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An experimental on office comfort of intelligent cockpit based on subjective evaluation

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Abstract
In this paper, a new research and development method of office comfort experiment is proposed. From five indicators of sound, light, heat, arm and leg, the evaluation experiment of office comfort by intelligent vehicles is carried out.Then the comfort fitting model and change trend of each experimental index were summarized. The importance of the five aspects of sound, light, thermal, arms and legs is scored by interviewing practitioners in the automotive field and experts and scholars in the field by means of questionnaires to derive the proportional weights, and then the relevant index weights are analyzed by AHP (analytic hierarchy process), and finally the comprehensive evaluation model is derived by using the idea of penalty-type substitution. The summarized comprehensive evaluation model solves the limitations of single-factor evaluation in the evaluation of the comfort of intelligent car cockpit in the past, and can conduct a comprehensive subjective comfort evaluation of intelligent cockpit from multiple perspectives. Taking the perspective of the office in the car as the entry point, it better meets the urgent need to improve the comfort of the office in the car. And it has great reference value for the future design of the office field related to car companies.

Keywords: *Cockpit, Effective-Functions Comprehensive Evaluation, sound comfort, light comfort, thermal comfort, arm comfort, leg comfort.*

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I. INTRODUCTION

In the past, there were problems in working in automobiles, including insufficient space, no place to rest, insufficient temperature control and poor communication facilities[1]. With the trend of software-defined automobiles and the "new four" of automobiles, the era of automobile intelligence is opening[2, 3]. Modern electronic technologies are widely used in automobiles, which improve the functions related to automobiles and make them more humanized and intelligent[4, 6]. The continuous development of in-vehicle network systems effectively ensures the normal communication of automobile electronics[7, 8]. The rapid development of autonomous driving technology has gradually freed people from the heavy driving tasks[9, 12]. In the near future fully, autonomous driving will gradually become popular[13, 15]. The roles assumed by smart automobiles will also become more and more diversified[16]. The automobile is no longer simply a means of transportation, but as an independent and private space. People also gradually use the automobile as a place for office, rest and entertainment[17, 19]. Therefore, people have put forward higher requirements for office comfort in intelligent automobile cockpits[20].

In 1976, Hoblock established the relationship between subjective passenger comfort and vehicle motion parameters by having passengers score different driving conditions in a vehicle or special equipment[21]. In 2004, MKolich used a neural network to obtain an overall comfort index by inputting eight seat interface pressure measurements, three anthropometric and demographic variables, and a subjective evaluation of the aesthetic quality of the seat. The feasibility of neural networks to predict the subjective perception of car seat comfort was verified[22].In 2007, Farzaneh used the PMV index as a feedback interior temperature controller to better control the thermal comfort in the car. And the optimization parameters of the fuzzy controller were obtained by genetic algorithm[23]. In 2020, S. Hiemstra - van Mastrigt investigated the effect of actively adjustable seat systems on passenger comfort improvement. The active seating system was found to have significant advantages compared to regular seats[24]. In December of the same year, Chang Wang conducted artificial driving experiments to simulate typical driving conditions of future self-driving cars and developed a passenger comfort prediction model based on a bidirectional long- and short-term memory network model[25]. In 2021, Choi investigated the effect of self-adjusting seat mechanisms on improving driver comfort and found that SSA seats could improve passenger comfort by comparing with conventional seats in a contact pressure to improve passenger comfort[20].

Most traditional automotive comfort studies have considered only the relationship between a single metric and automotive comfort. However, for smart car cockpits, a single indicator usually cannot accurately describe passenger comfort[26]. Therefore, in our experiments, multiple indicators affecting car comfort are proposed to obtain a more accurate comprehensive comfort evaluation model.

At present, the mainstream methods in the study of multiple factors are: fuzzy mathematical method, cluster analysis method, main into component method, gray system theory method and artificial neural network technology method. These comprehensive evaluation methods have certain usability and rationality though. However, the calculation process is too complicated and must rely on specific computer software to complete[27, 31].In an invisible way, it increases the cost and time of the experiment, and the key of the comprehensive evaluation method lies in the rationality and scientific of the evaluation idea[32]. The Effective-Functions Comprehensive Evaluation refers to the following: multiple indicators are dimensionless and then synthesized into a comprehensive model according to certain weights[33]. Such a method is not only simpler and clearer in the calculation process, but also more intuitive in the presentation of results. Therefore, this paper uses the Effective-Functions Comprehensive Evaluation to conduct comprehensive comfort evaluation.

