Improving Older Drivers’ Behaviors Using Theory of Planned Behavior

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Abstract: The proportion of older drivers has increased with the aging population. In order to improve the driving behavior and safety of older drivers, we aim to analyze behavior differences between older and younger drivers and then study an improvement strategy based on the older drivers’ behavioral characteristics. Older drivers’ behaviors can be enhanced through training, thereby improving driving safety. Simulated scenarios for behavior analysis and training are constructed for drivers who are recruited from the general driving population. Data on the drivers’ eye movement, physiological and psychological conditions, operation behavior, and vehicle status are collected and analyzed. The theory of planned behavior is adopted to construct a driving behavior enhancement training model for older drivers. Finally, a structural equation model is developed to comprehend the relationship between training level, driver characteristics, and traffic safety. The ability and speed of older drivers to obtain traffic information is worse than those of young and middle-aged drivers, and the vehicle control capability of older drivers has a larger volatility. The driving behavior training model can improve older drivers’ driving stability and safety, as follows: the positive effect of training on driving behavioral improvement is larger than the negative effect of aging; the negative effect of training level on dangerous driving tendency is larger than the positive effect of driver’s aging. The driving behavior of older drivers should be improved for the safety and stability of driving operations through the PNE (perceived-norm-execution) model. The relationship between training level, driving behavior characteristics, and traffic safety is discussed using the structural equation model, and results show that the training can improve the effect of the drivers’ age on the characteristics of driving behavior, and that older drivers tend to decrease dangerous driving tendencies.

Keywords: traffic safety; driving simulator; older driver; theory of planned behavior; structural equation model

1. Introduction

In China, older drivers have become a large proportion of the driving population. According to the latest statistics from the Chinese Ministry of Public Security and China Statistical Yearbook of 2020, the number of drivers over 60 years old is about 14.24 million, accounting for 3.23% of the total number of drivers, and drivers over 50 years old account for 15.3% [1]. The number of older drivers in the country will be close to 20% of all drivers in the next 10 years, combined with the policy of canceling the application age limit for driver’s licenses. Older drivers are a vulnerable group due to the weakening of physiological factors with age, making it easy to encounter traffic crash risks. The main factors affecting driving behavior among older drivers are age [2], gender [3], attitude [4] and road environment [5]. In the process of real driving, the decline in older drivers’ physical strength and endurance lead to greater fatigue [6]. The weakening of vision and hearing make it difficult for them to obtain traffic information quickly in complex driving
environments [7]. The weakening of memory and cognitive ability cause a decline in the ability to process information, and it increases the driving risk of older drivers [8].

About 80 percent of traffic information is derived through vision, which drivers obtain in the process of driving [9], but older drivers may not get complete and effective visual traffic information due to the decline in visual ability in areas of fixation, saccade, and blink [10]. The driver’s effective vision begins to decline with age [11], older drivers are more concentrated on the fixation area [12] and the field of visual search is narrower [13] than in young and middle-aged drivers. At the same time, the visual characteristics of older drivers are affected by the traffic environment [14]. A driver’s body and operation will change after received visual information. Older drivers need to spend more time on decision and execution while driving due to the nerve-muscle recession [15], and cognitive ability is lower than that of young and middle-aged drivers [16]. The ability of response [17] and attention span [18] also have various degrees of decline. The driver’s operational behavior is affected by visual, physiological and psychological change. It has been found that there is a higher risk posed by older drivers through their driving behavior [19], which is characterized by various factors, including space headway, velocity change amplitude, time of acceleration and deceleration [20].

Older drivers have a higher accident rate compared to young and middle-aged drivers [21], and the seriousness of the injury is higher when the accident occurs [22]. Researchers have adopted safety education and training to reduce the accident rate and then improve the safety of the driver [23]. In recent years, studies on driving risks and behaviors have been mainly concentrated on training methods, using simulators [24], mobile apps [25], and risk scenario videos [26]. Training with a driving simulator was found more convenient in the above studies, but there are few training methods used to improve the traffic safety of older drivers through driving simulators. Many studies focused on improving the effectiveness of driver training methods. The BASIC project in Europe believes that the best driver training model should include perception training and operation training [27]. The IPDE model (Identification, Prediction, Decision, Execution) has been used widely in driving training, which has achieved great training effects [28]. The improvement in driving behavior has become the target of training models [29]. In addition, studies have shown that the use of mixed reinforced learning is better than that based on the enhancement of knowledge or estimation [30]. For example, training is performed by guiding the driver to imitate or observe. Methods of trial and error are applied to lead drivers to respond quickly when facing new conditions in the traffic environment [31,32]. In addition, cooperative learning is often used for data exchange between drivers to reach learning and knowledge sharing, so that the driver’s driving behavior can be improved [33].

