Heliyon 10 (2024) e31975

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Influence of conventional driving habits on takeover performance in joystick-controlled autonomous vehicles: A low-speed field experiment

Shijian He [a], Xinyi Liu [a], Jie Wang [a,*], Hongcheng Ge [b], Kejun Long [a], Helai Huang [c]

[a] School of Traffic and Transportation Engineering, Changsha University of Science & Technology, Changsha 410114, China
[b] Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, Shanghai, China
[c] School of Traffic and Transportation Engineering, Central South University, Changsha 410018, China

ARTICLE INFO

Keywords:
Driving habit
Takeover
Joystick-controlled autonomous vehicles
Low-speed condition

ABSTRACT

Takeover is a critical factor in the safety of autonomous driving. Takeover refers to the action of a human driver assuming control of an autonomous vehicle from its automated driving system. This can occur when the vehicle encounters a situation it cannot handle, when the system requests the driver to take control, or when the driver chooses to intervene for safety or other reasons. This study explored how traditional steering-wheel driving habits affect takeover performance in joystick-controlled autonomous vehicles. We conducted an experiment using a joystick-controlled Dongfeng Sharing-VAN autonomous vehicle in a low-speed campus environment. The participants were divided into three groups based on their driving experience: the individuals who have no licence and no experience (NN Group), the drivers who have licence but not experienced (HN Group), and the drivers who have licence and have been experienced (HH Group), representing varying levels of driving habits. The experiment focused on two takeover tasks: passive takeover and active takeover. We evaluated takeover performance using takeover time and takeover quality as key metrics. The results from the passive takeover task indicated that traditional driving habits had a significant negative impact on takeover performance. The HH Group took 2.65 s longer to complete the task compared to the NN Group, while the HN Group took 3.78 s longer. When we analyzed takeover time in stages, the initial stage showed the most significant difference in takeover time among the three groups. In the active takeover task, driving habits did not significantly affect takeover braking in front of obstacles in a low-speed driving environment. These findings suggest that conventional driving habits can hinder passive takeover in joystick-controlled autonomous vehicles. This insight can be valuable for developing training programs and guidelines for drivers transitioning from conventional to autonomous driving.

1. Introduction

Autonomous driving is becoming a significant trend in transportation. Different levels of autonomous vehicles are gradually entering the automotive market, changing the way people drive. Level 1 and Level 2 advanced driver assistance systems (ADAS) are widely used and have improved the driving experience by providing features like automatic emergency braking, automated parking,

* Corresponding author.
E-mail address: wangjie@csust.edu.cn (J. Wang).

https://doi.org/10.1016/j.heliyon.2024.e31975
Received 9 April 2024; Received in revised form 8 May 2024; Accepted 24 May 2024
Available online 28 May 2024

and lane-keeping assistance. These systems enable vehicles to correct some of the driver's mistakes for safety. However, most driving operations still rely on the driver's responsibility and active involvement.

Level 3 autonomous driving allows drivers to let go of the steering wheel and pedals, but they still need to monitor the vehicle in real time [1]. In many emergency situations, drivers must intervene quickly to navigate safely through critical events. As a result, a distinct "takeover" process emerges, which is different from conventional driving operations. The effectiveness of this takeover is a crucial factor that directly impacts driving safety.

Some automakers have recently adopted an innovative approach to vehicle control in autonomous driving vehicles: joystick control, where a joystick is used to steer the vehicle. This method is designed to maximize passenger space. However, it raises the question of whether drivers accustomed to traditional driving methods can perform well in this joystick control mode during a takeover.

1.1. Takeover ability

Driver takeover ability is typically measured by takeover performance, which includes both time and quality dimensions [2]. Takeover time is often defined as the interval between the takeover request (TOR) and the driver's initial response. Experiments typically focus on eye movements and behavioral responses to record the initial reaction. The interval between eye movement and TOR represents the time it takes for the driver to shift attention to the driving environment [3]. The interval between behavioral response and TOR measures the time it takes for the driver to initiate the takeover action. From a quality perspective, a driver's ability to maintain stable control of the vehicle after takeover indicates good takeover quality. The evaluation of takeover quality can be based on vehicle acceleration and speed during the takeover process [4,5]. Additionally, takeover quality is influenced by the driver's hazard assessment, such as judging distances in situations that require emergency braking.

1.2. Factors influencing takeover ability in autonomous driving

The central focus of takeover tasks is the transition of vehicle control from the automated system to the driver. These tasks are classified as either active takeover [6–8] or passive takeover [9], depending on who initiates the transfer of control. In active takeover, the driver is typically prepared to take control before issuing the takeover command. In passive takeover, however, the driver must respond quickly to a command to take control of the vehicle without prior warning. Compared to active takeover, passive takeover places higher demands on the driver's physical and psychological readiness, as well as their ability to manage stress. In other words, the performance requirements are greater for passive takeover, as it often occurs in more urgent or unexpected situations. This makes it crucial to analyze and assess drivers' performance during passive takeover, especially in the context of joystick control in autonomous driving.

In recent years, researchers have studied the factors affecting driver takeover performance, focusing on several key aspects: the takeover scenario, the takeover process (including mode and method), and the driver's state.

(1) Takeover Scenarios: In higher-level autonomous driving, drivers can engage in activities unrelated to driving, known as non-driving-related tasks (NDRTs). For instance, reading or watching videos are examples of NDRTs that can affect a driver's attention while driving. Most researchers believe that NDRTs may reduce the driver's awareness of the driving environment, potentially causing delays or difficulties in taking over control safely, thus impacting takeover performance [10]. For example, Ebru et al. studied how watching videos and writing emails, as NDRTs, affect takeover performance. They found that both activities had a negative impact, with video-watching tasks being more disruptive to the driving process than email-related tasks [11]. In another study by Lin et al. it was observed that NDRTs could increase the driver's takeover response time and, to some extent, compromise takeover safety, though they seemed to have a lesser impact on takeover stability [12].

(2) Driver's Physiological and Psychological State: Drowsiness and distraction are significant factors in road accidents, accounting for over 35 % of such incidents [13]. In some ways, autonomous driving can address or reduce the impact of driver drowsiness and distraction. However, when drivers are in a negative state, such as sleepiness or fatigue, which impairs their conventional driving abilities, receiving takeover requests from the autonomous driving system can increase their reaction time. This can lead to a decline in takeover quality. While sleep is an effective way to restore alertness in fatigued drivers [14], performance after sleep can suffer due to "sleep inertia" [15]. Research shows that the deeper the sleep, the worse the performance upon waking [13,16,17].