In this experiment, the comfort indexes are divided into two categories: interior comfort indexes and human comfort indexes. Among them, sound, light and the thermal comfort are the interior comfort indicators, while the arm and leg comfort are the human comfort indicators. As shown in Figure 1.

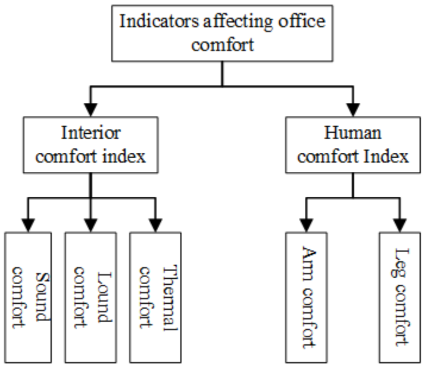


Figure1: Indicators affecting comfort

The current mathematical methods for synthesizing models can be broadly classified into: Arithmetic Average Synthesis Method, Geometric Method Average Synthesis Method, Square Average Synthesis Method, Reconciliation Average Synthesis Method, Hybrid Synthesis Method, Incentive Type Substitution Synthesis Method, and Penalty Type Substitution Synthesis Method[34, 35]. From the point of view of characteristics: the Penalty Type Substitution Synthesis Method has excellent compensatory properties. That is, it can compensate for the impact when a single environmental parameter has a low level of subjective human comfort by improving other indicators. Secondly, from the evaluation principle: when a certain index of the Punitive Substitution Synthesis Method reaches the lower limit, the total evaluation will also reach the lower limit[32]. So, the Penalized Substitution Synthesis Method is more suitable for the model synthesis of comfort evaluation.

II. METHODS

2.1 COMFORTEVALUATIONSCORE

Comfort is a subjective feeling for which there is no uniform and clear definition in academia[25]. The expression of the next dimensionless function needs to be considered when setting the comfort rating interval. The rating value should have a clear range of values or threshold, and the results of the values should be intuitive and have clear physical meaning. It is convenient to control the directionality, convexity and rate of change of the dimensionless function on the premise of making its mathematical form as simple as possible. Therefore, in this paper, the scoring range is set as (0-10 points), with 0 points representing unbearable, 2 points representing uncomfortable, 4 points representing less comfortable, 6 points representing comfortable, 8 points representing more comfortable, and 10 points representing very comfortable.

2.2 SOUND COMFORT EXPERIMENT

To avoid reflected noise from large objects, the car should be separated from such large objects by more than 20m during the test, and the temperature outside the car should be in the range of -5℃ to +35℃, atmospheric pressure: about 94.5kpa. To avoid the influence of the road structure itself, choose hardened road surface, smooth, no joints, no bump, and dry road. No other debris. The conditions inside the vehicle require closing all openings inside the vehicle, such as sunroof, windows, air inlet and air outlet. All auxiliary devices, such as rain scrapers, warm air devices, fans, and air conditioners, shall not work during the measurement test.

Most of the noise in the vehicle driving process in the low frequency band[36], the experimental test with Cool Edit Pro music editing software "drawing" experiment required white noise, by the software filter to select the low frequency band <1000Hz white noise through, the rest of the frequency attenuation off.

When the cockpit air temperature, pressure, temperature and humidity to reach a stable state before the formal start of the experiment. The first 10 min of the experiment is the subject's adaptation period in the cockpit, during which the subject needs to adjust his or her body and mind to a relaxed state and fill in personal information, and then enter the formal testing phase. The formal test phase lasted 3 min, the first 1 min was for the cockpit audio equipment to play a certain sound pressure level of a frequency noise source, and the second 2 min was for the subjects to score the comfort of the noise sound pressure level and frequency (0-10). As shown in Figure 2.