Currently, outdated demonstration materials and videos are used as training tools in driving training schools in China. Although driving simulator was used to train novice drivers and professional drivers, these training methods lack verified teaching principles and standard training procedures, and there are few studies on training methods for older drivers. Therefore, it is necessary to establish a training model framework for older drivers based on a driving simulator, to finally improve the traffic safety.

In this study, three types of driving scenarios (normal traffic scenario, accident traffic scenario, and emergency traffic scenario) are constructed and used to collect the data of drivers. The Kunming University of Science and Technology Driving Simulation System (KMRTDS) is used to realize dynamic operation and data collection. Differential analysis is conducted on eye movement data, psycho-physiological data, driving operation data and vehicle status data between older drivers and young and middle-aged drivers. A training model of perceived-norm-execution (PNE) is developed to improve the driving behavior of older drivers, based on the theory of planned behavior and used to analyze the difference in older drivers between training and no training. Finally, a structural equation model (SEM) is used to capture the complex relationship among the variables affecting driving training, driver characteristics and traffic safety.
2. Experimental Design
2.1. Construction of Experimental Route

Three types of traffic scenarios were constructed to comprehensively assess the driving behavior of older drivers. Normal traffic scenarios include driving straight and turning at intersections, accident traffic scenarios include distracted driving and lane changing, and emergency traffic scenarios include emergency brake. Driving behavior data were collected to analyze the operational response and physiological characteristics between drivers under three types of traffic scenarios, and then the difference of behavior characteristics was found between older drivers and young and middle-aged drivers in different scenarios.

(1) Experimental scenario for comparative analysis of driving behavior characteristics

The scenario (Figure 1) consisted of road sections and intersections. The route is two-way four-lane, six kilometers, and the width of each lane is 3.5 m. There are five intersections on the road, and the distance between intersections is 1 km. Plants and buildings were created on both sides of the road to increase environmental reality, and the weather was set to a sunny day to reduce the weather impact on the experimental results.

![Figure 1. Route of driving experimental scene.](image)

Experimental scenarios include five traffic scenarios (straight driving, lane change driving, intersection turning, emergency, and distracted driving), and the velocity limit is 40 km/h. Traffic scenarios are described as follows:

- **Straight driving:** low traffic flow, no dangerous vehicles or pedestrians, the driver is required to drive using their normal driving habits.
- **Turning at intersection:** no signal intersection with medium traffic flow, the driver is required to drive using their normal driving habits; there are oncoming conflict vehicles driving straight and turning left in the vision of the driver.
- **Lane change:** low traffic flow, no dangerous vehicles or pedestrians, the driver is required to change to the right lane using their normal driving habits.
- **Emergency:** low traffic flow, with the driver driving from west to east and entering the trigger zone, a large truck driving into the intersection from south to north out of the driver’s field of vision, the driver’s vision is blocked by vehicles parked on the roadside, resulting in a serious conflict with the driver’s vehicle.
- **Distracted driving:** low traffic flow, the driver is required to telephone someone who they are familiar with through the handheld mobile phone, while a pedestrian is crossing the road from the pavement.

(2) Training experimental scenarios of driving behavior characteristics.

The training experimental route (Figure 2) is different from the route shown in Figure 1. The sequence of all traffic scenarios is slightly modified to avoid drivers speculating upcoming scenarios and affecting the experimental results.
In the training route of the experimental scenario, the velocity limit is 40 km/h, and has five scenarios, just as for (1). There are traffic conflicts in the scenarios, and the description of the scenarios is as follows:

- **Straight driving**: low traffic flow, the driver is required to drive using their normal driving habits, and a bicycle crosses the road in front of the driver when they enter the trigger zone along the road.
- **Turning at intersection**: no signal intersection with a low traffic flow, the driver turned from north to east, and a large truck drives from east to west when the driver’s vehicle enters the trigger zone.
- **Lane change**: low traffic flow, a bicycle crosses the road in front of the driver when they changed lane to right.
- **Emergency**: no signal intersection with low traffic flow, a large truck drives from west to east when the driver turns from south to east.
- **Distracted driving**: low traffic flow, the driver is required to call someone who they are familiar with, and there is a pedestrian crossing the road from the pavement.

2.2. Participants

Forty drivers were selected as subjects of the experiment after excluding the drivers with discomfort and dizziness. There were 20 older drivers (aged over 60; 5 female and 15 male drivers; average age 65; SD of the age 3.268) and 20 young and middle-aged drivers (aged between 18 and 60; 6 female drivers and 14 male drivers; average age 33; SD of the age 6.249). To avoid the influence of objective factors, such as driving age and driving experience on the experimental results, all drivers had more than three years of driving experience and more than 10,000 km of driving mileage. All participants were recruited in Yunnan Province of China.

