Study on the Evaluation of Automotive Seat Comfort during Prolonged Simulated Driving

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Abstract. Prolonged driving can affect driver's lumbar and neck such as low back pain and cervical spondylosis. The purpose of this study is to clarify the relationship between drivers' comfort and their physiological parameters, the seat pressure distribution during prolonged driving in order to evaluate the comfort of different automotive seats. The experiment was performed on two actual automobiles. Six male drivers, aged 20 to 24 years participated in the simulated driving experiment in which the drivers sat in the car and simulated the driving movements in 2 hours. Electromyography (EMG), seat pressure distribution and oxygen saturation were measured during the experiment with subjective questionnaire. According to the results, MPF, MF, Pm and longitudinal pressure integral (PL) are high significant with the subjective comfort, otherwise the oxygen saturation was almost constant during the whole experiment which has little significance. Therefore from the study we can see the most sensitive part to feel discomfort during prolonged driving and the relationship between discomfort and physiological parameters was also clarified which can be used to find which automotive seat is more comfortable.

Keywords: automotive, seat comfort, electromyography, pressure distribution.

1 Introduction

In common parlance comfort may refer to both comfort and discomfort. But speaking precisely the item 'comfort' is associated with feelings of relaxation, well-being and aesthetics. While 'comfort' is connected with the aspects of 'favor', the item 'discomfort' characterizes the aspects of 'suffering'. Discomfort is associated with biomechanical factors that produce feelings of pain, numbness and stiffness.[1]

Time to spend on driving is increasing as the automotive becomes more and more popular. The comfort of automobile driving is one of the most important factors for consumers to assess the performance of automobile, it's related to the automobile's natural vibration performance and the driving environment, driver's physiological and Psychological status. However, prolonged driving can affect driver's lumbar and neck

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such as low back pain and cervical spondylosis. So it's important to find how to evaluate the comfort during prolonged driving in order to choose a more comfortable vehicle, especially for the automotive seat.

For car manufacturers, seating comfort is becoming more and more important in distinguishing themselves from their competitors. There is a simultaneous demand for shorter development times and more comfortable seats. Comfort in automobile seats is a multidimensional and complex problem. Many current sophisticated measuring tools were consulted, but it is unclear on which factors one should concentrate attention when measuring comfort.

The previous study mainly concentrate on the subjective survey, sitting posture analysis, pressure distribution, performance analysis and electromyography. Otherwise, simulation method is also used to evaluate the comfort of automotive seat which is more convenient and timesaving. The subjective survey is commonly used and is relatively reliably which because it doesn't need special measurement instrument and it's visual and easy to operate. However, it requires the experimenter to be professional and the results is hard to be quantified. Pellettiere, Parakkat [2] developed objective methods for determining and predicting human comfort in operation and prototype U.S. Air Force crew seat cushions and found some factors, such as muscular fatigue levels, that are suspected of being significant contributors of discomfort during seated long-term flight. Andreoni, Santambrogio [3] present a multi-factor method for the analysis of sitting posture and the resulting interactions of the car driver body with the cushion and the backrest. Kolich [4] demonstrates the viability of employing a neural network for the purpose of predicting subjective perceptions of automobile seat comfort. This study suggests that subjective perceptions of automobile seat comfort can be predicted using a neural network. Grujicic, Pandurangan [5] study the seating comfort for passenger-vehicle occupants using a finite element model which includes seat-cushion and soft-tissue material.

The purpose of this study is to clarify the relationship between drivers' comfort and their physiological parameters, the seat pressure distribution during prolonged driving in order to evaluate the comfort of different automotive seats.

2 Method

Experiment Design. The experiment was performed on two actual automobiles, automobile A is Chevrolet LOVA and automobile B is Volkswagen Santana. Six male drivers, aged 20 to 24 years participated in the simulated driving experiment in which the drivers sat in the car and simulated the driving movements in 2 hours (Fig.1). The subjects could adjust the automobile seat and tilt steering wheel initially but were not allowed to make readjustments thereafter. Electromyography (EMG), seat pressure distribution and oxygen saturation were measured during the experiment with subjective questionnaire.

