Elderly-Oriented Design for the Instrument Panel and Central Console of Intelligent Passengercars

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Abstract. Based on the elder drivers' perceptual experience, this paper makes a study on the design of human-machine interface of intelligent passenger cars. The study focuseson finding the interior structure which conforms with users' behavioral habits under the background of driving assistance technologies. By means of System Usability Sale (SUS), elder users' perceptual data are collected and the most suited interior structure ($p < 0.001$) will be clarified according to the Analysis of Variance (ANOVA) of the SUS scores. The cross-section shape of the instrument also influenced the in-vehicle interactive performance. Based on Analytic Hierarchy Process (AHP), the shape of upright is given the highest weight. In order to make designs for central console, arc-cotangent function is used to calculate the tilt angle of the line connecting the upper edge of the instrument panel and the transmission lever, and it can be known that a tilt angle of about 48° is preferred by senior people. Following the basic in-vehicle dimension parameters, an instrument panel and central console design is proposed.

Keywords: Senior people · Intelligent car · Instrument panel · Central console · Sensory information · Perceptual evaluation

1 Introduction

Contemporarily, with Chinese cars entering families widely, consumers' attitude towards consumption is also changing gradually. They no longer pursue mechanical properties and functions only, but the design quality and user experience of passenger cars also start to influence consumers' choice. Interior design, as the most intimate part of passenger car design, will naturally attract consumers' attention, especially those in the senior-middle and old age. The success of interior design will directly affect consumers' driving experience and interactive performance.

There have been more and more intelligent cars. Almost all of the new types of passenger cars have some intelligent functions. In an aging society, this may bring about problems of learnability and the degree of acceptance. Senior people's ability in moving their limbs is different from the young group. So it is necessary to clarify what kind of style and interior structure are more suited for them.

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Generally, automotive interior includes instrument panel (or dashboard), central console, door trim panel and seats. Hundreds of independent components constitute different subsystems of a car's interior. Each subsystem bears part of the functions, while among them the most important one is the dashboard system as well as the central console, which carries the most critical driving and operating functions in the interior. The carrier of operation and interaction is structure and modeling. Thus it is meaningful for drivers' interactive performance to make a study on the structural and style design of the two subsystems [1].

New driving assistance technologies and automatic driving technologies will change the driving mode of future passenger cars. The style design of the dashboard system and central console may change a lot under the new driving modes. New designs will evolve towards driving convenience and commodious interior space, driver-passenger interaction, privacy of space, personalized customization, health, environmental protection and high expectations. Based on the drivers' perceptual experience, this paper makes a study on the style design of the dashboard system and central console of intelligent passenger cars.

2 Background

The contemporary pre-elderly in China were born in the era of the 1950s to 1960s. The special historical background and the physiological change brought about by age make this generation have a series of driving psychological characteristics, such as pride, a heavy mental burden and the decline of cognitive functions [2]. In the near future when smart cars play a more and more important role, it is useful to find points that conform with the elderly's psychological characteristics by design.

Psychology of pride. Because of the rich experience in driving, senior drivers always hold an overestimate to their driving abilities while ignore operating according to rules. Some inappropriate behaviors may happen such as turning without turn signals, driving on the wrong side of the road, overtaking, changing lanes at will or talking with passengers in the car, etc. If something emergent happens, senior people will not react in time, which is likely to cause traffic accidents. Some driver assistance systems and alarm devices are needed to compensate for senior drivers' pride for their driving experience.

Excessive psychological burden. The physical activities of the elderly are easily inhibited by negative emotions, resulting in inattention and a decline in self-control, which have an impact on the response and accuracy of thinking and action. Driving with emotions often leads to incorrect steering wheel operation, heavy throttling, untimely braking control and misjudgement of emergencies. And driver assistance systems can make up for these problems.

Besides, senior people present a decline in cognitive functions. Thus it is necessary to consider the size of screens, control units and other elements of the human-machine interface (HMI) in design. With the rise of smart cars, new technologies, devices and abundant non-driving operations in entertainment system compensate for the decline and their negative psychology, such as advanced driver assistance systems (ADAS), head up display (HUD), in-vehicle advanced reality (AR), gesture recognition and high definition (HD) screens in the area of the front passenger seat. But new interactive technologies make senior people feel hard to learn [3] and put forward new requirements for interior design of intelligent cars. In order to present these information interactive systems on the instrument panel and the central console, the shape and structure, which exert an influence on interactive performance and can be seen as the core factor of the instrument system, needs to be considered. And the key of design is the proportional relationship of interior spatial layout.

