Finally, people may be both fascinated and reserved toward automated vehicles regarding their advanced intelligent driving manipulation (Omozik et al. 2019). Therefore, it is expected that drivers may feel emotions such as surprise (H11) and sadness (H12). According to Oliver (1993), the greater the consistency between one's experience and expectation, the higher is the level of positive emotions elicited by the subjects, and on the contrary, the lower the consistency, the higher is the level of negative emotions.

3 Methods

3.1 Research design

This research adopts both off-line and online surveys. The survey assistants visited major car brand stores in Hefei City and conducted a field survey to test the natural emotions of the store experience group who experienced the automated vehicles. To expand the sample size, the questionnaire online was posted on the Chinese website "Wen Juanxin". We also contacted the sales department of the automated vehicle enterprises by e-mail to help send the questionnaire link to customers who bought automated vehicles equipped with an automated driving system. After the questionnaire passed our examination, all the interviewees received a reward of 20 yuan. The survey started on March 2021 and lasted for 3 weeks. A total of 95 off-line and 52 online questionnaires were collected. Finally, 133 valid questionnaires (95%) were obtained after eliminating 14 invalid ones.

The average age of the respondents was approximately 30, and most of them were employees. The models of the automated vehicles mainly included Tesla Model 3 (28%), GM Buick GL8 Avenir (24%), Cadillac CT6 Super Cruise (18%), China NIO ES6 (10%), and other types of automated vehicles (some of them may have belonged to experimental modified vehicles). The diversity of car models is another necessary factor for testing a wide range of emotional responses of the drivers.

The survey results showed that the respondents had started the automated driving system on test tracks (78%), urban roads (6.4%), rural roads (12.5%), or other areas (3.1%). The duration required to activate the automated driving system was expected to be 10 min (39.1%), over half an hour (50.3%), at least 1 h (7.5%), and longer (3.1%). They were asked to take over driving in scenarios such as encountered complex road conditions ahead (30.4%), lack of road signs (3.8%), avoiding pedestrians (4.3%), changing lanes and overtaking (16.7%), exposure to a stalled vehicle in the driver's lane (5.2%) (Alambeigi and McDonald 2021), and road shoulder construction (4.2%). However, the automatic system did not prompt to take over, but the driver took the initiative to take over which accounted for 35.4%.

3.2 Measures

The questionnaire included three parts: demographic information, intention scale, and special emotion of experiencing automated driving scale. To ensure effectiveness, the items in the scale are referred from previous research results. The scale of the cognitive project refers to the safety gain and safety hazard (Gold et al. 2015). The project of satisfaction with automated driving performance was adapted from the study by Yu et al. (2020). The emotional items in the questionnaire are referred from the original difference emotional scale proposed by Izard (1977), and the scale of the emotional responses of drivers who drove the automated vehicle with four stages is compiled to evaluate their discrete emotional responses. The scale contains ten basic emotions. A detailed description of the ten basic emotions in the questionnaire was made to ensure that any semantic misunderstandings made by the respondents were eliminated. The respondents were asked ten types of questions pertaining to their emotional reactions in each stage (a total of 40 questions). Among them, the test with the ten emotions has been proven by much evidence to be an effective tool and applicable to measure the emotion of experiential activities. In addition to demographic variables, other options of the scale are designed on the basis of a five-point Likert scale ranging from "totally disagree" (1) to "totally agree" (5). A small sample was tested in advance, and the initial questionnaire was then revised. For example, some words were changed to enforce the differences in the emotional responses in the four driving stages.

Table 1 shows the content of the scale of intention toward automated driving system. Ten types of emotional items related to the drivers who drove the automated vehicles are listed, as shown in Table 2.

4 Data analysis and results

4.1 Reliability and validity analyses

Table 3 presents the reliability and validity analysis of the intention scale. Table 4 gives the reliability and validity estimates of the emotion scale based on the experience of the drivers driving the automated vehicle. The results ($n = 133$) showed that the factor load values of intention items in Table 3 and ten types of emotional experiences in Table 4 were > 0.72. The validity test of Cronbach's α for all items was > 0.7, and the average variance extraction (AVE) of each potential variable was > 0.48, which indicates a good validity test result of the emotion scale. The composite reliability (CR) of the potential variables was > 0.7, and the KMO value was 0.864. The ball test of each index was significant, which met the design requirements of the questionnaire (Ball et al. 1993). The Pearson's correlation analysis were used to examine the correlation between the variables of the ten emotions and the intention to start the automated driving system. Table 5 presents a correlation matrix, which shows the Pearson's correlation coefficients of all the structures. The correlation between the factors (mostly at a level of 0.01) shows significant correlation and has statistical significance, reflecting that the scale has good validity.

The emotion of drivers' experiencing automated vehicles seems to be related to the positive effects of higher levels of joy, interest, and surprise, as well as negative emotions related to lower levels of disgust, anger, guilt, contempt, sadness, shame, and fear. In addition, the Pearson's correlation analysis shows that interest and joy are most correlated across the entire sample, indicating that the two emotions often appear simultaneously ($r = 0.765^{**}$, $^{**}p < 0.01$). The same applies to the negative emotions of disgust and contempt ($r = 0.765^{**}$,

Table 1 Scale of intention toward automated driving system

Items	Measures
Safety gain (four items)	SG1: An automated driving system reduces the problems I encounter when driving SG2: An automated driving system makes me manage useful activities while driving and saves me time compared to driving manually SG3: An automated driving system supports the driver to discover the danger in time SG4: An automated driving system helps reduce the risk of collision
Safety hazard (four items)	SH1: An automated driving system distracts the attention from detecting danger in time SH2: I drive safer than the automated driving system SH3: The risk posed by the automated driving system seems to be more serious SH4: The automated driving system may have problems or it may not work properly
Satisfaction of automated driving performance (six items)	AVS1: The automated driving runs smoothly, changes lanes and turns smoothly, and is competent for all types of road conditions, which makes me satisfied AVS2: The reminder mode of the automated vehicles is voiced clearly and in the right way, which makes me satisfied AVS3: The high degree of intelligence of the automated driving system makes me satisfied AVS4: The design of smooth and natural takeover's procedure makes me satisfied AVS5: I can perform other activities during automated driving, which makes me satisfied AVS6: I am very satisfied that the automated driving vehicle maintains a constant driving speed (up to 70 km/h)
Intention to start the automated driving system (three items)	BI1: If necessary, I will start the automated driving vehicle again to take over driving BI2: I would like to experience the automated driving vehicle again BI3: I think I will turn on the automated driving vehicle again and have a high willingness to take over driving

$^{**}p < 0.01$), shame and contempt ($r = 0.705^{**}$, $^{**}p < 0.01$), guilt and depression ($r = 0.624^{**}$, $^{**}p < 0.01$), and anger and fear ($r = 0.597^{**}$, $^{**}p < 0.01$).

In addition to guilt and fear, the other eight emotions (joy, disgust, interest, shame, anger, fear, surprise, and contempt) are closely related to the intention to start the automated driving system. In terms of positive emotions, the test levels of joy ($r = 0.733^{**}$, $^{**}p < 0.01$), interest ($r = 0.692^{**}$, $^{**}p < 0.01$), and surprise ($r = 0.614^{**}$, $^{**}p < 0.01$) are high. The negative emotions, including disgust ($r = -0.418^{**}$, $^{**}p < 0.01$) and contempt ($r = -0.460^{**}$, $^{**}p < 0.01$), have a greater effect on the intention toward starting the automated driving system.

The results showed that drivers mainly feel emotions, such as surprise, joy, and interest, while driving a real-world automated vehicle; this seems to verify Oliver's (2014) expectation disconfirmation theory. Drivers are seeking the unexpected (McNeely 2020), and perhaps the perception of an automated vehicle's novelty evokes enthusiasm; therefore, the attitude of the drivers toward automated vehicles was positive. In addition, not very low levels of negative emotions, such as fear and anger, were tested in the study. The reason may be that the automated vehicle replaces the drivers' job (Koo et al. 2015), making them more anxious, or because it failed to meet the expectations, and drivers worried about unpredictable collisions with pedestrians (Techer et al. 2019a).

