Subjective and Objective Measurements for Comfortable Truck Driver's Seat

CheeFai Tan, Frank Delbressine, Wei Chen and Matthias Rauterberg

Designed Intelligence Group,
Department of Industrial Design
Technical University Eindhoven,
Den Dolech 2, P.O.Box 513,
5600 MB Eindhoven, THE NETHERLANDS.
Phone: (+3140) 247 2514
Fax: (+3140) 247 3285
E-mail: c.f.tan@tue.nl

Technology has changed trucks significantly over the years. As a result, consumer expectations, in terms of performance, have risen. In Western society, the comfort of products has developed into an important issue. Truck manufacturers recognize comfort as one of the major selling point, as it is thought to play an important role for buyers as well. In addition, employers are getting interested in comfortable equipment for their employees in order to create a healthy and stimulating working environment. The seat is one of the most important components for truck driver. They are the place where professional truck driver spend most of their time. The aim of this paper is to describe the measurement methods that are used to improve the physiological comfort of truck driver's seat. The paper has 3 sections. First, we explain the nature of sitting comfort and discomfort. Secondly, we describe the subjective and objective measurement methods that are used to evaluate the truck seat. Thirdly, we propose a methodology for the development of comfortable truck driver's seats.

24. Truck & Heavy Duty Vehicle

1. INTRODUCTION

Comfort is an attribute that today's drivers demand more and more. The driver comfort depends on different features and the environment during driving. Seat comfort is a subjective issue because it is the customer who makes the final determination and customer evaluations are based on their opinions having experienced the seat [1]. One of the products often considered in truck industry is the driver's seat. The truck driver's seat has an important role to play in fulfilling the driver comfort expectations. The seat is one of the important features of the vehicle and is the place where the truck driver spends most of time. According to the 'European Union Legislation for Drivers and Promote' [2], the weekly driving time for truck drivers shall not exceed 56 hours. Assuming nine weeks of vacation, results in 2408 hours driving time per year. Commercial trucks are unique in that they are specifically designed to transport loads over long distances, in contrast to passenger vehicles which are designed for individual comfort. Therefore the truck driver's seat plays an important role to position the driver to perform the task of driving, meet the safety requirements, and be acceptable to the driver's comfort needs. In this paper, we describe sitting comfort and discomfort, in particular objective and subjective measurement of truck seats, and proposes a methodology for comfortable truck driver's seats.

2. SITTING COMFORT AND DISCOMFORT

The Cambridge Advanced Learner's Dictionary defines comfort as a pleasant feeling of being relaxed and free from pain. Hertzberg [3] describes comfort as absence of discomfort. The term "seat comfort" is typically used to define the short-term effect of a seat the human body [4]. Comfort is a generic and subjective feeling that is difficult to measure, interpret, and related to human physiological homeostasis and psychological well being [5]. Generally, comfort issues not under debate by researchers are [6]: (1) comfort is a construct of a subjectively-defined personal nature; (2) comfort is affected by factors of various nature (physical, physiological, psychological); and (3) comfort is a reaction to the environment.

The concepts of comfort and discomfort in sitting are under debate. There is no widely accepted definition, although it is beyond dispute that comfort and discomfort are feelings or emotions that are subjective in nature [6]. Seating discomfort has been examined from a number of different perspectives. The problem with evaluating comfort in regards to pressure or any other factor is that, comfort is subjective and not easy to

Table 1 Causes of Seating Discomfort [10]

Human experience mode	Biomechanical		Seat/environment
	Physiology causes	Engineering causes	source
Pain	Circulation occlusion	Pressure	Cushion stiffness
Pain	Ischemia	Pressure	Cushion stiffness
Pain	Nerve occlusion	Pressure	Seat contour
Discomfort	-	Vibration	Vehicle ride
Perspiration	Heat	Material Breathability	Vinyl upholstery
Perception	Visual/auditory/tactile	Design/vibration	Vehicle cost

quantify. Seating discomfort varies from subject to subject and depends on the task at hand. Comfort, however, is a vague concept and subjective in nature. It is generally defined as lack of discomfort [7].