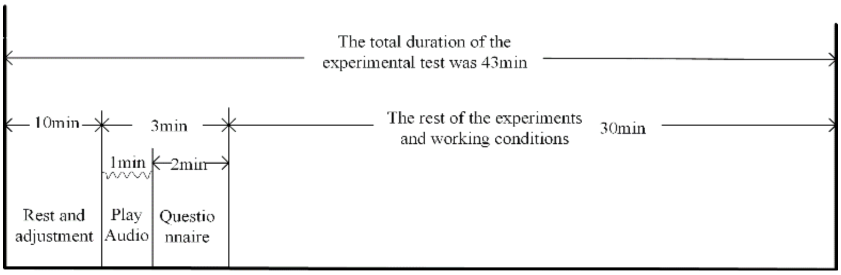


Figure 2: Flow chart of sound comfort experiment

2.3 LIGHT COMFORT EXPERIMENT

In order to exclude the influence of external light on the illumination of the experiment and the psychological factors of the personnel to achieve a variable single light source experimental environment, the scene is set at night and surrounded by no strong light source interference environment (such as a dim underground garage). The only variable light source was placed directly above the subject during the experiment, and the person was allowed to read, operate the cell phone and other daily operations under the light.

First light the light source of the lamps and lanterns for 5min, to be its light source light output stability to reach a stable state before measurement, this time at the same time to explain the information and fill in personal information to the personnel. The voltage must be kept stable during the experimental works so that the light source can work at the rated power. According to the national standard indoor lighting design , the illuminance(lx) control in the following multiple values near 50,100,150,200,250,300,350,400,450,500,600,700,800, 1000, the instrument color temperature adjustment in 3500k and 5000k. experiments are divided into measuring data in three cases, each lighting conditions Lasted 2min, 1min for comfort scoring (0-10), and each group of data between the interval of 2min, the interval of 2min to adapt to the next to change the light source. The illuminance of light gradually increasing that is from 50lx-1000lx change. As shown in Figure 3.

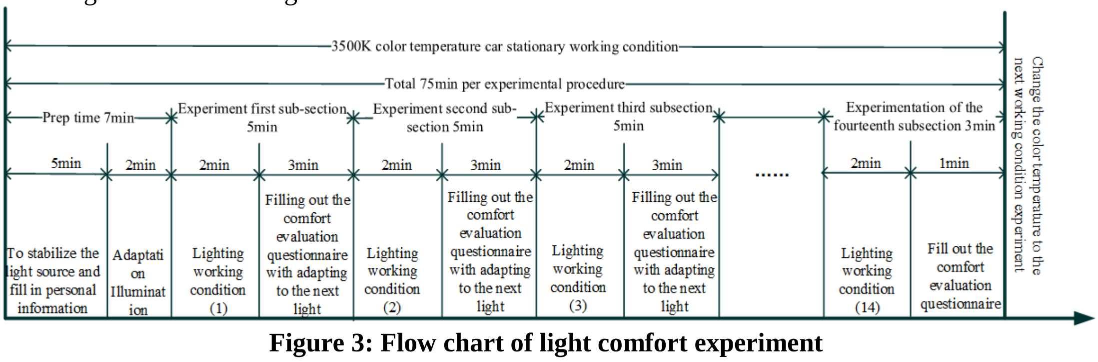


Figure 3: Flow chart of light comfort experiment

2.4 THERMAL COMFORT EXPERIMENT

Ambient temperature: ≥35℃, ambient relative humidity: 40 to 75solar radiation intensity:≥800W/m^2, wind speed:≤2m/s, location: open flat land, with direct sunlight, and the entire test process will not be affected by buildings or trees. When the outdoor environmental conditions meet the test requirements, the interior of the car for the sensor arrangement. Thermoplastic are arranged in several locations inside the vehicle to measure air temperature or wall temperature.

(1) Preheating stage 1: After arranging the sensors in the car, park the car in an open and unobstructed place. Open all the doors and windows, turn off the car engine and evaporator fan, and leave it for 30min.(2) Preheating stage two: close all the doors, open all the windows, set the evaporator fan to medium speed and let

the car engine at idle speed, and leave it for 30min.(3) warm-up stage: close all doors and windows, turn off the evaporator fan and engine, wait for the car's internal temperature to rise until the temperature inside the car is stable (about 45min).