Fig. 1. Simulated driving posture

Subjective Survey. It was decided to concentrate on physical discomfort of drivers rather than on mental discomfort in this study. Subjective surveys on comfort of several body parts (such as neck, shoulders, back, lumbar, thighs and buttocks) were conducted twice: ten minutes after the beginning of the experiment and ten minutes before the ending of the experiment. Discomfort in whole body is also included. Depending on the degree of discomfort, the test items were classified into seven levels from “very comfort” to “very discomfort” which were “very comfort”, “comfort”, “a little comfort”, “feel nothing” , “a little discomfort”, “discomfort” and “very discomfort”. Each level was accredited with different points ranging from 7 (very comfort) to 0 (very discomfort).

Electromyography. The instrument used in this experiment is MP150 (Fig.2), and the recording software is Acqknowledge 3.8.1.

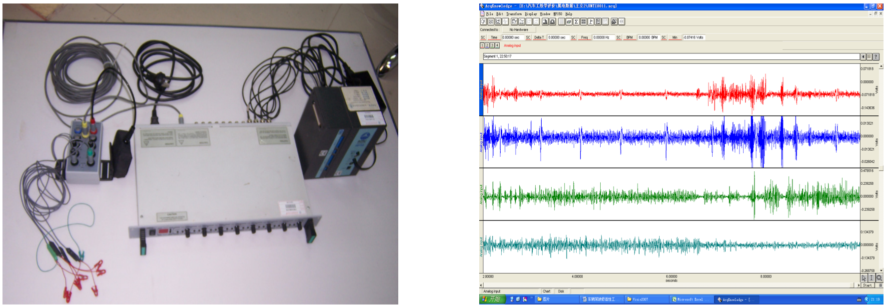


Fig. 2. EMG test device and measurement output screen

EMG (electromyography) was continuously monitored from 4 muscle sites during the 120-minute simulated driving with bipolar surface electrodes through a 50–200 Hz band-pass filter. Sampling rate was 1000Hz. Each electrode in a pair was set 5 cm apart from each other. Two pairs of surface EMG electrodes (Ag/AgCl electrodes) were, after abrasion and cleaning of the skin with alcohol, bilaterally attached to the skin over: the left and right latissimus dorsi (L1 level) and the left and right trapezius muscles. (Fig.3)

Fig. 3. Location sites of the electrodes

Pressure Distribution. The pressure distribution appears to be one of the most objective measure comprising with the clearest association with the subjective ratings.

During the experiment the subject-cushion and subject-backrest seat pressure distribution was measured with two sensor sheets (Pliance X. System, Germany-Novel Electronics, Germany) (Fig.4) and it was measured only once, ten minutes after the beginning of the experiment.

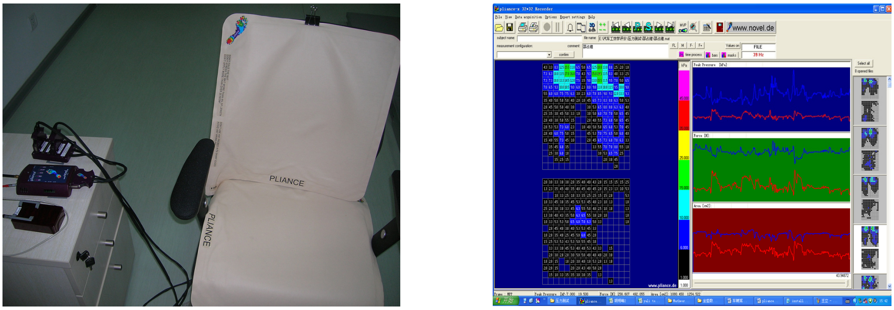


Fig. 4. Pliance X. System and measurement output screen

The experimental procedure is as follows:

1. Fix the sensor sheets on the seat cushion and backrest;
2. Let the participant sit on the sensor sheets and keep the driving posture;
3. When the pressure is steady, start to acquire the pressure data which lasts 20 seconds.

Oxygen Saturation. Regional blood oxygen saturation of right foot thumb in the lower extremities was measured every 20 minutes with clop-on oximeter (Fig.5).

Data Analysis. The root-mean-square (RMS), mean power frequency (MPF) and medium frequency (MF) of the EMG signal for each muscle measured were calculated. The contact area, maximum pressure (Pm) and longitudinal pressure integral (P_L) of pressure distribution for each automotive were got. The correction between these parameters with the subjective results was also studied to find their relationship.