For example, truck drivers require sitting for long periods of time approximately eight hours. The extended period of sitting includes higher risk of back problems, numbness and discomfort in the buttocks due to too high surface pressure under the thighs [8]. The study by Adler et al. [9], shows that the driver posture is not static and changes over time. Posture changes and continuous motion are strategies of the driver to avoid mechanical load and ischemia of tissue, which has been identified as one main reason for discomfort. Discomfort feelings, as described by Helander and Zhang [10], is affected by biomechanical factors and fatigue. The sources of such discomfort are listed in Table 1. Zhang [11] presented a model that illustrates the interaction of comfort and discomfort as shown in Fig. 1. Transition from discomfort to comfort and vice versa are possible in the intersection of the axes. Hence, if discomfort is increased, such as with a longer time within task and fatigue, comfort will decrease. Its means that good biomechanics may not increase the level of comfort, it is likely that poor biomechanics turns comfort into discomfort.

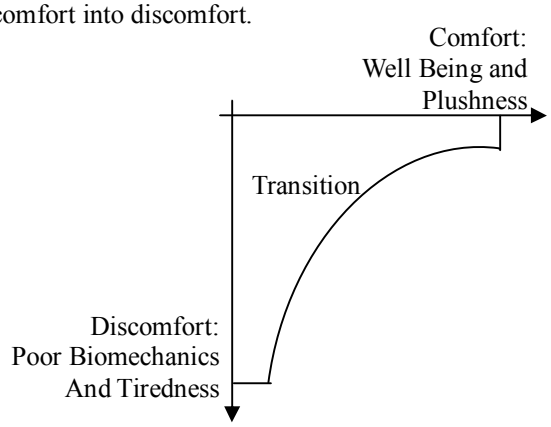

Fig.1 Hypothetical Model of Discomfort and comfort [11]

3. OBJECTIVE AND SUBJECTIVE MEASUREMENT OF SEAT COMFORT AND DISCOMFORT

The comfort experienced by humans while seating can be classified as a subjective assessment, because it is possible to find a variation with different people in a same situation. Nevertheless, the factors on which the opinions of people on comfort or discomfort level are based on physical variables that characterize the seat, for example, pressure, vibration, posture and temperature.

The comfort offered by a seat is relatively easy to determine by many measures [12, 13], the most effective of which is to survey potential users of the seat as they compare the "feel" of a seat for a short period of time against other seats in the same class. This practice is often adopted for different vehicles, ranging from passenger vehicles to commercial vehicles such as trucks, busses, and off road vehicles. The problem, however, with subjective evaluations is that they are costly and time-consuming. A great deal of research has been performed in recent years to find objective measures for predicting seat comfort perception. Some of the proposed objective measures include vibration, interface pressure, and muscle activity. These objective measures are correlated with subjective data to determine the relative effects of each measure related to comfort [14]. Research has shown that some of the main factors that affect seating comfort are seat-interface pressure distribution, whole-body vibration and pressure change rate [15].

A literature search in ScienceDirect and SAE Technical Paper databases obtained various studies that related to the objective and subjective measurements in relation to vehicle seat.

3.1 Objective Measurements of Automotive Seat Comfort

A vast majority of objective measures used for evaluating comfort and discomfort. From the literature search, the objective measurement methods for seat such as pressure distribution, posture, computer-aided design (CAD), computer-aided engineering (CAE), temperature, humidity, vibration, electromyography (EMG), and adrenaline. Fig. 2 shows an overview of studies in relation to objective measurements for seat comfort and discomfort.

From our findings, nine studies were found in which pressure measurement are used to study the discomfort feeling among truck drivers. Pressure measurement methods are the most used method for the seat developer to measure the comfort and discomfort of seated persons. The instruments that are used in pressure measurement such as pressure mat, pressure monitor system (Tekscan), force sensor, seat deformation measuring device and pressure imaging system.