2.3. Conduct of Experiment

First, the eye tracker, driving simulator, and physiological psychology instrument were adjusted to prepare for the driving simulation experiment (explanation of instruments was described in the Materials and Apparatus Section). Then, drivers from both age groups were randomly assigned to the training and non-training groups. A pre-experiment was necessary to ensure that each driver was familiar with the driving simulator. Drivers were asked to wear the measurement device in the pre-experiment to test that it worked properly. In the experiment, the training group of drivers had to complete training experimental scenarios and comparative experimental scenarios, with a five minute break; the non-training group of drivers had to complete comparative experimental scenarios. Drivers
needed to finish a driving attitude questionnaire after completing the driving experiment. Each diver’s data should be checked and the driver will be required to repeat the experiment after taking a break if the data are missing or there are other problems.

2.4. Experimental Data

There are three types of experimental data, including drivers’ eye movement data (fixation time, saccade amplitude) from the I-view HED4 eye tracker, drivers’ physiological psychology data (HR, EDA, EMG) from the Ergo LAB instrument, drivers’ operational data (steering wheel angle, gas pedal, brake pedal, and steering lamp usage) from the KMRTDS driving simulator system, and vehicle status data (velocity, acceleration, and horizontal position). Appropriate statistics were selected to measure the indicator in response to these 12 driving behavior indicators (Table 1). The data in Table 1 includes all participants—those who attended the training drive and those who did not.

Table 1. Evaluation of the indicator statistics.

| Behavior Indicator | Straight | Lane Changing | Intersection Turning | Emergency | Distracted Driving |
|--------------------|----------|---------------|----------------------|-----------|--------------------|
| Fixation time      | Mean     | Mean          | Mean                 | Mean      | Mean               |
| Saccade amplitude  | Growth rate | Growth rate  | Growth rate          | Growth rate | Growth rate       |
| Heart rate         | Growth rate | Growth rate  | Growth rate          | Growth rate | Growth rate       |
| EDA                | Growth rate | Growth rate  | Growth rate          | Growth rate | Growth rate       |
| EMG                | Median frequency | Median frequency | Median frequency | Median frequency | Median frequency |
| Steering wheel angle | Angle entropy | Angle entropy | Angle entropy | Angle entropy | Angle entropy |
| Gas pedal          | SD       | SD            | SD                   | SD        | SD                 |
| Brake pedal        | -        | -             | SD                   | SD        | SD                 |
| Steering lamp usage | Duration | Duration      | Duration             | -         | -                  |
| Velocity           | Mean     | SD            | SD                   | Rate      | Rate               |
| Accelerate         | SD       | SD            | SD                   | Maximum   | Maximum            |
| Horizontal position| SD       | -             | Maximum              | Maximum   | SD                 |

3. Method

3.1. Materials and Apparatus

The KMRTDS driving simulation system was developed by the road traffic simulation laboratory at the Kunming University of Science and Technology. It is based on real scenarios and uses VR technology to build simulation scenarios. It can realize high-resolution driving scenarios and can collect data relevant to the driver’s driving behavior characteristics and vehicle operating characteristics in the driving process. The system platform (Figure 3) is composed of a driving system, a control system, and a display system; it has a real vehicle chassis and can implement a closed-loop experiment of road traffic systems by controlling the experimental conditions. It has conditions to carry out the overall road traffic research including “human-vehicle-road-environment”, and the validity has been verified [34].

Figure 3. (a) Driving system. (b) Control system. (c) Display system. KMRTDS driving simulator system.

Ergo LAB physiological psychological instrument was used to collect the drivers’ physiological data and psychological data, and the sample rate is 512 Hz. I-View HED4 eye tracker was used to collect the saccade and fixation data, and the sample rate is 60 Hz. The output parameters of driving simulation system are shown in Table 2.
Table 2. Output parameters of driving simulation system.

| Apparatus       | Output Parameters                                                                 |
|-----------------|-----------------------------------------------------------------------------------|
| Driving simulator | Velocity (km/h), Brake pedal (mm), Gas pedal (mm), Wheel steering (Deg), Longitudinal acceleration (m/s$^2$) |
| Ergo LAB        | ECG, EDA, EMG                                                                     |
| IView HED4      | Saccade amplitude (°), Fixation time (s)                                           |

3.2. Theory of Planned Behavior (TPB)

To develop a training method for older drivers, theory of planned behavior (TPB) [35] was used as the basic framework to construct a PNE training system for older drivers’ behavior characteristics through a driving simulator. The system was designed to reduce the human errors of older drivers in the process of driving and then improve the safety.

The attitude–behavior relationship theory is well known in social psychology, and the desired value theory was used as the starting point of the TPB. It was explained that an individual consciously performs a specific behavior process from the perspective of information processing. Behavioral attention was thought to be the most direct factor affecting behavior, and behavioral intention was determined by three elements: attitude of behavior, subjective norm, and perceived behavior.