(3) Takeover mode: The quality of the takeover process can vary significantly depending on how takeover signals are issued, as people respond differently to various types of alerts. The most common method currently used is the single-step takeover, where the takeover signal is issued only once. This approach gives drivers little time to take control, often leading to lower takeover quality [9]. With the development of connected vehicle technologies, the range for acquiring road information has expanded. Intelligent connected vehicles can now detect potential hazards earlier. This has led to the emergence of a new takeover mode called the dual-stage takeover. In this mode, the takeover signal is issued in two stages. The first stage serves as a preliminary warning to direct the driver's attention back to the driving environment, while the second stage serves as the final alert, indicating that the driver must take control. Compared to the single-step method, the dual-stage takeover allows for a transitional period, providing drivers with more time to react, leading to better takeover quality and higher acceptance of the dual-stage request.

1.3. Takeover mode and driving ability training

Driving ability is acquired through training. Drivers do not start with driving skills; they gain them by attending driving schools, undergoing repetitive training, and passing a driver's licence examination [18–20]. Repetitive training improves driving skills, but it can also lead to the formation of driving habits. Studies have shown that drivers operating in familiar modes can become less attentive, relying solely on habit and failing to carefully observe their surroundings, which increases the risk of accidents [21,22]. In conventional driving modes, drivers can develop habits specific to those modes. Their accumulated experience can lead to habitual behaviors that make them more proficient in traditional driving. However, it's unclear how these habits, formed through conventional steering-based driving, impact takeover performance in a completely new joystick-controlled autonomous driving mode.

While the steering wheel is the more common method of operation in everyday driving, handle-based controls are a potential alternative in the development of autonomous driving technology. This is especially relevant for high autonomous driving, where handle-based control may be introduced as an innovative driving mode. Therefore, studying its takeover performance is crucial, there are two key issues that we need to explore.

(1) If takeover performance in joystick-controlled autonomous vehicles affect by traditional steering-wheel driving habits?
(2) How do individual with different levels of driving habits perform in takeover tasks?

To address this, the study conducted an experiment on joystick-controlled autonomous driving, focusing on three groups of drivers with varying levels of driving habits. The experiment included both passive takeover and active takeover tasks. The aim was to quantitatively analyze the impact of conventional steering-based driving habits on takeover performance in joystick-controlled autonomous vehicles. This analysis was done from two perspectives: takeover time (e.g., reaction time, operation time) and takeover quality (e.g., distance to hazards, acceleration). In addition, the experimental results were supplemented with a questionnaire survey to provide further context and justification for the findings. The goal was to offer insights into designing autonomous driving takeover modes and informing driving training programs.

In addition, low-speed driving scenarios were chosen to ensure the safety of the experiments. In takeover performance tests, the experimenter might need to intervene frequently during the driving process. Conducting these tests in low-speed environments significantly reduces the risk. Therefore, studying the takeover performance of handle-based control in low-speed road scenarios can help us better understand this mode's characteristics and limitations. It also provides valuable insights for designing future autonomous driving systems.

In summary, studying takeover performance in specific scenarios—such as handle-based control and low-speed driving—not only contributes to the development of autonomous driving technology, but also enhances road safety and provides crucial technical support for the future of intelligent transportation.

2. Method

2.1. Participants

Similar to previous related research [23], in this experiment, drivers were divided into three groups: the individuals who have no licence and no experience (NN Group); the drivers who have licence but not experienced (HN Group), this group comprised individuals who have passed their driving test within three months and have less than 3000 km of driving experience before this experiment; the drivers who have licence and have been experienced (HH Group), this group includes those who have passed the driving test for over two years and have over 10,000 km of driving experience before the experiment.

To minimize the impact of age on learning ability and avoid its interference in the experimental results, the experiment focused on

Table 1
Description of parameters associated with Task 1.

Parameter	Description
T0	The moment when the takeover command is issued
T1	The moment when the driver initiates a takeover maneuver in response to the command.
T2	The moment when the driver, in manual driving mode, brings the vehicle to a stop.
T3	The moment when the driver, in manual driving mode, shifts the vehicle into Drive (D).
T4	The moment when the driver, in manual driving mode, shifts the vehicle into Neutral (N).
T5	The moment when the vehicle transitions back to autonomous driving mode.
T2–T1	The time taken for the vehicle speed to stop after the driver initiates manual takeover.
T3–T2	The duration between the vehicle reaching a complete stop and the driver shifting into Drive (D)
T4–T3	The time taken for the driver to shift from D to N.
T5–T4	The duration from shifting into Neutral (N) to the vehicle transitioning back to autonomous driving mode.
Reaction time (T1–T0)	The time taken for the driver to respond to the takeover command issued by the researchers.
Operation time (T5–T1)	The duration from the driver's response to the takeover command to the completion of Task 1.
Total time (T5–T0)	The total time from when the command is issued to the completion of Task 1.

young participants. Table 1 shows the driving characteristics for each group. The NN group consisted of 28 participants with an average age of 19.86 years, including 16 males and 12 females, all of whom did not have a driver's licence. The HN group consisted of 33 participants with an average age of 20.06 years, with 22 males and 11 females. Of these, 26 held a C1 driver's licence, and 7 held a C2 driver's licence, but they had limited driving experience. The HH group consisted of 28 participants with an average age of 22.79 years, including 19 males and 9 females. Among them, 22 held a C1 driver's licence, and 6 held a C2 driver's licence. All 28 participants in the HH group had extensive driving experience. Overall, the participants were 64.8 % male and 35.2 % female, with 67 % holding a driver's licence and 33 % without one. The small age differences among the three groups minimized the impact of age and learning ability on the experiment, ensuring relative consistency in psycho-physical characteristics like reaction time and manual control ability (see Table 2).

We selected participants from an age group known for having strong learning abilities. This approach minimizes the impact of age and learning capacity on our experiment. In China, traffic safety education is comprehensive, so even unlicenced individuals from this age group are familiar with basic traffic rules and safe driving practices. Before the experiment, we also explained the fundamentals of traffic safety and the basics of handle-based driving to the participants.

In this study, none of the participants had prior experience with autonomous driving. Considering the significant differences between joystick-controlled driving and conventional steering wheel driving, we thoroughly trained all participants before the experiment began to ensure they understood and mastered the skills required for joystick-controlled driving. During this process, we clearly distinguish three groups of participants: NN Group, HN Group, and HH Group. We found that even participants without a driver's licence could operate the handle smoothly, demonstrating the unique advantages of joystick-controlled controls. Compared to conventional steering wheel driving, joystick-controlled operation is more intuitive and straightforward, requiring less prior knowledge or skill, making it accessible to a broader range of participant.

2.2. *Experimental equipment*

The study used the Dongfeng Sharing-VAN, a Level 3 autonomous vehicle equipped with joystick control. As illustrated in Fig. 1(a), the vehicle is operated using a joystick that controls the steering wheel, accelerator, and brake. The vehicle doesn't have a conventional driver's seat and features only two rows of passenger seating. When manual control is required, the driver uses the joystick, as depicted in Fig. 1(b). The joystick controls the vehicle with a brake button in the upper left corner, an accelerator button in the upper right corner, and various gear-shifting buttons. These include Y for Reverse (R), A for Drive (D), X for Park (P), B for Neutral (N), and SHIFT for mode switching. For this study, the Sharing-VAN was set to operate at low speeds, specifically below 10 km/h.