3 Methods and Results

3.1 Study of Interior Design Language

The structure of automobiles interior is basically T-shaped. It is mainly because of the basic frame formed naturally by the vertical-placed shifting device of transmission gears and the steel beams that support the instrument panel. Automotive interior can be mainly divided into two types: wraparound structure and driver orientation structure. And in the dimension of symmetry, the symmetrical and asymmetrical structure will bring about different interactive performance of the drivers, and their cognitive efficiency will also be diverse.

In this way, there are four kinds of basic structures: symmetrical wraparound structure (such as Nissan Qashqai), asymmetrical wraparound structure (such as Mercedes Benz W222), symmetrical driver orientation structure (such as Ferrari 812) and asymmetrical driver orientation structure (such as Porsche 928).

Sensibility is people's psychological feelings or images of things or phenomena [4]. In the process of user's subjective perception evaluation of products, the processing of sensory information will be based on the inherent psychological model of different users. The level and content of perceptual demands for product quality described by sensory information become more diversified with the rapid development of science and technology and the change of consumption concept, which is more suitable for researches of user experience that are difficult to apply objective measurement methods [5]. This study collects senior drivers' sensory evaluation and quantifies the 4 design languages with the System Usability Scale (SUS). A large sample study shows that SUS is effective and the reliability coefficient of SUS is 0.91, which shows an excellent and reliable internal consistency [6]. When the participants finish a series of tasks, they can quickly score the items in the SUS scale. Then it is needed to transform the scores of each item. For the odd numbered items, the converted values are calculated by "the original score minus 1" and for the even numbered items, "5 minus the original score" is used. By adding up the converted scores of all the items and multiplying the summation by 2.5, the SUS score can be obtained. Each kind of interior structure is scored by SUS to calculate the usability of the four structures. The significance of the differences is judged by analysis of variance (ANOVA). The SUS questionnaires were distributed to senior drivers aged 50–65 and with automobile driving experiences. A total of 158 valid questionnaires were collected, of which 96 were males and 62 were females. The statistical results are shown in Table 1. The results show that the four structures have significant differences in system availability ($F = 12.26$, $p < 0.001$), which is in line with consumers' preferences. And among them, asymmetrical driver orientation structure presents the highest score, which means the subjects prefer this structure most.

Table 1. Results of SUS of instrument panel structure

	Symmetrical wraparound structure	Asymmetrical wraparound structure	Symmetrical driver orientation structure	Asymmetrical driver orientation structure
Mean	81.778	79.241	83.886	84.652
Std. Deviation	9.501	6.790	9.898	8.305

The interior is mainly constructed by the instrument panel. In addition to the structure, the cross-section shape of the instrument panel plays an important role in the shape style and information recognition of the whole interior. Besides, there are air conditioning outlets, glove boxes and a few controllers on the panel. The layout of them also affects the user's interactive experience.

The cross-section shape of the instrument panel is generally divided into three types: upright, layered, and sporty. The panel with an upright cross-section often appears in SUVs. The cross-section is straighter and more vertical, which presents all the information directly to the driver. The layered cross-section means that if the volume of the instrument panel is too large in the vertical direction, it can be processed by dividing the shape with more layers, separating the entirety with different colors and so on to make a design. The sporty cross-section also layers the shape of the instrument panel, but it shows a strong sense of speed. The upper level of the panel is more protruding than the lower level, so the posture is very vivid.

To evaluate the design of vehicles, Technology Acceptance Model (TAM) can achieve effective results [7, 8]. Based on TAM, we use *usability*, *ease of use*, *compatibility* and *perceived risk* as main indexes to set up an analytic hierarchy process (AHP) model (Fig. 1) to evaluate the three kinds of cross-section shapes and find out the one with the best interactive performance.

