Review of the Research on Car Seating Comfort

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Abstract. Improving car seating comfort is very important in the process of car development and design. This paper reviewed the research progress of car seating comfort at home and abroad. Firstly, the related concepts related to the comfort of car seats were introduced, and then the factors affecting the comfort were analyzed in depth. Finally, the subjective evaluation, objective behavior evaluation and physiological parameter evaluation methods for seating comfort were introduced with their advantages and possible problems being analyzed respectively. This paper will provide a large number of theoretical basis and important reference significance for the subsequent development of car seating comfort.

Keywords: Seating comfort · Subjective evaluation · Objective behavior evaluation · Physiological parameter evaluation

1 Introduction

Sitting posture is one of the most commonly used postures in people's work and life. However, being in a static sitting position for a long time can cause low back pain, cervical pain, sciatica, etc., and people with these painful conditions also feel uncomfortable [1, 2], which will affect people's work and living efficiency seriously. In addition, the comfort of people in a dynamic sitting position also requires special attention, especially the impact of collision and other special circumstances on the human body from car driving and airplane driving. People's daily lives are inseparable from cars, that is, cars have established connections with everyone as a means of off-road vehicles or transportation in today's society. China is in a rapid development, and more people will buy cars with the improvement of living standards. People' requirement for car is higher and higher, from to the prevention of collision damage in the past to the comfort requirements at present. Car seat is closely related with the driver. The number of vehicles in China has exceeded 100 million according to relevant

F. Rebelo and M. M. Soares (Eds.): AHFE 2019, AISC 955, pp. 296–304, 2020.
https://doi.org/10.1007/978-3-030-20227-9_27

literature, meanwhile the number of drivers suffering from back pain is more than 100 million [3]. Therefore, improving car comfort, especially seating comfort, has become particularly important in the development and design of cars. In recent years, car seating comfort has been studied as a unique subject.

At present, there have been many studies on the comfort of factory and office seats, but relatively few studies on the comfort of car seats. The research methods of car seating comfort mainly include experiment, computer simulation and prediction. The experiment mainly includes subjective investigation and analysis of vehicle comfort, sitting posture analysis, measurement of body pressure distribution, performance observation and electromyography based on physiology, etc. In addition, considering the convenience and low-cost of simulation calculation more and more researchers began to evaluate car driving comfort by simulation, such as the maximization analysis of driver's visual field, analysis of control distance of steering wheel and rudder and so on. Liqun et al. [4] established a multi-body dynamic model of the seat by using MATLAB to analyze the factors that had the greatest impact on the vibration transmission characteristics of the car seat, and made corresponding improvements. Kolich [5] in University of Windsor in Canada predicted the comfort of the car seating by using the neural network method, while Grujicic [6] in University of Clemson in the United States used finite element method to study the pressure of the driver and the car seat, and used it to evaluate the comfort of the car seat. The following is a detailed introduction of the research methods and theories of car seating comfort.

2 Theories

The comfort of car seating mainly includes static comfort, dynamic comfort (also known as vibration comfort) and operation comfort. Static comfort refers to the comfort characteristics provide by the seating to the human body in the static state, which is mainly related to the seating size parameters, surface, quality, adjusting characteristics etc. Dynamic comfort refers to the comfort characteristics of the vehicle which transmits vibration to the human body through the seating skeleton and cushion in the moving state, it mainly related to the vibration characteristics; Operational comfort refers to the comfort of the seating in the driver, the comfort characteristics for completing the driving action in the driving process [7]. In order to systematically understand the comfort of car seating, the following concepts are explained here.

(a) Static characteristics

The static characteristics of the seating mainly include the form and size of the seating, the material used in the seating and the coordination between the seating position and the working space.

(b) Dynamic characteristics

The dynamic characteristics of seating [8] refer to the relative subjective comfort that human body feels in the vibration environment. The dynamic characteristics of driving seating are mainly related to the vibration characteristics [9]. Vibration mainly comes from random vibration and mechanical vibration of the vehicle itself. It mainly brings vertical, longitudinal and transverse linear and angular vibration to the driver. Vertical vibration and angular vibration around longitudinal and transverse direction have the greatest influence.