In the theory of planned behavior, attitude of behavior, subjective norm, perceived behavior, and behavior intention of individuals are the main variables. The explanation is as follows:

(1) Attitude of behavior (AB)

The attitude of behavior is the corresponding evaluation of the behavior before the individual was finished, and it is the most important variable in the theory of planned behavior. The attitude of behavior is determined by the corresponding behavioral belief and the individual’s evaluation of the belief, which can be expressed as Equation (1):

$$ AB \propto \sum b_i e_i $$

(1)

In Equation (1), AB is the attitude of behavior, b is the behavioral belief, e is the evaluation of the result, and i is the amount of belief.

(2) Subjective norm (SN)

Subjective norm indicates that the individual can experience pressure from the environment, organizations, groups, and other individuals before they are ready to complete the behavior. It mainly manifests via the impact of other people and organizations on individual behavioral judgements. It can be described by Equation (2):

$$ SN \propto \sum n_j m_j $$

(2)

In Equation (2), SN is the subjective belief, n is the norm belief, m is the dependent motivation, and j is the amount of the norm belief.

(3) Perceived behavior control (PBC)

Perceived behavior control is an individual’s perception of their ability and environment before the behavior was completed. Behavioral intention is directly affected by behavioral control that then causes the behavior; it also has a direct impact on the behavior. Perception strength is constructed from the awareness of behavioral beliefs to individual ability and environment. This relationship can be described by Equation (3):

$$ PBC \propto \sum c_k p_k $$

(3)

In Equation (3), PBC is the perceived behavior control, c is the control belief, p is the perceived strength, and k is the amount of control belief.
(4) Behavior intention (BI)

BI is the degree of psychological tendency and the execution of behavior from individuals before the behavior was completed. It is a necessary process before the individual’s behavior is completed and is the direct factor of whether the behavior can be completed.

The PNE model in this study includes three sections based on TPB: perceived, norm and execution. Each section corresponds to a main element of TPB. The intention is the determined factor close to the behavior from the theory of planned behavior, which refers to intention, which is the degree of difficulty in attitude (active/negative assessment of behavior), subjective norm (perception of social pressure on behavior), and perceived behavior control [36]. The framework of the PNE model is shown in Figure 4.

![Figure 4. Framework of PNE model.](image)

3.3. PNE Model

Perceived (P): Older drivers with dangerous driving behavior understand that their driving behavior can lead to traffic accidents. Older drivers’ risk awareness can be enhanced and their attitude of dangerous driving tendency can be changed through the “P” model. In the driving behavior training experiment, many risk conflicts were created in different scenarios. This includes an audio and video effect simulating a collision when the driver collided in the risk scenarios during the experiment. In this way, older drivers could understand the consequence of dangerous tendencies, and their attitude to dangerous tendencies could be changed.

Norm (N): Older drivers could experience social pressure and motivation through watching the video taken from the “Vehicle Driving Teaching Materials” issued by the Public Security Traffic Authority. Traffic scenarios involved in the study were extracted from the “premier” software and each video includes two parts: (1) errors in driving behavior (traffic condition determination error, operation error, etc.) and damage by collision (injury, property loss, etc.); (2) correct driving behavior (correct judgment, correct operation, etc.). In the driving behavior training experiment, the driver was required to park the car and watch these specific video clips to enhance the social pressure and motivation while completing a traffic scenario. Ultimately, the purpose of enhancing the subjective norm could be achieved.

Execute (E): Older drivers could improve the control of perception behavior through verbal guidance after watching the edited video. Verbal instructions include three parts: (1) Drivers were instructed that they should evaluate traffic conditions carefully before taking any measures. (2) Drivers were required to complete the driving scenario correctly following the verbal directions. The driver was instructed to carry out the correct actions by verbal command, and told that they should pay attention to the surrounding vehicle status and what driving actions they should take. (3) Drivers were required to park the car and review the operation process.

3.4. Structure Equation Model (SEM)

To study the effectiveness of driving training, driving training was considered as the variable that influences the relationship between driver characteristics and traffic safety.
SEM was used to determine the complicated relationship between variables and discuss the relationship between training level, driver characteristics and traffic safety.

There are two basic models in the SEM model: measurement model and the structural model. The measurement model is composed of potential variables and observation variables; it is a dominant combination of observation variables from the angle of mathematics. The measurement model uses confirmatory factor analysis (CFA) in the SEM model, which is used to detect the degree to which the variable in the model can constitute a potential variable, which can reflect that the causal model corresponds to observation data between observation variables and potential variables in the measurement model. The equation for the measurement model is as follows:

\[ x = \Lambda_x \xi + \delta \]  
\[ y = \Lambda_y \eta + \epsilon \]  

In Equations (4) and (5), \( x \) is the independent variable vector of the outline variable, \( y \) is the indicator vector of the endogenous variable, \( \xi \) is the outline variable vector, \( \eta \) is the endogenous variable vector, \( \Lambda_x \) is the relationship between \( x \) and \( \xi \), \( \Lambda_y \) is the relationship between \( y \) and \( \eta \), \( \delta \) is the vector of the observation error of \( x \), and \( \epsilon \) is the vector of the observation error of \( y \).