4.2 Intention model

In the study, the AMOS software was used to analyze the data for the structural equation modeling (SEM) analysis (Yu et al. 2020). After solving the first equation, the SEM was found to not work well. Therefore, the ten emotions were divided into positive emotions (happiness, interest, and surprise) and negative emotions (depression, disgust, and fear). Because the remaining emotions made the structural equation unstable, they were not selected. The reclassified structural equation test fit multiple metrics, including the Chi-square degrees of freedom, CFI, AGFI, NFI, and GFI. Based on the analysis of the results, all the indicators of the overall fitting met the requirements (GFI = 0.89, AGFI = 0.84, NFI = 0.84, CFI = 0.86, RMSEA = 0.08, $\chi^2/df = 3.16$, $p > 0.001$).

Figure 2 shows the test results of the SEM output. H1, H2, H3, H4, and H5 are all consistent with the hypothesis, indicating that the factors influencing the driver's activation of the automated driving system include positive emotions, satisfaction of the automated driving performance, and cognition of security gains. However, the hypothesis that the perceived risk and negative emotions influence the use of automated driving systems was rejected. In addition, emotions played a mediating role between the cognition of safety gain, satisfaction, and intention to start automated driving.

Table 2 Ten types of emotional items related to drivers who drove automated vehicles

Emotions	Measures
Joy	Stage1: I am optimistic that the automated driving vehicle will drive well Stage 2: I feel happy when the automated driving takes over and starts driving (Yang et al. 2015) Stage 3: I am optimistic that the automated driving system will take over and drive smoothly Stage 4: I am very happy with my sense of achievement in taking over an automated vehicle
Disgust	Stage 1: When I realized the automated driving system will take over from manual driving, I felt disgust Stage 2: The automated driving system takes over and starts automatic driving. It seems that nothing has changed, which annoys me Stage 3: When I realize I will take over from automated driving vehicle soon, it annoys me Stage 4: I am worried that I do not do well in driving the automated vehicle (e.g., untimely steering), and I am tired of it
Interest	Stage 1: I am interested in the fact that automated vehicle will take over driving Stage 2: I find it interesting when the automated driving system takes over and starts driving Stage 3: I am looking forward to taking over from the automated driving vehicle Stage 4: Driving the automated vehicle makes me very happy and gives me the motivation to continue to drive more frequently
Shame	Stage 1: I am ashamed that I am a little afraid of the vehicle taking over driving Stage 2: When the vehicle took over and started driving, I was ashamed that I did not have to do anything Stage 3: I am ashamed that I am dependent on automatic driving and do n'o wish to take over and drive the car Stage 4: When I cannot control the automated vehicle during the takeover, I do not want anyone to know
Anger	Stage 1: I was annoyed when I found that the automated vehicle was going to take over driving Stage 2: I was angry that the speed remained constant when the vehicle took over and started automatic driving Stage 3: I was annoyed when I found that the alarm did not remind me to take over driving Stage 4: While driving the automated vehicle during the takeover, I was irritated
Guilt	Stage 1: I found that the automated vehicle after takeover driving might distract me (e.g., texting on the phone) and violate traffic regulations, which makes me feel guilty Stage 2: The vehicle started automatic driving, and this distracted me, which made me feel guilty Stage 3: I was embarrassed when I found out that I was going to take over driving Stage 4: I feel embarrassed when I am driving the automated vehicle during the takeover
Fear	Stage 1: I felt uneasy and frightened when I found that I handed over the driving right to the automated driving system Stage 2: I felt uneasy and frightened that the vehicle took over and started automatic driving Stage 3: I felt uneasy and frightened when I had to try to take over and drive Stage 4: I am scared when I cannot handle the automated vehicle very well during the takeover
Sadness	Stage 1: I am not happy that automated vehicle takes over driving Stage 2: I feel frustrated, because I found that automated driving is not everything after the vehicle takes over and starts driving Stage 3: I felt sad that I am going to take over from the automated vehicle and drive Stage 4: I am worried that I do not do well in driving the automated vehicle, and I am tired of it
Surprise	Stage 1: I was surprised that I could do some other activity when the automated vehicle took over driving Stage 2: I was surprised that the vehicle took over and started driving, which was different from manual driving Stage 3: I was surprised to take over from an automated vehicle immediately and be able to operate the vehicle Stage 4: I am proud of driving the automated vehicle (e.g., slow down the speed of vehicle to avoid a collision after taking over) and cannot wait to share it with my family and friends
Contempt	Stage 1: I do not want to try it because I feel bored when the automated vehicle takes over driving Stage 2: I am bored when the car takes over and starts driving Stage 3: I do not want to try to drive because I feel bored to take over driving Stage 4: Because I had a lot of trouble driving the automated vehicle (e.g., pedestrian crossing the road) during the takeover, I tried not to discuss it

4.2.1 Emotions of experience

The positive emotion of experiencing the automated driving vehicle had a positive effect on the driver's intention to start the automated driving system ($\beta = 0.432$, $p < 0.01$), and the path coefficient was the highest. The results showed that the emotion of experiencing automated driving had a significant positive correlation with intent. Drivers were more willing to activate the automated driving system to take over driving again after experiencing a positive emotional experience of joy, surprise, and interest in an autonomous vehicle. This finding is similar to that made by Raue et al. (2019), who found that people's emotional information about driving affects their judgments about autonomous driving vehicles. Negative emotions of experiencing autonomous driving vehicles had no effect on the driver's intention to activate

Table 3 Factor analysis ($n = 133$)

Factors	NO	Standard loadings	Cronbach's alpha	CD	AVE
Factor 1: safety gain			0.856	0.827	0.546
	SG1	0.725			
	SG2	0.729			
	SG3	0.736			
	SG4	0.765			
Factor 2: safety hazard			0.815	0.815	0.577
	SH1	0.747			
	SH2	0.756			
	SH3	0.783			
	SH4	0.752			
Factor 3: AV satisfaction			0.859	0.900	0.676
	AVS1	0.826			
	AVS2	0.894			
	AVS3	0.909			
	AVS4	0.850			
	AVS5	0.768			
	AVS6	0.654			
Factor 4: behavior intention			0.900	0.858	0.629
	BI1	0.793			
	BI2	0.781			
	BI3	0.805			

Table 4 Factor analysis of emotions ($n = 133$)

Factors	Average value	Standard loading	Cronbach's alpha	Composite reliability (CD)	Average variance extracted (AVE)
Factor 1: Joy (4 items)	3.748	0.725	0.815	0.804	0.515
Factor 2: Disgust (3 items)	2.450	0.765	0.741	0.781	0.545
Factor 3: Interest (4 items)	3.742	0.757	0.872	0.809	0.515
Factor 4: Shame (4 items)	2.457	0.633	0.710	0.730	0.483
Factor 5: Anger (4 items)	2.529	0.704	0.710	0.79	0.489
Factor 6: Guilt (4 items)	2.715	0.757	0.754	0.746	0.496
Factor 7: Fear (4 items)	2.838	0.801	0.832	0.796	0.495
Factor 8: Sadness (4 items)	2.706	0.699	0.730	0.730	0.485
Factor 9: Surprise (4 items)	3.542	0.729	0.807	0.739	0.486
Factor 10: Contempt (4 items)	2.346	0.730	0.819	0.804	0.506

