Research on Evaluation Methods of In-Vehicle Screen Interaction Based on Ergonomics

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Abstract. The rapid advancement of intelligent technologies has introduced an array of advanced functionalities into automotive cockpits, leading to increasingly complex and extensive human-vehicle interactions. As the most important interaction method, the central console display has the advantages of presenting a large amount of information and providing a simple interaction. Consequently, research investigating both the objective efficacy and subjective user experience of in-vehicle screen interactions is of paramount importance. This paper synthesizes ergonomic and cognitive psychological factors to establish a comprehensive evaluation framework for screen interactions in automotive cockpits. By constructing systematic experimental conditions, standardized procedures, and assessment methodologies, the research utilizes both objective eye-tracking data and subjective user evaluations to drive continuous improvement in related R&D designs and product experience.

Keywords: Intelligent Cockpit, Screen Interaction, Human Factors Analysis, Analytic Hierarchy Process

1 Introduction

With the rapid development of intelligence and connectivity, the automotive cabin has gradually evolved into the new concept of an intelligent cabin, characterized by iterative upgrades in interaction methods and a significant enrichment of functional experiences[1]. Against this backdrop, the in-vehicle screen, as the core channel for human-machine interaction, is carrying an increasing amount of interactive content. Even with the presence of voice interaction, button interaction, or other advanced interaction methods, designers still choose to place almost all cabin functions within the in-vehicle screen[2]. The reason for this is that in-vehicle screens have advantages such as a large capacity for content and intuitive interactive display[3]. Such as Tesla's dashboard-free solution, BYD's rotating screen, Hummer's 3D HMI design, and so on, keep emerging one after another.

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Unlike traditional consumer electronic products, the vast majority of the interaction and usage time of in-vehicle screens still occurs during driving. Therefore, driving safety is always the most important consideration for in-vehicle screen interaction. That is, the distraction impact and system stability play a dominant role in product development[4], while also taking into account the completion of human-machine interaction tasks. This is the biggest difference between in-vehicle screen interaction and ordinary tablet application interaction.

At present, the development of human-machine interaction for in-vehicle screens mainly consists of two parts: on the one hand, traditional human-machine layout, which involves the position and size of the screen, and the main design basis is the characteristics of human visual perception and the eye ellipse theory[5]; on the other hand, screen interaction also involves psychological factors such as psychological cognition and interaction habits, corresponding to the UI/UE design work in in-vehicle screens, including elements such as fonts, colors, and layouts[6]. In the design phase, these two aspects are usually treated separately, meaning that the factors of both experience design and test verification are not comprehensively considered. In the research field, Yuxiao, W. et al. studied the impact of large-sized screens on drivers' cognitive load[7]. Li, W. et al. evaluated drivers' interaction experience using human factors data[8]. Xue, H. J. et al. attempted to propose an evaluation method for the usability of screen interaction[9]. Wang Peiyao et al. evaluated the intelligent cockpit in 2024 using user feedback and fuzzy assessment[10].

2 Experimental Environment and Test Methods

2.1 Introduction to the Experimental Environment

The hardware solution of this experiment is a virtual driving test bench, which is divided into two parts. One part is the virtual driving section, including a forward view system in the form of an LED screen and a driving control system. The former is mainly used to display the simulation driving scene, while the latter consists of a steering wheel, an accelerator pedal, and a brake pedal, enabling real-time control of the virtual main vehicle in the scene.

Fig. 1. Screen flexible adjustment mechanism.

As shown in Figure 1, the other part is a verification mechanism for the central control screen, composed of a flexible adjustment bracket and a 15.6-inch central control screen. Through electric adjustment, it can be moved forward and backward, left and right, up and down, and rotated around three axes, allowing the screen to be switched to any position within a reasonable viewing range. It also supports the replacement of screens of different specifications.

The software aspect includes autonomous driving simulation scenarios and HMI interaction prototypes. The former encompasses a complete simulation driving chain, such as dynamic and static elements, random traffic flow, intelligent traffic lights, and other components, aiming to build a realistic simulation driving environment and enhance the simulation degree of experiments. The latter mainly transforms the screen interaction plan into a high-fidelity interaction prototype that can be clicked and navigated, which is the core object under test.