The autonomous driving system of the Sharing-VAN consists of three main components: the perception system, the path planning system, and the control system. The overall structure is divided into three layers: the perception layer, the decision-making layer, and the control layer, each of which can record log data. In this study, we used log information, vehicle speed, gear changes, and other relevant data with an update rate of 20 ms to ensure experimental accuracy. During the experiment, audio recordings were made with a recorder, and the audio file timestamps were synchronized with the vehicle's log files.

2.3. *Experimental design*

2.3.1. *Experimental scenario*

To minimize the impact of factors like road environment (e.g., road geometry, traffic conditions), driving tasks (e.g., acceleration, steering, distraction), and personal characteristics (e.g., sociodemographic traits, driving experience, travel habits, safety attitude), this experiment simulated a bus route on a university campus by programming an autonomous vehicle to follow a predetermined path. The simulated route was a one-way loop within the campus, as shown in Fig. 2(a). It included two bus stations where the autonomous vehicle would automatically park upon arrival. To study the impact of conventional driving habits on autonomous driving takeover and identify specific effects, two takeover tasks were designed, and participants from three groups with different levels of driving habit were compared.

Task 1 was a passive takeover scenario, primarily assessing the driver's speed in responding to takeover commands issued by the autonomous vehicle. Task 2 was an active takeover scenario, evaluating the driver's ability to proactively take control and perform safe evasion maneuvers when the autonomous vehicle encountered a hazard while operating in joystick mode.

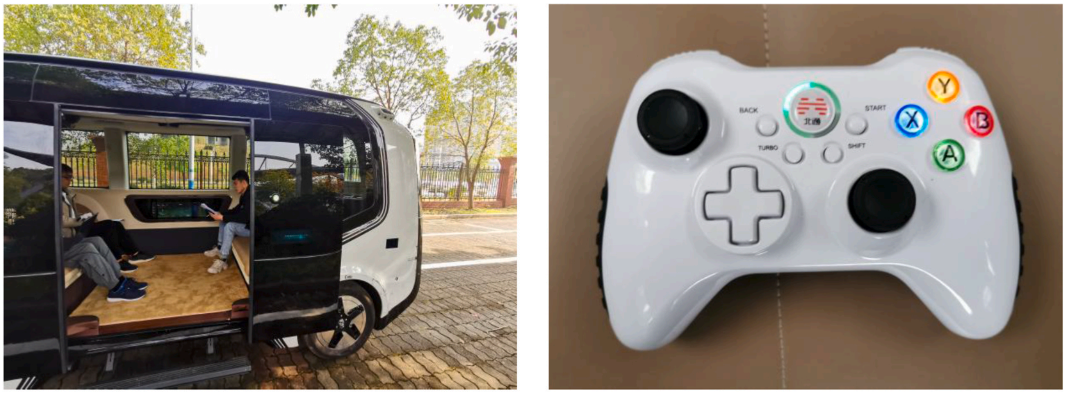
The route in this study was divided into four stages. Stages 1 and 3 served as buffer and adaptation phases. Stage 2 involved Task 1, where participants took over control of the autonomous vehicle. Stage 4 involved Task 2, which required participants to stop the vehicle before reaching an obstacle.

2.3.2. *Pre-experiment preparation*

As shown in Fig. 2(b), the experiment designers provided a brief overview of the Dongfeng Sharing-VAN, informed participants

Table 2
Description of parameters associated with Task 2.

Parameter	Description
a	The maximum deceleration of the vehicle during task 2
D	The final stopping position of the vehicle and the distance to the red plastic barrier



(a) Dongfeng Sharing-Van (b) Joystick controller

Fig. 1. Detailed view of the Dongfeng sharing-VAN vehicle.

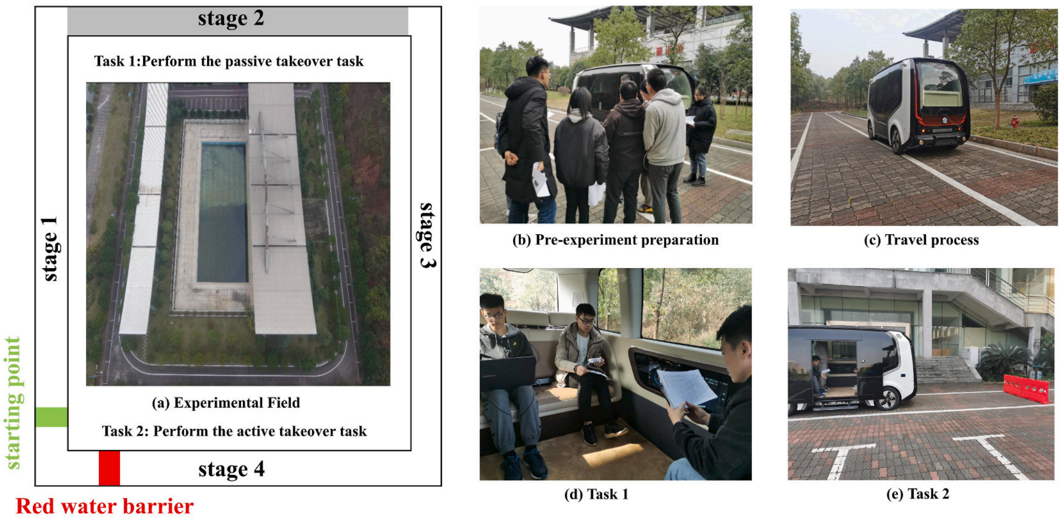


Fig. 2. Overview of the experimental design.

about the vehicle's features, and conducted training sessions on proper joystick usage to ensure correct handling. They also evaluated the participants' comprehension and proficiency with the joystick. The designers informed the participants that the vehicle would operate at a low speed—less than 10 km/h—throughout the experiment to maintain safety. Acting as safety supervisors, the experiment designers monitored participants' actions to prevent accidents due to operational errors.

During the experiment, all driving actions performed by the participants were recorded in the vehicle's log. Additionally, continuous audio recordings were made, with their timestamps synchronized with those in the vehicle's log.

2.3.3. *Experimental procedure*

The experiment comprised four stages.

Stage 1 (Adaptation Stage): The autonomous vehicle starts, and the driver familiarizes themselves with the driving environment. The vehicle autonomously parks and starts at station 1. There is no takeover task for the driver during this stage, as shown in Fig. 2 (c). The length of this road segment is 100 m.

