CCF Transactions on Pervasive Computing and Interaction (2023) 5:139–156
https://doi.org/10.1007/s42486-022-00122-5

REGULAR PAPER

Effect of cognitive-behavioral therapy for the elderly on driving behavior and emotional state: a randomized controlled trial

Ying Wang[1] · Rufeng Feng[1] · Defu Bao[2]

Received: 4 September 2022 / Accepted: 10 December 2022 / Published online: 13 February 2023

Abstract
With the increase of age, the cognitive ability and psychological flexibility of elderly drivers decrease, which will affect their driving behavior. The purpose of this study is to explore the driving characteristics of the elderly by comparing the driving behavior differences between 17 young drivers and 16 elderly drivers and then examine the effectiveness of cognitive-behavioral therapy (CBT) in driving training for the elderly through a randomized controlled experiment (RCT). Young drivers and elderly drivers were divided into the control group (CG) and intervention group (IG). The CG received routine driving training, and the IG received cognitive-behavioral training. During the experiment, we measured driving skills, cognitive load, emotional state, and eye movement data. Results showed that elderly people have poor driving performance and mental flexibility, but they can adopt conservative compensation measures to adapt to driving tasks. In addition, compared with the CG, the acceleration of the IG group decreased, and IG group showed more positive emotional state. Analysis of eye-movement data also showed that CBT was more effective at improving visual attention and risk perception in elderly adults. In conclusion, driving training based on CBT can improve the driving skills and emotional state of the elderly better than conventional training. Future studies should consider applying this method in driving training for the elderly to enhance their cognition of driving behavior.

Keywords Cognitive behavioral therapy · Driving training · Elderly · Risk perception

1 Introduction

As the population ages, the number of elderly drivers is also increasing. An aging society has a profound impact on road traffic safety and has become an increasingly important topic in research (Ji 2015; Rhiu et al. 2015). According to statistics, there were 45.2 million drivers aged 65 or older in the US in 2018, up 40.1 percent from 2008, and 86 percent of senior citizens chose to drive (Federal Highway Administration 2018). There is a similar trend for the number of elderly drivers in China, and according to the latest data on motor vehicles and drivers in China for 2020 released by the Road Traffic Administration of the Ministry of Public Security, the total number of motor vehicle drivers in China reached 456 million by the end of 2020, accounting for 3.36 percent of drivers over 60 years of age according to age distribution (data released by the Traffic Administration of the Ministry of Public Security in January 2021). Moreover, starting on 20 November 2020, China relaxed the age limit for small car driver's license applications and lifted the age limit to 70 years old. However, older people have an increased risk of being injured or killed in a traffic crash compared to younger people as they get older (Papa et al. 2014). The causes of car accidents are usually related to the cognitive decline and attention dispersion of the elderly. Previous studies (Adrian et al. 2011; Kaneko et al. 2021) reported that cognitive decline in older adults leads to reduced processing speed, attention, and executive function, which can affect their safe driving. For example, Bélanger et al. (2010) found it is harder for the elderly to start multiple vehicle control devices simultaneously than the young. Accidents requiring

✉ Ying Wang
winered@zstu.edu.cn

Rufeng Feng
f2564186379@163.com

Defu Bao
490343007@qq.com

1 Universal Design Institute, Zhejiang Sci-Tech University, Hangzhou 310018, China

2 Zhejiang Sci-Tech University, Hangzhou 310018, China

multiple synchronized reactions (such as overtaking, pedestrian crossing, and vehicle intrusion) will lead to higher traffic accident rates in driving simulators for the elderly. At the same time, the driving level of the elderly in different age groups also varies greatly. Stutts et al. (2009) report analysis showed that drivers over 70 years old are more vulnerable to traffic accident risk than drivers between 60 and 69 years old. They pointed out that the driving risks of the elderly usually include complex visual search and rapid processing of multiple information in the case of distraction. However, the visual search ability and information processing speed of elderly drivers are significantly worse than those of young drivers. Fortunately, it has been proven (Seidler et al. 2010; Lee et al. 2020) that the elderly can be trained to improve cognitive processes (e.g., attention control, memory, and processing speed). Driving can promote the physical and mental health of the elderly. More and more elderly people are engaged in driving activities. At present, researchers have shown great interest in developing ways to improve driving skills and reduce the risk of traffic accidents, trying to help the elderly drive safely through simulated driving training (Nouchi et al. 2019).

1.1 Improving driving ability through game training

Game-based training is a new method for professional training and scene simulation using game mechanisms and game thinking. Sue et al. (2014) found that using driving games helps reduce traffic accidents and applies to the elderly, representing the latest trend in the development of driving training. Intel Laboratory jointly developed CARLA with Toyota Research Institute and Barcelona Computer Vision Center to support the development, training, and validation of urban autonomous driving systems (Dosovitskiy et al. 2017). CARLA is flexible and authentic in rendering and physical stimulation and can create open-source digital resources for autonomous driving (including urban layout, buildings, and vehicles), combined with driving games and simulating traffic events, helping to train more complex scenes (Pappas et al. 2021).

Cognitive training based on the driving simulator can improve the driving skills of the elderly (Casutt et al. 2014). Participants can conduct simulation training through simulators and receive feedback promptly to help correct errors in driving. In addition, the driving simulator can also help participants to conduct hazard perception training and alleviate the distraction. For example, Milleville-Pennel and Marquez (2020) used driving simulators to build traffic scenarios to study differences in risk perception among different populations by allowing participants to respond to different scenarios. Petzoldt et al. (2013) showed that participants are quicker to spot danger and more flexible in visual search after driving training. In addition, the simulation platform can provide signals to reflect user driving strategies, such as GPS coordinates, speed, acceleration, and detailed data on collisions and other violations (Dosovitskiy et al. 2017). These indicators can measure changes in drivers' driving ability. For example, Ting et al. (2008) showed that the drivers' speed, acceleration, and steering wheel acceleration will change to a certain extent in fatigue driving. Similarly, these data can be obtained through driving simulators as a basis for measuring participants' driving proficiency and psychological flexibility and further assessing the impact of different driving training methods on participants' driving performance (Roenker et al. 2003).

In addition, Likitweerawong and Palee (2018) used VR serious games for driving training, arguing that virtual reality games can help players gain confidence and driving skills. Similarly, Nouchi et al. (2016) found that game-based driving training can improve participants' emotional states. However, the current driving training games are designed for young people, there are relatively few studies on the intervention of elderly driving cognition. Therefore, it is necessary to further understand whether driving-related game training can improve the emotional state of the elderly, and explore the relationship between driving training, emotional state, and driving ability, to evaluate the effectiveness of driving training in the elderly.

1.2 Effect of cognitive behavior therapy on driving emotion

Cognitive behavioral therapy (CBT) with psychological intervention as the core can improve negative emotions, reduce drivers' negative symptoms, and correct driving behavior. Grant et al. (2018) indicated that CBT is designed to help patients achieve valuable desires and maintain positive attitudes and that positive motivation and interpersonal communication are strengthened through the cooperation of the therapists with patients, leading to immediate goals related to behavioral activities. In addition, using simulators to provide real experiences can be used as exposure therapy, which is a common way for CBT to improve negative emotions in driving training (Trappey et al. 2020; Fischer et al. 2021). Negative emotions are the main reason for drivers' dangerous driving. With the decline of cognitive ability, the elderly is more likely to have negative emotions such as depression and anxiety, thus affecting their normal driving. CBT can change psychological problems by changing patients' views and attitudes towards themselves or things, which is also applicable to the elderly with cognitive decline. In past research, cognitive behavior training has been applied in the field of elderly driving (Ball et al. 2010). They found that cognitive speed processing and reasoning training can effectively reduce the frequency of motor vehicle collisions among elderly drivers. Hu et al. (2013) found through experimental investigation that negative emotions would destroy drivers' rational judgment and affect drivers' driving behavior through risk perception and risk attitude. For example, when people are unhappy, they would try to get rid of this state, so they usually choose higher risk driving behavior (Hocey et al. 2000). But relevant research (Deffenbacher 2016; Feng et al. 2018) proved that cognitive interventions can encourage drivers to use positive cognitive strategies to improve negative emotions and misbehaviors.

Kogan et al. (2001) showed that cognitive-relaxing interventions have been effectively applied to reduce driving anger and stabilize the driver's emotional state. Molloy et al. (2019) verified that the two training methods based on cognitive behavior, "comprehensive feedback" and "self-explanation", are effective in improving driver speed management behavior through auditory alarm feedback (speeding alarm), comprehensive feedback (providing speeding times and corresponding penalties) and self-explanation (asking to explain their performance in speed management to themselves). In addition, Zinzow et al. (2018) conducted virtual reality exposure therapy and cognitive behavioral intervention (VRET + CBT) for veterans. By simulating real driving scenarios and behavioral perception combined interventions, the driving-related anxiety and aggression of veterans were alleviated, which proved the feasibility of the intervention. Baker-Ericzén et al. (2021) combined CBT with other cognitive enhancement strategies, including identifying anxious or negative thoughts and turning them into positive rational thoughts, emotional awareness and management skills, and practicing behavioral skills through graded progressive contact. The feasibility and acceptability of driving cognitive behavioral intervention (CBID) were investigated by enhancing driving executive function (EF) and emotion regulation (ER). The results show that CBID can affect autistic people's pursuit of driving goals by increasing driving attitude and behavior and reducing anxiety. Although these data are encouraging, their universality is limited, and the application of CBT in elderly drivers needs to be examined further. In addition, it is necessary to distinguish emotion regulation-focused CBT from other driving training techniques, such as driving norm training and use it as a method of driving emotion management in the future.