Fig. 5. Oximeter

3 Results and Dopiscussion

3.1 Subjective Survey

The subjective questionnaire showed that the first three discomforting parts are lumbar, thigh and the neck. From the results, we can see that after prolonged driving the lumbar will be affected most significantly which is due to there is no support for the lumbar. Figure 6 shows the comfort rating of lumbar before and after the driving experiment for automobile A and B. It shows that the lumbar comfort decreased significantly for both automobile A and B. However, there is no significant difference between automobile A and B which automobile B is a little more comfort after the driving experiment than automobile A. From figure 7, we can see that automobile B is more comfort overall than A both before and after the experiment.

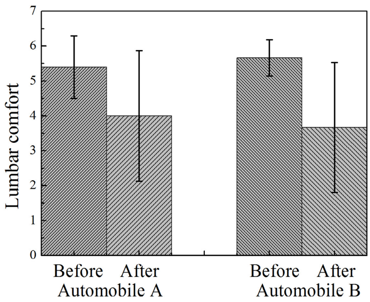


Fig. 6. Lumbar comfort rating before and after the experiment for automobile A and B

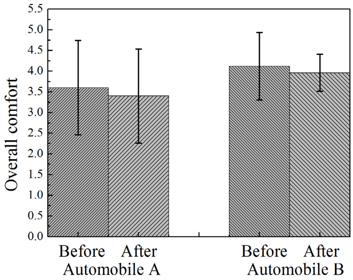


Fig. 7. Overall comfort rating before and after the experiment for automobile A and B

3.2 Electromyography

The EMG root-mean-square (RMS), median frequency (MF) and mean power frequency (MPF) are analyzed to find the correction of these parameters with subjective ratings.

RMS is calculated through (1)

$$RMS=\sqrt{\frac{1}{n}\sum_{i=1}^{n}s_i^{\ 2}} \qquad (1)$$

Where S_i is the EMG signal.

MF is calculated through (2)

$$\int_0^{MF} PSD(f)df = \int_{MF}^{0} PSD(f)df = \frac{\int_0^{\infty} PSD(f)df}{2} \tag{2}$$

Where PSD is the power spectral density.

MPF is calculated through (3)

$$MPF = \frac{\int_{-\infty}^{+\infty} \omega F(\omega)d\omega}{\int_{-\infty}^{+\infty} F(\omega)d\omega} \tag{3}$$

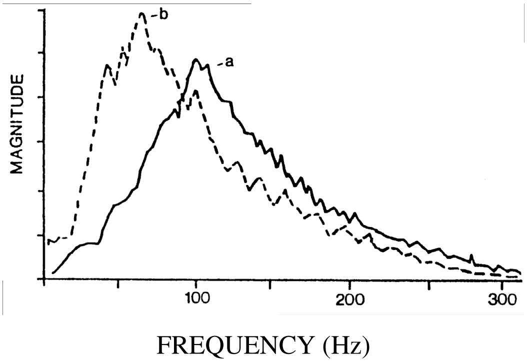


Fig. 8. Power density spectra of the EMG signal at the beginning (a) and the end (b) of the constant force segment of the muscle contraction[7]

According to the previous study, fatigue-related decreases in voluntary muscle activation to maintain given muscle power output (i.e. dynamic task failure) have been exclusively assessed by the measurement of the EMG signal during maximal voluntary isometric contractions[6]. The EMG MF is an effective parameter for measuring changes in EMG waveform that are associated with metabolic correlates to fatigue (Fig. 8)[7]. Because the MF is a spectral estimate of a stochastic signal, it was necessary to monitor this parameter only during isometric, constant-force contractions (i.e. during lifting of some weight) when conditions of EMG signal stationarity could be satisfied.[8] Generally, the MF will shift to the lower frequency while the relevant muscle becomes fatigued[9-11]. The overall decrease in the initial value of the MF for each test contraction was used as an indication of whether localized physiological fatigue was present. The RMS, MF and MPF were calculated using a program developed by MATLAB.

Figure 9 and figure 10 shows the change in the mean normalized RMS of the EMG for each automobile tested in lumbar and shoulder. The RMS measures were normalized

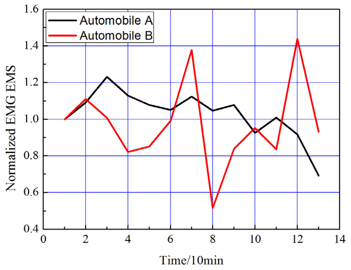


Fig. 9. Normalized RMS value of EMG for lumbar

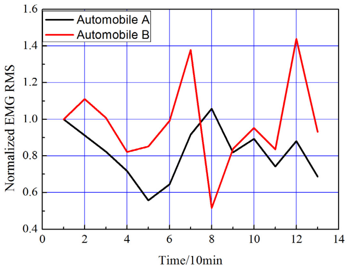


Fig. 10. Normalized RMS value of EMG for shoulder

to the baseline value as level 1. The results of figure 9 and 10 both demonstrate that automobile A was associated with the greatest decrease in RMS, whereas automobile B showed slight decrease in RMS activity during the two hour driving period. The results mean that automobile A is easier to make drivers fatigued than automobile B which is consistent with subjective ratings.