Stage 2: The passive takeover task was carried out (Task 1). In this task, the driver must take over the autonomous driving operation using the joystick upon receiving a takeover command from the experiment designers. The procedure for this task is as follows: (1) The takeover command is issued. (2) The driver presses the brake button to manually take over control of the autonomous vehicle. (3) The vehicle comes to a complete stop, reducing speed to 0, and the system automatically shifts the gear to the neutral (N) position. (4) The driver then shifts the gear to the drive (D) position and maneuvers the vehicle forward until it is stable. (5) The driver shifts the gear to the neutral (N) position and presses the switch button to return control of the vehicle to the autonomous driving system. As shown in Fig. 2(d), during Task 1, the driver controls the vehicle using the joystick, while the experiment recorders make audio recordings and observations.

For Task 1, we evaluated the driver's takeover performance based on takeover time, which includes takeover response time and takeover operation time. Additionally, to track the driver's progress during the task, we identified five key time points, representing when the driver performs critical actions, as shown in Table 1. The gear position and vehicle speed at each of these time points are depicted in Fig. 3.

Stage 3 (Buffer Stage): The autonomous vehicle drives to station 2 and autonomously completes the parking and startup operations. During this stage, the driver has no takeover task for the driver.
Stage 4: The active takeover task is carried out (Task 2). As shown in Fig. 2(e), Task 2 requires the driver to proactively take control and stop the vehicle before it reaches an obstacle. In this stage, a 1-m-high red water barrier is placed on the road as a hazard. The barrier is made of plastic, so even if the vehicle collides with it, it won't cause significant damage. The driver must take over control from the autonomous system to avoid hitting the barrier. The researchers record the distance between the vehicle and the barrier when the vehicle stops. To ensure the safety of the vehicle and personnel, an emergency protection algorithm is embedded in the system. If the vehicle comes within 0.5 m of the obstacle, the system automatically issues a parking command to stop the vehicle. Each test is also monitored by an onboard safety officer. The seat next to the door has an emergency brake button, which the safety officer can press in an emergency to ensure the safety of the test personnel.

For Task 2, we evaluated the driver's takeover performance based on takeover quality. The key metrics for assessing takeover quality are vehicle speed and acceleration. In this analysis, we focus on acceleration during the two experiments. As takeover quality also depends on the driver's response to the takeover event [3], we will use the distance between the vehicle and the hazard as an additional quality indicator.

2.3.4. Post-experimental questionnaire

After the experiment, the driver is asked to fill out two questionnaires. Using the TOC (Task-Objective Control) rating questionnaire developed by Naujoks et al. [5]. as a reference, the researchers designed two sets of questionnaires to evaluate the difficulty of the autonomous driving tasks and the overall experience with the system.

Participants will complete two sets of questionnaires: the Sense of Operation Questionnaire and the Sense of Habituation Questionnaire. These questionnaires use a Likert scale for ratings. The scale ranges from 1, indicating "perfect," to 10, indicating "uncontrollable" [24]. Fig. 4 illustrates the meaning of each rating level.

Fig. 4(a) displays a flowchart for the subjective rating questionnaire on operation. This questionnaire measures the driver's perception of control over the autonomous vehicle. The sense of operation refers to the perceived controllability and quality of the vehicle's operation. A higher score on this scale suggests the driver feels they have less control over the autonomous vehicle. In contrast, a lower score indicates the driver feels they have greater control and a more positive experience with the autonomous driving operation.

Fig. 4(b) presents a flowchart for the subjective rating questionnaire on habituation. This questionnaire gauges the driver's perception of using a joystick to operate the autonomous vehicle. The sense of habituation measures the driver's comfort and adaptation to joystick-based operation. A lower score on this scale suggests that the driver is more accustomed to using a joystick for controlling the autonomous vehicle.

3. Results

This study involves two takeover tasks. Task 1, the passive takeover task, evaluates the takeover ability of three groups of drivers

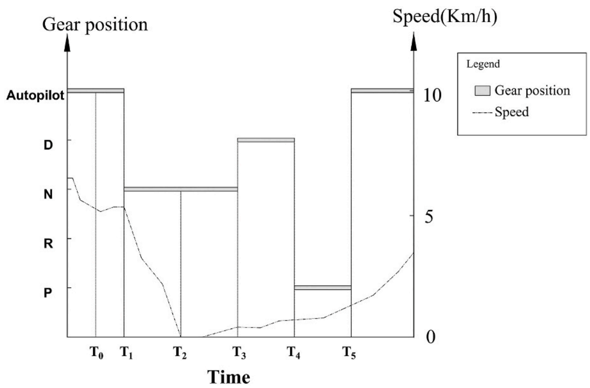
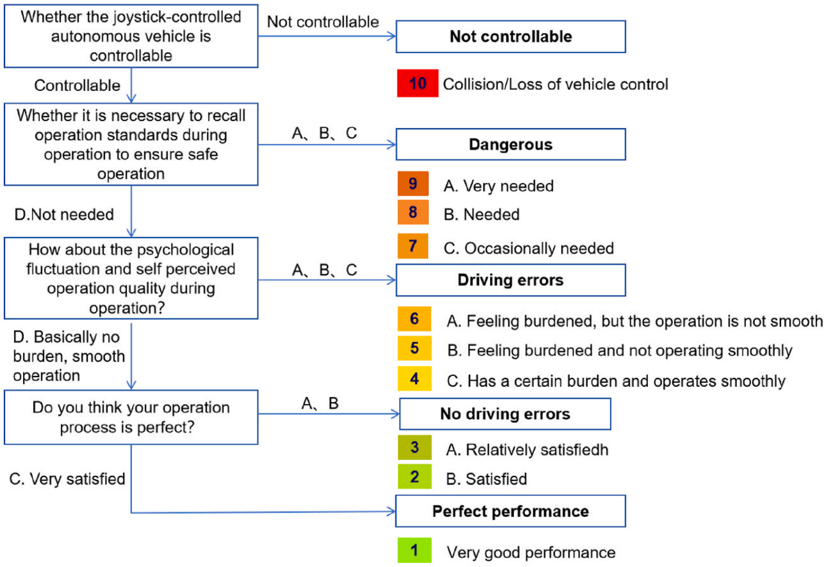
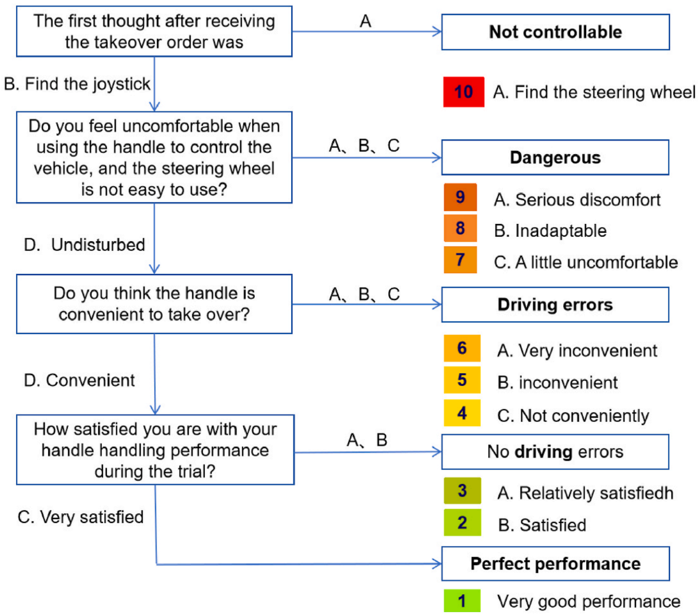


Fig. 3. Gear position and vehicle speed at each time point.