1.3 Research questions

At present, the application of CBT in the field of driving training is mainly concentrated in the young and middle-aged groups, but there are few studies on the acceptability and effectiveness in the elderly driver groups. However, the application of CBT in elderly drivers deserves further exploration. To determine whether their driving habits and cognitive load are different from those of young drivers, and to provide theoretical support and specific programs for the subsequent promotion of cognitive training in driving behavior among older drivers. To evaluate the training effect, we used road simulation driving to analyze participants' driving skills, visual search, and emotional state, to study the applicability of CBT in the elderly (over 55 years old) from these three dimensions. We aimed to answer the following questions:

- RQ1: Are there any differences in driving skills, cognitive load, and visual search between the elderly and young people during driving? What are the implications of this difference for the subsequent application of CBT in older drivers?
- RQ2: What is the training effect of CBT compared with ordinary simulator training?
- RQ3: How does CBT as an adjunctive training approach change the driving behavior of the elderly compared with young people?

2 Method

2.1 Study design

This study used a randomized controlled trial (RCT) to stratify the subjects according to age. The young group and the elderly group were randomly divided into four groups, the control group (CG) used the ordinary driving simulation training method, and the intervention group (IG) combined CBT for driving simulation training. The t-test, variance analysis, and factor analysis were used to explore the influence of CBT on driving training of the elderly. This experiment had five independent variables: average speed, acceleration, driving emotion, cognitive load, and eye gaze. The main result was driving skill, which was measured by performance on the driving simulator and the eye gaze duration during driving. The faster the driving speed was, the smaller the acceleration was, and the more skilled and stable the driving was. Eye gaze duration was used to evaluate the flexibility of visual search and the perception of danger. The secondary results were cognitive load and emotional state.

2.2 Participants

Thirty-three experienced drivers were invited to participate in this study. They had normal vision and no cognitive impairment. The young group consisted of 17 people (13 males and 4 females), aged 22–26 years ($M = 23.35$, $SD = 1.41$), and the elderly group consisted of 16 people (7 males and 9 females), aged 55–70 years ($M = 64.19$, $SD = 4.59$). Young members were recruited from Zhejiang Sci-Tech University, and elderly members were recruited in communities near the school. They had been studying driving at a nearby driving school and had just got their licenses. They were volunteers and were told the specific process of the experiment. Participants were randomly assigned (they did not know whether they were in the intervention group or the control group). Table 1 presents the baseline characteristics of all participants. There was a significant difference in driving speed between the two groups of elderly on urban streets ($p < 0.05$). In addition, there were no significant differences in other variables ($p > 0.10$) (t-test of two independent samples).

2.3 Apparatus

2.3.1 Subjective assessment scale

We selected the Multidimensional Driving Style Scale to evaluate the driving style of different groups (Taubman-Ben-Ari et al. 2004). The questionnaire included 25 questions: participants' personal information (age, gender, education level, driving age) and 20 questions about illegal driving behavior, wrong behavior, and wrong behavior. The higher the score, the more dangerous the driving. In addition, the task load index (NASA-TLX; Hart and Staveland 1988) and Profile of Mood States (POMS; Xianglong et al. 2018) were used to evaluate drivers' cognitive load level and emotional state during driving. Furthermore, this experiment improved the original emotional state scale (Aluoja et al. 1999), measuring the driving emotions of participants from four dimensions tension, anger, depression, and energy, and evaluated whether CBT could effectively improve the negative emotions of participants in the driving process.

All the questions in the questionnaire were completed in collaboration to ensure a clear and correct understanding of the problem.

2.3.2 Driving simulator and Tobii Glasses

The study was conducted in a driving simulator (Reich et al. 2017; Pv 2021), We used the Unreal Engine 4 (UE4) software to build driving scenes, combined with the CarSim vehicle dynamics model and Logitech G27 force-feedback steering wheel pedal set, to simulate driving and provide real input behavior to control the simulated vehicle. The virtual environment was displayed on a 32-inch LCD monitor (Fig. 1). The driving simulator could collect the speed of the driving process in real-time, which was convenient for subsequent analysis.

For eye tracking, a Tobii Pro Glasses 2 wearable eye tracker with a sampling rate of 100 Hz was used in this experiment. Tobii Pro Lab software was used to extract original data and analyze visual information, such as participants' fixation area, fixation count, the average duration of fixation, etc. (Čegovnik et al. 2018).

Fig. 1 Driving simulator

Table 1 Baseline characteristics by age and training method (n = 33)

	22-26 years (n = 17)					55-70 years (n=16)				
	CG (n = 9)		IG (n = 8)		p value	CG (n = 8)		IG (n = 8)		p value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Age (years)	23.78	1.39	23.88	1.89	0.91	62.75	5.52	65.63	3.16	0.23
Driving behavior (score)	19.22	10.81	17.88	8.46	0.78	9.38	5.26	9.63	2.83	0.91
Urban speed (km/h)	46.51	10.82	43.20	5.97	0.46	21.61	3.17	27.04	4.84	0.02*
Urban acceleration (m/s²)	5.43	1.42	5.70	1.63	0.72	3.58	1.06	4.59	1.37	0.12
Suburban speed (km/h)	62.44	8.74	57.70	10.79	0.33	47.95	7.73	50.54	5.24	0.45
Suburban acceleration (m/s²)	6.94	2.11	7.46	1.77	0.59	6.2	2.15	5.63	1.5	0.55

Group comparison (two sample t-tests) of pre-training scores revealed there was no significant difference in other measurements ($p > 0.10$) except urban speed ($p < 0.05$)

CG control group; *IG* intervention group (combined with cognitive behavioral therapy)

2.3.3 Test and correct misconceptions (cognitive reconstruction)

Before the experiment, it is the first step of CBT to establish a good cooperative relationship with the participants in the IG and ease their tense emotions. Then selected part of the test questions in the domestic driving license subject one as the interview content (Fig. 2) to test the participants' misconceptions. Through scene display and reminders, participants are encouraged to enter real or imagined situations, so that they can think about the way the wrong driving concept works, and finally make the right choice and explain the reasons for this choice. Testing and correcting misconceptions can help participants recognize their dangerous driving behaviors, correct them in time, and rebuild new cognition.

Fig. 2 Examples of interview questions

2.3.4 Driving scene design (behavioral modification)

Set up test scenarios and training scenarios. The IG used specific training scenes to simulate real driving situations to consolidate new cognitive structures and then asked them to carry out driving activities in the test scenes according to these new cognitive structures. The participants in the CG did the same training in the scene without word intervention, then they also did the driving test in the test scene after the training. The test and training scenarios are as follows:

2.3.4.1 Test scenario There were two different scenes, urban streets and suburban roads (Fig. 3). Participants drove on urban streets and had to choose the right route from the urban streets to the suburbs. The roads in urban were crowded, which implied more complex driving situations; The roads in suburban were less restrictive, but they were undulating and curved. The speed of participants in different scenarios can be used as an indicator of self-regulation behavior, and the acceleration at braking can reflect the participants' ability to deal with danger.

2.3.4.2 Training scenario The training scenario of the CG (see Fig. 4a), required participants to follow traffic light rules during simulated driving and avoid passing vehicles by controlling the brake, accelerator and steering wheel. The training scenarios of the IG (Fig. 4b, c and d) are shown in the text reminder based on the CG. The intervention measures are as follows: when passing the intersection, if there are pedestrians, the reminder "pedestrians passing" was triggered (Fig. 4b); When the left lane is changed, the steering wheel rotates to trigger the reminder of "Pay attention to the rearview mirror" (Fig. 4c); When the road distance from the vehicle in front is too small, the trigger will remind "there is a vehicle ahead" (Fig. 4d). The text appears for 1 s. Without affecting normal driving, participants' cognition of driving behavior was deepened through intuitive text intervention.

Fig. 3 Participants can choose two scenarios: urban or suburban

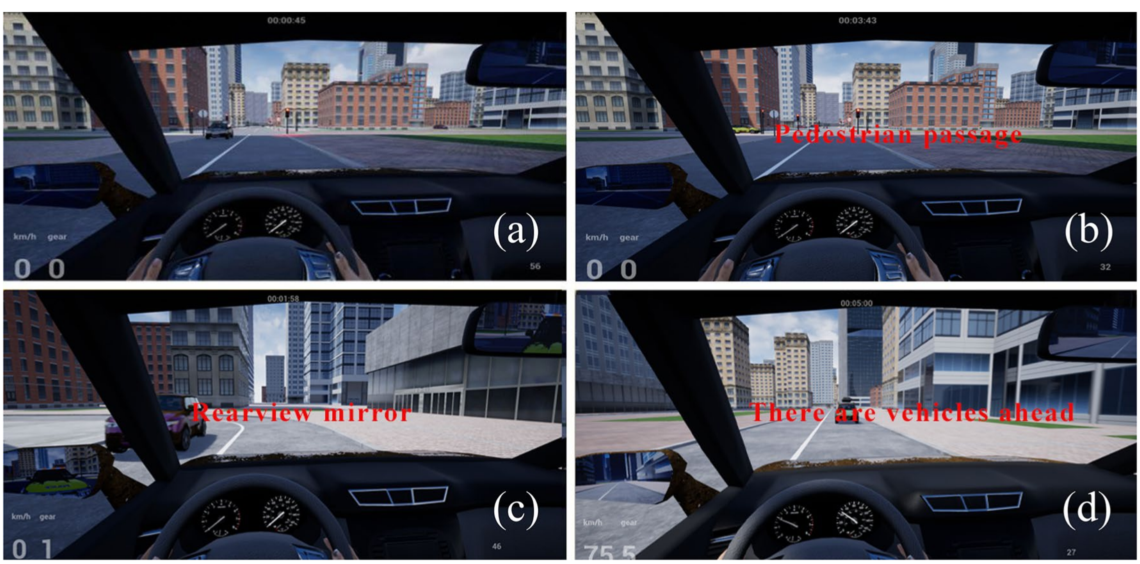

Fig. 4 Map of the Scenario management of critical event: control group: no text intervention (**a**). Pedestrian event (**b**). Turn left event (**c**). Keep distance event (**d**)