Table 5 The correlation matrix between the factors of the scale

Factors	1	2	3	4	5	6	7	8	9	10
1. Joy	1									
2. Disgust	– .326**	1								
3. Interest	.765**	– .300**	1							
4. Shame	– .264**	.605**	– .286*	1						
5. Anger	– .361**	.666**	– .302**	.682**	1					
6. Guilt	– .219*	.657**	– .133	.581**	.584**	1				
7. Fear	– .136	.475**	– .296**	.464	.597**	.563**	1			
8. Sadness	– .244**	.604**	– .280**	.574**	.583**	.624**	0.633**	1		
9. Surprise	.706**	– .237	.632**	– .199*	– .315**	– .095	– .056	– .255**	1	
10. Contempt	– .441**	.773**	– .435**	.705**	.595**	.560**	.490**	.640**	– .293**	1
11. Intention	.733**	– .418**	.692**	– .328**	– .355**	– .148	– .151	– .222*	.614**	– .46**

$^{*}p<0.05$, $^{**}p<0.01$

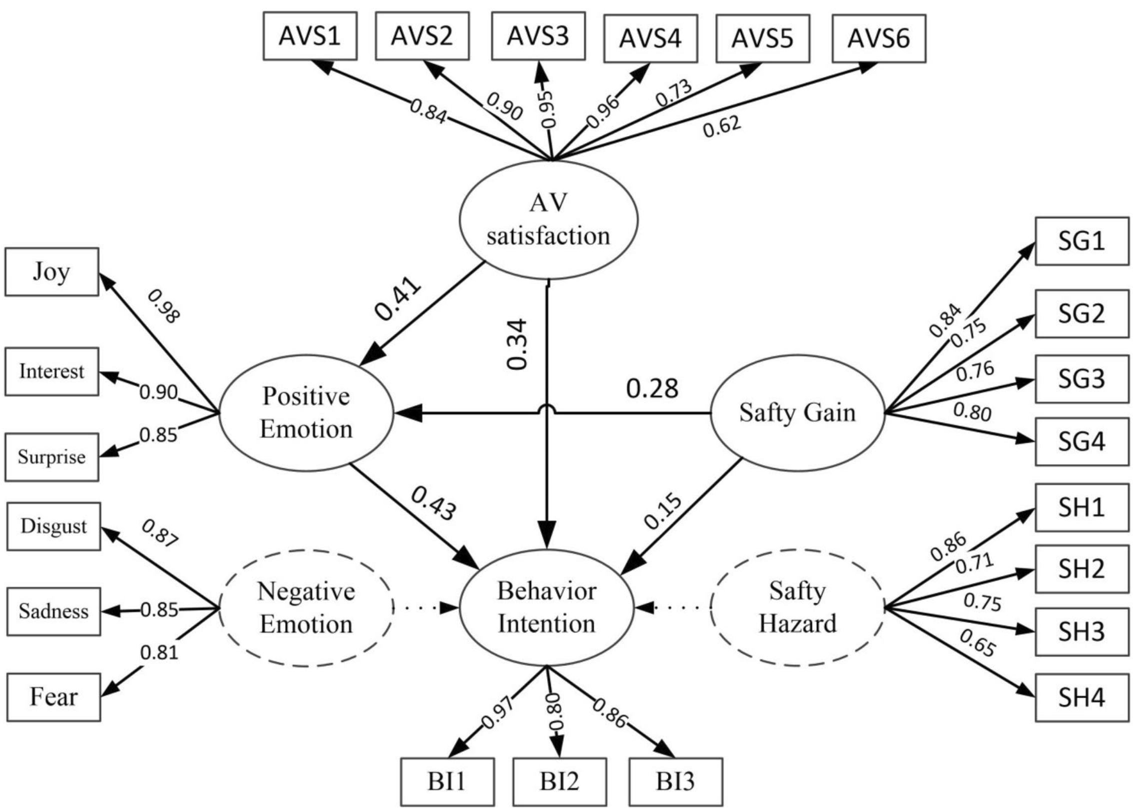

Fig. 2 Model of the hypotheses of this research

the automated driving system. Negative emotions, such as frustration, disgust, or contempt, after the driver experience are ignored (Dube et al. 1996).

4.2.2 Cognition

The driver's cognition of the safety gain of automated driving vehicles passed the SEM test, and it had a significant effect on the driver's intention to activate the automated driving system ($\beta=0.15$, $p<0.05$). However, people's perception that automated driving vehicles could pose a threat to their safety did not affect their continued use of the system. In addition, this study verified the complete mediating effect of emotion on the relationship between cognition and behavioral intention ($\beta=0.28$, $p<0.001$). The results showed that the higher the driver's cognition of the safety gain of automated driving, the greater is the positive sentiment toward starting the automated driving system. The above two results further confirm the importance of experiencing emotions in influencing the intent of activating the system. Positive emotions, such as joy, interest, and surprise, felt during the driving experience changed the original cognition of the benefits and risks of automated driving, which was different from the cognitions of drivers who did not experience such vehicles. In Raue et al. (2019)'s report, drivers with no experience in automated driving followed their past experience of driving a normal car when experiencing automated driving; they were hesitant to give up their current style of driving because they thought it was a skill they mastered. They may be more skeptical of the autonomous vehicle's ability in complex road traffic situations. Moreover, they worried about their capabilities and challenges while driving. Drivers who experienced automated driving in this study had increased cognition of the safety gains of automated vehicles, demonstrating that, for driver's experiencing automated driving systems, cognition may be an accurate predictor of future behavioral intentions. Emotions had a significant impact on the driver's experience and cognition at the start of automated driving (Lee 2016). This should further encourage the government and car companies to improve the automation technology, devise efficient measures to coordinate and balance between automation technology and human driver operations (Vanderhaegen 2016), and enhance the emotional experience of drivers (Liu et al. 2021).

4.2.3 Satisfaction of automated driving performance

The satisfaction of automated driving performance had a positive effect on the driver's intent toward starting the automated driving system ($\beta = 0.34$, $p < 0.001$), and the path coefficient was high. The results showed that the satisfaction of automated driving performance is an important factor influencing a driver's intention to activate the automated driving system. In addition, this study verified the complete mediating effect of emotion on the relationship between the satisfaction of automated driving performance and behavioral intention ($\beta = 0.41$, $p < 0.001$). With a higher positive sentiment toward automated driving, drivers may be more willing to accept automated driving owing to some of the characteristics of autonomous vehicles, including takeover program and alarm, automated handling performance, constant speed control, and the degree of intelligence. In fact, an automated driving system is a new technology, and most drivers are unfamiliar with how and when it will replace manual driving and give back control to the driver. When exposed to an autonomous vehicle environment and on taking test drives, drivers will gain more knowledge and understanding of the co-control environment (Vanderhaegen 2010, 2021b) in an automated vehicle. For example, they can form an intuitive positive impression on takeover procedures and alarm and automatic control performance (Xu et al. 2021).

4.3 Emotional changes in drivers while experiencing automated vehicles

The structural equation results verified the influence of the emotion of experiencing automated driving on the driver's intent to start the automated driving system; however, the specific emotional changes need to be further verified. The emotional changes in the drivers who experienced automated vehicles in the two stages were detected, i.e., during conditional automated driving and during takeover driving, as shown in Figs. 3 and 4. The conditional automated driving stage was defined as the period wherein the drivers played the monitor role, and the takeover driving stage was defined as the period where the drivers played the controller role. Tables 6 and 7 show the average scores of emotions during driver' experiencing automated driving vehicle.