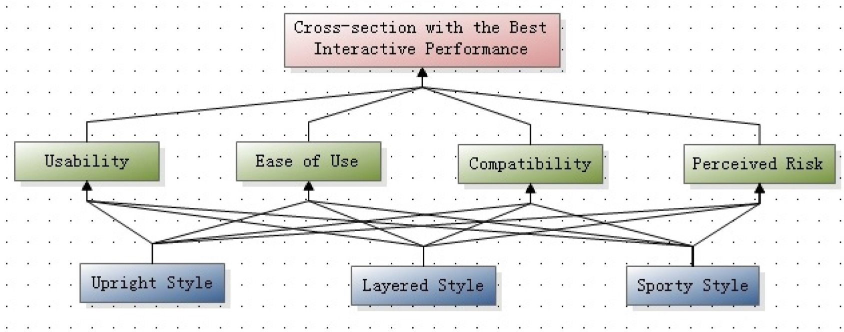

Fig. 1. AHP model for the evaluation of cross-section shape

The evaluation is made by 4 professional designers in the automotive industry who know the interior design of intelligent cars well. Using the software Yaahp 10.3, total order weight values of every evaluator's judgment matrix are generated. C.I. Values of all their judgment matrices are less than 0.1, passing the consistency test. After dealing with the 4 experts' total order weight, the group-decision results are listed as Table 2:

Table 2. Results of AHP for the evaluation of cross-section shape

	Usability	Ease of use	Compatibility	Perceived risk	Weight of total order	Total order sorting
	0.2321	0.1080	0.4782	0.1817		
Upright	0.3874	0.2970	0.5278	0.5396	0.4822	1
Layered	0.1692	0.1634	0.1369	0.1571	0.1522	3
Sporty	0.4434	0.5396	0.3325	0.2493	0.3655	2

From the results, it can be seen that the upright cross-section won the highest weight (W = 0.4822) among the three kinds of shapes. Among the 4 indexes, the weight of *compatibility* is highest (W = 0.4782). It means *compatibility* plays the most important role in interactive performance. And among the shapes, compatibility of the upright shape performs best (W = 0.5278). The results show that for elder drivers, the driving experience of intelligent cars may be improved if the cross-section is *upright*.

3.2 Design of the Spatial Layout of the Central Console

Human-Machine Relationship Analysis. Besides the style of the instrument panel, the structure of spatial layout also affects human-machine interaction. In intelligent cars, there are more non-driving interactive behaviors and searching behaviors. Thus the analysis for HMI should be more detailed. Especially for the elderly, a reasonable space layout helps to ease their heavy psychological burden. The structures of spatial layout can be devided into dynamic ones and static ones. If the relationship among different elements is fixed, it is a static spatial layout. Like the central console is always on the central axis of the interior and under the windshield. It will not be laid out as an aircraft or tank cockpit. On the contrary, dynamic spatial layout is often embodied in some parts which do not require too much about function and structure. Its parameters rely on human-machine interaction, which makes the spatial layout has more freedom. In view of the dynamic spatial layout structure, designers can obtain satisfactory layout scheme through interactive adjustment, so as to ensure that the layout has a certain degree of creativity and openness on a reasonable basis.

There are two main constraints on parameters of the parts of HMI: dimensional constraints (such as the deviation and angle of a surface from its reference plane) and topological constraints (such as the fitting relationship, vertical relationship and coaxial relationship of two surfaces, etc.). Among them, the amenity design of HMI, the check of driving postures, the layout design of control and display devices are mainly based on the size of human bodies and interior key points, which belong to static measurement. And the parameters such as the tilt angle of the instrument panel, the spatial relationship between the transmission lever and the instrument panel, which can be judged by the perceived comfort degree in the process of interaction, belong to the dynamic measurement. If the height of the surface on which the transmission lever locates is low while the upper edge of the instrument panel is too higher, a longer moving route of hand will be formed and the misoperation rate will be increased. The joints movements involved in driving postures are shown in Fig. 2. In driving tasks, the angle of A3 generally changes greatly, which makes against to the elderly whose limb functions decline to some extent. Therefore, it is necessary to locate the appropriate position of A3 that is suitable for the elderly.

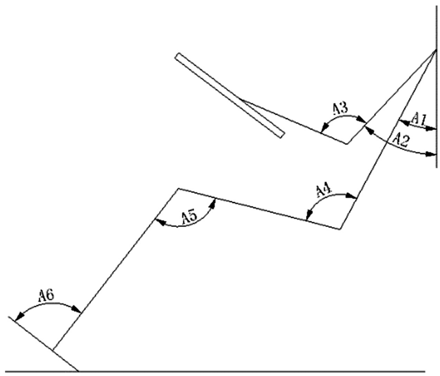

Fig. 2. Movement of joints under sitting posture

Existing researches always focus on traditional HMI such as seats, steering wheels, pedals and doors, while ignoring information exchange media such as central console, central monitor and so on. In this study, we collected the most comfortable spatial position of the hand and elbow joints when the elderly subjects operated the transmission lever at the datum point, along with the appropriate height of the instrument panel, and signed it with color tape in the vehicle. The relative position of the panel on which the lever is located is calculated by the arc-cotangent function, and the inclination angle of the transition surface between the instrument panel and the central console is estimated to achieve the central console design.