(a) Flowchart for operation questionnaire



(b) Flowchart for habituation questionnaire

Fig. 4. Decision flowchart for subjective rating questionnaire.

from a timing perspective. It measures their reaction time and operation time in a passive takeover scenario, focusing on how quickly they respond to the takeover command from the autonomous vehicle. Task 2, the active takeover task, assesses the takeover ability of the same three groups from a qualitative perspective. In this task, drivers manually operate the joystick to perform a parking maneuver. The main objective is to evaluate their ability to proactively take control and safely maneuver the autonomous vehicle when approaching potential hazards in joystick operation mode.

A comparative analysis was conducted among three groups of drivers: Group 1 (NN group) consists of participants who have not obtained a driver's licence. Group 2 (HN group) includes individuals who have a driver's licence but lack extensive driving experience. Group 3 (HH group) is made up of individuals who have a driver's licence and substantial driving experience.

3.1. Takeover performance for task 1

Kruskal–Wallis (K–W) analysis was conducted to examine differences of takeover time among three groups of participants. Based on the normality test of the data concerning partcipants' takeover time, the majority of the data follow a normal distribution; however, there are a few exceptions that do not conform to a standard normal distribution. For this case, we abandoned the commonly used ANOVA method for differential analysis and opted for the Kruskal–Wallis (K–W) test, since K–W test does not require the data to strictly follow a normal distribution. Specifically, significance tests using K–W test method were conducted to examine differences among the three driver groups (NN, HN, and HH) in terms of total time, reaction time, operation time, T2–T1, T3–T2, T4–T3, and T5–T4. The results are presented in Table 3 and Fig. 5.

For Task 1, the total takeover time, as shown in Table 3, follows this order: HN group (Mean = 12.22, SD = 2.68) > HH group (Mean = 11.09, SD = 3.31) > NN group (Mean = 8.44, SD = 2.12). There are significant differences in the total time for Task 1 among the three groups ($p < 0.01$).

Total takeover time consists of reaction time and operation time. The results indicate significant differences in both operation time and reaction time among the three driver groups. The order for operation time is as follows: HN group (Mean = 10.62, SD = 2.06) > HH group (Mean = 8.86, SD = 2.64) > NN group (Mean = 6.91, SD = 3.37), with a significant p-value of less than 0.01. The order for reaction time is: HH group (Mean = 2.23, SD = 0.93) > HN group (Mean = 1.60, SD = 1.00) > NN group (Mean = 1.53, SD = 0.81), with a significant p-value of 0.014.

Operation time can be broken down into different stages. For T2–T1, there is a marginally significant difference ($p = 0.053$), with the order as follows: HH group (Mean = 1.38, SD = 0.79) ≈ HN group (Mean = 1.37, SD = 0.87) > NN group (Mean = 0.97, SD = 0.53). There is a significant difference in T3–T2 ($p = 0.008$), with the order: HN group (Mean = 4.63, SD = 2.45) > HH group (Mean = 3.64, SD = 2.48) > NN group (Mean = 2.70, SD = 1.52). For T5–T4, there is also a significant difference ($p = 0.001$), with the order: HN group (Mean = 1.28, SD = 1.72) > HH group (Mean = 1.04, SD = 0.64) > NN group (Mean = 0.66, SD = 1.32). However, there are no significant differences in T4–T3 among the three groups.

3.2. Takeover performance for task 2

As shown in Table 4, a significance test using the Kruskal–Wallis (K–W) analysis was conducted to examine differences in takeover quality among the three driver groups. The analysis focused on two specific factors: the distance (D) between the vehicle and the hazard at the end of the takeover and the maximum vehicle acceleration (a) during the takeover process.

For Task 2, we observed no significant differences in acceleration among the three groups. However, there was a significant difference in distance (D) ($p = 0.064$), with the order as follows: HH group (Mean = 5.32, SD = 2.69) > HN group (Mean = 4.24, SD =

Table 3
K–W analysis of takeover time for Task 1.

Parameter	Group	Case number	Mean value	Standard deviation	Minimum	Maximum	P	H
T2–T1	NN	28	0.97	0.53	0.57	3.29	0.053*	5.893
	HN	33	1.37	0.87	0.62	3.55		
	HH	28	1.38	0.79	0.27	3.27		
	Total	89	1.25	0.76	0.27	3.55		
T3–T2	NN	28	2.7	1.52	0.17	6.88	0.008***	9.742
	HN	33	4.63	2.45	1.02	10.30		
	HH	28	3.64	2.48	0.27	9.19		
	Total	89	3.71	2.33	0.17	10.30		
T4–T3	NN	28	2.58	1.50	0.91	8.30	0.298	2.422
	HN	33	3.34	2.48	0.30	13.21		
	HH	28	2.8	1.36	0.16	5.07		
	Total	89	2.93	1.90	0.16	13.21		
T5–T4	NN	28	0.66	1.32	0.00	5.61	0.001***	13.818
	HN	33	1.28	1.72	0.00	6.16		
	HH	28	1.04	0.64	0.19	2.36		
	Total	89	1.01	1.34	0.00	6.16		
Operation time (T5–T1)	NN	28	6.91	1.95	3.70	12.23	0.000***	24.607
	HN	33	10.62	2.64	5.90	18.74		
	HH	28	8.86	3.37	3.30	16.04		
	Total	89	8.90	3.09	3.30	18.74		
Reaction time (T1–T0)	NN	28	1.53	0.81	0.14	3.29	0.014**	8.58
	HN	33	1.60	1.00	0.28	3.87		
	HH	28	2.23	0.93	0.57	4.03		
	Total	89	1.78	0.96	0.14	4.03		
Total time (T5–T0)	NN	28	8.44	2.12	5.38	14.76	0.000***	25.429
	HN	33	12.22	2.68	8.05	19.90		
	HH	28	11.09	3.31	4.40	17.20		
	Total	89	10.68	3.15	4.40	19.90		

Note: * * *, * * and * represent the significance levels of 1 %, 5 % and 10 %, respectively.