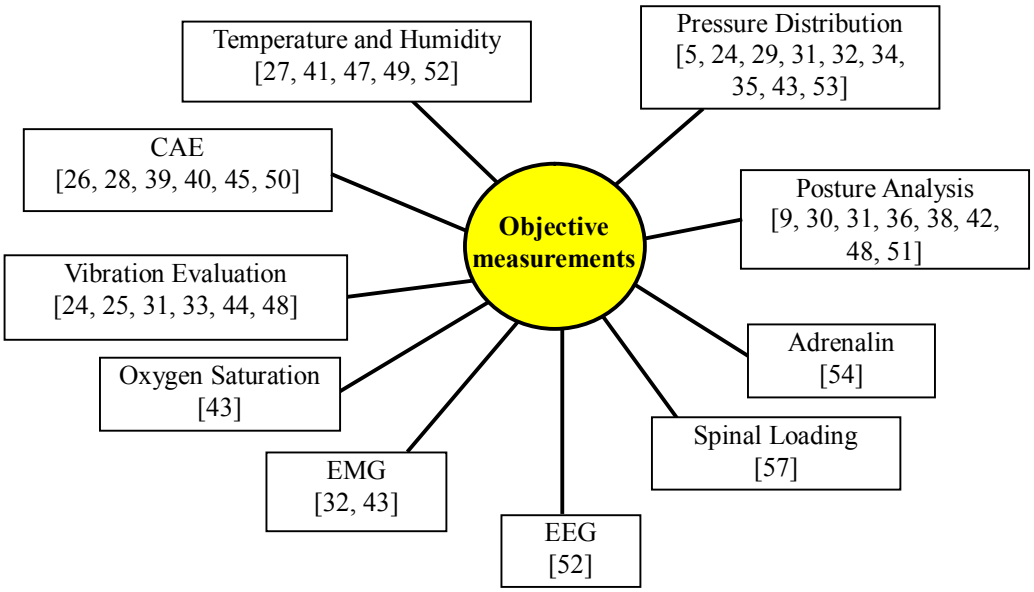

Fig. 2 Overview of Studies Related to Objective Measurements for Seat Comfort and Discomfort.

There are eight studies were related to posture measurements. The automotive industry strongly encourages research in the field of objective comfort assessment, especially dedicated to the seat and the related postures [16, 17]. Driver posture is one of the most important issues to be considered in the vehicle design process [18] regarding not only the car and the user [19, 20] but also the experimental conditions. The instruments used in posture measurement are camera, optoelectronic system (ELITE), a driving posture monitoring system, digital signal processing, ultrasonic device (Zebris), 3D motion analysis (Vicon), and a motion measurement system (Qualisys).

For vibration measurement methods, six studies were found. A major portion of the vibrations experienced by the occupants of an automobile enters the body through the seat [21]. Whole-body vibrations, which are vertical vibrations, tend to affect the human body the most. These vibrations are transmitted to the buttocks and back of the occupant along the vertebral axis via the base and back of the seat [22]. The instruments used is a vertical vibration simulator, angulator rate sensor, accelerometers and a whole body vibration measurement (Maestro).

Six studies used computer-aided engineering (CAE) methods to measure the seated person comfort such as finite element method (FEM), virtual humans, simulation software (Ramsis and Madymo), and artificial intelligence software (Neural Networks).

Other studies for objective measurements are related to the human physiology. The physiology of human such as the brain, muscles, heart, skin and spine can be used to measure the seated person comfort or discomfort level. Spinal load measurements have been performed in two studies. Five studies are carried out to measure the skin temperature and humidity level. Two studies using electromyography (EMG) to measure the muscle reaction in relation with the subject discomfort feeling. There is a study which used the Adrenalin content in the urine to measure the driver's stress level. Besides, the brain activity can be detected by electroencephalography (EEG) as well as oxygen saturation can be used to measure discomfort level of seated persons.

3.2 Subjective Measurements of Automotive Seat Comfort

Kolich [4] described that due to the lack of proven analytical metrics, vehicle manufacturers have opted to rely on subjective evaluations as the main indicator of seat comfort. The vehicle manufacturers developed elaborative subjective evaluation protocols that involved highly structured questionnaires. The questionnaires direct occupants to assign feelings of discomfort to a specific region of seat. The questionnaires, which typically contain numeric scales (e.g. 1 = very uncomfortable to 10 = very comfortable), produce subjective ratings that are translated into performance requirements/specifications [24]. A properly designed questionnaire is paramount because it gives researchers an instrument from which to establish theories [23]. Fig. 3 shows the overview of studies in relation to subjective measurements for seat comfort and discomfort.

Local discomfort ratings are used to measure the discomfort of subjects while sitting. According to Kolich [4], many researchers have adopted Hertzberg [3] definition because, in the current environment, it is more straightforward to quantify discomfort than to measure comfort. The local discomfort rating scale can be rate on a scale such as 1 to 10 or -10 to 10. Shen and Parsons [5] used the category partitioning scale (CP50) for rating seated pressure intensity and perceived discomfort. There are sixteen studies related with local discomfort rating. Whereas there are six studies related to local comfort rating.