Design of the Spatial Layout. Taking the seating reference point (SgRP) as the datum point, researchers collected data of 158 drivers of intelligent car. Field assistance is provided by the specialist on the front passenger seat. Adjusting the seat to the position of SgRP, the driver was asked to find the most comfortable spatial position of his/her right hand and elbow and signed it in the space by color tape. The collected data include:

X1: the distance from the right hand to the ground (mm);
X2: the distance from the top of the transmission lever to the panel on which the lever locates (mm);

X3: the distance from the panel on which the lever is located to the ground (mm), and $X3 = X1 - X2$;
X4: the appropriate height of the upper edge of the instrument panel (mm);
X5: the horizontal distance from the right hand to the point, which locates against the top of transmission lever, on the upper edge of the instrument panel (mm).

In this position, three key points are signed in Fig. 3. Point A is the top of the transmission lever of a passenger car. Point B is on the upper edge of the instrument panel and it is located on the same line as Point A on the Y axis. And Point C is the SgRP.

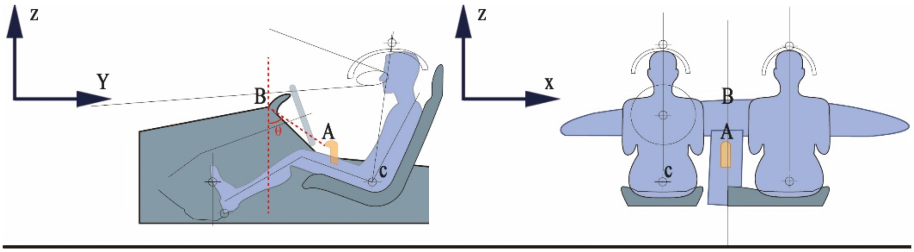

Fig. 3. Human-machine relationship and key points

By arc-cotangent function, the tilting angle of the line between Point A and Point B can be obtained as Eq. (1):

$$y = \operatorname{arccot}\left(\frac{X4 - X3}{X5}\right) \tag{1}$$

After transforming y into angle value (θ), the results are listed in Table 3. The mean value of $\angle\theta$ is less than 48°, and the value of *X3* is about 532 mm. So in order to make the form of the central console consistent with the instrument panel, it is reasonable to design three surfaces in a mellow form: an inclined transition surface (Surface α), the instrument panel (Surface β) and the panel on which the transmission lever locates (Surface δ). Surface α should connect with Surface β smoothly and naturally. And Surface δ should be about 532 mm's high to shorten the hand moving path.

The part that consists of Surface α and Surface δ, which starts from the upper edge of the instrument panel and stretches to the tail of the T-structure, can be used to place the central screen and the transmission lever. It can improve the degree of senior drivers' comfort to some extent.

Table 3. Key dimensions suitable for elderly drivers

Variables	Mean	Std. Deviation	Minimum	Maximum
θ(°)	47.751	1.618	42.982	52.895
X1 (mm)	622.55	16.111	586	668
X2 (mm)	90.58	4.532	81	103
X3 (mm)	531.975	16.624	491	578
X4 (mm)	912.35	12.217	879	948
X5 (mm)	418.41	10.964	391	453

4 Discussion

4.1 Platform Thinking and Perceptual Compensation

For the interior design for elderly drivers, their perceptual performance needs to be taken into consideration. In the process of driving, operations related to visual resource consumption mainly includes information inputting and display observing. For solving the problem of senior drivers' occupancy rate of visual attention resource, platform thinking can play an important role especially in instrument panel design of intelligent cars [9]. The panel carries most of the interior controlling devices, so the whole instrument panel system can be seemed as a platform. The essential components such as instruments, transmission lever, steering wheel and auxiliary devices, are all products on this platform. For the elderly, the too much information display needs to be organized flexibly to compensate for the weakening of their psychological functions while not taking up their cognitive resource excessively. An effective solution is to make users selectively install some intelligent devices on the instrument panel according to their own needs, such as ADAS, HUD, AR display, gesture recognition and HD screens in the area of the front passenger seat [10]. Therefore, the panel needs to be concise enough to embody inclusive semanteme in design, so that users can install auxiliary functions on demand.