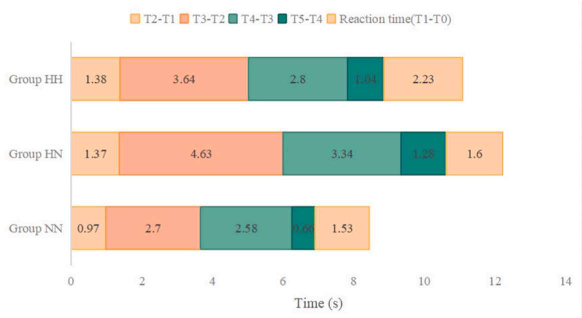


Fig. 5. Takeover time for the three groups.

Table 4
K–W analysis of takeover quality for Task 2.

Parameter	Group	Case number	Mean value	Standard deviation	Minimum	Maximum	P	H
D	NN	28	3.90	2.33	1.30	10.00	0.064*	5.507
	HN	33	4.24	3.58	0.70	20.00		
	HH	28	5.32	2.69	0.70	10.60		
	Total	89	4.47	2.98	0.70	20.00		
a	NN	28	3.25	1.29	0.66	4.95	0.261	2.689
	HN	33	2.70	1.46	0.54	4.83		
	HH	28	2.89	0.91	0.98	4.62		
	Total	89	2.93	1.26	0.54	4.95		

Note: * * *, * * and * represent the significance levels of 1 %, 5 % and 10 %, respectively.

3.58) > NN group (Mean = 3.90, SD = 2.33). This suggests that drivers with different levels of driving habits show minimal variation in takeover quality during active takeovers.

3.3. Questionnaire analysis

A Likert scale questionnaire was used to measure the drivers' subjective perceptions. The scores for operational sensation and habitual sensation were analyzed with a variance analysis to compare takeover effectiveness among the three groups. The results are presented in Table 5 and Fig. 6.

An analysis of the operational sensation questionnaire data, as shown in Fig. 6, revealed significant differences among the three groups. The HN group had higher scores than both the HH and NN groups, indicating that drivers with lower operational sensation scores, particularly those in the NN group, are more adaptable to taking over control in joystick-controlled autonomous vehicles.

Moreover, an analysis of the habitual sensation questionnaire data, as presented in Table 5, also revealed significant differences among the three groups. The HH group had higher scores than the HN and NN groups, indicating that individuals with established conventional driving habits find it more challenging to adapt to joystick-controlled autonomous driving compared to those without these habits.

4. Discussion

Understanding the impact of conventional driving experience and habits on takeover performance in autonomous driving is critical for improving safety in new driving environments. This study focuses on a joystick-controlled autonomous driving system, examining

Table 5
Subjective evaluation score differences among the three groups.

Parameter	Group	Case number	Mean value	Standard deviation	Minimum	Maximum	P	H
Operation sense score	1	28	3.80	2.06	1	8	0.000* * *	21.008
	2	33	6.88	2.27	2	10		
	3	28	4.75	2.41	1	9		
	Total	89	5.27	2.58	1	10		
Habitual sense score	1	28	3.57	1.97	1	10	0.000* * *	51.92
	2	33	5.73	2.76	1	10		
	3	28	9.68	0.91	6	10		
	Total	89	6.27	3.24	1	10		

Note: * * *, * * and * represent the significance levels of 1 %, 5 % and 10 %, respectively.

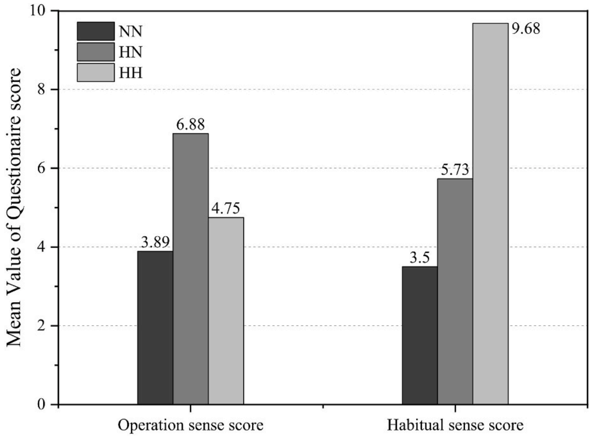


Fig. 6. Subjective evaluation scores for the three groups.

variations in takeover performance among drivers with different levels of conventional driving experience and habits. The results provide insights into how habitual driving behavior affects passive takeover performance in autonomous driving systems.

The experimental results suggest that conventional driving habits negatively affect passive takeover performance in a joystick-controlled autonomous driving system. In Task 1, we found significant differences in total takeover time among the three groups. Drivers in the HH and HN groups, who had conventional driving training, took significantly longer to complete the task compared to those in the NN group, who had no conventional driving training. Specifically, the HH group took, on average, 2.65 s longer than the NN group, while the HN group took 3.78 s longer on average.

As noted by Du et al. [25] in a study on gear-shifting behaviors, once drivers develop a habitual shifting pattern, they can still perform new shifting tasks with a low error rate, but their response time is longer. Drivers give themselves more time to adapt to new requirements to avoid errors. Similarly, in this study, Task 1 is novel for participants without conventional steering training (Group NN), but for those with traditional steering training (Groups HN and HH), it represents a change from a familiar task. Consequently, drivers with conventional steering training tend to take more time to respond to new requirements and avoid errors, leading to longer takeover times in Task 1. This finding demonstrates that conventional driving habits can increase the takeover time during passive takeover in joystick-controlled autonomous driving.

The results from the habit perception questionnaire further support this finding. Both the HH and HN groups, consisting of drivers with conventional driving training, had significantly higher scores for habitual sense compared to the NN group, which consists of drivers with no driving experience. These higher scores indicate that participants in the HH and HN groups were less accustomed to the joystick-controlled takeover mode used in this study. This suggests that drivers who are skilled in operating conventional vehicles find it more challenging to adapt quickly to joystick-controlled autonomous driving. When receiving instructions, drivers influenced by conventional driving habits might instinctively consider using the steering wheel for operation. This could be one of the reasons the HH and HN groups, with traditional driving training, took significantly longer to complete Task 1 compared to the NN group, which had no conventional driving experience.

Interestingly, when we break down the takeover operation time into different stages, we find significant differences among the three groups in the T2–T1 and T3–T2 intervals. The T2–T1 interval represents the braking phase after drivers take over control from the autonomous system, requiring them to use the brake pedal to decelerate the vehicle. This is the first stage where drivers use the joystick controller to alter the vehicle's state. Similarly, the T3–T2 interval represents the stage where drivers perform their first gear shift with the joystick. Beyond these initial phases, there are no significant differences in operational actions among the three groups. This pattern aligns with the typical characteristics of the "psychological adaptation phenomenon."

This is consistent with the findings of Kevin and George [26], who observed that habits have the most influence on behavior during the initial stages of a task when environmental changes occur. In this experiment, the transition from a conventional driving environment to a joystick-controlled driving environment represents a significant environmental shift, creating a mismatch with the behavioral habits of drivers accustomed to conventional driving. Consequently, drivers with established driving habits experienced longer response times (T1–T0), braking times (T2–T1), and shifting times (T3–T2). These three actions represent the initial steps participants take in adjusting to the new mode. This illustrates the psychological adaptation phenomenon, where participants gradually become accustomed to joystick-controlled takeover tasks, much like "entering a room fragrant with orchids and slowly losing awareness of the scent."