2.2 Basic Test Methods

This experiment is a driving-in-the-loop test. At the beginning of the experiment, the participants need to first enter a normal driving state. In this experiment, the participants are required to drive in a straight line at a speed of 60 km/h and keep the vehicle in the center of the lane. At an appropriate time, the tester will issue instructions, requiring the participants to perform screen interaction operations on specific test objects, such as adjusting the air conditioning temperature through the dock bar. During the operation, the tester will record the participants' operation data, including the number of operations and operation duration, etc. At the same time, an eye tracker will be used to record the participants' gaze points throughout the process, obtaining the number of fixations and gaze duration, etc. Finally, the participants will give subjective scores to evaluate the performance of the test objects.

3 Score Conversion and Evaluation System Construction

3.1 Indicator System Construction

To conduct a more comprehensive evaluation of interactive behaviors, this project aims to establish an index system framework that encompasses both subjective and objective indicators. Through reasonable score conversion and weight addition, it accurately reflects the results of interactive performance. Specifically, the interactive process is mainly evaluated from three dimensions, as shown in Figure 2.

The ease of information acquisition A_1 refers to whether drivers can quickly and accurately obtain key information during driving. It is directly related to factors such as font, color, icons, layout, and information prompt forms. Objectively, it is measured by eliminating the gaze duration during the operation process and combining it with subjective evaluation.

Operational accessibility A_2 refers to the driver's accuracy in locating the intended operation area, that is, whether the fingers can quickly locate the hot zone. This is directly related to the position of the interaction area and the size of the delivered hot zone, and is influenced by both the screen human-machine layout and HMI design. It is measured by using the number of reviews and operation failures in objective data, and combined with subjective evaluation.

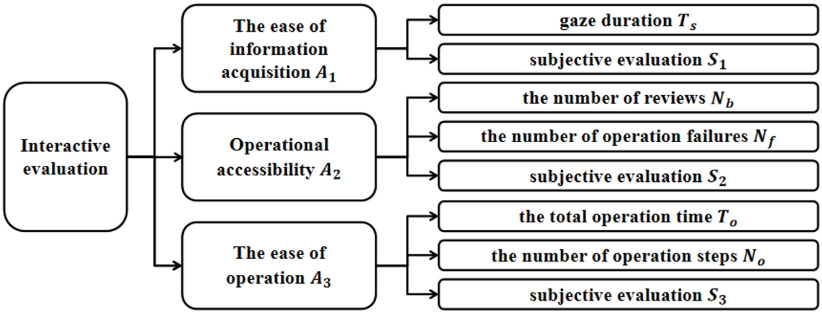

Fig. 2. The index system for evaluating screen interaction.

The ease of operation A_3 refers to whether the driver can quickly complete the specified interaction actions and achieve the interaction results in the interaction area. This mainly depends on whether the interaction method conforms to common sense, is easy to accept, and saves time and effort. It is directly related to the design of the interaction logic hierarchy and the operation method design. It is measured by the total operation time and the number of operation steps of the successful rounds using objective data, combined with subjective evaluation.

3.2 Convert to Score

In order to better integrate the results of both objective and subjective evaluations and to facilitate a more effective comparison among different test cases, it is necessary to convert the test data into a 10-point scoring system. Meanwhile, subjective evaluations are directly scored out of 10 points based on the subjective judgment of the test subjects.

The method for converting objective data into scores is shown in Equation (1).

$$\mathrm{C_m} = \frac{\mathrm{A_m} - \mathrm{P_m} + 1}{\mathrm{A_m}} \times 10 \tag{1}$$

In the formula, $\mathrm{C_m}$ is the transformed score, $\mathrm{A_m}$ represents the total number of records of this data in the database, and $\mathrm{P_m}$ represents the ranking position of the data collected this time in the database. m is the objective indicator of the final stage.

3.3 Weighted Calculation of Scores

Firstly, the objective evaluation results corresponding to A_1, A_2, A_3 are obtained through the weighted average method.

$$\mathrm{O_i} = \frac{\sum_{n=1}^{N_i} \mathrm{C_n}}{\mathrm{N_i}} \tag{2}$$

In the formula, O_i represents the total score of the objective data corresponding to the first-level indicator, N_i represents the number of objective parameters under this first-level indicator, and C_n represents the converted score of each objective parameter under this first-level indicator.