4.3.1 Emotional changes in the drivers during the monitor role

From the status of human driving to machine control, respondents were asked about their emotional changes during the period wherein they were ready to expect automated driving and the next stage of realized automated driving. During this period, the drivers' emotions seem to change in terms of disgust ($r = 0.248$*, *$p < 0.05$), interest ($r = -0.287$**, **$p < 0.01$), guilt ($r = -0.225$*, *$p < 0.05$), sadness ($r = 0.597$**, **$p < 0.01$), and contempt ($r = 0.403$**, **$p < 0.01$). During this period, drivers became less interested in automated driving, and felt less guilty. However, the negative feelings of disgust, sadness and contempt enforced. Compared with the expected greater interest ($M = 3.84$) before turning on automated driving, the drivers became less excited ($M = 3.55$) about

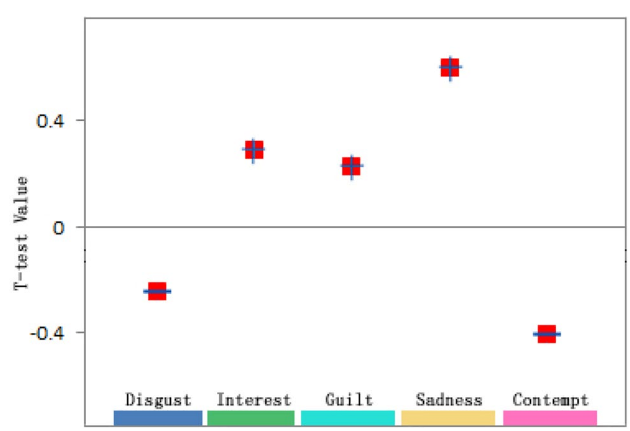

Fig. 3 The emotional changes during conditional automated driving

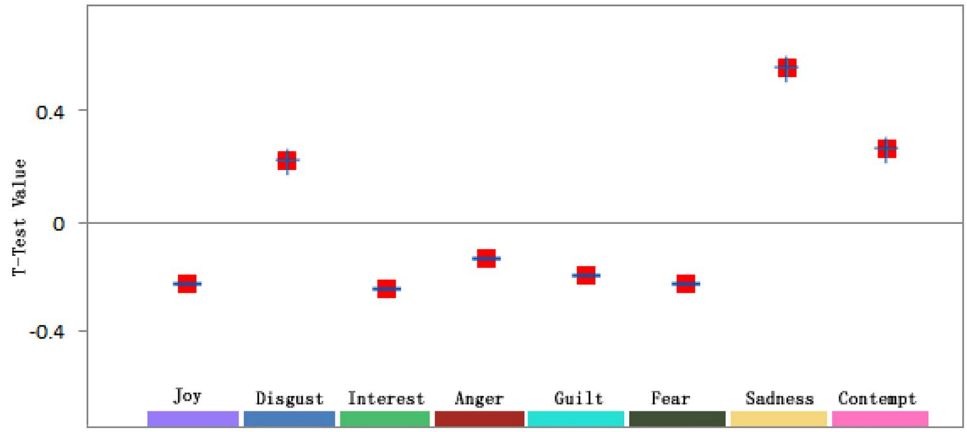

Fig. 4 The emotional changes during takeover driving

Table 6 The average scores of emotions during conditional automated driving

Different stage	Disgust		Interest		Guilt		Sadness		Contempt	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	SD	MEAN	Sd
Before automated driving	2.49	1.13	3.84	1.11	2.78	1.15	2.48	1.10	2.19	1.09
AV takeover driving	2.74	1.12	3.55	0.903	2.56	1.04	3.08	1.15	2.60	1.03

Sd standard deviation

Table 7 The average scores of emotions during takeover driving

Different stage	Joy		Disgust		Interest		Anger		Guilt		Fear		Sadness		Contempt	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
AV driving	3.78	1.02	2.39	1.09	3.74	1.08	3.16	1.19	2.81	1.03	2.62	1.11	2.55	1.03	2.28	1.03
Driver takeover	3.89	0.90	32.47	1.03	3.84	0.93	2.45	1.04	2.66	1.09	3.06	1.10	2.66	1.12	2.30	0.99

Sd standard deviation

the takeover and start of automated driving. For fear of distraction during automated driving, the drivers felt some guilt ($M = 2.78$); however, after the takeover, the drivers became less guilty ($M = 2.56$), which seems that they considered automation as a means of emotional regulation. For example, texting during automated driving may reduce people's sense of ethics (Bayer et al. 2012). On the other hand, the driver's negative emotions of disgust, sadness, and contempt for automated driving increased. Drivers felt bored ($M = 2.19$), disgusted ($M = 2.49$), and frustrated ($M = 2.48$) during automated driving. When automated driving system really took over driving, they thought that the system is not omnipotent and has not changed anything. Drivers also exhibited contemptuousness ($M = 2.60$), disgust ($M = 2.74$), and sadness ($M = 3.08$) toward automated driving. No significant emotional changes were detected in terms of joy, shame, anger, fear, and surprise. According to the report, respondents felt a certain degree of anger when the autonomous system maintained a constant speed just as they initially expected automated driving to take over.

4.3.2 Emotional changes in the drivers during the controller role period

From the status of machine control to human takeover, respondents were asked about their emotional changes in the period wherein they were ready to expect taking over automated driving and the next stage of manual driving again. During this period, the drivers' multiple emotions fluctuated: the feelings of joy ($r = 0.271^{**}$, $^{**}p < 0.01$), disgust ($r = 0.264^{*}$, $^{*}p < 0.05$), interest ($r = 0.287^{**}$, $^{**}p < 0.01$), sadness ($r = 0.519^{**}$, $^{**}p < 0.01$), and fear ($r = 0.271^{*}$, $^{*}p < 0.05$) and contempt ($r = 0.295^{*}$, $^{*}p < 0.05$) intensified. The process of taking over the automated vehicle seem to have stimulated their mental nerves, and emotions, such as anger ($r = -0.202^*$, $^*p < 0.05$) and guilt ($r = -0.248^*$, $^*p < 0.05$) reduced to different degrees. Specifically, drivers were full of joy ($M = 3.78$) and great interest ($M = 3.74$) before taking over automated driving. After taking over driving, they were satisfied with their takeover performance and felt happier ($M = 3.89$). They also felt motivated and interested ($M = 3.84$) and wanted to know more about automated driving vehicles. Drivers felt slightly tired before taking over from automated driving ($M = 2.39$). After the takeover, they thought less of the automated driving system, which led to boredom ($M = 2.47$). In addition, the thoughts of taking over from automated driving made them feel overwhelmed. They felt upset ($M = 2.55$) and uneasy ($M = 2.62$). After taking over, they found themselves to be in a hurry and found it difficult to control the vehicle, which increased their sense of sadness ($M = 2.66$) and fear ($M = 3.06$). Surprisingly, drivers had a certain degree of contempt while expecting to take over from the automated driving system ($M = 2.28$). They thought taking over driving was boring, and this feeling was stronger after manual driving again ($M = 2.30$). According to the report, drivers may have encountered some problems in the taking over process (such as holding the steering wheel and forgetting to step on the brake (Merat et al. 2012)); therefore, they do not wish to discuss automated driving in depth. The feelings of anger ($M = 3.16$) and guilt ($M = 2.81$) decreased after experiencing driving takeover (anger: $M = 2.45$) (guilt: $M = 2.66$). The automated driving function may not have been as powerful as imagined or expected, and the individual has sufficient ability to control the automated driving vehicle (Tang et al. 2020). In addition, no changes in terms of shame and surprise were detected. According to a report, drivers felt slightly ashamed that they were unable to control and take over driving. Nevertheless, they felt surprised that they could take over driving smoothly and were willing to share this experience (Pink et al. 2020) with their family and friends ($M = 3.71$, $^{**}p > 0.01$).

4.3.3 Verification of hypothetical emotional responses with satisfaction of automated driving performance

The results of the structural equation could only show that the driver's satisfaction with automated driving performance had a positive effect on the emotion of experiencing automated driving; however, it is impossible to determine which characteristics of the automated driving experience stimulated which type of emotion. Thus, the relationship between automated vehicle performance of operation control experience and the corresponding hypothesized emotion are summarized in terms of the Chi-square value in Table 8. Most of the hypotheses are supported, notably between the smooth operation of automated vehicles and joy/interest (H6), between the method whereby the automated vehicles remind the takeover process and disgust (H8), between the constant speed of the automated vehicles (up to 70 km/h) and anger (H9), and between takeover program design and fear (H10). Although distracted driving can easily lead to drivers' guilt, the satisfaction that automated vehicles allow people to engage in nondriving tasks was not correlated with shame/guilt (H7). Finally, drivers who believed automated vehicles are highly intelligent were higher in terms of surprise (H11). On the contrary, drivers' sadness toward this characteristic could be detected (H12).