Subjective measurement also involve the used of body mapping technique. In this the subject will be rating the body areas experiencing discomfort and to rate this discomfort on a scale. Seven studies are

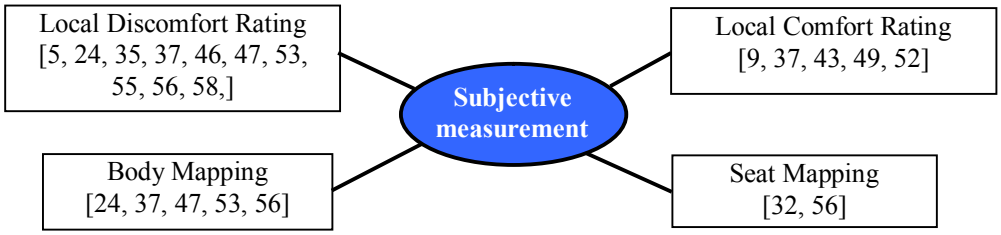

Fig. 3 Overview of Studies Related to Subjective Measurements for Seat Comfort and Discomfort.

rate this discomfort on a scale. Seven studies were involved in the use of body mapping method. In addition, there are two studies involving seat mapping. Like body mapping method, seat is divided in different areas and subject is asked to rate on a scale.

5. PROPOSED METHODOLOGY FOR COMFORTABLE TRUCK DRIVER'S SEAT

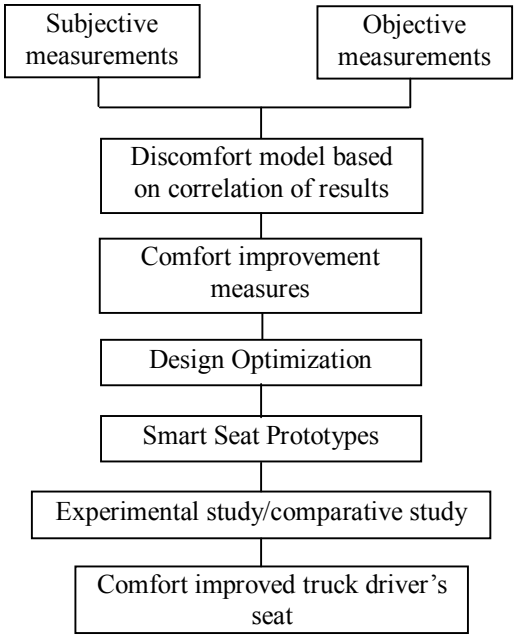

Fig. 4 Proposed Methodology Framework for Comfortable Truck Driver's Seat

A methodology is proposed to improve the comfort of truck driver's seat as shown in Fig. 4. Subjective and objective measurement methods are used to study the truck driver's sitting discomfort while driving. The subjective methods will be a questionnaire and an observation technique. The objective methods will be integration of bio sensors and measurement equipment into the seat to obtain physiological and postural data from driver. After that, both subjective and objective data will be analyzed to obtain the correlation data. A comfort improvement measure will be designed based on comfort ranking. After that, the design will be optimized and prototypes will be developed with the optimized comfort characteristics. The developed prototypes will be tested through experiment to validate the design. Finally, a comfort improved truck driver's seat will be developed.

6. CONCLUSION

In this paper, a methodology framework for the development of comfortable truck driver's seat has been proposed. The literature review from various studies related to seat comfort research show that the pressure distribution method is the most common method for objective measurement of seat (dis)comfort. It is followed by posture analysis method. The local discomfort rating and body mapping method is the most frequently used methods for subjective measurement. Discomfort is the subjective experience, which can result from a combination of physiological and psychological processes, total time spend on task and body posture assessed for the task related to the muscle fatigue. Our aim is to improve current truck driver's seat to reduce driver fatigue especially for long haul truck drivers.

REFERENCES

[1] Runkle, V.A., "Benchmarking Seat Comfort", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 1994, SAE Technical Paper No. 940217.

[2] http://www.euractiv.com/en/transport/drivers-deplore-inconsistent-eu-working-time-laws/article-166879. Accessed on 10 November 2007.