2.4 Procedure

The experiment was conducted separately in a quiet place. Before the experiment, explain the research process to each subject, and sign the informed consent form after obtaining consent. Then, we used SPMSQ to screen and evaluate the psychological status of the subjects and screened out the subjects who scored 8 points or more. In addition to considering SPMSQ, we also collected the eye information of the subjects to ensure that their vision is normal and will not interfere with normal driving. Each subject was tested twice. The experimental process is as follows:

- Introduced the experimental equipment and process, and asked participants to fill in the multidimensional driving style scale.
- Participants took a short exercise to make sure they were used to the driving simulator controls. After that, we asked participants to wear an eye tracker for 6 min of simulated driving in the test scenario and fill in the NASA-TLX at the end of the task to obtain baseline characteristics of each age group.
- To avoid participants' long-term fatigue driving, let participants forget the events in the test scene, and avoid the influence of the pre-test on the post-CBT test. The second experiment was conducted after three days and was divided into four groups (the young CG, the young IG, the elderly CG, and the elderly IG). The CG was trained in a virtual scene without intervention. The IG combined with CBT, tested and corrected the participants' wrong driving concepts through semi-structured interviews (see 2.3.3 for details). Later, participants were asked to train according to these new cognitive structures, and text reminders were used in the scene to consolidate the new cognitive structures. Each group was trained for 20 min.
- After the training, participants were asked to wear an eye tracker to perform a 6-min simulated driving again in the original test scene. After the task was completed, participants in each group were asked to fill in the NASA-TLX and POMS.

3 Results

3.1 Influence of age difference on baseline characteristics of drivers

3.1.1 Performance of young and old people on simulated drivers

The baseline characteristics of the young and elderly were shown in Table 2. The data presented normal distribution (Shapiro–Wilk test, $p > 0.05$). According to the data recorded on the simulator, the elderly drove slower on both urban streets and suburban roads than the young, and the difference was significant ($p < 0.05$). In addition, the change in average speed was more pronounced among the young than the elderly, especially in crowded streets such as urban areas (Mean accelerations were 5.56 m/s^2 (SD = 1.48) and 4.08 m/s^2 (SD = 1.29); $t = 3.04$, $df = 31$, $p = 0.005$). This indicated that the driving speed of the elderly was slower, acceleration and braking were not obvious, and the driving process was smoother than that of the young. Combined with the subjective evaluation results of the multidimensional driving style scale, it was found that the self-report of elderly drivers showed they were more cautious during driving, and the difference was significant ($t = 3.61$, $df = 21.99$, $p = 0.002$). Older drivers have higher compliance with road signs and fewer road violations. This view is consistent with the research results of Ebnali et al. (2016). Adaptive safety measures (reducing speed, reducing overtaking behavior, etc.) can compensate for the cognitive driving difficulties of the elderly.

Concerning drivers' self-report on the task load, we found the mean score of mental workloads was not statistically different between young and elderly participants (respectively 320.59 and 316.88, $t = 0.14$; $p > 0.05$). Then we considered how this mental workload was distributed among the six dimensions of the scale, to further explore the psychological cognitive differences between the young and the elderly (Fig. 5). The results showed that older drivers had higher mental demands than younger drivers, but the difference was not significant ($t = 1.12$; $p > 0.05$). In terms of driving

Table 2 Speed, acceleration, driving behavior scores and NASA-TLX scores of both groups at baseline

	Young		Elderly			
	Mean	SD	Mean	SD	Cohen's d	P-value
Urban speed (km/h)	44.95	8.78	24.33	4.85	2.91	0.000 ***
Urban acceleration (m/s²)	5.56	1.48	4.08	1.29	1.07	0.005**
Suburban speed (km/h)	60.21	9.75	49.24	6.52	1.32	0.001 ***
Suburban acceleration (m/s²)	7.19	1.92	5.92	1.82	1.92	0.059
Driving behavior (score)	18.59	9.50	9.5	4.08	0.68	0.002 **
NASA-TLX (score)	320.59	76.44	316.88	75.78	0.05	0.890

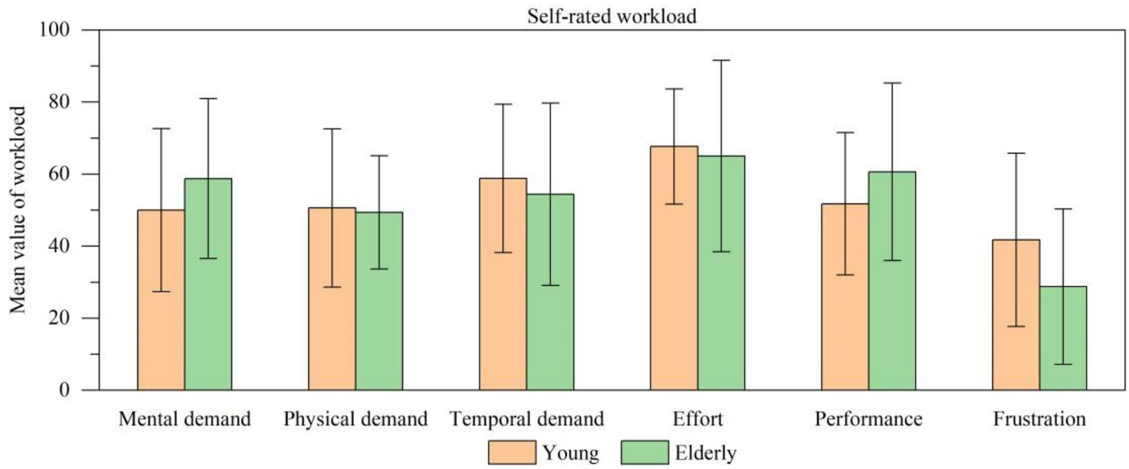

Fig. 5 Mean self-rated workload for each sub-scale of the NASA-TLX

performance and driving performance, elderly drivers did not show more pressure and effort. On the contrary, they were more satisfied with their driving process and had a good perception of the difficulties they encountered on the road.

In the follow-up interview, we found the elderly had poor control of the pedal of the simulator, and their feet were not flexible enough to control the speed through the switch between brake and accelerator, especially in urban street scenes, so they were more inclined to drive at a slow speed. In addition, the number of collisions between the elderly and obstacles in the simulated driving process was significantly more than that of the young. Although driving errors occurred during the simulation, they showed higher interest in the simulation driving game and expressed willingness to accept the training method, which also explained their lower self-evaluation of frustration in the subjective cognitive load assessment. The elderly participants emphasized these points in the following statements:

"... This is good. It's like driving. I need to slow down...".

"I think this driving scene is very good, but it is difficult to control the accelerator and brake, and it is difficult to master the speed...".

"There are many obstacles and turns on the road. When driving, I'm afraid that I can't control the steering wheel and speed well, so I can easily collide with the railings".

"... This will improve driving attention and limb coordination... I think driving training games that can play this role are good".

3.1.2 Comparison of driving ability between young and old people

To compare the driving ability of young and old people, a principal component analysis (PCA) was carried out. Table 3 showed the correlation matrix for the baseline characteristics, the NASA-TLX was not significantly correlated with other variables, so it was not included in the analysis.

The KMO test result showed that KMO = 0.64, $p < 0.05$, is suitable for principal component dimension reduction analysis. The PCA showed two main components, "urban

Table 3 Correlation matrix for baseline characteristics

	Urban speed	Urban acceleration	Suburban speed	Suburban acceleration	Age	Driving behavior	NASA-TLX
Urban speed	1.000	0.521	0.725	0.375	– 0.819	0.497	– 0.215
Urban acceleration	0.521	1.000	0.225	0.410	– 0.485	0.501	0.044
Suburban speed	0.725	0.225	1.000	0.573	– 0.557	0.122	– 0.252
Suburban acceleration	0.375	0.410	0.573	1.000	– 0.384	0.224	– 0.098
Age	– 0.819	– 0.485	– 0.557	– 0.384	1.000	– 0.567	– 0.049
Driving behavior	0.497	0.501	0.122	0.224	– 0.567	1.000	0.144
NASA-TLX	– 0.215	0.044	– 0.252	– 0.098	– 0.049	0.144	1.000

velocity" and "urban acceleration", each explaining 56.43% and 18.11% of the total variance. Based on principal component analysis, spatial rotation is carried out to obtain the component matrix (Fig. 6). The load diagram (Fig. 7) was obtained by factor analysis of the above variables, which showed two different dimensions. "Driving behavior" was positively correlated with "Urban acceleration", "Suburban acceleration" was positively correlated with "Suburban speed", and both factor loads were greater than 0.5. This indicated that drivers with more cautious driving behavior have less speed change and drive more smoothly on crowded roads such as urban areas. The faster a driver drives, the greater the change in speed, making it harder to control driving speed.

In addition, age is negatively correlated with the two dimensions. As age increases, drivers will be more cautious in driving tasks, avoid sudden acceleration and emergency deceleration, and tend to avoid illegal driving in the process of driving. As Milleville-Pennel and Marquez (2020) explained, with cognitive decline, elderly drivers will adopt some compensation strategies to avoid driving risks, and they tend to drive slowly to increase the reaction time.

3.2 Comparison of the training effect of participants in each group

We conducted ANOVA to determine whether there was any difference in the influence of CBT and general training on driving performance of the elderly. Figure 8 showed the speed and acceleration of young (left) and old people (right) before and after training. It can be found that after training, the driving speed of the participants in the four groups increased, indicating that the participants are more proficient in driving operation after training.