Figure 11 and figure 13 show that the MF and MPF of people in automobile A decrease during the simulated driving experiment which showed the driver felt uncomfortable with fatigue.

Figure 12 and figure 14 show that the MF and MPF of people in automobile B slightly increase during the simulated driving experiment which show the driver didn’t get fatigued. It’s not sure to conclude that people can become comfortable during the prolonged driving, however based on the variation of MF and MPF automobile A is easier to make people uncomfortable than automobile B. Meanwhile, the MF of latissimus dorsi decreased faster than the trapezius muscles which meant the lumbar was easier to get fatigued or uncomfortable than the shoulder during the prolonged simulated driving, and this did also match with the subjective feelings. The MPF of automobile A decreased larger than automobile B which meant automobile A was easier to make the driver fatigued than automobile B.

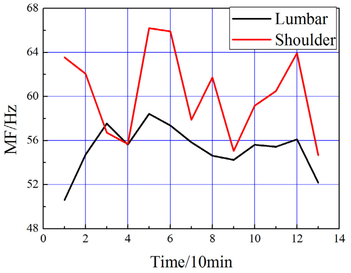


Fig. 11. MF along with time for automobile A

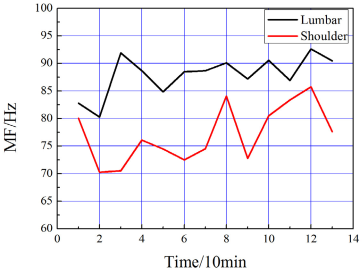
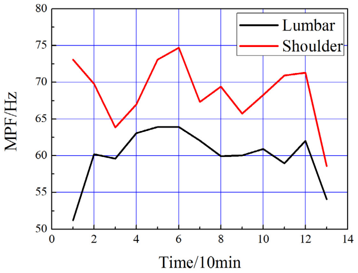


Fig. 12. MF along with time for automobile B



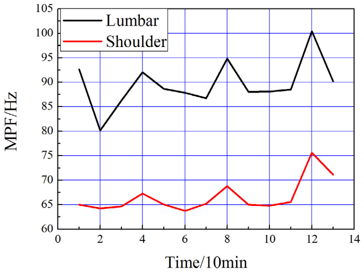


Fig. 13. MPF along with time for automobile A

Fig. 14. MPF along with time for automobile B

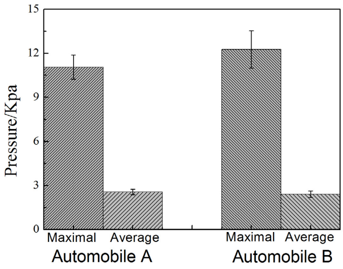
3.3 Pressure Distribution

According to figure 15 and figure 16, the maximal pressure of automobile 2 is higher than automobile A, otherwise the average pressure of automobile A and B is similar. The maximal pressure on seat cushion is 10kPa for automobile A and 12kPa for automobile B. The maximal pressure on backrest is about 5kPa for automobile A and 6kPa for automobile B. The results mean that the hardness of automobile B's seat cushion and backrest is larger than automobile A's. Since the soft interface will be easier to make people fatigue than hard interface, so automobile B will make people feel more uncomfortable than automobile A during prolonged driving.

Pm is calculated through (4)

$$P_m = \max(P_1, P_2, \ldots\ldots P_N) \tag{4}$$

Where N is the number of sensors in the sensor sheets.