Furthermore, by using Equation (3), the subjective and objective integrated scores of each first-level indicator are combined through a weighted approach.

$$G_i = \alpha \cdot O_i + (1 - \alpha)S_i \tag{3}$$

G_i is the comprehensive evaluation result of the first-level indicators. α is the weight coefficient of objective performance, and it is set to 0.75 in this experiment.

For the single evaluation result of a certain interactive object, the comprehensive scores of all first-level indicators need to be weighted and calculated. In this paper, the fuzzy analytic hierarchy process is used to obtain the corresponding weights.

Therefore, the experiment integrated five professionals with rich experience in screen interaction testing to conduct pairwise comparisons of the importance between indicators, obtaining a fuzzy matrix $A = \left(a_{ij}\right)_{n\times n}$, as shown in Table 1.

Table 1. Fuzzy complementary matrix

Matrix A	***The ease of information acquisition***	***Operational accessibility***	***The ease of operation***
The ease of information acquisition	0.500	0.675	0.439
Operational accessibility	0.325	0.500	0.325
The ease of operation	0.561	0.675	0.500

According to formulas (4) and (5), the fuzzy complementary matrix is transformed into the fuzzy consistency matrix $B = \left(b_{ij}\right)_{n\times n}$, as shown in Table 2.

$$b_i = \sum_{k=1}^{n} a_{ik} (i = 1,2,3 \dots, n) \tag{4}$$

$$b_{ij} = \frac{b_i - b_j}{2(n-1)} + 0.5 \tag{5}$$

In the formula, b_i represents the sum of the elements in the i-th row of the fuzzy complementary matrix A; b_{ij} represents the elements of the fuzzy consistency matrix B.

Table 2. Fuzzy consistency matrix

Matrix A	***The ease of information acquisition***	***Operational accessibility***	***The ease of operation***
The ease of information acquisition	0.500	0.616	0.470
Operational accessibility	0.384	0.500	0.354
The ease of operation	0.531	0.647	0.500

According to Formula (6) and (7), the weight vector C of the above fuzzy consistency matrix B is obtained by using the row sum normalization method.

$$C_i = \frac{\sum_{j=1}^{n} b_{ij} + \frac{n}{2} - 1}{n(n-1)}, i = 1,2,3 \ldots, n \tag{6}$$

$$C = (c_1, \ c_2 \ldots \ldots c_n)^T = (0.348, \ 0.290, \ 0.363)^T \tag{7}$$

In the formula, C is the weight vector of the fuzzy consistency matrix B; C_i is an element in matrix C.

Ultimately, the single-use-case test evaluation result G is obtained, as shown in Equation (8).

$$G = \sum_{i=1}^{n} G_i \cdot c_i (i = 1,2,3 \ldots n) \tag{8}$$

Subsequent research can be conducted through rigorous testing, with a series of analytical studies performed based on the variation patterns derived from single-test results.

4 Experimental Procedures and Conclusions

4.1 Introduction of the Scheme

This experiment employs a mainstream automotive air conditioning control interface as the test subject, which is not vehicle-specific and is solely utilized for the validation of the evaluation methodology, as illustrated in Figure 3.

Fig. 3. Interface designated for testing purposes.

Three male participants were invited for this experiment, with heights of 1700mm, 1750mm, and 1800mm respectively. Before the experiment, each participant adjusted to their most comfortable screen operation position. The test results of the three participants under the same test case were arithmetically averaged.

During the experiment, the position of the screen was adjusted, starting from the far left position where the screen did not block the driver's view of the steering wheel. A position point was set every 4 centimeters to the right, and the points were marked from left to right as numbers 1 to 7. On this basis, all points 1 to 7 were moved down by 8 centimeters to obtain the second row of points numbered 8 to 14.

4.2 Analysis of Use Case Results

4.2.1 Experimental Protocol I.

The air conditioning temperature adjustment knob specified in Figure 3 serves as the test object. After calibrating the screen hardware to positions 1 through 7, participants performed interactive operations while maintaining stable driving conditions at 60 km/h. Simultaneous video recording and eye-tracking data collection were conducted. Applying the aforementioned scoring conversion and comprehensive evaluation methodology, assessment results for each position were obtained and plotted as shown in Figure 4(a).

Analysis of the curve trend reveals that as the interaction area progressively shifts away from the driver's side, the overall interactive performance deteriorates gradually. This decline becomes increasingly pronounced with further lateral displacement from the driver's position. Conversely, while the leftmost measurement point yields a relatively high score, it does not represent the optimal performance—indicating that an overly left-biased layout exceeds the comfortable operational range for the driver's manual control.