The structural model, also known as variable–potential model, is used to describe relationships between potential variables. The expression is as follows:

\[ \eta = B\eta + \Gamma\xi + \zeta \]  

In Equation (6), \( \eta \) is the endogenous variable vector, \( \xi \) is the outline variable vector, \( B \) is the structural coefficient matrix of endogenous potential variables, \( \Gamma \) is the structural coefficient matrix of the outline variable and endogenous variable, and \( \zeta \) is the residual value of structural equation.

Potential variables include driving attitude, driving behavior characteristics, and dangerous driving tendencies. Measurement indicators of driving attitude include traffic congestion, dissatisfaction, slow driving, and unreasonable driving behaviors [37,38]. Measurement indicators of driving behavior characteristics include velocity, acceleration, horizontal position, and steering lamp usage. Measurement indicators of dangerous driving tendencies include accident rate and driving behavior score (through expert score method) in the experiment. Observation variables are age and training level of the driver. SEM indicators are shown in Table 3.

The initial model (Figure 5) is proposed from above measurement indicators.

In the initial model, the ellipse represents the potential variable and the rectangles represent the observation variable. Endogenous variables include driving attitude, driving behavior, and dangerous driving tendencies. Exogenous variables include age and training level.

![Figure 5. Flow chart of initial model.](image-url)
Table 3. Measurement indicators of SEM.

| Name of Variables          | Name of Indicators          | Type of Variables | Explanation                                      |
|----------------------------|-----------------------------|-------------------|--------------------------------------------------|
| Driver’s age (AGE)         | Driver’s age (Age)          | Categorical       | Older driver is 1, Young and middle-aged driver is 0 |
| Driver’s training level (LEV) | Driver’s training level (Lev) | Categorical       | Training is 1, No training is 0                  |
| Driving attitude (ATT)     | Traffic congestion (Att1)   | Ordinal           | scale by DAS table                               |
|                           | Dissatisfaction mood (Att2) | Ordinal           | scale by DAS table                               |
|                           | Slow driving (Att3)         | Ordinal           | scale by DAS table                               |
|                           | Unreasonable driving behavior (Att4) | Ordinal | scale by DAS table                               |
| Driving behavior (BEH)     | Velocity (Beh1)             | Continuous        | Velocity Acceleration                            |
|                           | Acceleration (Beh2)         | Continuous        | Distance of deviation from the road              |
|                           | Horizontal position (Beh3)  | Continuous        | Time of steering lamp usage before turning       |
|                           | Steering lamp usage (Beh4)  | Continuous        |                                                  |
| Dangerous driving tendency (DAN) | Amount of accident (DAN1)   | Ordinal           | Number of accidents in the experiment            |
|                           | Score of driving behavior (DAN2) | Ordinal | Score of driving behavior                        |

4. Results

4.1. Difference in Driving Behavior Indicators

Indicators of 12 driving behavior characteristics were compared and analyzed in different scenarios between older drivers and young and middle-aged drivers; neither group was trained. Differences were found between two types of drivers in various scenarios. The results are presented in Table 4.

Table 4. Driving behavior difference of two types of drivers.

| Behavior Indicator        | Straight | Lane Changing | Turning at Intersection | Emergency | Distracted Driving |
|---------------------------|----------|---------------|-------------------------|-----------|-------------------|
| Fixation time             | No       | No            | Yes                     | Yes       | Yes               |
| Saccade amplitude         | Yes      | Yes           | Yes                     | Yes       | Yes               |
| Heart rate                | Yes      | Yes           | Yes                     | Yes       | Yes               |
| EDA                       | No       | Yes           | No                      | Yes       | Yes               |
| EMG                       | No       | Yes           | Yes                     | Yes       | Yes               |
| Steering angle            | -        | Yes           | Yes                     | Yes       | No                |
| Gas pedal                 | No       | Yes           | Yes                     | Yes       | No                |
| Brake pedal               | -        | -             | Yes                     | Yes       | Yes               |
| Turning lamp usage time   | -        | No            | No                      | -         | -                 |
| Vehicle velocity          | No       | Yes           | Yes                     | Yes       | Yes               |
| Vehicle acceleration      | Yes      | Yes           | Yes                     | Yes       | Yes               |
| Vehicle horizontal position | Yes    | -             | Yes                     | Yes       | Yes               |