In the HH and HN groups, which consist of participants who have undergone driving training, novice drivers without prior conventional driving experience (HN group) showed longer takeover times compared to experienced drivers (HH group). We hypothesize that this difference could be due to varying levels of psychological confidence in driving safety between novice and experienced drivers. Although novice drivers have acquired some proficiency in driving tasks, their lack of experience leads to longer deliberation times during operations, as they may be more cautious about performing the correct actions to ensure safety. In contrast, experienced drivers tend to be more confident in adapting to the new driving mode. This hypothesis is supported by the results of the questionnaire on operational feelings, which show significant differences in operational sense scores among the three groups: HN group > HH group > NN group. The HN group, consisting of novice drivers, had the highest scores for operational sense, indicating that these drivers were more concerned about their ability to control the autonomous vehicle. Conversely, the NN group, which includes participants without driving training, reported the lowest level of concern about controlling the autonomous vehicle.

Under low-speed conditions, conventional driving habits do not affect the quality of active takeover operations. The criteria for assessing takeover quality in this experiment were acceleration and the distance from the hazard to the stop point. The maximum deceleration during Task 2 showed no significant differences among the groups. The stopping distance D, which reflects participants' perception of the hazard and their subsequent safe stopping operations, showed only minor differences among the groups. Chen et al. [27] noted that psychological factors such as safety attitude, risk perception, and safety knowledge are significantly related to driving safety. In this experiment, the similar stopping distances across the groups when perceiving the same hazard suggest that participants in all three groups had comparable safety attitudes and safety knowledge. When they detected a hazard, all three groups used the joystick to control the autonomous vehicle for stopping operations at a similar level.

Based on the analysis above, we found that traditional driving experience has a significant negative impact on the takeover process in the handle driving mode. Specifically, participants with driving licences—those who have undergone traditional steering training and have driving experience—took longer to complete the takeover task. This is primarily due to the influence of their traditional driving habits, requiring more time to adapt to new driving modes and avoid action errors when faced with unfamiliar controls.

Additionally, we found significant differences in takeover performance between novice and experienced drivers among those with driving licences. This difference is primarily due to varying levels of psychological confidence in driving safety. Novice drivers, lacking experience, tend to have more concerns about operational correctness and safety, which leads them to spend more time deliberating during the takeover process. In contrast, experienced drivers exhibit greater self-confidence in the new driving mode and can complete the takeover task more quickly.

This study also highlights the importance of psychological factors in the autonomous driving takeover process. Even in cases where operational skills are comparable, psychological factors like confidence and reaction speed can significantly impact task completion time and overall performance.

5. Conclusion

This study examined the impact of conventional driving habits on the takeover of joystick-controlled autonomous vehicles in a low-speed experiment on a campus. The takeover performance in both active and passive takeover tasks was evaluated among three groups of drivers. The passive takeover evaluation focused on how quickly drivers responded to a takeover command issued by the autonomous vehicle or by the experimenters. The active takeover task assessed the drivers' ability to take control and maneuver the autonomous vehicle safely when approaching potential hazards. The study included three groups of drivers with varying levels of experience: the individuals who have no licence and no experience (NN Group), the drivers who have licence but not experienced (HN Group), and the drivers who have licence and have been experienced (HH Group). These groups represented different degrees of ingrained driving habits. The results showed that, compared to those without a licence, experienced drivers took an additional 2.65 s to complete the passive takeover task, while novice drivers took an extra 3.78 s. However, the results from the active takeover task indicated that ingrained driving habits did not significantly impact the execution of takeover braking maneuvers in a low-speed driving environment when facing obstacles.

The results of this study suggest that conventional steering driving habits negatively impact passive takeovers in joystick-controlled autonomous vehicles under low-speed conditions. To address this issue, special attention should be given to individuals with traditional driving training. Drivers who already hold a manual vehicle driving licence should receive additional training and assessment in autonomous driving, with their licence updated to include autonomous driving capabilities, in order to reduce or eliminate the influence of manual driving habits. Furthermore, special emphasis should be placed on novice drivers with limited driving experience. When providing autonomous driving training to these individuals, stricter training measures should be applied compared to experienced drivers.

In summary, our research findings highlight the complex role traditional driving experience plays in autonomous driving takeover and underscore the significant impact of psychological factors on takeover performance. These insights have important implications for the ongoing development of autonomous driving technology, user training, and adaptive programs. Going forward, we need to focus more on the psychological needs and reactions of users during autonomous driving takeovers to design more human-centered, safe, and reliable autonomous driving systems.

While this study offered valuable insights, it is important to acknowledge its limitations. First, the study experiment is limited to simulating a campus bus scenario under low-speed conditions, which represents a single and relatively simple context. However, this simplicity also means that several potentially influential factors were omitted from the experimental design. These factors include various aspects such as the road environment, encompassing its geometry and traffic conditions, the range of driving tasks involving acceleration, steering, and potential distractions, as well as individual differences in socio-demographics, travel habits, and safety attitudes. It's unclear whether the findings from this study can be generalized to more complex scenarios or high-speed roads. To understand the impact of conventional driving habits on joystick-controlled autonomous driving takeovers in more complex environments, future research should consider modifying the experimental setup to include a wider range of realistic driving situations. Second, the study sample may not represent the general population. The experiment focused on a young adult population, so it's unclear how older adults, who may have lower learning abilities, would perform in joystick-controlled autonomous driving takeovers. Future research should involve participants from different age groups to assess the impact of factors like age on joystick-controlled autonomous driving takeovers.

Data availability statement

Data will be made available on request.

Ethical statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

CRediT authorship contribution statement

Shijian He: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Xinyi Liu:** Writing – original draft, Formal analysis, Data curation. **Jie Wang:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Hongcheng Ge:** Writing – review & editing, Investigation, Formal analysis. **Kejun Long:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Helai Huang:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors report no declarations of interest.

Acknowledgements

This study was supported by the following funds: 1) National Natural Science Foundation of China (No. 52102406 and No. 52302428); 2) Changsha Natural ScienceFoundation (No. kq2202212); 3) Scientific Research Fund of Hunan Provincial Education Department (No. 21B0288); 4) Natural ScienceFoundation of Hunan Province (2022JJ40476); 5) Changsha Science and Technology Major Special Project (No.kh2301004). Thank you to Dongfeng Yuexiang Technology Co., Ltd. for providing test vehicles and data extraction devices.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31975.