4.3.4 Discussion on emotional change and automated driving vehicle's performance

Based on the four stages of the drivers' driving experience of automated vehicle proposed in this study, the emotional

Table 8 Relationship between satisfaction of automated driving's performance and emotion

H: Operation and performance of automated vehicle Specific emotions	Value of Chi square	Sig	Prob	Evaluation
H6: Manipulation performance of automated vehicle Joy	172.565	0.000	0.564	Supported
H7: Engage in nondriving tasks instead of driving Shame/guilt	54.762	0.060	−0.211	Not supported
H8: Reminder mode of automated vehicle for taking over Disgust	58.762	0.028	−0.287	Supported
H9: Constant-speed control in automated driving Anger	97.118	0.002	−0.228	Supported
H10: Program design of automated vehicle as drivers' taking over Fear	86.631	0.031	−0.087	Supported
H11: Intelligent design of automated vehicle Surprise	118.584	0.000	0.405	Supported
H12: Intelligent design of automated vehicle Sadness	60.702	0.103	−0.175	Not supported

changes in the drivers and attribute these changes to the performance and operation control attributes of the automated vehicle were detected.

First, generally, there is little emotional change in the stage where the drivers' role changes to that of monitors, which may be due to the long psychological preparation period, drivers' concentration on nondriving tasks, and relaxation owing to reduced workload. In this period of automated driving, it was found that the speed setting of the vehicle, i.e., maintaining a constant speed (up to 70 km/h), made the drivers angry, and this emotion continued throughout the automated driving process. When the automated vehicle is driving slowly, the drivers may have the impulse to take over the driving to save time. The pressure of time may lead to a bad mood (such as anger). This phenomenon has also been noticed by Techer et al. (2019b). Fortunately, this situation have been tested.

Notably, there was a significant emotional change in the subjects when they went to take over control, indicating that this is a new task and a challenge for them. In this study, it is found that the method of taking over under the early warning system of the automated vehicle enhanced the drivers' aversion, and the sudden sound and flashing of the warning light when taking over seemed to have challenged the subjects. Grillon et al. (2020) believed that this is an autonomous and behavioral response activated by human defense mechanism.

An inappropriate design of the takeover program makes drivers fearful; nevertheless, the intensity of fear is reduced during the taking over. The reason could be that drivers may feel the threat of not being able to complete the task at the time of taking over, which is different from that in the case of manual driving. Based on the conclusions drawn by LeDoux (2004), the generation of fear is related to past cognitive experience, which is the possible mechanism whereby a subject realizes the danger. After the experience of taking over the driving, the subjects already knew the taking-over procedure, no longer required context information, and their unconscious fear turned into conscious prevention.

Encouraging findings with regard to certain positive emotional dimensions are reported in the study. The high degree of intelligence of the automated vehicles makes drivers surprised and joyful. Positive events occur in the subject's driving experience of the automated vehicle, which may be the reason for content regarding the vehicle performance, namely smooth driving, smooth lane changing, competent for various road conditions, sufficient information feedback, and comfortable handling posture. The certainty of this good experience leads to curiosity and interest (Ellsworth 1994).

Past research has shown that obstacles to manipulation can lead to prejudice and depression. In this study, it was found that the negative emotions of subjects were enhanced as they took back control from automated driving. The reason may be the frustration caused by the lack of control, and the automated driving vehicle may provide inappropriate driving control to drivers, whose bad direct experience leads to negative emotions. Thus, the control must be understandable and visible, and it is necessary to design appropriate driving control systems (Wegner and Bargh 1998); otherwise, the control itself will be an obstacle.

The questionnaire survey results of this study showed that more than 78% of the respondents drove the automated driving vehicle on the test track (the testing ground of the car sales department or the closed ground of the vehicle test site). Most people's experience of automated driving was controlled within half an hour, and they tended to take over the vehicle initiatively and not wait to receive the signal of takeover. The road was equipped with safety test equipment and personnel, which might have enhanced the confidence of the experimenters, and they could control the length of time for which they experienced automated driving based on their own ideas at any time. The drivers exhibited a cautious attitude toward experiencing automated driving to a certain extent. The driver takes the initiative to take over the vehicle, indicating that the shared control design between humans and autonomous systems should have a common reference or baseline (from information perception to action implementation) to deal with conflicts between them (Vanderhaegen 2021a, b). Therefore, it is necessary for the department of transportation to pay attention to this aspect. This study suggests that attention should be paid to the careful construction of the driving road environment before promoting automated driving vehicles, such as the matching between the use of planned lanes and the automation degree (Aeberhard et al. 2015). If necessary, special lanes for autonomous vehicles can be developed to further strengthen traffic safety measures when the automated driving system is operational.

4.4 Classification analysis of emotions

4.4.1 Clustering groups

Not every emotion sample can explain the intention to start an automated driving system. Therefore, the K-means clustering method was used to classify the ten types of emotions. To study the clustering characteristics of these emotions, the minimum square value of the distance from each one to the center of the emotion clustering through continuous iteration was examined, and the classification result seems to meet the most standard interpretation (Celebi et al. 2013).

The ten emotion cluster markers were classified into five emotional experience groups:

1. Fear/angry drivers (10% of respondents), with highly elevated levels of emotions in the anger group (fear and anger) ($S_{fear}=3.41$, $S_{anger}=2.91$), along with low levels of joy and interest ($S_{joy}=3.01$, $S_{interest}=3.23$).

The low levels of sadness, disgust, contempt, and shame ($S_{disgust} = 1.98$, $S_{sadness} = 1.9$, $S_{shame} = 2.65$, $S_{contempt} = 1.83$) are also not apparent.

2. Emotionless drivers (15% of respondents), who reported a low emotional level on all measures of driving experience ($S_{joy} = 2.92$, $S_{disgust} = 3.08$, $S_{interest} = 2.95$, $S_{shame} = 3.13$, $S_{anger} = 3.08$, $S_{guilt} = 3.09$, $S_{fear} = 3.07$, $S_{sadness} = 3.05$, $S_{surprise} = 2.76$, $S_{contempt} = 3.09$).
3. Hostile/depressed drivers (21% of respondents), with a high level of emotion (disgust, guilt, fear, and anger) ($S_{disgust} = 3.59$, $S_{guilt} = 3.80$, $S_{fear} = 3.92$, $S_{sadness} = 3.96$) in this group. The negative emotion was evident, and the low level of pleasure ($S_{joy} = 3.312$, $S_{interest} = 3.325$) was easy to identify.
4. Pleased/contented drivers (24% of respondents), with a high frequency of joy, interest, and surprise ($S_{joy} = 4.35$, $S_{interest} = 4.39$, $S_{surprise} = 4.46$), along with low levels of negative emotions (sadness, anger, and disgust) ($S_{disgust} = 1.77$, $S_{anger} = 1.93$, $S_{sadness} = 1.76$).
5. Emotional drivers (27% of respondents). Almost all the positive ($S_{joy} = 3.78$, $S_{interest} = 3.89$, $S_{surprise} = 3.76$) and negative emotion ($S_{disgust} = 3.225$, $S_{guilt} = 3.012$, $S_{fear} = 3.45$) indices were higher than the average level.

Figure 5 shows the average scores of the ten emotion measures based on the cluster group. The results of the multivariate analysis of variance showed significant differences among the five clusters (Wilks' lambda = 0.107, $f = 17.546$, $P < 0.001$) as well as significant differences in the test of each single variable. Therefore, our multivariate analysis of the above five clustering groups provides a clue, indicating that the next step of external variable analysis may be feasible and that it may provide a reasonable explanation.