4.2.2 Experimental Protocol II.

To further validate the perspective articulated in Protocol I, the screen was fixed at position 2, and the test subjects were shifted to the home-screen climate control temperature adjustment and internal/external air circulation switching functions from Figure 3, thereby mitigating the influence of environmental variations caused by hardware relocation. The driving state conditions remained unchanged.

As shown in Figure 4(b), the overall interaction effect of the air conditioning temperature adjustment on the home page is significantly better than that of the internal and external circulation switch. This further proves the significant influence of the horizontal distance on the interaction experience.

4.2.3 Experimental Protocol III.

In comparison to Protocol II, this study altered the test objects to two distinct methods of air conditioning temperature adjustment—namely, stepwise adjustment by 0.5 degrees Celsius increments via arrow clicks or sliding adjustment activated by long-pressing the slider. The experimental task required an increase of 3 degrees Celsius in temperature, while all other conditions remained identical to those in Protocol II. The results are depicted in Figure 4(c).

Comparative analysis reveals that the click-based operation method offers greater simplicity despite involving more procedural steps overall. Its primary advantage lies in the capacity for resumptive adjustment after multiple interruptions, coupled with lower cognitive load during the adjustment process, thereby yielding superior performance compared to the slide-based adjustment approach.

4.2.4 Experimental Protocol IV.

For most vehicles, the center console screen should not be set too high to obstruct the driver's view. However, there are cases where the center console screen is placed lower or in a vertical orientation. To address these scenarios, a control group experiment was set up as described in Protocol I. The experimental requirements remain unchanged, with the test points changed to 8-14 in the lower row. The comparison results are shown in Figure 4(d).

Comparative analysis reveals a generally consistent trend between the two, aligning with the principle that closer proximity to the driver yields better operational experience. When comparing corresponding upper and lower positions along the two curves, it is observed that all lower-positioned points scored lower than their counterparts at standard height. This phenomenon occurs because excessively low placement of observation and operation areas significantly compromises peripheral visibility of the roadway, resulting in markedly increased glance-back frequency during operations and reduced duration per operational cycle.

4.3 Conclusions

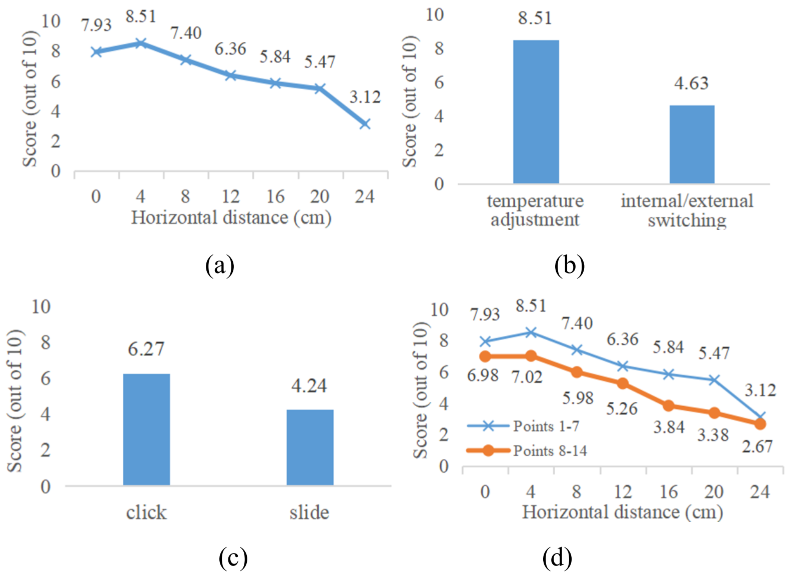

Fig. 4. Use case results.

An analysis of the aforementioned cases demonstrates that the proposed evaluation framework can be effectively applied to diverse technical scenarios, such as human-machine layout design, HMI solution validation, and competitive product assessment.

Through detailed technical indicators, including human factors, the framework enables the identification and interpretation of how underlying UI/UE design elements impact the interactive experience with in-vehicle screens. This provides an effective evaluation method for future cockpit screen interaction design, thereby better addressing the engineering design under advanced delivery requirements such as human-machine co-driving and multimodal interaction.

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