[3] Hertzberg, H.T.E. 1972, "The Human Buttocks in Sitting: Pressures, Patterns, and Palliatives", Society of Automotive Engineers, Inc., New York, NY, USA, 1972, SAE Technical Paper no. 72005.

[4] Kolich, M., "Review: A Conceptual Framework Proposed to Formalize the Scientific Investigation of Automobile Seat Comfort", Applied Ergonomics, Vol. 39, No. 1, 2008, pp. 15-27.

[5] Shen, W. and Parsons, K. C., "Validity and Reliability of Rating Scales for Seated Pressure Discomfort", International Journal of Industrial Ergonomics, Vol. 20, 1997, pp. 441-461.

[6] De Looze, M. P., Kuijt_Evers, L. F. M. and Dieen, J. V., "Sitting Comfort and Discomfort and the Relationship with Objective Measures" Ergonomics, Vol. 46, No. 10, 2003, pp. 985-997.

[7] Shen, W. and Vertiz, A., "Redefining Seat Comfort", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 1997, SAE Technical Paper No. 970597.

[8] Floyd, W.F. and Roberts, D.F., "Anatomical and Physiological Principles in Chair and Table Design", Ergonomics, Vol. 2, 1958, pp. 1-16.

[9] Adler, S., Friedrichs, A. and Blickhan, R., "Analysis of Driver Seated Posture to Objectively Measure Long-term Discomfort", Proc. of 6th World Congress