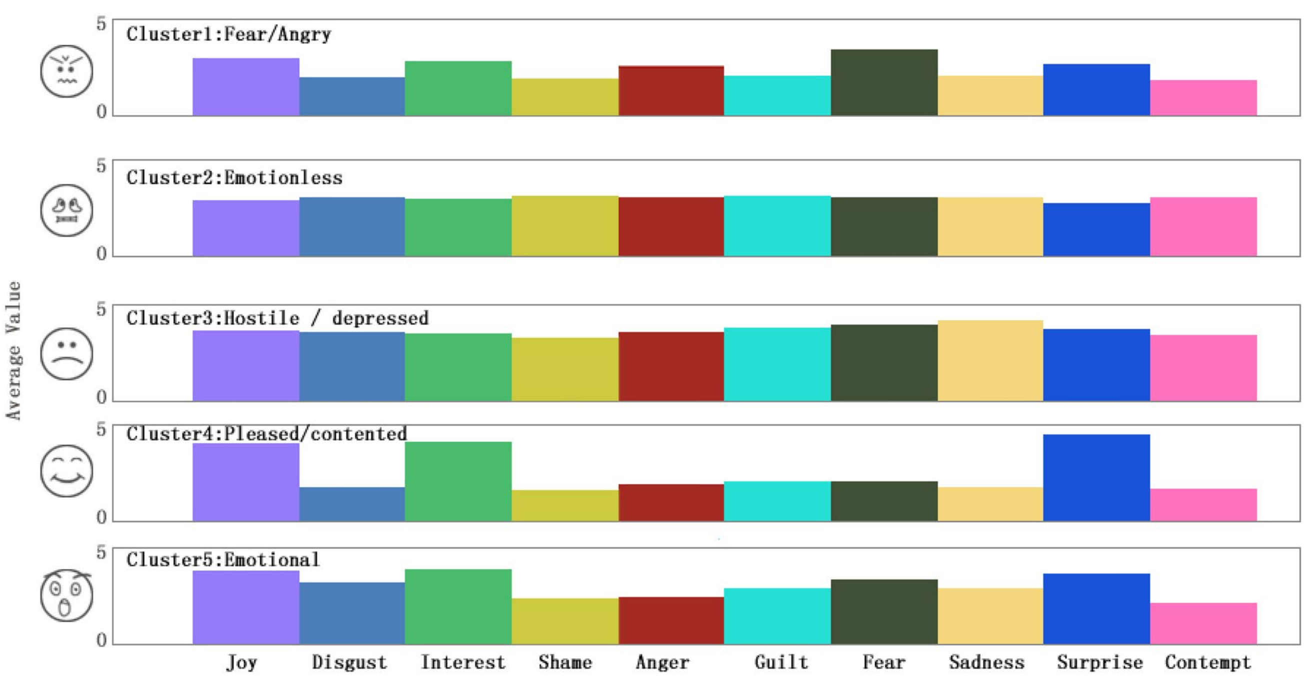

Fig. 5 The average scores of the ten emotion measures based on the cluster group

Table 9 Average scores of each cluster on the scale

Items of intention to start an automated driving system	Fearful/angry drivers, the 1st group	Emotionless drivers, the 2nd group	Hostile/depressed drivers, the 3rd group	Pleased/contented drivers, the 4th group	Emotional drivers, the 5th group	F	d.f
Behavior Intention 1	3.27	3.25	2.89	4.74	4.00	1.138	0.342
Behavior Intention 2	3.50	3.55	2.71	4.45	4.08	1.05	0.385
Behavior Intention 3	3.79	3.55	3.04	4.65	4.11	2.79	0.029

4.4.2 Report on intention to use autopilot system for clustered groups

The driver sample was marked by five groups. This study examined the relationship between the emotional response patterns and intention of drivers to start an automated driving system. Table 9 lists the average scores of each cluster on the scale. The group comprising pleasant/contented drivers (the 4th group) showed the highest intention to start the automated driving system, followed by the emotional group (the 5th group) and the unemotional group (the 2nd group). The intention to start the automated driving system was close to or higher than the average level of the total sample. In addition, the intention to start the automated driving system was lower in the first group (anger/fear), and the average score in the third group (hostile/depressed drivers) was the lowest, which was below average. One-way ANOVA was used to test the significance of the measurement difference in the emotional experience group's intention to start the automated driving system.

4.4.3 Demographic and driving characteristics of groups

In the questionnaire, the items of the demographic and vehicle usage characteristics of the five groups were tested. It mainly involves four aspects: age, frequency of driving the automated vehicles, education level, and drivers' skill of self-report. Fifty-nine percent of the subjects were younger than 30, and 41% were older than 31. The respondents were divided into a younger group and a middle-aged group. Thirty-six percent of the respondents have junior high school and senior high school education, and 64% have received a bachelor's degree or above. They were divided into groups with low and high education levels. The questionnaire also reported the cognitive results of the respondents' driving skill. Among them, 9.3% of the respondents believed their driving skill was not good, more than 59.6% of the respondents recognized their driving level as average, and 31% of the respondents believed they had a very high driving skill. They were divided into groups with low, average, and high driving levels. Finally, in the past year, the number of drivers who experienced driving an automated vehicle only once accounted for 48%. The number of respondents who had experienced automated driving twice accounted for 36.4%, whereas 15.6% of those who had experienced driving such vehicles multiple times or started automated driving systems were divided into less experienced, general, and rich experience groups. The intensity proportions of these variables in the cluster were measured and compared. Figure 6 shows the results.

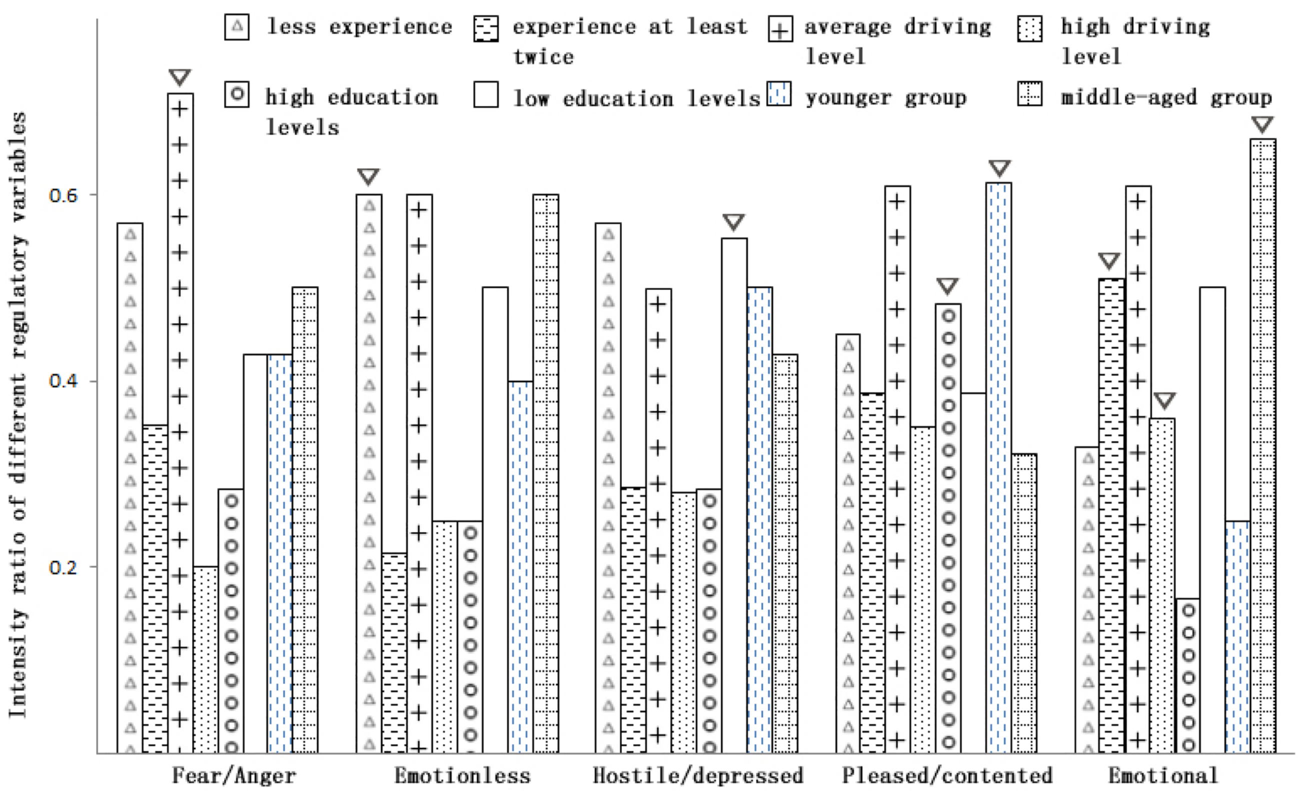

Fig. 6 The demographic and vehicle usage characteristics of the five groups

4.4.4 Clustering groups and intention to start automated vehicles

Based on the cluster analysis of the ten discrete emotions of drivers experiencing an automated vehicle, this study found five such states which, in the descending order of the degree of intention to start the automated driving system, can be described as pleased/contented, emotional, fear, emotionless, and hostile/depressed. In addition, the demographics and driving cognitive and behavioral characteristics across the sample presented by the research team support the cluster analysis.