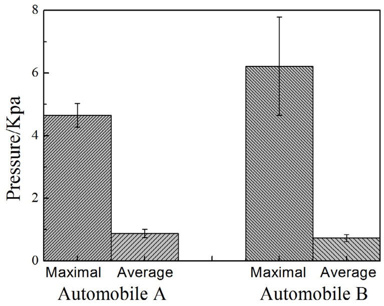


Fig. 15. Maximal and average pressure on seat cushion

Fig. 16. Maximal and average pressure on backrest

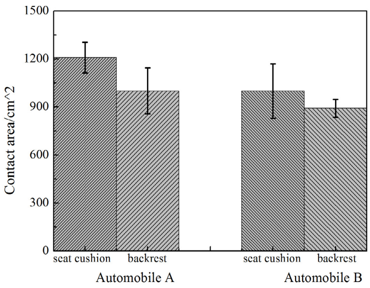


Fig. 17. Driver-seat contact area

Figure 17 shows the driver-seat interface contact area for automobile A and B. The results demonstrate that automobile A's contact area is larger than automobile B which means automobile is softer than automobile. So during prolonged driving, automobile A is easier to make people fatigued.

According to figure 18 and figure 19, the longitudinal pressure integral (P_L) of automobile A and B is similar with each other. However the maximal pressure of automobile B appears earlier which is near to the truck than automobile A. In figure 18, the proximal thigh of automobile B will bear larger pressure and compress the nerve and vascular which will make people fatigue.

P_L is calculated through (5)

$$P_L(x_i)=\sum_{j=1}^{N}P(x_i,y_j)\bullet\Delta L_j \tag{5}$$

Where $P(x_i, y_j)$ is the pressure in site (x_i, y_j).

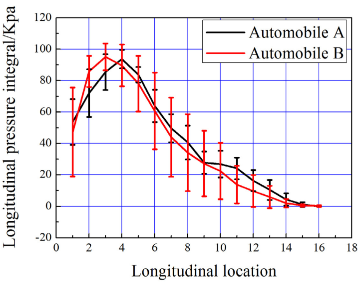


Fig. 18. Longitudinal pressure integral on seat cushion

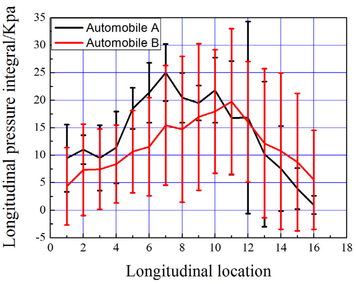


Fig. 19. Longitudinal pressure integral on backrest

3.4 Oxygen Saturation

Figure 20 shows the variation of oxygen saturation during the prolonged driving which the oxygen saturation was steady and didn't change much in the whole time. That's perhaps the vascular doesn't be compressed and the toe's blood is sufficient.

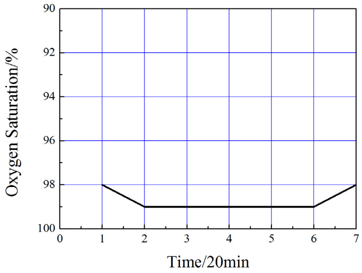


Fig. 20. Oxygen saturation along with time

4 Conclusion

Subjective ratings, EMG, sitting pressure distribution and oxygen saturation were measured to evaluate the comfort of two kinds of automobiles. Subjective ratings of the lumbar are sensitive to the driving comfort. By comparing the variation of MPF and MF with the subjective ratings, the decrease of MPF and MF can indicate the fatigue of drivers or discomfort. The maximal pressure, average pressure, contact area and longitudinal pressure integral were analyzed, maximal pressure is relate to the hardness of seat cushion and backrest. According to previous study, driver will be easier to get fatigued with soft seat cushion during prolonged driving and hard seat cushion will make driver more comfort. From the results, automobile B's seat cushion is harder than automobile A, so we can conclude that automobile B can be more comfort than automobile A which is in accordance with the subjective ratings. The longitudinal pressure integral is relate to the feeling of numbness from thigh that larger longitudinal pressure integral will easier to make driver fell uncomfortable. The results of oxygen saturation show that it is constant during the prolonged driving, so in this experiment this index is not suitable.

Overall, MPF and MF of EMG, Pm and P_L of pressure distribution are high significant with the subjective comfort, otherwise the oxygen saturation was almost constant during the whole prolonged simulated driving experiment which has little significance. The decrease of MPF and MF indicate the fatigue or discomfort of driver, large Pm and PL are in favor of the comfort of driver. Based on the objective results, automobile A is more comfortable than automobile B which is in accordance with the subjective results. Therefore from the study we can see the most sensitive body part to feel discomfort during prolonged driving and the relationship between discomfort and physiological parameters was also clarified which can be used to find which automotive seat is more comfortable.

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