We conducted ANOVA for the average speed and average acceleration of the whole process respectively: average speed = (urban speed + suburban speed)/2, average acceleration = (urban acceleration + suburban acceleration) /2. The independent variable is the training mode (IG and CG), the covariate is the average speed and average acceleration before training, and the dependent variable is the average speed and average acceleration after training. The Shapiro–Wilk test was performed on the average speed and average acceleration of the elderly before and after training. The p was greater than 0.05, which was by the normal distribution and was suitable for covariance analysis (Table 4). The results showed that, in the elderly participants, baseline speed affected the post-training speed ($F = 18.698$, $p = 0.001 < 0.05$), but the comparison between the two training methods ($F = 0.887$, $p = 0.363 > 0.05$), indicating that baseline speed affected the post-training speed, while there was no significant difference between the two training methods on the driving speed of the elderly. Baseline acceleration of the elderly affected their post-training acceleration ($F = 4.755$, $p = 0.048 < 0.05$), and the comparison between the two training methods ($F = 5.456$, $P = 0.036 < 0.05$). This indicated that baseline acceleration has an impact on

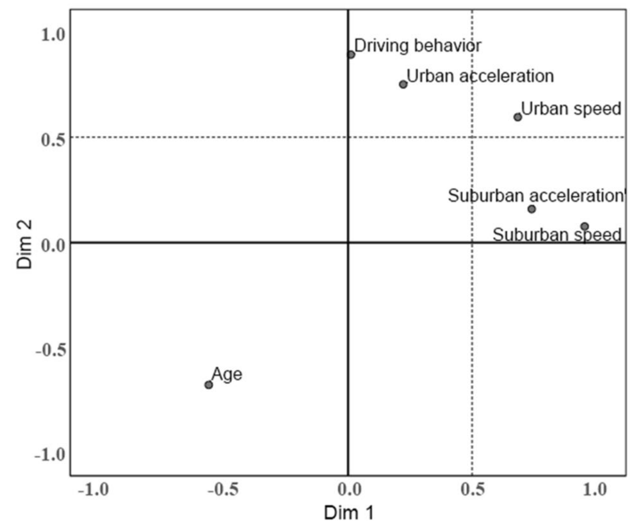

Fig. 7 Load diagram of the PCA integrating Age. 6 variables: Age/Driving behavior/Urban acceleration/Urban speed/Suburban acceleration and Suburban speed

Component matrix a

	component 1	component 2
Age (years)	-0.873	0.092
Driving behavior (score)	0.636	-0.630
Urban speed (km/h)	0.903	0.050
Urban acceleration (m/s²)	0.686	-0.382
Suburban speed (km/h)	0.728	0.609
Suburban acceleration (m/s²)	0.635	0.401

Extraction method: principal component
a. Two components were extracted.

Component matrix after rotation b

	component 1	component 2
Age (years)	-0.557	-0.678
Driving behavior (score)	0.011	0.896
Urban speed (km/h)	0.679	0.598
Urban acceleration (m/s²)	0.221	0.754
Suburban speed (km/h)	0.946	0.077
Suburban acceleration (m/s²)	0.734	0.160

Extraction method: principal component
Rotation method: Caesar normalized maximum variance method.
b. The rotation converges after 3 iterations.

Fig. 6 Component matrix (**a**) and Component matrix after rotation (**b**)

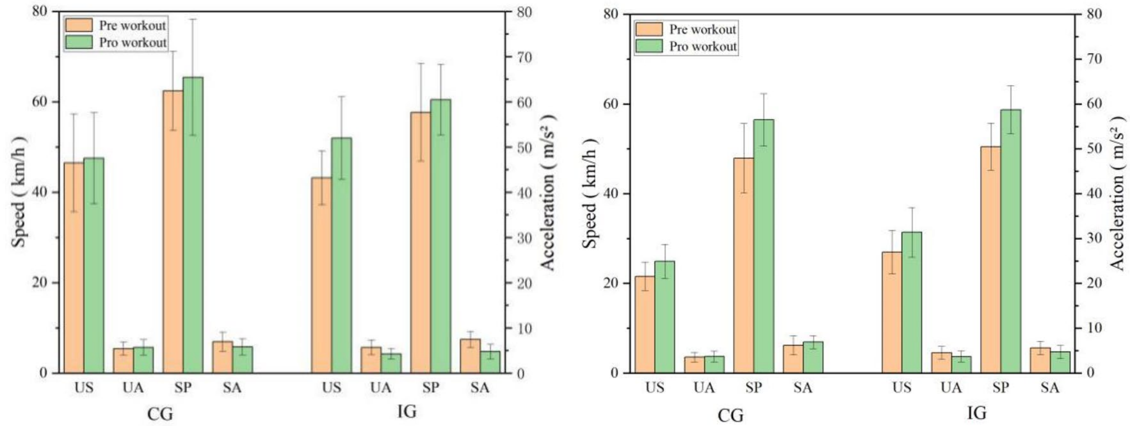

Fig. 8 Comparison of training in simulator between control group (CG) and intervention group (IG): Urban speed / Urban acceleration / Suburban speed and Suburban acceleration. (left: young, right: elderly)

Table 4 Average speed and average acceleration of the elderly before and after training

	CG					IG				
	Mean	SD	statistic	df	Sig	Mean	SD	statistic	df	Sig
Speed (betore training)	34.79	1.77	0.892	8	0.245	38.79	1.56	0.985	8	0.982
Acceleration (before training)	4.89	0.55	0.972	8	0.914	5.11	0.47	0.949	8	0.698
Speed (after training)	40.74	1.46	0.924	8	0.463	45.12	1.65	0.896	8	0.268
Acceleration (after training)	5.33	0.45	0.898	8	0.280	4.24	0.35	0.871	8	0.153

Table 5 Comparison of driving emotions among different groups

Age	Methods	Mean	SD	N
Young	CG	106.56	17.00	9
	IG	92.25	4.62	8
	Total	99.82	14.42	17
Elderly	CG	99.00	7.64	8
	IG	96.00	13.69	8
	Total	97.50	10.82	16
Total	CG	103.00	13.60	17
	IG	94.13	10.06	16
	Total	98.70	12.66	33

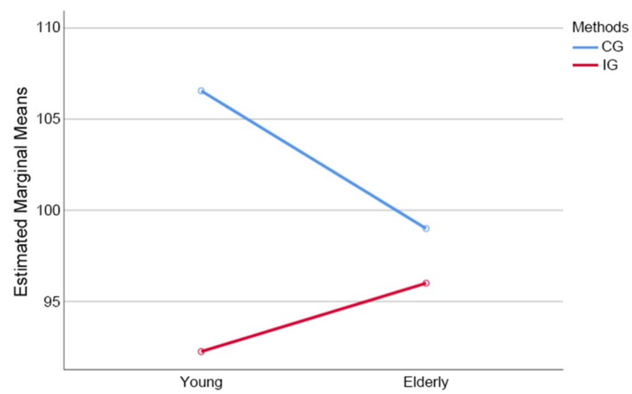

Fig. 9 Outline: estimated marginal means of POMS

post-training acceleration, and the training method based on CBT can better help the elderly control driving speed, to drive more smoothly.

3.3 Effect of CBT on driving emotion of drivers

TO investigate the influence of age and CBT on driving emotion, we performed a 2 × 2 factorial analysis for the driving emotions in the young (CG and IG) and the elderly (CG and IG). Table 5 showed the POMS values of each group (POMS value = negative emotion score–positive emotion score + 100, $F_{(age)} = 0.207$, $p > 0.05$; $F_{(methods)} = 4.275$, $p < 0.05$), which indicated that CBT can effectively improve participants' driving emotions, but age difference had no significant influence on participants' driving emotions. Additionally, from the POMS mean value of each group, the effect of CBT on the driving mood of young drivers is more obvious than that of old drivers, and young people are more likely to accept the training method of CBT.

Then we analyzed the interaction of the two factors (Fig. 9) and found that age difference and CBT might have a reverse interaction, but the effect was not significant (p > 0.05). It can be seen from Fig. 5 that the elderly need to pay more mental activity in the task, and their thinking and memory ability decrease. Therefore, the effect of cognitive behavioral therapy on the improvement of driving emotions of the elderly may be reduced. The study by Wagner and Nef (2011) showed that with the increase of age, cognitive ability and memory are often decreased, which may lead to an increased risk of bad driving and car accidents. Similarly, cognitive decline in the elderly affects the effectiveness of CBT. Older drivers with cognitive decline are also less receptive to CBT to some extent than younger drivers. However, this interaction needs further validation.

3.4 Effects of CBT on visual fixation of drivers

3.4.1 Baseline eye movement data of young and old people

One participant in the young group and three participants in the old group were unable to calibrate the eye tracker, so their eye movement data were not collected. A total of 29 valid samples were collected, including 16 people in the young group (12 males and 4 females) and 13 people in the old group (7 males and 6 females).

Before the experiment, the driving scene was divided into three areas of interest (Fig. 10), and participants' eye movements were coded according to the distribution of areas of interest. We recorded each participant's eye parameters, such as fixation count, average duration of fixation and total duration of fixation, and by analyzing these parameters, it was possible to identify the speed at which different groups perceived potential driving risks as well as their visual flexibility.

We performed fixation analysis for each participant (Fig. 11). The results stated that elderly drivers focused more on the car environment than young drivers, and the difference was statistically significant ($t = 2.54$, $p < 0.05$). Meanwhile, younger drivers looked more in the rearview mirror and central field of vision than older drivers. Further, it can be found according to the hot spot map (Fig. 12) that drivers' fixation on the central area is significantly higher than that of the peripheral area (Zhao et al. 2014). However, elderly drivers tend to focus their visual fixation on the car interior and dashboard and pay less attention to the rearview mirror. This behavior greatly increases the driving risk of the elderly group. In addition, many elderly people also reported poor perception of speed and needed to be reminded by the speed display on the dashboard. According to the eye-movement fixation, the self-report of the elderly was consistent with their behavior on the simulator.