When the car is exposed to the sun for about 50 min, the tester enters the experimental vehicle from the thermal comfort area, closes the door, opens the air conditioner, refers to the standard [37] to place the temperature adjustment switch in the maximum cooling mode, the air conditioner circulation switch in the internal circulation position, opens the blowing face and foot mode, in order to avoid the impact of too large wind speed on the local thermal comfort of the tester, adjusts the blades of the middle air conditioner vents to face the front Windshield position, the two sides of the air conditioning vents will be adjusted to face the side window glass blade position. Turn on the data collector to collect relevant data, and the data collector collects data every 1 second. At the same time, the subjective scoring of human thermal comfort (0-10) was carried out, and the testers scored the thermal comfort of various parts of the body according to the subjective evaluation form issued, and the evaluation time was 30 min. Finally, the air conditioner and data collector were turned off and the data were saved. As shown in Figure 4.

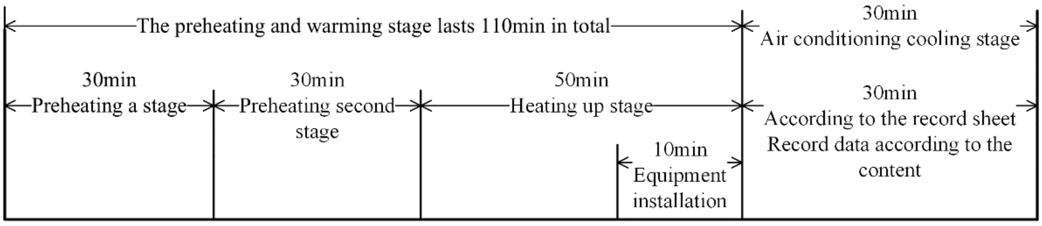


Figure 4: Flow chart of thermal comfort experiment

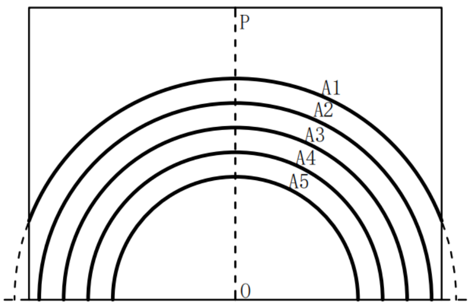
2.5 ARM AND LEG COMFORT EXPERIMENT

Based on the use of vision or arm strength, seated operations are classified into three categories namely: manual fine operations using mainly vision, general operations using mainly arm strength while using vision, and operations that take into account both vision and arm strength [38]. While most of the work performed on the cockpit is dominated by manual fine operations, the relative height is generally 400-550 mm (distance from the manually operated surface to the seat surface).

In general, the arm extension range is the distance from the center of the fingertip (index or middle finger) to the center of the body or the seat reference point when the arm is extended [39]. In this experiment considering the need for office typing and writing comfort is defined as the distance from the center of the body to the center of the palm (the distance that the arm can reach in natural extension), range 350mm-450mm.

Leg depth is a key factor affecting leg comfort in everyday office conditions (the distance between the hand-operated plane and the seat design plane when sitting) is generally ≥ 330 mm [38].

The test setup consists of a working platform that can be lifted and lowered, a foot stop that can be moved longitudinally, and a fixed position seat. The working platform is divided into five arc-shaped areas according to the radius of 250mm, 300mm, 350mm, 400mm and 450mm (Figure 5). It is divided into three heights respectively. And the seat according to the leg depth T in 280mm-380mm every 20mm divided into a total of 6 files. The physical diagram of the experimental setup is shown in Figure 6.



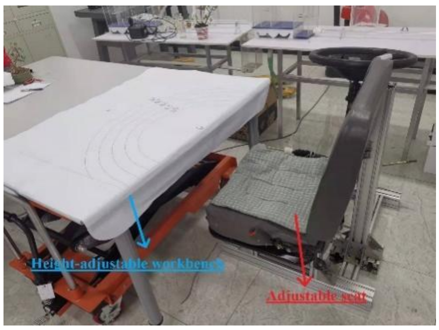


Figure 5:Arm comfort test device diagramFigure 6:Leg comfort test device diagram

Test posture: The subject sat on a fixed chair with the back close to the backrest of the chair, and the centerline of the body was kept coincident with the center line to ensure that the subject was located in a position right in the center of the working platform.(2) Measurement of arm working range comfort: The test platform was adjusted to a height of 700 mm, and the subject simulated writing, reading, and computer typing on the working platform. The tester reduced the subject's working area in turn, and the subject scored the comfort level according to his subjective feeling (0-10).(3) Measurement of leg working range comfort: the test platform is adjusted to 700mm height, the subject's leg is naturally placed on the adjustment pedal, the tester adjusts the foot stopper block in turn, and the subject scores the comfort level according to his subjective feeling (0-10).(4) By completing steps (1) to (3), the subject's arm working range comfort and leg working range comfort were measured at the remaining two experimental heights (800 mm and 900 mm).