Some of the observations about these findings are correct. First, the extremely low intention score registered by the hostile/depressed group and the extremely high intention score registered by the pleasure/contented group indicate that the element of surprise plays an important role in the evaluation of intention to start an automated driving system. This is because the average score for surprise is the highest in these groups; furthermore, it seems that surprise acts as an emotional "amplifier" (Westbrook and Oliver 1991). Therefore, when these results are translated into an intention assessment, the potential favorableness and unfavorableness of the outcome experiences are amplified. In this study, the above two groups of subjects probably found that their driving experience of automated vehicles did not match their expectations. In other words, the pleased subjects found it far better, whereas the disgusted subjects found it much worse and were reluctant to try again. In terms of the demographic characteristics, most of the subjects in the hostile group had a low education level ($\beta = 0.56$), which is consistent with the Berger and Anaki (2014) theory that the contribution of lower education level in inducing the feeling of disgust was considerable. The possible explanation is that subjects' perception of automated vehicles is insufficient or even biased; therefore, they have a negative attitude toward the use of automated driving systems. In addition, the characteristics of the subjects in the joy group were evident; among them, they were the highly educated group ($\beta = 0.51$) and those under 30 years old ($\beta = 0.612$). These two characteristics support the cluster analysis. A highly educated group may be more objective and comprehensive in their recognition of automated vehicles, may well measure the time and opportunity costs, and may feel joy, interest, and satisfaction while driving automated vehicles; therefore, they have a positive attitude toward the use of the automated driving system. In addition, younger people are more willing to try new ways of driving (Yu et al. 2020; Morenoet al 2018) and are interested in driving automated vehicles.

In the "emotional" group, the subjects reported experiencing moderate levels of positive emotions, such as joy, interest, and surprise, and not very low levels of negative emotions, such as disgust, fear, and anger, which may be due to their strong personal emotions, where they are not limited to a specific emotional state, but support the intention to experience automated driving and express their fierce attitude with various emotions. The characteristics of the emotional group were evident. Among them, they were the middle-aged group (30–50 years old) ($\beta = 0.66$), the group that experienced automated driving at least twice ($\beta = 0.53$), and the group that reported high driving level ($\beta = 0.36$). The three characteristics support this cluster analysis. The reasons for the above results may be as follows. First, the higher experience has an impact. They may recognize the safety of the automated driving service and the reliability during its cruise, which is consistent with the passenger's intention to experience an automatic bus service (Chee et al. 2021), and both have a high degree of acceptance. Second, drivers (De Craen et al. 2011) tend to overestimate their driving skills, but they are optimistic and may be more likely to accept the challenges of new technologies. In addition, age was found to be the driving factor of drivers' intention toward starting an automated driving system in this study. With increasing age, people's intention to drive an automated vehicle was stronger, which is consistent with the findings of Gold et al. (2015), who reported that older drivers feel higher driving safety after taking over from automated vehicles.

The performance of the "fear/anger group" is puzzling. They exhibited a high level of fear when experiencing automated driving; however, their mean evaluation scores were in the "willing" area on every measure of reported intention indicated in this study (see Table 9). These intention readings may somewhat be misleading in that the scores could simply mean that the reasons for unintention are yet to appear. The characteristics of the fear emotion group were examined, who generally believed that their driving level was average ($\beta = 0.71$), which supported the cluster analysis. The reasons for the above results may be as follows. First, the confidence of drivers who reported an average driving level is different from that of drivers who reported a high driving level. They are prone to hold back and show negative emotions in the face of controlling the sub-task. In addition, anxiety depends on the drivers' personal characteristics. The self-report assessment of drivers in this group indicated a more cautious behavior (Pêcher et al. 2009), which reflects their positive attitude toward traffic safety when driving automated vehicles.

In the "emotionless" group, compared with the sample mean value, these subjects did not show any evident extreme emotions when experiencing automated driving, which may indicate their lack of personal involvement. The intention score to start an automated driving system in this group is also in the "low- intention" range. These people may be emotionally dissociated and evaluate the experience of automated vehicles in a nonemotional manner, where feelings are nonexistent. The group was the drivers with the least experience of driving automated vehicles ($\beta = 0.60$). In fact, people have a positive preference for familiar things (Raudenbush and Frank 1999). People's lack of experience of unfamiliar automated vehicles reduces their tendency to experience them again, particularly in a nonemotional manner.

4.5 Test of moderation

The adjustment interference of the SEM in the questionnaire mainly involves three factors: workload, stress level, and frequency of experience. In this study, 133 valid samples were divided into two groups in terms of these factors. The interference of moderating variables can be analyzed by conducting a multigroup analysis (Yu et al. 2020). Dummy variables were set: perceived low-workload group (LOW-WORKLOAD = 0, $N = 54$), perceived high-workload group (HIGH-WORKLOAD = 1, $N = 79$), perceived low-stress group (LOW-STRESS = 0, $N = 73$), perceived high-stress group (HIGH-STRESS = 0, $N = 60$), low-frequency experience group (SELDOM-EXPERIENCE = 0, $N = 69$), and high-frequency experience group (OFTEN-EXPERIENCE = 1, $N = 64$). Figure 7 presents the test results of the effects of the moderating variables.

For groups with a low frequency of experiencing autonomous driving, their emotions ($\beta = 0.618$, $p < 0.001$) and cognitions ($\beta = 0.397$, $p < 0.05$) were significantly positively correlated with the intention to use an automated driving system. For drivers who often started an automated driving system, their emotions became less relevant to their intention to drive an automated vehicle. According to the excitation transfer (Zillmann 1991), it takes some time for the activated autonomic nervous system to return to its inactive state after the occurrence and disappearance of the stimulus that caused the emotion. In some sense, habituation is the opposite of excitation transfer. Assuming that people use automated driving systems for a long time, which means they experience emotions repeatedly, the intensity of the emotions will decrease over time. An analysis of the moderating variables verified the above hypothesis. Multiple experiences of autonomous driving reduce the intensity of emotions, which also explains the evaluation theory in that emotions arise due to actual or expected changes in favorable or unfavorable conditions (Saariluoma 2020). When autonomous driving operation becomes familiar to people, the intensity of this change weakens, and the expectation naturally will be less; however, a repeated pleasant emotional experience will make the user feel positive. In addition, groups who frequently experience autonomous vehicles have a more positive impact on the intention to use in terms of their satisfaction with the autonomous driving system. This shows that, the more they drive, the more satisfied they are with the performance of the vehicle and the higher is their intention.

For the driver groups with perceived low workload ($\beta = 0.602$, $p < 0.001$) and perceived low stress ($\beta = 0.626$, $p < 0.001$), their emotional changes were more positively correlated with the intention to use the autonomous driving system. Workload (Wulvik et al. 2020) is defined as the sum of physical effort, mental effort, and attention required to maintain a given level of performance. According to literature (Zohar et al. 2003), energy resources expended can have a direct or indirect effect on emotion. When encountering an emotional event, the level of available energy affects the intensity of emotional responses and fatigue.