It can be seen from Table 4 that in the straight scenario, there is a significant difference in average saccade amplitude, increase in heart rate, the standard deviation of vehicle acceleration, and the standard deviation of vehicle horizontal position between older drivers and young and middle-aged drivers. In the lane-changing scenario, there is a significant difference in average saccade amplitude, increase in heart rate, increase in EDA, median frequency of EMG, entropy of steering angle, the standard deviation of gas pedal, vehicle velocity, and vehicle acceleration between older drivers and young and middle-aged drivers. In the scenario of turning at an intersection, there is a significant difference in average fixation time, average saccade amplitude, increase in heart rate, median frequency of EMG, entropy of steering angle, the standard deviation of gas pedal, the standard deviation of brake pedal, vehicle velocity, and vehicle acceleration between older drivers and young and middle-aged drivers. In the emergency scenario, there is
a significant difference in average fixation time, average saccade amplitude, increase in heart rate, increase in EDA, entropy of steering angle, the standard deviation of gas pedal, the standard deviation of brake pedal, vehicle velocity, vehicle acceleration, and vehicle horizontal position between older drivers and young and middle-aged drivers. In the distracted driving scenario, there is a significant difference in average fixation time, average saccade amplitude, increase in heart rate, increase in EDA, median frequency of EMG, the standard deviation of brake pedal, vehicle velocity, vehicle acceleration, and vehicle horizontal position between older drivers and young and middle-aged drivers.

4.2. Driving Behavior Training Model Based on TPB

The effectiveness of driving behavior training is evaluated by driving performance, based on three dimensions: security, comfort, and time spent [39]. Combined with experimental data, the vehicle velocity, steering lamp usage, and vehicle horizontal position were used as security indicators, vehicle acceleration was used as comfort indicator, and the lowest amount of data was used to represent the driving behavior, considering the time spent. The driving behavior data of older drivers with and without training were collected and analyzed, and the results are shown in Table 5.

Table 5. Analysis of older driver’s indicators with training and no training.

| Traffic Scene           | Indicator                          | No Training | Training | p       |
|-------------------------|------------------------------------|-------------|----------|---------|
| Straight                | Velocity (km/h)                    | 39.19       | 32.44    | 0.049 * |
| Lane change             | Velocity (km/h)                    | 4.11        | 3.60     | 0.018 * |
|                         | Usage time of turning lamp (s)     | 1.11        | 4.90     | 0.000 * |
|                         | Acceleration (m/s²)                | 0.20        | 0.23     | 0.355   |
| Turning at intersection | Velocity (km/h)                    | 5.72        | 5.83     | 0.285   |
|                         | Usage time of turning lamp (s)     | 3.67        | 7.80     | 0.003 * |
|                         | Acceleration (m/s²)                | 1.04        | 0.32     | 0.017 * |
| Emergency               | Velocity (km/h)                    | 20.62       | 17.32    | 0.025 * |
|                         | Acceleration (m/s²)                | −4.73       | −2.23    | 0.002 * |
|                         | Vehicle horizontal position (m)    | 1.09        | 0.59     | 0.028 * |
| Distracted driving      | Velocity (km/h)                    | 27.67       | 21.00    | 0.000 * |
|                         | Acceleration (m/s²)                | −4.38       | −2.05    | 0.001 * |
|                         | Vehicle horizontal position (m)    | 0.17        | 0.18     | 0.256   |

Notes: * represents significance at 0.05.

4.3. Structural Equation Model (SEM)

Mplus software 7.0 was used to estimate the model parameters [40]. The model is modified by the model parameter and correction index from the software during the estimation of the model. The final fit index of the model is presented in Table 6.

Table 6. Fit index of model.

| Fit Indicator | $\chi^2$ (df) | $\chi^2$/df | CFI  | TLI  | SRMR |
|---------------|--------------|--------------|------|------|------|
| Suggested value | $p > 0.05$ | <3.0 | >0.9 | >0.9 | <0.05 |
| Index value   | 80.812 (46)  | 0.0012       | 1.76 | 0.940 | 0.915 | 0.034 |

Factor load estimates of the potential variable and the observation indicator were calculated. Factor loads between variables were estimated and the route map of potential variables and indicator variables was drawn (Figure 6).
The AGE has a significant negative impact on ATT and BEH, which indicates that older drivers tend to have a negative driving attitude and driving behavior characteristics compared to young and middle-aged drivers. The AGE has a significant positive impact on DAN, which indicates that older drivers have higher dangerous driving tendency. The LEV has a significant positive impact on ATT and BEH, which indicates that drivers with training have a positive driving attitude and better driving behavior characteristics. The LEV has a significant negative impact on DAN, indicating that drivers with training have a lower dangerous driving tendency. The ATT has a positive impact on BEH and negative impact on DAN, which indicates that drivers with a positive attitude have better driver behavior characteristics and lower dangerous driving tendency.

To explore the influence of exogenous variables, such as driver age and training level, on traffic safety, the indirect impact and overall impact of exogenous variables on endogenous variables were calculated. The results are presented in Table 7.