III. RESULTS

3.1 Office sound comfort

According to the Figure 7, it can be seen that the office sound comfort is in the best range of about 50 decibels, and decreases with the increase of decibel value, and the two are roughly linear and inversely proportional. In general, considering the requirements of the acoustic environment of people in the office, the smaller the noise decibel, the best comfort. The results of the experimental data are shown in Table 1.

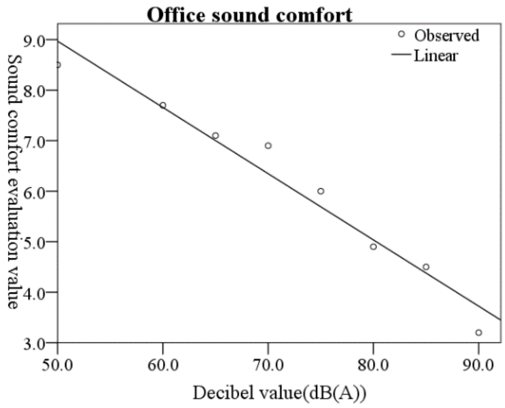


Figure 7:Fitted curve of low frequency sound comfort

Table 1: Sound comfort experimental data.

Decibel value (dB(A))	Score
50	8.5
60	7.7
65	7.1
70	6.9
75	6.0
80	4.9
85	4.5
90	3.2

3.2 Office light comfort

According to the Figure 8 and 9, it can be seen that the most comfortable illuminance at 3500K working condition is around 452.8lx, and the most comfortable illuminance at 5000K working condition is around 509.6lx. By comparing the comfort data of the two groups under different color temperatures, it can be seen that the illuminance value corresponding to the most comfortable area at 5000K is larger than the illuminance value corresponding to the most comfortable area at 3500K, and the office light comfort is higher at higher color temperature (warm color), which is more conducive to people to improve their work. The results of the experimental data are shown in Table 2.

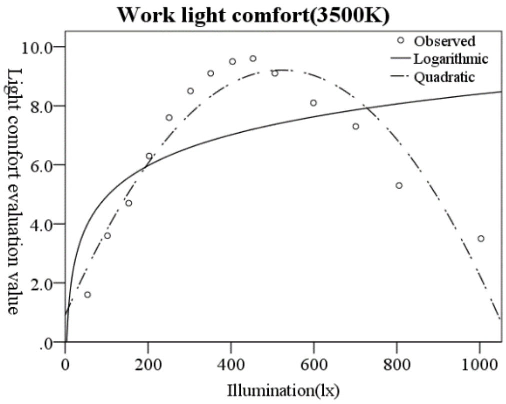


Figure 8:3500K Light Comfort Fitted Curve Chart

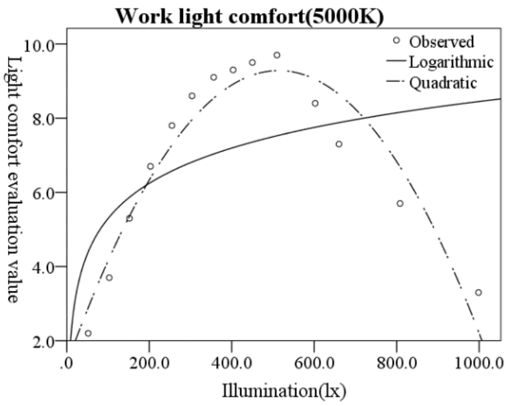


Figure 9:5000K Light Comfort Fitted Curve Chart

Table 2:Light comfort experiment data.