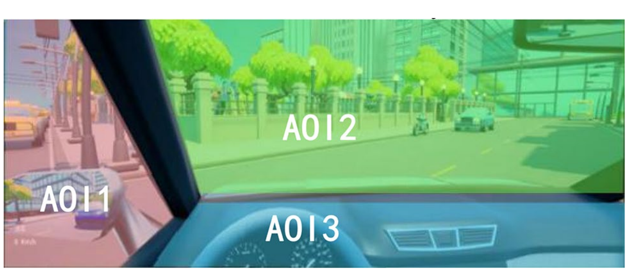

Fig. 10 Area of interest: rearview mirror (AOI 1), road ahead (AOI 2), vehicle interior (AOI 3)

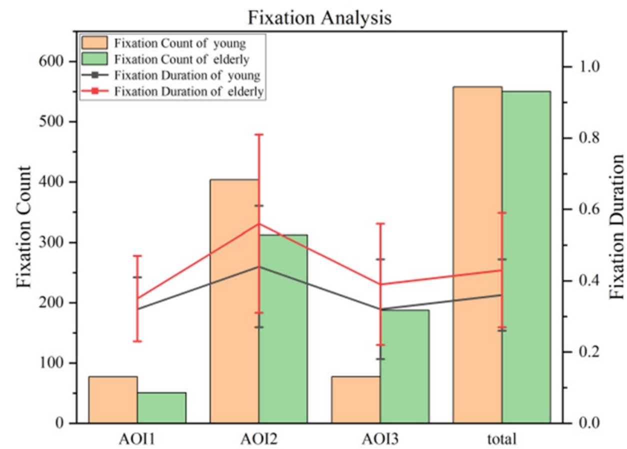

Fig. 11 Fixation analysis of young and elderly

The results of the average duration of fixation analysis showed that the single fixation duration of elderly drivers was larger than that of young drivers in the three regions, but the difference was not significant. The average single fixation time of young drivers and elderly drivers was 0.36 s and 0.43 s ($t = 1.43$; $p = 0.16$), the difference was also not significant ($p > 0.05$). Average single fixation time reflects the flexibility of participants' visual search (Hooge & Erkelens 1996), which indicates that young drivers perceive potential driving risks faster than elderly drivers, but it still needs to be verified by subsequent experiments.

3.4.2 Comparison of eye movement data after training

We performed fixation analysis for each each group of participants (Fig. 13), respectively. The results showed that after training, the average fixation duration in all three areas of the two elderly groups decreased, and the flexibility of visual search increased. In terms of fixation count, the fixation frequency of the elderly on the road ahead (AOI 2) has significantly increased after the CBT ($t = 4.053$, $p = 0.002 < 0.05$), and the fixation frequency of the instrument panel and other vehicle environment (AOI 3) has significantly decreased ($t = 2.961$, $p = 0.019 < 0.05$). But in the CG, the eye movement line of sight did not improve, and the fixation count on the road ahead decreased. As for young drivers, both groups of participants had good eye-movement fixation, and

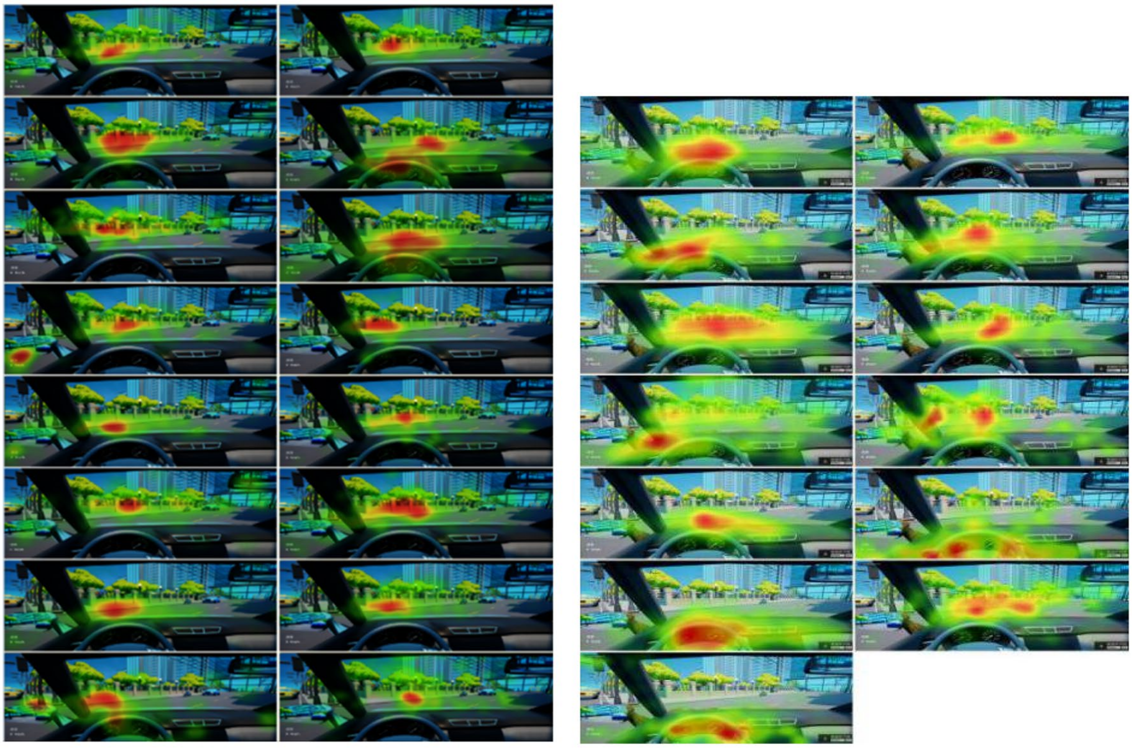

Fig. 12 Hot spot map for the young (left) and elderly (right)

there was no significant difference in the influence of the two training methods on the eye-movement fixation of young drivers. Then, we analyzed the distribution of fixation time in the three areas of the four groups after training (Fig. 14). The elderly IG looked at the road ahead longer than the CG and paid more attention to the road ahead. This further indicated that the driving training method based on CBT can correct the driving vision of elderly drivers and improve their danger perception ability.

4 Discussion

The purpose of this study has two aspects. The first purpose is to compare whether the driving performance of young and old people is significantly different through simulation driving and provide some specific guidelines for the design of CBT proposed by middle-aged and old drivers in this work. Another purpose is to verify the effectiveness of the newly developed cognitive training game in improving the driving ability of the elderly, as well as its impact on visual attention and emotional state. The results were basically in line with these goals and expectations. The elderly intervention group received cognitive behavior training, significantly improved driving skills and visual attention, and promoted driving emotions. Through the factorial analysis of the four groups of samples, it is found that there may be inter-group differences in the impact of CBT on the elderly and young groups. We will discuss these findings in detail in the following sections.

4.1 Behavioral characteristics of elderly drivers

We observed that the mental workload of older adults was greater than that of younger adults, suggesting that older participants perceived the driving task as requiring more mental demand and being more difficult to perform, which may be caused by cognitive decline. For example, Lundqvist and Eriksson (2019) believed that the driving ability of the elderly would decline with age, and the response of the elderly would become slower after increasing cognitive load tasks. Moreover, Horswill et al. (2008) also confirmed this view, they found the elderly have a poor perception of danger and a slower response time to deal with danger than the young. In terms of driving skills, we found that the elderly was slower on the simulator and had less variation in speed during driving, meaning that the elderly performed driving operations more smoothly with less acceleration and braking. This is consistent with the conclusion obtained by Hakamies-blomqvist et al. (1999), who observed that the elderly generally drove more slowly, but they did not show more lane edge deviation during driving. Moreover, concerning drivers' self-report (results of multidimensional driving style scale), the elderly thought they drove more