Table 7. The influence of exogenous variables on driving behavior characteristics.

| Variable       | Group                       | Driving Behavior Characteristic (BEH) | Direct Influence | Indirect Influence | Overall Influence |
|----------------|-----------------------------|---------------------------------------|------------------|--------------------|-------------------|
|                |                             |                                       |                  |                    |                   |
| Age            | Young and middle-aged driver (Reference) |                                       |                  |                    |                   |
|                | Older driver                |                                       | -0.170 *         | -0.284 *           | -0.454 *          |
| Training level | Young and middle-aged driver (Reference) |                                       |                  |                    |                   |
|                | Older driver                |                                       | 0.212 *          | 0.437 ***          | 0.649 *           |

Notes: * represents significance at 0.05; *** represents significance at 0.001.

The age of the driver has a significant negative indirect influence and overall influence on driving behavior characteristics, and the training level has a significant forward indirect influence and overall influence on driving behavior characteristics.

The influence of exogenous variables on dangerous driving tendencies was calculated, and the results are shown in Table 8.

The driver age has a significant forward indirect influence and overall influence on dangerous driving tendency, and the training level has a significant negative indirect influence and overall influence on driving behavior characteristics.
Table 8. The influence of exogenous variable on dangerous driving tendency.

| Variable | Group                        | Dangerous Driving Behavior (DAN) | Direct Influence | Indirect Influence | Overall Influence |
|----------|------------------------------|----------------------------------|------------------|--------------------|-------------------|
|          |                              |                                  |                  |                    |                   |
| Age      | Young and middle-aged driver  | 0.249 *                          | 0.337 *          | 0.586 *            |                   |
|          | (Reference)                  |                                  |                  |                    |                   |
|          | Older driver                 |                                  |                  |                    |                   |
|          |                              | −0.280 ***                       | −0.517 **        | −0.797 **          |                   |
| Training level | Young and middle-aged driver  |                                  |                  |                    |                   |
|          | (Reference)                  |                                  |                  |                    |                   |
|          | Older driver                 |                                  |                  |                    |                   |
|          |                              | −0.280 ***                       | −0.517 **        | −0.797 **          |                   |

Notes: * represents significance at 0.05; ** represents significance at 0.01; *** represents significance at 0.001.

5. Discussion

5.1. Driving Behavior Characteristics

The fixation time and saccade amplitude were used as indicators to analyze the driver’s vision behavior characteristics. The fixation time represents the time spent on the fixation behavior, which reflects the degree of the driver’s interest in the target object and the speed of the driver in handling traffic information [16]. In scenarios of turning at an intersection, emergency, and distracted driving, the time taken to handle traffic information in older drivers is longer than that for young and middle-aged drivers, because the average fixation time is longer. The saccade amplitude represents the time spent on saccade behavior and reflects the ability of the driver to obtain traffic information [41]. It appears that the ability of older drivers to obtain traffic information is lower than that of young and middle-aged drivers because the saccade amplitude is smaller in all scenarios.

The increases in heart rate [42], EDA [8], and EMG [43] were used as indicators to analyze drivers’ physiological psychological characteristics. The increase in heart rate can reflect the traffic load of the driver in a complex traffic environment. It can be seen that the traffic load of older drivers is higher than that of young and middle-aged drivers, due to the mean of the increase in heart rate being higher in all scenarios. The increase in EDA is a characterization of the driver’s emotional activity and can reflect the degree of alertness in the traffic environment. In the scenario of lane change, emergency, and distracted driving, it can be seen that the alertness degree of older drivers is lower than that of young and middle-aged drivers, from the lower mean of the increased rate of EDA. EMG is a characterization of the driver’s muscle contraction activity, and the median frequency of EMG can reflect the degree of a driver’s tension [43]. In scenarios of lane change, turning at intersection, emergency, and distracted driving, the nervousness degree of older drivers is higher than that of young and middle-aged drivers because the median EMG frequency is higher.