Illumination(xl)/3500K	Score	Illumination(xl)/5000K	Score
53.8	1.6	51.7	2.2
101.7	3.6	102.9	3.7
153.2	4.7	152	5.3
202.5	6.3	202.9	6.7
250.7	7.6	255	7.8
302.1	8.5	303.7	8.6
350.8	9.1	356.3	9.1
403.5	9.5	403.4	9.3
452.8	9.6	450.1	9.5
505.6	9.1	509.6	9.7
598.8	8.1	602.5	8.4
700.6	7.3	660	7.3
805.3	5.3	808.2	5.7
1002.8	3.5	998.5	3.3

3.3 Office Thermal comfort

According to the Figure 10, it can be seen that the comfort evaluation value keeps increasing as the temperature increases between 17.1℃ and 24.8℃, and decreases as the temperature increases between 24.8℃ and 30.9℃, reaching the maximum value at about 24.8℃. The results of the experimental data are shown in Table 3.

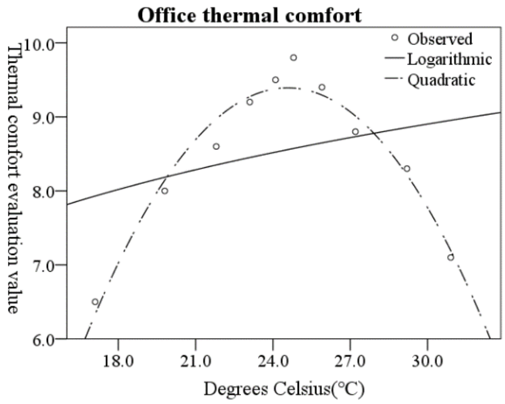


Figure 10:Thermal Comfort Fitted Curve Chart

Table 3:Thermal comfort experimental data.

Celsius(℃)	30.9	29.2	27.2	25.9	24.8	24.1	23.1	21.8	19.8	17.1
Score	7.1	8.3	8.8	9.4	9.8	9.5	9.2	8.6	8.0	6.5

3.4 Office arm comfort

According to the Figure 11, 12 and 13, among the three working heights of 700 mm, 800 mm and 900 mm, the average comfort level of 800 mm is the highest, followed by 900 mm and finally 700 mm. With the increase of the working circle radius, the comfort value of the arm also increases. The increase in the radius of the working circle is conducive to the continuous improvement of the arm comfort evaluation, which can effectively relieve the problem of soreness brought about by the bending of the arm when writing in the office. The results of the experimental data are shown in Table 4.

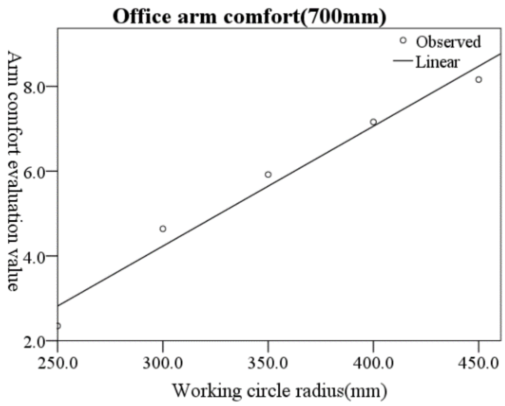


Figure 11:700mm Arm Comfort Fitted Curve Chart

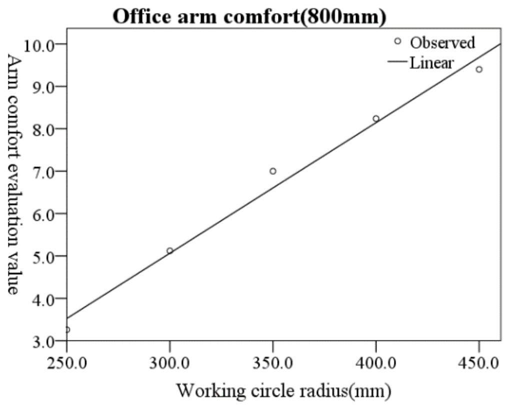


Figure 12:800mm Arm Comfort Fitted Curve Chart

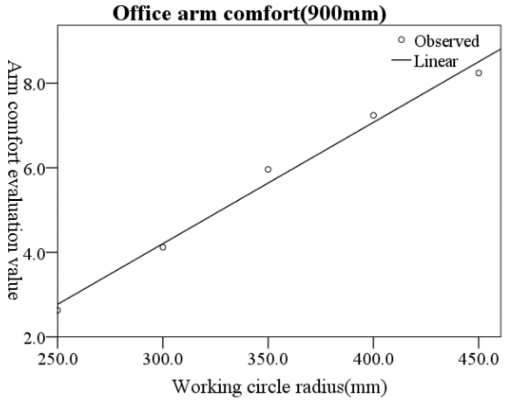


Figure 13:900mm Arm Comfort Fitted Curve Chart

Table 4:Arm comfort experimental data.