Fig. 7 Comparisons of the test results of the adjustment variables

The intensity of emotion decreases as the drivers encounter high workload. The results of the study confirmed this hypothesis. Drivers are physically and mentally exhausted in the face of high workload and stress and cannot take advantage of new opportunities provided by environmental changes, resulting in a weakening of positive emotions.

5 Conclusion and significance

It is of great significance to understand people's cognition of the actual use of an automated driving system, which is key to determining whether people decide to adopt it or not. Based on the principle of cognitive processing and appraisal theories of emotion, this study focused on how a driver's emotion of experiencing an autonomous vehicle in the real world affects his/her cognition and intention of starting the automated driving system. Therefore, the study was conducted from three aspects. First, a cognition–emotion–intention framework was constructed and the relationship between the investigated variables was tested. The results showed that emotion, as an intermediary variable, changes people's cognition of autonomous vehicles and affects their intention to use them. The satisfaction of automated driving performance, cognition of safety gain, and positive emotion all had a significant positive impact on the intention to start the automated driving system. Second, this study observed ten types of emotional response changes in the entire process of automated driving (including role transformation between the driver and the supervisor). The results showed that the driver's emotional changes were not evident from the driver's role in the monitoring stage; however, when the driver was faced with taking over control, their emotional changes were very strong. Third, five emotional patterns were found through a cluster analysis, and the relationship between these patterns and the driver's intention to start automated driving was studied. The results showed that the happy group had the strongest intention to start the automated driving system, whereas the disgusted group had the lowest intention.

This study has some theoretical significance. First, thus far, few have studied the emotion of experiencing real-world automated driving to explore the driver's intention to start autopilot. Emotions of drivers experiencing automated vehicles are complex (Izard 1977), where two or more discrete emotions may be co-evoked. Dealing with complex emotions requires at least three parts (Fischer et al. 1990). (1) Emotions trigger functional behavioral tendencies of drivers that enable them to accept or refuse automated vehicles through their emotional evaluation. (2) The categories of emotions form a three-layer hierarchy of superordinate (positive and negative), basic and subordinate. For example, emotions are defined to some extent as positive or negative emotions. (3) Each category of emotion is defined in terms of a prototype delineating a sequence of events of this category. Therefore, to fill the research gap, a cognitive–emotion–intention functionalist framework was constructed for studying the emotions, which helped systematically explore the relationship between emotion, cognition, and intention. In a sense, this study enriches research on the intent to adopt autonomous vehicles. Second, this study reveals the unique emotional process of drivers during automated driving and provides new insights and perspectives for studying the intention of drivers toward starting an automated driving system, which can help understand a driver's psychological activity process when he/she decides to start the automated driving system. Third, this study explored the emotional changes in drivers when they experienced the exchange between two roles (driver and supervisor roles) in the process of automated driving. Extensive studies have been conducted on the state of drivers as a supervisor monitoring the automated driving system with an intention to use automated driving; however, few have considered the emotion and cognition of drivers during the period of taking over from the automated driving system and how this affects their intention to start the automated driving.

This study has some practical significance and is expected to provide some suggestions and hints for enterprises and society. First, a higher experience with real-world automated vehicles has a positive effect on starting automated driving systems. According to emotion theory, the interaction with the object that has attached emotion (in this paper, the object is the automated driving vehicle) will awaken emotions, or recall past interactions (drivers drive manual vehicle), or expect the current interaction (Brave and Nass 2009). For example, a driver who likes to drive and control the vehicle by himself may feel frustrated with the automatic driving system controlling the vehicle, and may exit the automatic driving system if it continues. Second, emotions are considered evaluative states of situations related to personal needs and goals. Compared to drivers without experience, direct experience with autonomous driving resulted in drivers' stronger evaluations and greater variation in evaluations. Of course this emotional change depends on whether drivers' needs and goals lead to desirable or undesirable outcomes (Holden 2011). When these needs are met, positive emotions arise. Negative emotions arise when these needs are blocked. For example, if automated driving system satisfies the driver's interest, curiosity, or wish, then it will be seen as intelligent and likable. Therefore, automobile manufacturers should take advantage of this merit (Hohenberger et al. 2017) to enhance the reliability of the automated vehicles, such as by using data mining or machine learning algorithms to improve the stability of automated driving system control and minimize the risk of machine learning error (Vanderhaegen 2017; Inagaki and Sheridan 2019). This can help reduce the uncertainty and improve the comfort and preference for automated driving experience.

Second, drivers need to improve their driving skills. To be specific, drivers with a high level of driving skill have a high degree of self-confidence, which is conducive to changing the vehicle atmosphere and making participants to exhibit calm emotions while driving automated vehicles (Techer et al. 2019b). Therefore, drivers should enhance their driving skills, which can help improve self-confidence (Merat et al. 2019), and user training on how to use the automated driving system should be provided.

Third, attention should be paid on the operational performance, intelligence, and control power distribution of the automated driving system, which are important factors for the government and enterprises to promote this system. Improving the performance can help drivers to clear their doubts about the automated driving operating system and guide them to experience the charm of automated driving. In addition, experiencing emotions enhances their awareness of the safety gains of automated driving, such as reducing collisions and helping to identify road risks (Zhang et al. 2021). On the contrary, drivers no longer emphasize the idea (Nees 2019) that "I drive safer than automated driving". They have experienced the process of automated driving operation, vehicle control, and decision-making (Zhang et al. 2021), and have a comprehensive understanding of automated driving vehicles. Therefore, in the design of automated vehicles, the focus should be on improving the satisfaction of autonomous driving performance. The system should provide a clear, transparent, reliable, and easy-to-access form to coordinate and control the vehicle with drivers. A better mechanism for the transition (Carsten and Martens 2019) from automated driving to manual driving should be designed to avoid anxiety, depression, and other emotions.

Fourth, the way human drivers take over automated driving should be designed more intuitively to reduce emotional fluctuations of the experimenters. The takeover performance of automated vehicles has a significant influence on the emotional changes in drivers. The worry due to any inappropriate takeover procedure design and the reminder-to-takeover mode of the early warning system reduces the user expectation of the automated driving system. Therefore, adaptive assistance systems for takeover automated vehicles should be appropriately designed (Sullivan et al. 2016). For example, the haptic shared control program proposed by Abbink (2012) can help drivers understand the modes, capabilities, and limitations of automated vehicles. In addition, the low-speed cruise strategy designed into autonomous vehicles has a time pressure on drivers, making them angry. Therefore, it is necessary to negotiate with the users to start the automated driving system, so as to help users rationally allocate the start choice.

6 Limitations and future research

This study has certain limitations. First, users who refused to turn on the automated driving system due to fear were not included in the sample. These groups completely evaded the opportunity of experiencing the automated vehicles, and the reasons for their refusal are worth exploring. Therefore, in the next step, their opinions could be included in the questionnaire or experiment to expand the emotional test sample. Second, driver's emotional feedback is not static but dynamic (i.e., people may change their viewpoint in dynamic situations). However, in this study, due to the limitation of the investigation, the dynamic emotional feedback of drivers at each stage could not be immediately obtained. Therefore, this condition should be considered in future experimental designs. Third, emotional measurement is obtained in the form of respondents' self-reports. Although self-report is the most direct way to measure emotion and a reasonable substitute for the direct measurement of emotion (Izard 1977), the answer may depend on imperfect or possible biased memories of respondents. Emotional state should be assessed using various methods: not only self-reports, but also observations or physiological indicators (Mesken et al. 2007). In addition, the drivers' initial emotional state and the traffic situation while driving should be considered; these factors affect their driving experience in automated vehicles when starting the automated driving system. In future studies, these factors will be considered, such as the timing of users' starting the automated driving system to cope with different road traffic density, and further investigate the attitudes and emotions of drivers while driving automated vehicles.

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Declarations

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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