(c) Transfer rate

Seating vibration transmission rate [10], also known as acceleration transmission rate, is the ratio of acceleration on the contact surface between seating and human body to the input acceleration of vehicle chassis excitation. The transmission rate of seating vibration is determined by the dynamic behavior of human body and seating systems.

(d) Apparent mass

Apparent mass [11] is the ratio between the excitation applied to a system and the response of the system to it. For example, the apparent mass of the human body in the vertical direction is the ratio between the force F exerted on the human body in the vertical direction and the acceleration a produced by the human body. That is $M = F/a$.

(e) Human body vibration sensitive frequency

The experimental results showed that the sensitive frequencies of human upper and lower vibration are within 4–8 Hz, and within 1–2 Hz, resonance occurs in some parts of the body.

(f) WILL Concept Seating

The design principle of WILL concept seating [13] is to provide safety support for the whole spine and head synchronously when collision occurs. When rear-end collision occurs, the back of the WILL Concept Seating will improve the fitness between the body and the seat.

(g) Parallel Vibration Reduction Principle of Positive and Negative Stiffness

Stiffness is defined as the ratio of load to deformation of spring. When the load increases with the increase of deformation, it is positive stiffness, and vice versa, it is negative stiffness. When the positive stiffness spring and the negative stiffness spring are connected in parallel, the total stiffness of the system in the negative stiffness region of the negative spring is smaller than that of the positive spring. The reduction is caused by the negative spring, which is the principle of the parallel elimination of the positive and negative stiffness [14].

(h) Five-degree-of-freedom model of human body-seating

In this model, the human-seating system is divided into five parts: head, upper trunk, lower trunk, buttocks, legs and seats in the vertical direction. The corresponding stiffness and damping coefficients are added to the model.

3 Influencing Factors of Car Seating Comfort

Among many factors, the car seating is an important part which links the occupant and driver with the body of the car, and the impact on comfort is the most direct. Vehicle seat comfort is a system engineering, which involves almost all the components of the car, including power, transmission, chassis, suspension, car shape, glass, seat, tire, sound, air conditioning, electronic configuration, noise and so on. These factors will produce different sensory stimuli to the driver and other passengers in the car, thus deciding the driving and riding comfort of the whole car from different aspects to different degrees. The factors affecting the comfort of car seats can be roughly divided into vehicle factors, social factors, individual factors and seating factors. Vehicle factors mainly include seating height, pedal and steering wheel orientation, body expansion space and shape setting of variable speed rocker. Social factors mainly include car brand and price, and the comfort level of car seats with different brand and price is different.

Individual factors mainly include demographic factors, anthropometric parameters, culture and sitting posture. Seating factors mainly include seat stiffness, geometric parameters, fabric permeability and seat style.

In addition, the noise environment inside and outside the car, air conditioning performance, operation panel, and luggage compartment also affect the rider's evaluation of seating comfort to varying degrees.

4 Evaluation Methods

At present, the evaluation methods of car seating comfort are mainly divided into three kinds: subjective evaluation, behavior detection evaluation and physiological parameter evaluation. Each comfort evaluation has several corresponding evaluation methods.

4.1 Subjective Evaluation

Subjective evaluation is an old and practical evaluation method, which can directly and clearly reflect the driving comfort performance of automobiles. Therefore, subjective evaluation method has been widely used and studied. In China, the study of automobile comfort is mostly based on subjective evaluation method. There are many methods of subjective evaluation. This paper briefly introduces several typical evaluation methods:

(a) Multi-level Fuzzy Comprehensive Evaluation

The multi-level fuzzy comprehensive evaluation is to quantify the fuzzy indicators reflecting the evaluated things by constructing a hierarchical fuzzy subset (determine the membership degree), and then use the principle of fuzzy transformation to evaluate the indicators comprehensively. The advantages are: the mathematical model is simple, the context is clear, and the multi-factor and multi-level complex problem evaluation effect is incomparable to other mathematical branches and models. The factors to be evaluated of the seat selected by the method include seat height, seating width and depth, seating angle, waist height, lumbar inclination and lumbar shape curvature [15].

(b) Body part discomfort size

This method divides the body into several parts, the subjects point out which they feel discomfort, and choose the degree of discomfort on the scale. Then the discomfort is sorted and processed. Finally, the BPD index of discomfort is obtained [16].