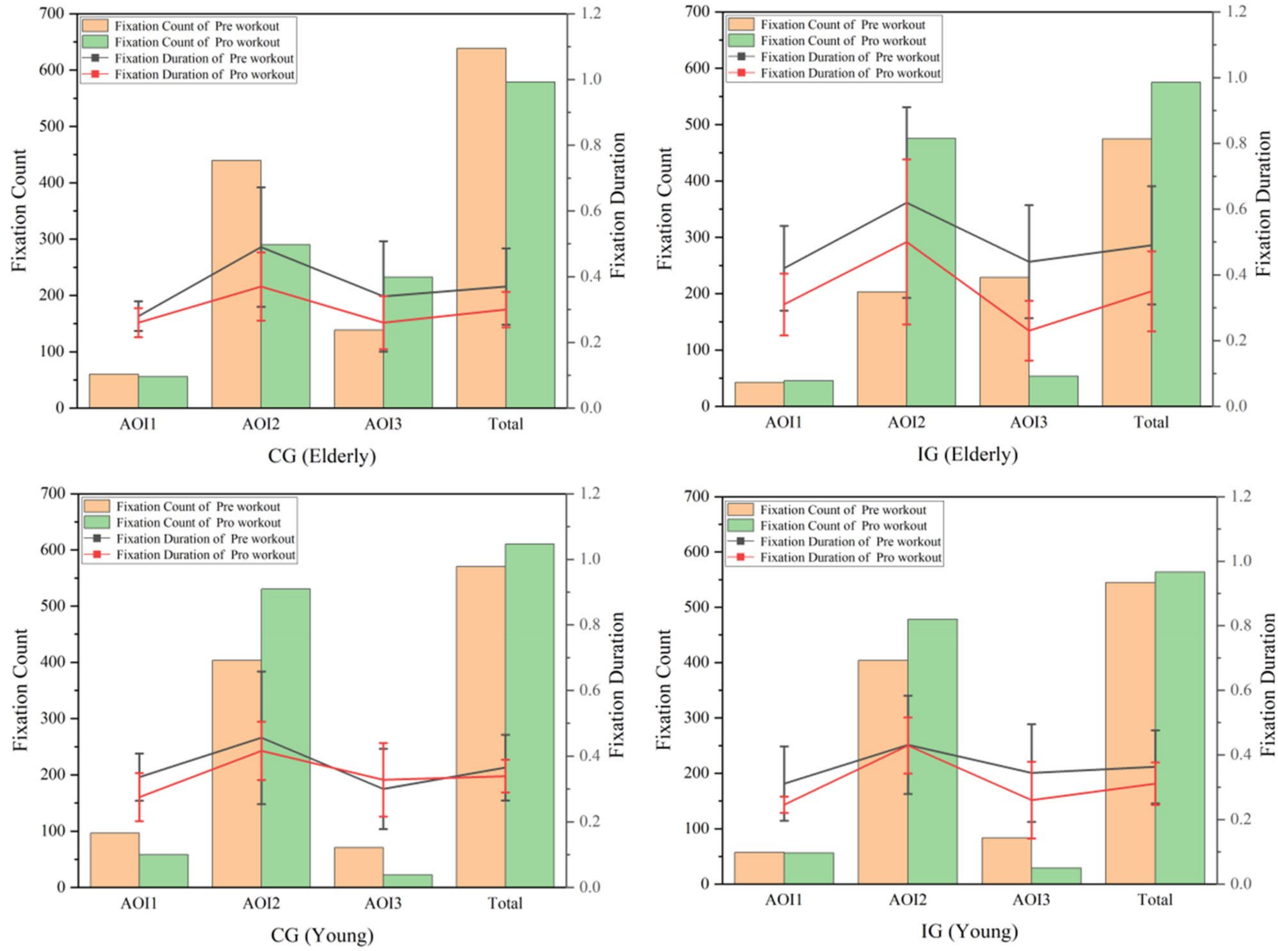

Fig. 13 Fixation analysis of four groups of participants

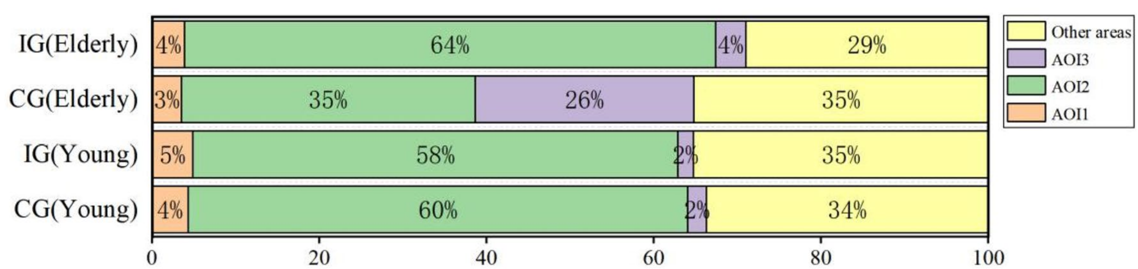

Fig. 14 The total duration of fixation in three visual areas of four groups

carefully to avoid overtaking and lane changing, which was consistent with their performance on simulated drivers. In this sense, they drove slowly and smoothly, which may be a compensatory strategy. Through years of driving experience, they adjusted their driving behavior to adapt to the negative effects of cognitive decline, and these measures may help reduce the mental load caused by the driving environment, as was also shown to be the case in studies by Cantin et al. (2009) and Davis et al. (2016). Their previous results suggest that the elderly may adopt the conservative compensation strategy to reduce driving risk due to difficulties with speed control and distance traveled. This behavior may also reflect a driving attitude (Ball et al. 1998). For example, older drivers have a high degree of compliance with road signs and avoid driving on congested roads or in extreme weather. In addition, it is also consistent with the research on other types of road users (such as cyclists). For example, Useche et al. (2019) have pointed out in their survey report that with the increase of age, the dangerous riding behavior of cyclists decreases, and the degree of compliance with traffic rules and awareness of risks are on the rise. They have made statistics on bicycle traffic accidents in recent years and found that the number of collision accidents of older riders is less than that of young people, which shows that specific compensation strategies (reducing dangerous driving behavior, maintaining a cautious driving attitude, etc.) can effectively reduce the driving risk of the elderly and make up for physiological deficiencies.

4.2 The effectiveness of CBT in elderly drivers

The second main conclusion is that driving training based on CBT effectively improved driving skills in older adults, which is consistent with previous research (Nozawa et al. 2015; Hiraoka et al. 2016; Nouchi et al. 2019). The IG received CBT and showed significant improvements in speed control and visual attention, as well as slight improvements in emotional states. These results were consistent with expectations, as the focus of driving training was on cognitive areas related to driving safety, including visual processing, sensory function, and physiological function (Anstey et al. 2005). According to the data of driving simulator feedback, we found that the four groups of participants in driving speed were improved after training, but for the acceleration index, was only a drop in the average acceleration of IG, suggesting that the CBT can help drivers to better control the speed and drive more sedate. The discovery of changes in acceleration extends previous research. Previous studies using cognitive training for driving skills already showed cognitive training reduced the tendency of young drivers to speed and improved their speed management behavior (Krasnova et al. 2015; Molloy et al. 2019). Nevertheless, this experiment proved that cognitive training is equally effective in elderly drivers. In addition, since the experiment was a short-term cognitive exercise, it may not have long-term benefits for speed management in elderly drivers. Future studies should extend training cycles and follow-ups to assess long-term benefits.

The analysis of baseline eye movement data showed that the average fixation duration of the elderly was longer than that of the young during driving, which indicated that the elderly has poor visual searchability and lower mental flexibility. We found that previous studies have come up with similar ideas. For example, Maltz and Shinar (1999) found that aging affects visual information processing, with older people's visual searches having more fixation counts and fewer scanning counts. The average fixation duration was associated with hazard perception (Borowsky et al. 2010). Therefore, the longer fixation time of the elderly also reflected the decline of their risk perception ability. They processed driving information slowly, which affects normal driving. From the current results, compared with the training results of the CG, the driving training based on CBT can better correct the driving vision of the elderly. This was consistent with the results of previous studies that cognitive-behavioral training improved sensitivity to the hazard perception through real-time intervention to remind the elderly to pay attention to road conditions (Mayhew et al. 2014; Horswill et al. 2015).

Finally, according to the data of the POMS subjective scale, it was concluded that CBT can improve the driving emotional state of the elderly, but this improvement effect may be negatively correlated with age. We suspected that this might be because the elderly was less receptive to the same type of training than the young as their cognitive abilities decline. Another possible explanation is that the older participants in this experiment had better baseline mood traits and were less sensitive to cognitive training. One study found that training was more effective for participants with relatively poor baseline characteristics (Ball et al. 2007). This also indicated that the emotional state of young people in this experiment was worse, and they were more influenced by cognitive-behavioral training. But in either case, the results suggested that driving training based on CBT has a beneficial effect on the emotional state of driving in the elderly. Future work needs to focus on the acceptance of cognitive training in the elderly driving group, verify whether there is a negative correlation between cognitive-behavioral training and age, and design a cognitive training game more suitable for the elderly driving group.

4.3 Guideline of CBT in elderly driving training

From the above experimental results, we are inspired that the implementation of CBT will create more value in the field of driving for the elderly, to allow the elderly with different abilities and ages to use it. In turn, according to the characteristics of the elderly group, the driving level can be improved through appropriate CBT programs. For example, for the elderly who use the driving simulator for the first time, it is easy to feel nervous and anxious because they are not familiar with the equipment or are too afraid of the real scene during treatment. The virtual reality three-dimensional scene combining cartoon and realism can assist the elderly driver's mentality adjustment (Ettenhofer et al. 2019). In addition, the elderly group tends to drive at a steady low speed, and they are very cautious about road risks, which will limit the driving activities of the elderly. Future CBT design can help the elderly overcome this psychological problem. Interviews and cognitive reconstruction methods can alleviate their tension and fear, and then let the elderly train many times in the virtual scene built to improve the

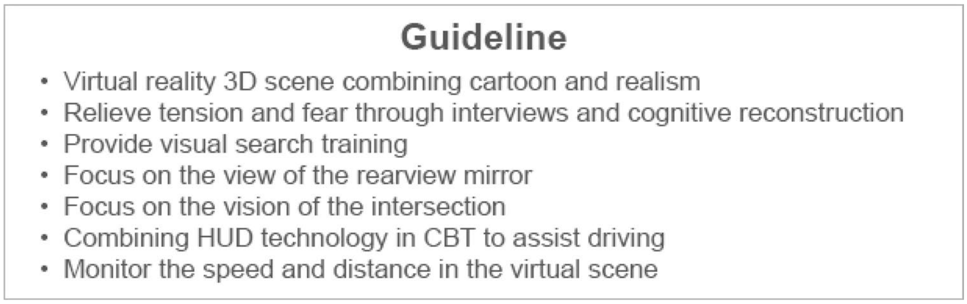

Fig. 15 CBT design guidelines for older drivers

driving speed of the elderly driver. According to the feedback results of eye movement data, older drivers are more susceptible to increased visual complexity when performing visual search tasks (Lee et al. 2019). The task design of CBT should provide visual search training (Lavallière et al. 2012; Dukic and Broberg 2012), such as the observation of the rearview mirror when overtaking or turning, the observation of pedestrians at the intersection, and the observation of the road ahead when driving. The application of CBT in elderly driving needs to strive to improve the driver's risk perception ability, correct the driving line of sight, and improve road vigilance. What's more, a new finding from the participants' visual distribution was that older drivers looked at the dashboard more often than younger drivers. The elderly reported poor perception of speed and needed to be reminded by the speed display on the dashboard. This also gives us inspiration. We can combine HUD technology in CBT training to assist novice and elderly drivers to drive (Bauerfeind et al. 2019). The interface display should strengthen the speed reminder function. Finally, the elderly has poor flexibility in both feet and cannot control their speed well. Therefore, it is necessary to add driving speed control and keep distance training in CBT. The speed and distance are monitored in the virtual scene and reminded in time so that the elderly driver can have an intuitive feeling of the safe speed. Figure 15 is a CBT guide related to elderly driving.