on Ergonomics, Maastricht, the Netherlands, 2006.
[10] Helander, M. G. and Zhang, L., "Field Studies of Comfort and Discomfort in Sitting", Ergonomics, Vo. 20, No. 9, 1997, pp. 865-915.
[11] Zhang. L., "Identifying Factors of Comfort and Discomfort in Sitting", Human Factors, Vol. 38, No. 3, 1996, pp. 377-389.
[12] Viano, D.C. and Andrzejak, D. V., "Research Issues on the Biomechanics of Seating Discomfort: an Overview with Focus on Issues of the Elderly and Low-Back Pain", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 1992, SAE Paper No. 920130.
[13] Gruber, G. J., "Relationship between Whole body Vibration and Morbidity Patterns Among Interstate Truck Drivers", Southwest Research Institute, San Antonio, Texas. Center for Disease Control Publication No.77-167, Cincinnati, Ohio, 1976.
[14] Nawayseh, N. and Griffin, M. J., "Effect of Seat Surface Angle on Forces at the Seat Surface During Whole-body Vertical Vibration", Journal of Sound and vibration, Vol. 284, 2005, pp. 613-634.
[15] Boggs, C. M., "Field Study to Evaluate Driver Fatigue on Air-inflated Truck Cushions", Master of Science thesis, Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, 2004.
[16] Ofori-Boetang, A. B., "A Study of the Effect of Varying Air-inflated Seat Cushion Parameters on Seating Comfort", Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, 2003.
[17] Gyi, D.E., Porter, J.M., and Robertson, N.K.B., "Seat pressure measurement technologies: consideration for their evaluation", Applied Ergonomic, Vol. 27, No. 2, 1998, pp. 85–91.
[18] Guenaelle, P., "One methodology to evaluate Automotive Seat Comfort", Proc. of the Third International Conference on Vehicle Comfort and Ergonomics, Bologna , Italy, 1995, pp. 231–240.
[19] Porter, J.M. and Gyi, D.E., "Interface pressure and the prediction of car seat discomfort", International Journal of Vehicle Design, Vol. 19, No. 3, 1998, pp. 255–266.
[20] Zhang, L., Helander, M. G., Drury, C. G., "Indentifying factors of comfort and discomfort in sitting", Human Factors, Vol. 38, No. 3, 1996, pp. 377–389.
[21] Ebe, K. and Griffin, M. J., "Factors affecting static seat cushion comfort", Ergonomics, Vol. 44, No. 10, 2001, pp. 901–921.
[22] Van Niekerka, J. L., Pielemeierb, W.J., Greenberg, J.A., "The use of Seat Effective Amplitude Transmissibility (SEAT) Values to Predict Dynamic Seat comfort", Journal of Sound and Vibration, Vol. 260, 2003, pp. 867–888.
[23] Falou, E. W., Duchêne, J., Grabisch, M., David Hewson, Yves Langeron, Lino, F., "Evaluation of Driver Discomfort during Long-Duration Car Driving", Journal of Applied Ergonomics, Vol. 34, No. 3, 2003, pp. 249-255.
[24] Mehta, C.R. and Tewari, V.K., "Seating Discomfort for Tractor Operators- A Critical Review", International Journal of Industrial Ergonomics, Vol. 25, 2000, pp. 661-674.
[25] Bouazara, M., Richard, M.J. and Rakheja, S., "Safety and comfort analysis of a 3D vehicle model with optimal non-linear active seat suspension", Journal of Terramechanics, Vol. 43, 2006, pp. 97-118.
[26] Cheng, Z., Smith, J. A., Pallettiere, J. A., and Fleming, S. M., "Considerations and experiences in developing and FE buttock model for seating comfort analysis", Society of Automotive Engineers. Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-2458.
[27] Cengiz, T.G. and Bablik, F.C., "An on-the-road experiment into the thermal comfort of car seats", Applied Ergonomics, Vol. 38, 2007, pp. 337-347.
[28] Choi, H. Y., Kim, K. M., Han, J., Sah, S., Kim, S.-H., Hwang, S.-H., Lee, K. N., Pyun, J.-K., Montmayeur, N., Marca, C., Haug, E., and Lee, I., "Human Body Modeling for Riding Comfort Simulation", Proc. of HCI2007, LNCS4561, 2007, pp.813-823.
[29] Dhingra, H. S., Tewari, V. K., and Singh, S., Discomfort, pressure distribution and safety in operator's seat- a critical review," Agricultural Engineering International: the GIGR Journal of Scientific Research and Development. Invited overview paper. Vol. V, 2003.
[30] Hanson, L., Sperling, L., and Akselsson, R., "Preferred car driving posture using 3-D information", International Journal of Vehicle Design, Vol. 42, No. ½, 2006, pp. 154-169.
[31] Hinz, B., Rutzel, S., Bluthner, R., Menzel, G., Wolfel, H. P., and Seidel, H. "Apparent mass of seated man- first determination with a soft seat and dynamic seat pressure distributions", Journal of Sound and Vibration, Vol. 298, 2006, pp. 704-724.
[32] Inagaki, H., Taguchi, T., Yasuda, E., and Iizuka, Y., "Evaluation of Riding Comfort: From the Viewpoint of Interaction of Human Body and Seat for Static, Dynamic, Long Time Driving", Society of Automotive Engineers. Inc., Warrendale, PA, USA, 2000, Technical Paper No. 2000-01-0643.
[33] Jang, H.-K., Choi, S.-H., and Ruquet, K., "Evaluation of discomfort due to vertical feet vibration at a driver's sitting posture", Society of Automotive Engineers. Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-2395.
[34] Kolich, M., and Taboun, S., "Ergonomics modelling and evaluation of automobile seat comfort", Ergonomics, Vol. 47, No. 8, 2004, pp. 841-863.
[35] Kyung, G., Nussbaum, M. A., and Babski-Reeves, K., "Driver sitting comfort and discomfort (part I): use of subjective ratings in discriminating car seats and correspondence among ratings", International Journal of Industrial Ergonomics, doi:10.1016/j.ergon.2007.08.010, 2007.
[36] Kyung, G., and Nussbaum, M. A., "Driver sitting comfort and discomfort—Part II: Relationships with and prediction from interface pressure",

International Journal of Industrial Ergonomics, doi:10.1016/j.ergon.2007.08.011, 2008.

[37] Kyung, G., Nussbaum, M. A., Lee, S., Kim, S., and Baek, K., "Sensitivity of preferred driving postures and determination of core seat track adjustment ranges", Society of Automotive Engineers. Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-2471.

[38] Marler, T., Yang, J., Rahmatalla, S., Abdel-Malek, K., and Harrisonq, C., "Validation methodology development for predicted posture", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-2467.

[39] Montmayeur, N., Marca, C., Cabane, C., Dwarampudi, R., Kolich, M., and Nunez, S., "Virtual seat comfort engineering through hardness and initial softness prediction", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-2455.

[40] Nilsson, H. O., "Local evaluation of thermal omfort", International Journal of Vehicle Design, Vol. 42, No. 1/2, 2006, pp. 8-21.