(c) Psychological measurement

Some researchers had cooperated in making used of SD method in psychological measurement to make a subjective evaluation of car ride comfort based on body vibration, indoor environment, occupant's psychological and physiological conditions. The hierarchical model of subjective evaluation of car ride comfort was constructed by introducing fuzzy measure and fuzzy integral in Fuzzy theory. The results showed that the hierarchical fuzzy integral model was suitable for subjective evaluation of vehicle ride comfort and had better calculation accuracy [17].

4.2 Objective Behavior Evaluation

The evaluation of objective behavior is mainly to provide quantitative testing results. Many evaluation methods have been developed. At the same time, with the development of testing technology, the testing of objective behavior has become more and more scientific. However, human comfort is a very vague concept, it is difficult to locate accurately, so there are still many areas to be improved in the existing testing methods.

(a) Measurement method of body pressure distribution

When a person sits on a chair, the gravity of the human body acts on the cushion and the backrest. The pressure distribution is called the body pressure distribution or the body stress distribution [18]. When a person sits down, most of the body weight (about 80%) is pressed on the seat surface through buttocks, back bulges and attached muscles. The reasonable distribution of body pressure is an important factor affecting ride comfort. At present, GM, Ford, Toyot, Honda, BMW, Volvo, Delphi and other companies are widely using Tekscan's pressure distribution measurement system to solve the seating comfort problem. In this system, more than 4000 sensors are arranged on the seating cushion and backrest to measure the effect of the support of the cover and the hardness of the sponge on the pressure distribution and comfort of the seating. At present, the body pressure distribution testing method has become a relatively simple and easy to operate seating comfort testing method.

(b) Apparent Mass Method

The driver is in a state of full body vibration during driving. The influence of vibration on driver's operation is mainly manifested in the decrease of visual operation efficiency and the deterioration of operation accuracy. In the vibration environment, human body will accelerate the fatigue process. If resonance occurs in a certain area or organ of human body, it will cause corresponding physiological changes, which involve muscular system, respiratory system, blood circulation system, vegetative nervous system and sensory system. When a certain limit is reached, the working intensity of cortical cells will be weakened, people will feel tired and work efficiency will be significantly reduced. Apparent mass method is to exert force on the human-seat system at different vibration frequencies, measure the acceleration of each part of the model, calculate the apparent mass of the corresponding part by using formula M = F/a, and get the relationship curve between the apparent mass and the vibration frequency. The dynamic performance of the seating is analyzed and vibration frequency has a great influence on the human body is determined, so as to improve and optimize the natural frequency of the seating and other parameters [11].

(c) Comparative method

The testing results showed that the factors affecting the dynamic characteristics of the seating were the stiffness and damping coefficient of the seating cushion, the mass, stiffness and damping coefficient of the suspension system and the dynamic performance of the seating frame structure, among which the stiffness and damping coefficient play a decisive role. The stiffness parameters determine the resonance frequency of the seating, while the damping coefficient determines the vibration attenuation characteristics of the seating. The comparison method is to measure the transmission rate of rigid seating and elastic seating under different vibration frequencies, and to compare the transmission rate of the two seats.

(d) Material performance testing of car seating cushion

When people are exposed to high humidity and high temperature, they often feel uncomfortable, limbs are weak and their work can not last long. Turkey's Tulin and Japan's Kazuaki's research on the influence of thermal environment on driver's driving comfort showed that the air permeability of backrest and cushion materials seriously affected sweat emission [18, 19]. In addition, the study also showed that drivers who prefer cushions and soft backs were susceptible to impact, but hard cushions were not susceptible to fatigue. Therefore, the air permeability and softness and hardness of cushion and backrest materials can be used as evaluation indexes of comfort.

e) Work Performance Testing

According to the statistics of relevant departments, there are as many as 1 billion road traffic accidents in the world every year. Recent studies showed that 25–30% of the causes of car crashes were caused by driving fatigue. Driving fatigue affects drivers' alertness and driving safety. Work performance testing is to evaluate the comfort of the seating by observing whether the performance of the driver after driving a car declines after a certain period of time.