Working radius/comfort value (mm)	700 score	800 score	900 score
250	2.4	3.3	2.6
300	4.6	5.1	4.1
350	5.9	7.0	5.9
400	7.2	8.2	7.2
450	8.2	9.4	8.2

3.5 Office leg comfort

According to the Figure 14, it is known that the comfort rating value increases continuously with the increase of leg depth. More leg room means better leg comfort experience. The results of the experimental data are shown in Table 5.

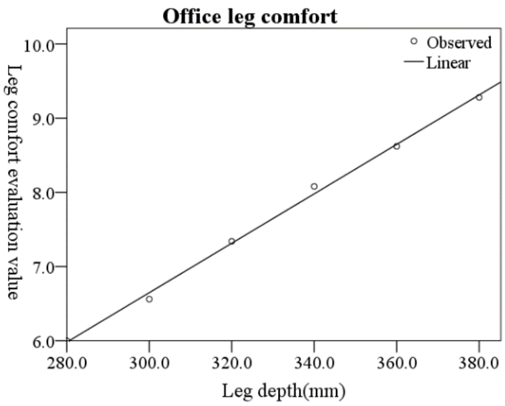


Figure 14:Leg Comfort Fitted Curve Chart

Table 5:Leg comfort experimental data.

Leg depth(mm)	Score
280	6.0
300	6.6
320	7.3
340	8.1
360	8.6
380	9.3

3.6 Comfort fit function

Based on the data results of the experiments a function was fitted using SPSS software to obtain Table 6.

Table 6:Fitting function of experimental data for each comfort level.

Sound comfort	Sound frequency working condition	Linear fitting function equation	R^2	Sig
	Low Frequency	$s_1 = -0.131d + 15.525$	0.958	0.000024
Light comfort	Color temperature working condition	Quadratic fitting function equation	R^2	Sig
	3500K	$L_1 = -0.00003i^2 + 0.0318i + 0.91$	0.894	0.000004
	5000K	$L_2 = -0.00003i^2 + 0.031i + 1.374$	0.918	0.000001
Thermalcomfort	Vehicle operating conditions	Quadratic fitting function equation	R^2	Sig
	Stationary	$T = -0.055c^2 + 2.695c - 23.717$	0.957	0.000017
Armcomfort	Height of working table from the ground(mm)	Linear fitting function equation	R^2	Sig
	700mm	$y_1 = 0.028x - 4.28$	0.977	0.001460
	800mm	$y_2 = 0.031x - 4.11$	0.988	0.000580
	900mm	$y_3 = 0.029x - 4.410$	0.990	0.000493
Legcomfort	Height of working table from the ground(mm)	Linear fitting function equation	R^2	Sig
	800mm	$y_4 = 0.033x - 3.334$	0.998	0.000002

3.7 Synthesis of comprehensive evaluation models

A survey questionnaire was conducted to consult practitioners and experts in the relevant fields. Statistically derive the judgment matrix D for sound, light, heat, arm and leg comfort in a vehicle office situation.

$$D = \begin{bmatrix} 1 & 1.92 & 1.25 & 0.81 & 1.18 \\ 0.52 & 1 & 0.65 & 0.42 & 1.82 \\ 0.8 & 1.54 & 1 & 0.65 & 2.27 \\ 1.24 & 2.38 & 1.55 & 1 & 2.82 \\ 0.85 & 0.55 & 0.44 & 0.35 & 1 \end{bmatrix}$$

The elements in the judgment matrix are normalized according to columns using the ensemble product method, and then the columns of the same row of the normalized matrix are summed up, and finally the weight ratio is calculated, and the calculation results are shown in Table 7.

Table 7:This is a hierarchical analysis of the judgment.