The steering wheel angle entropy, the standard deviation of the gas pedal, the standard deviation of the brake pedal, and turning lamp usage were used as indicators to analyze drivers’ operating characteristics. The steering wheel angle can represent the smoothness and estimation of the driver’s rotational operation, and the steering entropy is used to quantify the ability of the driver’s turning control. In the lane-changing scenario, the steering wheel control ability of young and middle-aged drivers is lower than that of older drivers, while in scenarios of turning at intersections and emergencies, the steering wheel control ability of older drivers is lower than that of young and middle-aged drivers, and the directional control ability of the two groups of drivers is relatively close, but the control ability of the steering wheel is weaker. The gas pedal can represent the stability of the driver’s operation in acceleration, and the standard deviation of the gas pedal was used to quantify the control ability of the driver’s acceleration on the vehicle. In the lane-changing scenario, the young and middle-aged drivers exhibits a higher volatility in terms of the gas pedal; in scenarios of turning at an intersection and emergency, the older driver exhibits a higher volatility in terms of the gas pedal; in the distracted scenario, both groups of drivers exhibit a higher volatility in terms of the gas pedal. The brake pedal can represent
the stability of the driver’s operation in braking, and the standard deviation of the brake pedal was used to quantify the driver’s ability to control the deceleration of the vehicle. In scenarios of turning at an intersection, emergency, and distraction, the older drivers exhibit a higher volatility in terms of the brake pedal. The steering lamp is used to inform the intention of turning or lane change to pedestrians and other vehicles, and the steering lamp usage time can reflect the risk perception of the driver from the side. In scenarios of lane changing and turning at an intersection, there are many cases where both groups of drivers forgot to use the steering lamp.

The velocity, acceleration and horizontal position were used as indicators for the analysis of vehicle status. The vehicle velocity can affect the driver’s judgment. In scenarios of lane changing and turning at an intersection, older drivers have a higher volatility of velocity; in scenarios of emergency and distraction, older drivers have a lower velocity mean compared to the young and middle-aged drivers, but there is a higher velocity volatility from the perspective of variance. Acceleration can reflect the acceleration and deceleration control of the driver in a vehicle. In scenarios of driving straight, lane changing and turning at intersections, the older drivers’ acceleration is higher in volatility; in scenarios of emergency and distraction, the maximum deceleration of the older driver has a larger peak. The horizontal position of the vehicle is the ability of the driver to keep the vehicle in the middle of the road, which is an indicator of the driver’s stability. In scenarios of driving straight, emergency and distraction, the lane-keeping ability of older drivers is weaker than that of young and middle-aged drivers.

5.2. PNE Driver Training Model

In the scenario of straight driving, it can be seen that older drivers with training have a better velocity perception because the average velocity mean is significantly lower than that without training. In the scenario of lane change, it can be seen that the velocity of old drivers with training tends to be stable and the risk awareness is stronger, as the standard deviation in velocity mean of older drivers with training is significantly lower than that without training, and the time of steering lamp use with training increased significantly. In the scenario of turning at an intersection, it can be found that the older driver’s velocity with training tends to be stable and they have higher risk awareness from the standard deviation in velocity mean, and the standard deviation in acceleration of the training group is significantly lower than that without training, where time of steering lamp use with training increased significantly. In the scenario of an emergency, it can be seen that the risk perception ability of older drivers has improved, as the velocity, maximum deceleration, and maximum horizontal position of older drivers with training are all lower than those without training. In the scene of distracted driving, the risk perception ability of older drivers has improved and they refuse to use the telephone as the velocity and maximum deceleration of older drivers with training are all significantly lower than those without training. In addition, in the statistical emergency and distracted driving scenarios, the accident rate of drivers with training was reduced by 44.4% and 66.7%, respectively, compared to those without training.

5.3. Analysis of Structural Equation Model (SEM)

The driver’s age has a negative influence on the driving behavior characteristics and indicates that the driver’s operating stability decreases with aging. The driver’s age has a positive influence on dangerous driving tendencies and indicates that the driver’s dangerous driving tendency increases with age. The training level has a negative influence on dangerous driving tendencies and a positive influence on driving attitude and driving behavior. It can be concluded that the driving attitude tends to be positive and the driving behavior can be improved to reduce dangerous driving tendencies through the driving training of the driving simulator. The positive influence of training level can reduce the negative influence of age on driving behavior characteristics, indicating that training can reduce the impact of the driver’s age on driving behavior, and that older drivers tend to
display better driving behavior characteristics. The negative influence of training level on dangerous driving tendency can reduce the positive influence of age on dangerous driving tendency, indicating that training can reduce the impact of driver age on dangerous driving tendency and older drivers tend to decrease dangerous driving tendencies.

6. Conclusions

The driving performance of older drivers is worse than that of young and middle-aged drivers, according to the multi-data analysis. A “Perceived-Norm-Execute” (PNE) model is constructed for older drivers based on the theory of planned behavior (TPB), with the aim of enhancing older drivers’ driving behavior by training them through the model to improve the safety and stability of their driving operation. Finally, the relationship between training level, driving behavior characteristics and traffic safety was discussed, using the structural equation model. The results showed that the training can counteract the effect of the driver’s age on the characteristics of driving behavior, and older drivers tend to have lower dangerous driving tendencies. The results of the paper can be useful to establish effective policies for improving the behavior and safety of older drivers in the future.

Nevertheless, the current study is not without limitations. The current study relied on an experimental driving simulator, and it should be validated with real driving experiments. The representation of the drivers needs be verified, as the training method with TPB was not compared to other training methods, to ensure the reliability. There are many problems that need be solved in the follow-up study.

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