(f) Modeling and simulation method

Due to the advantages of good repeatability, time-saving and labor-saving, more and more researchers had been beginning to use simulation methods to study the driving comfort of automobiles [20, 21]. Among them, more studies had been done on the vibration transmission characteristics of automobile seats and driver's posture prediction. A. Siefert et al. of Germany calculated the car seating and driver model by ABAQUS finite element method, and evaluated the comfort of the model according to the simulation results. This method can optimize the structure and comfort performance of the seat in the early stage of seat development and production, and could greatly reduce the production cost of the manufacturer [20]. Some used neural network, the method predicted the subjective evaluation of car seating and achieves good results, which could greatly reduce the number of evaluators and saved time and manpower when evaluating the seats comforting subjectively. Others used the optimized non-linear active suspension seating to conduct safety and comfort analysis, evaluated the comfort performance of different suspension seating, and concluded that they have. The seating comfort performance of semi-active or active suspension was improved by 20%–30% [22]. In addition, some people in China used MATLAB simulation to calculate the vibration transmission rate of the seat, which also had a good effect.

4.3 Physiological Parameter Evaluation

(a) EMG

The EMG mainly evaluates the driver's fatigue degree by testing the driver's EMG signal. The main muscles tested were left and right trapezius, erector spine and internal trapezius. The median frequencies of left and right trapezius, erector spine and internal oblique muscles are obtained by EMG signal analysis. The median frequencies can be used to determine whether the shoulder and waist muscles are fatigued due to the type and duration of the cushion (or both). The EMG signal of signal data acquisition system is usually collected by six electrodes.

Research showed that it could reflect the changes of muscle function. When muscle fatigue occurs, the power spectral density of EMG signals was gradually compressed in the direction of low frequency. This was due to the decrease of nerve conduction velocity directly related to membrane excitation, which leaded to the increase of low-frequency components of the signal, and the enhancement of this effect by the low-pass filter between the surface electrodes and the active muscle fibers. Calculated from the power spectrum was a very reliable index to measure this spectrum compression. The change of nerve conduction velocity of muscle fibers caused by lactic acid accumulation was related to the increase of frequency spectrum compression and fatigue degree, and then decreased with the increase of fatigue degree.

(b) Temperature and Humidity

Driver's comfort temperature is 18–23 °C, comfort humidity is 40%–60%, metabolic capacity is 1.0–2.0 met, higher or lower than this range will increase driver's fatigue degree. The main influence factors of driving seating on driver's thermal environment are temperature and humidity on the seating surface. The temperature and humidity characteristics of the seating surface will affect the heat dissipation performance of the back, buttock, lower body and the respiratory function of the skin. When the temperature and humidity characteristics of the seat surface do not adapt to the physiological function of the human body, it will cause the local discomfort of the human body, thus accelerating the formation of human fatigue. In the temperature and humidity testing method, the main test sensor is placed in the test site for testing. The data of skin surface humidity such as inner thigh, abdomen, chest, waist, buttock and back need to be tested.

(c) EEG

When the driver is tired, the brain responds slowly to traffic lights, speed restrictions, pedestrians and other traffic signals, and the corresponding electrical signals of brain tissue become weaker. EEG is to test the driver's EEG signal by EEG tester, analyze the EEG signal, judge whether the driving-related EEG is weakened, and then draw the conclusion of driver fatigue.

(d) Eye movement

Influenced by seating discomfort, drivers are prone to fatigue, eye observation ability is weakened, eye movement speed is reduced after long driving. Eye movement measurement is to use eye movement meter to test visual information, such as eye scanning trajectory, number of eyes, time of eyes, scanning range, interest area and so on. Through these basic features of the eye, we can judge whether the driver is tired when driving a car. At present, as a research means, this method has been widely used in the evaluation of driver fatigue, but it is different from seating comfort evaluation.

(e) Blood oxygen saturation

Measuring oxygen saturation of hip tissue is an important index for objective evaluation of comfort and endurance of subjects. The method of oxygen saturation testing is to use oxygen meter to collect oxygen saturation of lower limbs when subjects sit to reflect driver's comfort in the car seating. The measurement method is non-invasive and low-load. The main part of the medial gastrocnemius muscle is measured by near infrared light sensor.