	Sound	Light	Thermal	Arm	Leg	ω_i
Sound	1	1.92	1.25	0.81	1.18	0.22456
Light	0.52	1	0.65	0.42	1.82	0.14328
Thermal	0.80	1.54	1	0.65	2.27	0.20905
Arm	1.24	2.38	1.55	1	2.82	0.30801
Leg	0.85	0.55	0.44	0.35	1	0.11510

The consistency test of the judgment matrix is carried out below, and the maximum eigen root of the judgment matrix can be calculated based on the already derived weights$\omega_i = (0.22456, 0.14328, 0.20905, 0.30801, 0.11510)^T$.The maximum eigen root$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(c\omega)_i}{\omega_i} = 5.1097$. $CI = \frac{\lambda_{max} - n}{n-1} = 0.027425$.When n=5 check the table to get RI=1.12, then $CR = \frac{CI}{CR} = 0.024487 < 0.1$. So, the judgment matrix meets the consistency requirement.

When synthesizing the comprehensive evaluation model of intelligent cockpit comfort, it is necessary to consider the boundary values of each evaluation value because several evaluation factors are involved. Combined with the evaluation idea of penalty type substitution synthesis, when the evaluation value of comfort of any single factor is the lowest, the evaluation value of comprehensive comfort should also be the lowest, and when the evaluation value of any one of the evaluation indexes of sound, light, heat, arm and leg comfort of intelligent cockpit comfort evaluation is 0, the result of comprehensive comfort evaluation is 0.That is, when $y_i = 0$, the evaluation value of the comprehensive comfort of the intelligent cockpit($(y_i - L)^{\omega_i}$) should be the minimum value, i.e., $Y = 0$. Therefore, the dimensionless function of a single factor takes values in the range of [0, 10]. The mathematical function max can be used to process so that the corrected evaluation value of the comfort of each first-level evaluation index is between [0, 10], as shown in equation (1).

$$Y_1 = \max(y_i, 0) \qquad (1)$$

According to the principle of penalized substitution synthesis, the dimensionless functions obtained from the above noise and vibration environment, light environment, thermal environment and human-computer interaction environment, and the weights of each level of evaluation index factors are substituted to obtain the expression of the comprehensive evaluation model of intelligent cockpit comfort, which is shown in the following equation (2).

$Y = L + [\max(0, y_1) - L]^{0.22456}[\max(0, y_2) - L]^{0.14328}[\max(0, y_3) - L]^{0.20905}[\max(0, y_4) -$ L0.30801max0,y5−L0.11510, where L=0. (2)

In this paper, we studied the office comfort under the smart cockpit scenario by Effective-Functions Comprehensive Evaluation and obtained the corresponding fitting functions for each indicator by fitting the experimental data to find the best range and change law of sound, light, thermal, arm and leg comfort under the office requirements. Through a questionnaire survey of relevant practitioners and experts in the automotive field, the weight distribution of sound, light, thermal, arm and leg when working in the intelligent cockpit was obtained, and the weight value of each index was obtained by using hierarchical analysis. Finally, the function model of overall office comfort is synthesized by using the evaluation idea of Penalty Substitution Synthesis Method.

IV. DISCUSSION

The weight of the interior comfort index accounts for 60 percent of the overall comfort, while the human comfort index accounts for 40 percent. It shows that in for passenger's sound, light and thermal comfort indicators are more important, followed by human comfort indicators consisting of arm and leg comfort. Among them, the arm factor has the greatest impact on the overall office comfort, followed by sound, thermal, light and leg comfort. Compared with the traditional people's perception of vehicle comfort, arm comfort and sound comfort account for a larger proportion, which may be related to the fact that the area where the arms work in the office is too small may affect people's work efficiency, and that the sound of external interference during the office will distract people's attention if it is too large.

After getting the intelligent cockpit comfort comprehensive evaluation model, you can get the intelligent cockpit comprehensive comfort value by inputting the value corresponding to each index. By in this method the subjective comfort of the intelligent cockpit office can be quickly determined. It provides a reference literature for future vehicle companies to plan the office function area of the vehicle cockpit. This paper solves the problem of lacking a comprehensive evaluation model of intelligent cockpit office comfort and the single traditional car comfort evaluation index cannot evaluate the overall comfort. The related subjective comfort evaluation experiments provide new ideas for future experimental research on office comfort of related intelligent vehicles.

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