References

[1] SAE International, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, SAE International, New York, 2021.
[2] B. Zhang, J.d. Winter, S. Varotto, et al., Determinants of take-over time from automated driving: a meta-analysis of 129 studies, Transport. Res. F Traffic Psychol. Behav. 64 (2019) 285–307, https://doi.org/10.1016/j.trf.2019.04.020.
[3] L. Guo, L. Xu, Z. Qin, et al., How drowsiness and distraction can interfere with take-over performance: a systematic and meta-analysis review, Accid. Anal. Prev. 22 (2) (2022) 72–90, https://doi.org/10.16097/j.cnki.1009-6744.2022.02.008. https://link.cnki.net/doi/10.16097/j.cnki.1009-6744.2022.02.008.
[4] C. Gold, D. Damböck, L. Lorenz, et al., "Take over!" How long does it take to get the driver back into the loop? Proc. Hum. Factors Ergon. Soc. Annu. Meet. 57 (1) (2013) 1938–1942, https://doi.org/10.1177/1541931213571433.
[5] F. Naujoks, K. Wiedemann, N. Schömig, et al., Expert-based controllability assessment of control transitions from automated to manual driving, MethodsX 5 (2018) 579–592, https://doi.org/10.1016/j.mex.2018.05.007.
[6] P.A. Hancock, On the process of automation transition in multitask human-machine systems, IEEE Trans. Syst. Man Cybern. Syst. Hum. 37 (2007) 586–598, https://doi.org/10.1109/TSMCA.2007.897610.
[7] T. Inagaki, T.B. Sheridan, Authority and responsibility in human-machine systems: probability theoretic validation of machine-initiated trading of authority, Cognit. Technol. Work 14 (2012) 29–37, https://doi.org/10.1007/s10111-011-0193-4.
[8] Z. Lu, R. Happee, C.D.D. Cabrall, et al., Human factors of transitions in automated driving: a general framework and literature survey, Transport. Res. F Traffic Psychol. Behav. 43 (2016) 183–198, https://doi.org/10.1016/j.trf.2016.10.007.
[9] J. Zeng, J. Li, Z. You, Research progress of driver taking over ability in autonomous driving and self-driving environment, Transportation Technology and Economy 24 (5) (2022) 30–37, https://doi.org/10.19348/j.cnki.issn1008-5696.2022.05.005. https://link.cnki.net/doi/10.19348/j.cnki.issn1008-5696.2022.05.005.
[10] B. Wandtner, N. Schömig, G. Schmidt, Effects of non-driving related task modalities on takeover performance in highly automated driving, Hum. Factors: The Journal of the Human Factors and Ergonomics Society 60 (6) (2018) 870–881, https://doi.org/10.1177/0018720818768199.
[11] E. Dogan, V. Honnêt, S. Masfrand, et al., Effects of non-driving-related tasks on takeover performance in different takeover situations in conditionally automated driving, Transport. Res. F Traffic Psychol. Behav. 62 (2019) 494–504, https://doi.org/10.1016/j.trf.2019.02.010.
[12] Q. Lin, Z. Wang, G. Lu, Evaluation model for takeover safety of L3 autonomous vehicle, Automot. Eng. 41 (11) (2019) 1258–1264, https://doi.org/10.19562/j.chinasae.qcgc.2019.011.005. https://link.cnki.net/doi/10.19562/j.chinasae.qcgc.2019.011.005.
[13] G. Merlhiot, M. Bueno, How drowsiness and distraction can interfere with take-over performance: a systematic and meta-analysis review, Accid. Anal. Prev. 170 (2022) 106536, https://doi.org/10.1016/j.aap.2021.106536.

[14] B.M. Hartzler, Fatigue on the flight deck: the consequences of sleep loss and the benefits of napping, Accid. Anal. Prev. 62 (2014) 309–318, https://doi.org/10.1016/j.aap.2013.10.010.
[15] J. Wörle, B. Metz, M. Baumann, Sleep inertia in automated driving: post-sleep take-over and driving performance, Accid. Anal. Prev. 150 (2021) 105918, https://doi.org/10.1016/j.aap.2020.105918.
[16] C.J. Hilditch, A.W. McHill, Sleep inertia: current insights, Nat. Sci. Sleep 11 (2019) 155–165, https://doi.org/10.2147/NSS.S188911.
[17] P. Tassi, A. Muzet, Sleep inertia, Sleep Med. Rev. 4 (4) (2000) 341–353, https://doi.org/10.1053/smrv.2000.0098.
[18] D.G. MacKay, The problems of flexibility, fluency, and speed-accuracy trade-off in skilled behaviour, Psychol. Rev. 89 (1982) 483–506, https://doi.org/10.1037/0033-295X.89.5.483.
[19] D.A. Norman, Categorization of action slips, Psychol. Rev. 88 (1981) 1–15, https://doi.org/10.1037/0033-295X.88.1.1.
[20] R.M. Shiffrin, W. Schneider, Controlled and automatic human information processing.II. Perceptual learning, automatic attending and a general theory, Psychol. Rev. 84 (1977) 127–190, https://doi.org/10.1037/0033-295X.84.2.127.
[21] S.G. Charlton, N.J. Starkey, Driving on familiar roads: automaticity and inattention blindness, Transport. Res. F Traffic Psychol. Behav. 19 (2013) 121–133, https://doi.org/10.1016/j.trf.2013.03.008.
[22] Y. Lu, X. Fu, C. Lu, et al., Effects of route familiarity on drivers' psychological conditions: based on driving behaviour and driving environment, Transport. Res. F Traffic Psychol. Behav. 75 (2020) 37–54, https://doi.org/10.1016/j.trf.2020.09.005.
[23] S.D. Craen, D.A.M. Twisk, M.P. Hagenzieker, et al., Do young novice drivers overestimate their driving skills more than experienced drivers? Different methods lead to different conclusions, Accid. Anal. Prev. 43 (5) (2011) 1660–1665, https://doi.org/10.1016/j.aap.2011.03.024.
[24] A. Neukum, H.P. Krüger, Driver reactions in the event of steering system malfunctions investigation methodology and evaluation criteria, VDI-Ber. 1791 (2003) 297–318. http://worldcat.org/isbn/3180917911.
[25] Y. Du, J.W. Krakauer, A.M. Haith, The relationship between habits and motor skills in humans, Trends Cognit. Sci. 26 (5) (2022) 371–387, https://doi.org/10.1016/j.tics.2022.02.002.
[26] Kevin G. Volpp, George Loewenstein, What is a habit? Diverse mechanisms that can produce sustained behavior change, Organ. Behav. Hum. Decis. Process. 161 (Supplement) (2020) 36–38, https://doi.org/10.1016/j.obhdp.2020.10.002.
[27] C. Wang, C. Xu, J. Xia, Z. Qian, The effects of safety knowledge and psychological factors on self-reported risky driving behaviors including group violations for e-bike riders in China, Transport. Res. F Traffic Psychol. Behav. 56 (2018) 344–353, https://doi.org/10.1016/j.trf.2018.05.004.