5 Conclusions

Seating comfort is gradually attracting the attention of ordinary consumers and special workers, Diseases such as lower back pain, spine injury and pressure sore caused by seating discomfort will seriously affect the health and work efficiency of workers, and will increase the social medical burden. The research on sitting comfort is helpful to understand the indexes related to sitting comfort, and is of great value to the evaluation and improvement of seats and the improvement of driving comfort. From different angles, the advantages of experiment and simulation can be brought into play, which can help to accelerate the design of seating cushions with both comfort and safety.

Acknowledgments. This research was supported by 2017NQI project (2017YFF0206603), General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) science and technology planning project (2016QK177) and Project of the President's Fund for China National Institute of Standardization (522018Y-5984; 522016Y-4488).

References

1. Harrison, D.D.: Sitting biomechanics, part II: optimal car driver's seat and optimal driver's spinal model. J. Manipulative Physiol. Ther. **23**(1), 37–47 (2000)
2. Harrison, D.D.: Sitting biomechanics part 1: review of the literature. J. Manipulative Physiol. Ther. **22**(9), 594–609 (1999). Special subject of optimal seating in a car seat will be the subject of part II of this review
3. Concern about occupational diseases of driver's low back pain: "Car seat" affects health, in China Consumer Daily (2000)
4. Liqun, G.: Research on vibration transmission characteristics of commercial vehicle seats. Noised Vibr. Control **23**, 45–48 (2009)
5. Kolich, M.: Predicting automobile seat comfort using a neural network. Int. J. Ind. Ergon. **33**(4), 285–293 (2004)
6. Grujicic, M.: Seat-cushion and soft-tissue material modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants. Mater. Des. **30**(10), 4273–4285 (2009)
7. Xinglei, Z., Jianguo, G.: Research on automotive seat comfort technology. Traffic Stand. **7**, 200–203 (2009)
8. Tianbao, T.: Research on automotive seat comfort. Enterprise technology development. Technol. Dev. Enterp. **29**(1), 34–37 (2009)
9. Zilong, L.: Research on man-machine engineering design of automotive driving seat. Equip. Manuf. Technol. **7**, 21–23 (2009)
10. Demin, Z., Qichang, Z.: Research on vibration reduction of vehicle seats. J. Tianjin Univ. Technol. **22**(5), 34–38 (2006)
11. Stein, G.J.: Measurement and modelling of x-direction apparent mass of the seated human body-cushioned seat system. J. Biomech. **40**(7), 1493–1503 (2007)
12. Zuhua, J., Bin, H., Yuqing, Z.: Applied research on the comfort of bus driver seat system. Ind. Eng. Manag. **4**, 20–24 (2003)
13. Youzhi, X.: Improving design of automotive safety seat. J. Hubei Auto Ind. Inst. **23**(2), 78–80 (2009)
14. Qiang, Z., Lijie, G.: Design and simulation of positive and negative stiffness parallel spring vehicle seat suspension. Forest Eng. **25**(1), 33–36 (2009)
15. Jia, M.: Comfortable driving posture test and fuzzy evaluation. Ind. Eng. Manag. **4**, 121–125 (2008)
16. Zhenghua, W.: Subjective and objective evaluation models of car seat comfort. Autom. Eng. **28**, 817–819 (2006)
17. Jianzhong, L.: Construction of subjective assessment model for car ride comfort. Automob. Technol. **11**(9), 11–20 (1994)
18. Cengiz, G., Babalık, C.: An on-the-road experiment into the thermal comfort of car seats. Appl. Ergon. **38**(3), 337–347 (2007)
19. Yamashita, K.: Evaluation of summertime thermal comfort in automobiles. In: Yutaka, T., Tadakatsu, O. (eds.) Elsevier Ergonomics Book Series, pp. 299–303. Elsevier, Amsterdam (2005)
20. Siefert, A., Pankoke, S., Wölfel, H.P.: Virtual optimisation of car passenger seats: Simulation of static and dynamic effects on drivers' seating comfort. Int. J. Ind. Ergon. **38**(5), 410–424 (2008)
21. Kolich, M., Seal, N., Taboun, S.: Automobile seat comfort prediction: statistical model vs. artificial neural network. Appl. Ergon. **35**(3), 275–284 (2004)
22. Bouazara, M., Richard, J., Rakheja, S.: Safety and comfort analysis of a 3-D vehicle model with optimal non-linear active seat suspension. J. Terra Mech. **43**(2), 97–118 (2006)