The main manifestations of the aging mental functions are slowing thinking activities, declining memory and understanding abilities, weakening abilities to learn new things and adapt to new environment [11]. Because of the complexity of human body structure, all basic movements need to be perfectly coordinated through the brain, eyes, nervous system, hands and feet. For the elderly, compared with their adulthood the ability to cooperate with other parts of the human body will be much worse, which will lead to a decline in response ability [12]. To compensate for this, the rapid development of image recognition technologies and ADAS has brought great opportunities. And relying on the Internet technologies, intelligent in-vehicle information system is becoming more and more mature and has been widely used, which provides a guarantee for the elderly to set up their own instrument panel platform. In this study, we made an analysis for the auxiliary functions based on platform thinking. By means of AHP, the functions and devices that can be installed on the instrument panel are sorted to provide a reference to the design work.

According to the design language obtained from the above research, the basic structure of instrument panel is drawn (Fig. 4) to present an asymmetrical driver orientation structure with an upright cross-section shape. This design ensures the five auxiliary devices can be placed on the panel and the in-vehicle information can be presented intuitively.

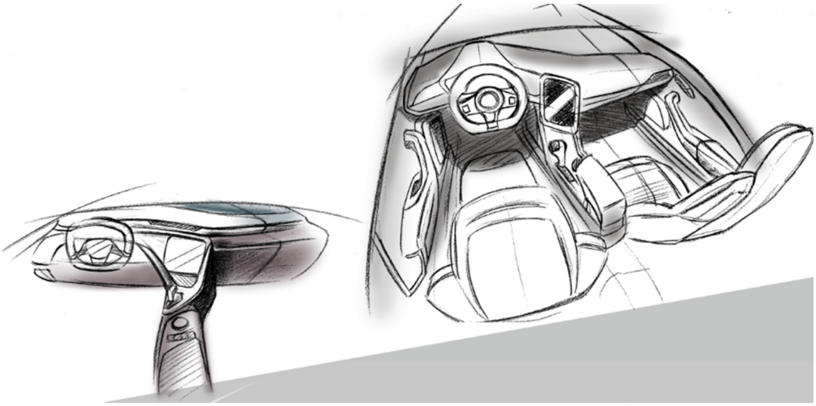

Fig. 4. Sketches of basic structure of instrument panel

After constructing the AHP model shown in Fig. 5, the 4 experienced professional designers are invited again to evaluate the weight value, with reference to the sketch. The importance of the five auxiliary functions under different indexes is evaluated.

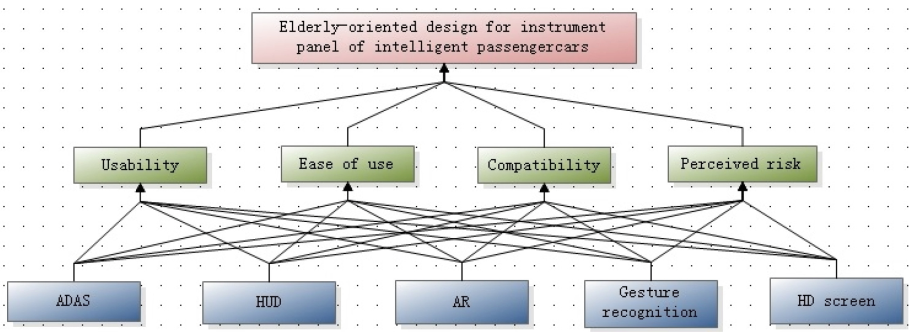

Fig. 5. AHP model for the evaluation of auxiliary functions

C.I. Values of all their judgment matrices are less than 0.1, passing the consistency test. The group-decision results are listed as Table 4.

From the results it can be seen that the weight of HUD is the highest (W = 0.3024). It means for senior people, HUD can compensate for their mental functions best. And on the aspects of *usability* and *compatibility*, HUD performs better. On the contrary, there are some deficiencies in other auxiliary functions. Especially for AR and gesture recognition, the weight values of *ease of use*, *compatibility* and *perceived risk* are all much lower than the others. So in order to improve elder drivers' experience in intelligent passengercars, it is reasonable to give priority to HUD devices. ADAS and HD entertainment screens in the area of the front passenger seat also have advantages and feasibility in some aspects. However, AR and gesture recognition cannot be trusted by experts, and could be ignored in platform design.