5 Conclusion

This study showed that elderly people drove more carefully, and although their driving performance was not as good as that of young drivers, they were nevertheless able to take some measures to help them drive safely. In addition, driving training based on CBT could better help the elderly control driving speed, alleviate negative emotions, and had a certain impact on their eye-movement fixation during driving, which can correct their vision driving. Finally, according to the psychological and behavioral characteristics of older drivers, some specific guidelines are provided for the design and application of CBT technology in older drivers. But the study has several limitations. The first one is that the number of participants was small, which might affect the reliability of the results. The second one is that the training time was short, with only one cycle of training, we can't conclude the effectiveness of the intervention over a longer period. In addition, simulation driving as a training game is still far from all kinds of situations that may be encountered in real life, and participants' performance on the simulator cannot fully represent their real driving situation. Despite these limitations, the results of this experiment provide a new experimental method for the application of CBT in driving training for the elderly. Future studies will explore these gaps in more detail.

Acknowledgements The authors would like to thank all individuals who took part in the study. The authors also sincerely thank the Kansei Engineering Institute of Zhejiang Sci-Tech University for providing equipment support for this experiment.

Funding This research is funded by the National Social Science Fund of China: Changes in demands of Chinese rural elderly and adaptive public services research (20BRK025).

Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Institutional Review Board Statement Ethical review and approval were waived for this study, due the evaluation tests performed with subjects simply being focused on usability and quality of experience, and no intrusive tests were performed that represent any danger to human health.

References

Adrian, J., Postal, V., Moessinger, M., Rascle, N., Charles, A.: Personality traits and executive functions related to on-road driving performance among older drivers. Accid. Anal. Prev. **43**(5), 1652–1659 (2011). https://doi.org/10.1016/j.aap.2011.03.023

Aluoja, A., Shlik, J., Vasar, V., Luuk, K., Leinsalu, M.: Development and psychometric properties of the Emotional State Questionnaire, a self-report questionnaire for depression and anxiety. Nord. J. Psychiatry **53**(6), 443–449 (1999). https://doi.org/10.1080/080394899427692

Anstey, K.J., Wood, J., Lord, S., Walker, J.G.: Cognitive, sensory and physical factors enabling driving safety in older adults. Clin.

Psychol. Rev. **25**(1), 45–65 (2005). https://doi.org/10.1016/j.cpr.2004.07.008
Baker-Ericzén, M.J., Smith, L., Tran, A., Scarvie, K.: A cognitive behavioral intervention for driving for autistic teens and adults: a pilot study. Autism Adulthood **3**(2), 168–178 (2021). https://doi.org/10.1089/aut.2020.0009
Ball, K., Owsley, C., Stalvey, B., Roenker, D.L., Sloane, M.E., Graves, M.: Driving avoidance and functional impairment in older drivers. Accid. Anal. Prev. **30**(3), 313–322 (1998). https://doi.org/10.1016/S0001-4575(97)00102-4
Ball, K., Edwards, J.D., Ross, L.A.: The impact of speed of processing training on cognitive and everyday functions. J. Gerontol. Ser. B **62**(1), 19–31 (2007). https://doi.org/10.1093/geronb/62.special_issue_1.19
Ball, K., Edwards, J.D., Ross, L.A., McGwin, G., Jr.: Cognitive training decreases motor vehicle collision involvement of older drivers. J. Am. Geriatr. Soc. **58**(11), 2107–2113 (2010). https://doi.org/10.1111/j.1532-5415.2010.03138.x
Bauerfeind, K., Drüke, J., Bendewald, L., Baumann, M.: When does the driver benefit from AR-information in a navigation task compared to a Head-Up Display? Results of a driving simulator study. In: Proceedings of the Human Factors and Ergonomics Society Europe, pp. 219–230 (2019)
Bélanger, A., Gagnon, S., Yamin, S.: Capturing the serial nature of older drivers' responses towards challenging events: a simulator study. Accid. Anal. Prev. **42**(3), 809–817 (2010). https://doi.org/10.1016/j.aap.2009.07.010
Borowsky, A., Shinar, D., Oron-Gilad, T.: Age, skill, and hazard perception in driving. Accid. Anal. Prev. **42**(4), 1240–1249 (2010). https://doi.org/10.1016/j.aap.2010.02.001
Cantin, V., Lavallière, M., Simoneau, M., Teasdale, N.: Mental workload when driving in a simulator: effects of age and driving complexity. Accid. Anal. Prev. **41**(4), 763–771 (2009). https://doi.org/10.1016/j.aap.2009.03.019
Casutt, G., Theill, N., Martin, M., Keller, M., Jäncke, L.: The drive-wise project: driving simulator training increases real driving performance in healthy older drivers. Front. Aging Neurosci. **6**, 85 (2014). https://doi.org/10.3389/fnagi.2014.00085
Čegovnik, T., Stojmenova, K., Jakus, G., Sodnik, J.: An analysis of the suitability of a low-cost eye tracker for assessing the cognitive load of drivers. Appl. Ergon. **68**, 1–11 (2018). https://doi.org/10.1016/j.apergo.2017.10.011
Davis, J., Conlon, E., Ownsworth, T., Morrissey, S.: Measuring situational avoidance in older drivers: an application of Rasch analysis. Accid. Anal. Prev. **87**, 68–77 (2016). https://doi.org/10.1016/j.aap.2015.11.018
Deffenbacher, J.L.: A review of interventions for the reduction of driving anger. Transp. Res. Part F **42**, 411–421 (2016). https://doi.org/10.1016/j.trf.2015.10.024
Dosovitskiy, A., Ros, G., Codevilla, F., Lopez, A., Koltun, V.: CARLA: An open urban driving simulator. In: Conference on robot learning, pp. 1–16. PMLR (2017)
Dukic, T., Broberg, T.: Older drivers' visual search behaviour at intersections. Transp. Res. Part F **15**(4), 462–470 (2012). https://doi.org/10.1016/j.trf.2011.10.001
Ebnali, M., Ahmadnezhad, P., Shateri, A., Mazloumi, A., Heidari, M.E., Nazeri, A.R.: The effects of cognitively demanding dual-task driving condition on elderly people's driving performance; real driving monitoring. Accid. Anal. Prev. **94**, 198–206 (2016). https://doi.org/10.1016/j.aap.2016.05.016
Ettenhofer, M.L., Guise, B., Brandler, B., Bittner, K., Gimbel, S.I., Cordero, E., Chan, L.: Neurocognitive driving rehabilitation in virtual environments (NeuroDRIVE): A pilot clinical trial for chronic traumatic brain injury. NeuroRehabilitation **44**(4), 531–544 (2019). https://doi.org/10.3233/NRE-192718
Federal Highway Administration, Department of Transportation (US).: Highway statistics. https://www.fhwa.dot.gov/policyinformation/statistics/2017/. (2018). Accessed 15 July 2020
Feng, Z., Zhan, J., Ma, C., Lei, Y., Liu, J., Zhang, W., Wang, K.: Is cognitive intervention or forgiveness intervention more effective for the reduction of driving anger in Chinese bus drivers? Transp. Res. Part F **55**, 101–113 (2018). https://doi.org/10.1016/j.trf.2018.02.039
Fischer, C., Heider, J., Taylor, J.E., Schröder, A.: Cognitive behavior therapy for driving fear: a pilot randomized controlled trial. Transp. Res. Part F **83**, 118–129 (2021). https://doi.org/10.1016/j.trf.2021.10.005
Grant, P.M., Perivoliotis, D., Luther, L., Bredemeier, K., Beck, A.T.: Rapid improvement in beliefs, mood, and performance following an experimental success experience in an analogue test of recovery-oriented cognitive therapy. Psychol. Med. **48**(2), 261–268 (2018). https://doi.org/10.1017/S003329171700160X
Hakamies-Blomqvist, L., Mynttinen, S., Backman, M., Mikkonen, V.: Age-related differences in driving: Are older drivers more serial? Int. J. Behav. Dev. **23**(3), 575–589 (1999). https://doi.org/10.1080/016502599383702
Hart, S.G., Staveland, L.E.: Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: Advances in psychology, 52nd edn., pp. 139–183. Elsevier, North-Holland (1988). https://doi.org/10.1016/S0166-4115(08)62386-9
Hiraoka, T., Wang, T.W., Kawakami, H.: Cognitive function training system using game-based design for elderly drivers. IFAC-PapersOnLine **49**(19), 579–584 (2016). https://doi.org/10.1016/j.ifacol.2016.10.613
Hockey, G.R.J., John Maule, A., Clough, P.J., Bdzola, L.: Effects of negative mood states on risk in everyday decision making. Cogn. Emot. **14**(6), 823–855 (2000). https://doi.org/10.1080/02699930050156654
Hooge, I.T.C., Erkelens, C.J.: Control of fixation duration in a simple search task. Percept. Psychophys. **58**(7), 969–976 (1996). https://doi.org/10.3758/BF03206825
Horswill, M.S., Marrington, S.A., McCullough, C.M., Wood, J., Pachana, N.A., McWilliam, J., Raikos, M.K.: The hazard perception ability of older drivers. J. Gerontol. Ser. B **63**(4), P212–P218 (2008). https://doi.org/10.1093/geronb/63.4.P212
Horswill, M.S., Falconer, E.K., Pachana, N.A., Wetton, M., Hill, A.: The longer-term effects of a brief hazard perception training intervention in older drivers. Psychol. Aging **30**(1), 62 (2015). https://doi.org/10.1037/a0038671
Hu, T.Y., Xie, X., Li, J.: Negative or positive? The effect of emotion and mood on risky driving. Transp. Res. Part F **16**, 29–40 (2013). https://doi.org/10.1016/j.trf.2012.08.009
Ji, Y.G.: HCI for Elderly and Smart Vehicle Interaction. Int. J. Hum. Comput. Interact. **31**(10), 633–634 (2015). https://doi.org/10.1080/10447318.2015.1070534
Kaneko, Y., Suzuki, M., Nagai, K., Uchiyama, M.: Differential effects of aging and cognitive decline on visual exploration behavior in the elderly. Neurosci. Res. (2021). https://doi.org/10.1016/j.neures.2021.03.007
Kogan, L.R., Richards, T.L., Deffenbacher, J.L.: Effects of relaxation and cognitive therapy for driving anger reduction. In: 109th Annual Convention of the American Psychological Association, San Francisco (2001)
Krasnova, O., Molesworth, B., Williamson, A.: The effect of cognitive-based training interventions on driver speed management behavior: a driving simulator study. In: Proceedings of the human factors and ergonomics society annual meeting, 59th edn., pp.