Table 4. Results of AHP for the evaluation of auxiliary functions

	Usability	Ease of use	Compatibility	Perceived risk	Weight of total order	Total order sorting
	0.1428	0.0825	0.2942	0.4805		
ADAS	0.1350	0.4060	0.1837	0.3271	0.2640	2
HUD	0.3365	0.0981	0.4321	0.2479	0.3024	1
AR	0.2550	0.0806	0.1794	0.0799	0.1342	4
Gesture recognition	0.1932	0.1374	0.0763	0.0972	0.1081	5
HD screen	0.0802	0.2778	0.1284	0.2479	0.1913	3

4.2 Design Proposals

Based on the above analysis, the interior design of intelligent passenger cars suitable for senior drivers is presented (Fig. 6). Following the research achievements, the design proposal has an asymmetrical driver orientation structure. Under such a structure, each component is encircled around the driver. The driver spends the least psychological resources in the process of obtaining information, and can quickly complete the required operation to compensate for the decline of their psychological functions. Besides, this kind of structure can produce a sense of security to the elderly, and also meet the psychological needs of them.

According to the results of Table 2, the cross-section shape of the instrument panel is upright. In this way a modeling language with strong usability and compatibility is formed. Down the instrument panel, a transition surface smoothly connects the dashboard and the central console. According to the result of arc-cotangent function, the tilt angle of this transition surface is approaching 48° and the position of the panel on which the transmission lever locates is elevated to a height about 532 mm from the interior ground. The overall appearance of the instrument panel and the central console shows a strong wholeness.

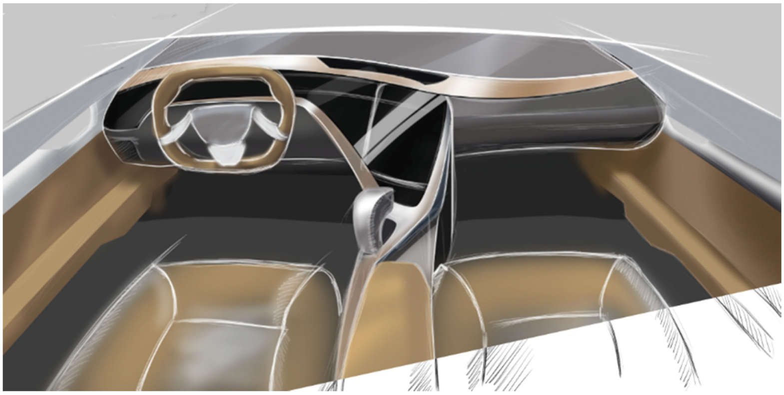

Fig. 6. A design proposal of instrument panel and central console

Ensuring the instrument panel works as a platform, there is enough space for users to install auxiliary functions on it according to their specific needs. In terms of color, warm grey is used. Elderly people prefer warm colors, which can reduce their aloneness and bring about a warm and intimate feeling to people [12]. The tendency of warm grey can play a better role in decorative color separation. Because the color conflict will not be very strong as well as making things harmonious.

5 Conclusion

Under the background of aging population, researchers from many countries have launched studies on driving behaviors for the elderly. With the popularization of Level 3 self-driving technology, methods to make intelligent car design conform to the physiological and psychological characteristics of the elderly is an important basis for carrying out the studies. Driving is a complex behavior. Analyzing the perceptual evaluation from elderly drivers in the context of intelligent vehicles is an important method to make the interior design reasonable and effective.

With the integration of a large number of intelligent driving assistance systems, automotive interior decoration becomes more complex. This research focuses on the instrument panel and the central console, which are the main carriers of in-vehicle information system. It analyzes the perceptual evaluation of the elderly drivers from the aspects of structure, cross-section shape, spatial layout, inclination angle and the height of the central console. And platform thinking is used to sort the auxiliary functions. According to the conclusions of the study, the output proposal could be feasible to some extent.

In the study of next phase, based on the conclusions of this study, the entity model of the design proposal could be built. Driving simulators can be used to collect the response time, operation completing time and EEG data of the elderly during driving and non-driving tasks. And the interior design of intelligent cars suitable for the elderly can be improved.

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