1796–1800. SAGE Publications, Los Angeles (2015). https://doi.org/10.1177/1541931215591388
Lavallière, M., Simoneau, M., Tremblay, M., Laurendeau, D., Teasdale, N.: Active training and driving-specific feedback improve older drivers' visual search prior to lane changes. BMC Geriatr. **12**(1), 1–9 (2012). https://doi.org/10.1186/1471-2318-12-5
Lee, S.C., Kim, Y.W., Ji, Y.G.: Effects of visual complexity of in-vehicle information display: Age-related differences in visual search task in the driving context. Appl. Ergon. **81**, 102888 (2019). https://doi.org/10.1093/geronb/62.special_issue_1.19
Lee, H.K., Kent, J.D., Wendel, C., Wolinsky, F.D., Foster, E.D., Merzenich, M.M., Voss, M.W.: Home-based, adaptive cognitive training for cognitively normal older adults: initial efficacy trial. J. Gerontol **75**(6), 1144–1154 (2020). https://doi.org/10.1093/geronb/gbz073
Likitweerawong, K., Palee, P.: The virtual reality serious game for learning driving skills before taking practical test. Int. Conf. Digit. Arts Media Technol. (2018). https://doi.org/10.1109/ICDAMT.2018.8376515
Lundqvist, L.M., Eriksson, L.: Age, cognitive load, and multimodal effects on driver response to directional warning. Appl. Ergon. **76**, 147–154 (2019). https://doi.org/10.1016/j.apergo.2019.01.002
Maltz, M., Shinar, D.: Eye movements of younger and older drivers. Hum. Factors **41**(1), 15–25 (1999). https://doi.org/10.1518/001872099779577282
Mayhew, D.R., Robertson, R.D., Vanlaar, W.: Computer-based cognitive training programs for older drivers: what research tells us. Traffic Injury Research Foundation, Ottawa (2014)
Milleville-Pennel, I., Marquez, S.: Comparison between elderly and young drivers' performances on a driving simulator and self-assessment of their driving attitudes and mastery. Accid. Anal. Prev. **135**, 105317 (2020). https://doi.org/10.1016/j.aap.2019.105317
Molloy, O., Molesworth, B.R., Williamson, A.: Which cognitive training intervention can improve young drivers' speed management on the road? Transp. Res. Part F **60**, 68–80 (2019). https://doi.org/10.1016/j.trf.2018.09.025
Nouchi, R., Saito, T., Nouchi, H., Kawashima, R.: Small acute benefits of 4 weeks processing speed training games on processing speed and inhibition performance and depressive mood in the healthy elderly people: evidence from a randomized control trial. Front. Aging Neurosci. **8**, 302 (2016). https://doi.org/10.3389/fnagi.2016.00302
Nouchi, R., Kobayashi, A., Nouchi, H., Kawashima, R.: Newly developed tv-based cognitive training games improve car driving skills, cognitive functions, and mood in healthy older adults: evidence from a randomized controlled trial. Front. Aging Neurosci. **11**, 99 (2019). https://doi.org/10.3389/fnagi.2019.00099
Nozawa, T., Taki, Y., Kanno, A., Akimoto, Y., Ihara, M., Yokoyama, R., Kawashima, R.: Effects of different types of cognitive training on cognitive function, brain structure, and driving safety in senior daily drivers: a pilot study. Behav. Neurol. (2015). https://doi.org/10.1155/2015/525901
Papa, M., Boccardi, V., Prestano, R., Angellotti, E., Desiderio, M., Marano, L., Paolisso, G.: Comorbidities and crash involvement among younger and older drivers. PLoS ONE **9**(4), e94564 (2014). https://doi.org/10.1371/journal.pone.0094564
Pappas, G., Siegel, J.E., Politopoulos, K., Sun, Y.: A gamified simulator and physical platform for self-driving algorithm training and validation. Electronics **10**(9), 1112 (2021). https://doi.org/10.3390/electronics10091112
Petzoldt, T., Weiß, T., Franke, T., Krems, J.F., Bannert, M.: Can driver education be improved by computer based training of cognitive skills? Accid. Anal. Prev. **50**, 1185–1192 (2013). https://doi.org/10.1016/j.aap.2012.09.016
Pv, S.: Introduction to unreal engine 4. In: Beginning unreal engine 4 Blueprints visual scripting, pp. 1–20. Apress, Berkeley (2021). https://doi.org/10.1007/978-1-4842-6396-9_1
Reich, D., Buchholz, C., Stark, R.: Methods to validate automotive user interfaces within immersive driving environments. In: Automotive user interfaces, pp. 429–454. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-49448-7_16
Rhiu, I., Kwon, S., Bahn, S., Yun, M.H., Yu, W.: Research issues in smart vehicles and elderly drivers: a literature review. Int. J. Hum. Comput. Interact. **31**(10), 635–666 (2015). https://doi.org/10.1080/10447318.2015.1070540
Roenker, D.L., Cissell, G.M., Ball, K.K., Wadley, V.G., Edwards, J.D.: Speed-of-processing and driving simulator training result in improved driving performance. Hum. Factors **45**(2), 218–233 (2003). https://doi.org/10.1518/hfes.45.2.218.27241
Seidler, R.D., Bernard, J.A., Buschkuehl, M., Jaeggi, S., Jonides, J., Humfleet, J.: Cognitive training as an intervention to improve driving ability in the older adult (No. M-CASTL 2010–01). Michigan Center for Advancing Safe Transportation Throughout the Lifespan. https://rosap.ntl.bts.gov/view/dot/18008. (2010)
Stutts, J., Martell, C., Staplin, L., TransAnalytics, L.L.C.: Identifying behaviors and situations associated with increased crash risk for older drivers. Nat. Acad. (2009). https://doi.org/10.21949/1525666
Sue, D., Ray, P., Talaei-Khoei, A., Jonnagaddala, J., Vichitvanichphong, S.: Assessing video games to improve driving skills: a literature review and observational study. JMIR Serious Games **2**(2), e3274 (2014). https://doi.org/10.2196/games.3274
Taubman-Ben-Ari, O., Mikulincer, M., Gillath, O.: The multidimensional driving style inventory—scale construct and validation. Accid. Anal. Prev. **36**(3), 323–332 (2004). https://doi.org/10.1016/S0001-4575(03)00010-1
Ting, P.H., Hwang, J.R., Doong, J.L., Jeng, M.C.: Driver fatigue and highway driving: a simulator study. Physiol. Behav. **94**(3), 448–453 (2008). https://doi.org/10.1016/j.physbeh.2008.02.015
Trappey, A., Trappey, C.V., Chang, C.M., Kuo, R.R., Lin, A.P., Nieh, C.H.: Virtual reality exposure therapy for driving phobia disorder: system design and development. Appl. Sci. **10**(14), 4860 (2020). https://doi.org/10.3390/app10144860
Useche, S.A., Alonso, F., Montoro, L., Tomas, J.M.: When age means safety: Data to assess trends and differences on rule knowledge, risk perception, aberrant and positive road behaviors, and traffic crashes of cyclists. Data Brief **22**, 627–634 (2019). https://doi.org/10.1016/j.dib.2018.12.066
Wagner, J.T., Nef, T.: Cognition and driving in older persons. Swiss Med. Wkly. (2011). https://doi.org/10.4414/smw.2011.13136
Xianglong, S., Hu, Z., Shumin, F., Zhenning, L.: Bus drivers' mood states and reaction abilities at high temperatures. Transp. Res. Part F **59**, 436–444 (2018). https://doi.org/10.1016/j.trf.2018.09.022
Zhao, N., Chen, W., Xuan, Y., Mehler, B., Reimer, B., Fu, X.: Drivers' and non-drivers' performance in a change detection task with static driving scenes: is there a benefit of experience? Ergonomics **57**(7), 998–1007 (2014). https://doi.org/10.1080/00140139.2014.909952
Zinzow, H.M., Brooks, J.O., Rosopa, P.J., Jeffirs, S., Jenkins, C., Seeanner, J., Hodges, L.F.: Virtual reality and cognitive-behavioral therapy for driving anxiety and aggression in veterans: a pilot study. Cogn. Behav. Pract. **25**(2), 296–309 (2018). https://doi.org/10.1016/j.cbpra.2017.09.002

Ying Wang is a professor at Zhejiang Sci-tech University and the president of Universal Design Institute. Ying's interests include user-centered design and HCI. Ying's research is about how to help the elderly bridge the digital divide. Ying is in charge of projects with the Chinese elderly demands and suitable design.

Defu Bao is an Fellow of the Zhejiang Sci-Tech University, is a lecturer and assistant Dean of the Dept. of Industrial Design at Art and Design College,and is also serving as President of Digital Cultural and Creative Research Institute. He studied industrial design at Zhejiang university(Ph.d) in China. His research interests include digital innovation design, cultural cognition and human–computer interaction.

Rufeng Feng is a graduate student in the Universal Design Institute, Zhejiang Sci-Tech University. His research interests include interactive system design and user cognitive behavior analysis.