[41] Nishimatsu, T., Hayakawa, H., Shimizu, Y., and Toba, E., "Influence of Top Coated Cloth for Sitting Comfort of Car Driver's Seat", Proc. of 17th IEEE Instrumentation and Measurement Technology Conference, Vol. 2, 2000, pp. 915-919.

[42] Park, S. J., Kim, C.-B., Kim, C. J., and Lee, J. W., "Comfortable driving postures for Koreans", International Journal of Industrial Ergonomics, Vol. 26, 2000, pp. 489-497.

[43] Parakkat, J., Pallettiere, J., Reynolds, D., Sasidharan, M., and El-Zoghb, M., "Quatitative methods for determining U.S. Air Force crew cushion comfort", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 2006, Technical Paper No. 2006-01-2339.

[44] Rakheja, S., Stiharu, I., Zhang, H. and Boileau, P. E. "Seated occupant interactions with seat backrest and pan, and biodynamic response under vertical vibration", Journal of Sound and Vibration, Vol. 298, 2006, pp. 651-671.

[45] Rasmussen, H., Zee, M. d., and Torholm, S., "Muscle relaxation and shear force reduction may be conflicting: a computational model of seating", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-2456.

[46] Smith, D. R., Andrews, D. M., and Wawrow, P. T., "Development and evaluation of the Automotive Seating Discomfort Questionnaire (ASDQ)", International Journal of Industrial Ergonomics, Vol. 36, 2006, pp. 141-149.

[47] Solaz, J. S., Page, A., Porcar, R., Mateo, B., Dura, J. V., Gomez, J. A., Prat, J., and Vera, P., "Functional data analysis as a tool to find discomfort evolution patterns in passenger car seats", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 2006, Technical Paper No. 2006-01-1296.

[48] Mohd. Tamrin, S.B., Yokoyama, K., Jalaludin, J., Abdul Aziz, N., Jemoin, N., Nordin, R., Li Naing, A., Abdullah, Y., and Abdullah, M., "The association between risk factors and low back pain among commercial vehicle drivers in Peninsular Malaysia: A Preliminary Result", Industrial Health, Vol. 45, 2007, pp. 268-278.

[49] Tsutsumi, H., Hoda, Y., Tanabe, S.i., and Arishiro, A., "Effect of car environment on driver's comfort and fatigue", Society of Automotive Engineers. Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-0444

[50] Verver, M.M., Van Hoof, J., Oomens, C.W.J., Wismans, J. S. H. M., and Baaijens, F.P.T., "A finite element model of the human buttocks for prediction of seat pressure distribution", Computer Methods in Biomechanics and Biomedical Engineering, Vol. 7, No. 4, 2004, pp. 193-203.

[51] Wu, Q., Luo, S., and Sun, S., "A computer-aided driving posture prediction system based on driver comfort," Proc. of ICAT2006, 2006.

[52] Zhang, Y. F., Wyon, D. P., Fang, L., and Melikov, A. K. "The influence of heated or cooled seats on the acceptable ambient temperature range" Ergonomics, Vol. 50, No. 4, 2007, pp. 586-600.

[53] Zenk, R., Franz, M., and Bubb, H., "Spine load in the context of automotive seating", Society of Automotive Engineers. Inc., Warrendale, PA, USA, 2007, Technical Paper No. 2007-01-2485

[54] Uenishi, K., Tanaka, M., Yoshida, H., Tsutsumi, S., and Miyamoto, N., "Driver's fatigue evaluation during long term driving for automotive seat development", Society of Automotive Engineers. Inc., Warrendale, PA, USA, 2002, Technical Paper No. 2002-01-0773.

[55] Park, S.-J., Lee, Y.-S., Nahm, Y.-E., Lee, J.-W., and Kim, J.-S., "Seating physical characteristics and subjective comfort: design considerations" Society of Automotive Engineers, Inc., Warrendale, PA, USA, 1998, Technical Paper No. 980653.

[56] Mergl, C., Klendauer, M., Mangen, C., and Bubb, H., "Predicting long term riding comfort in cars by contact forces between human and seat", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 2005, Technical Paper No. 2005-01-2690.

[57] Eklund,J.A.E. and Corlett,E.N., "Evaluation of Spinal Loads and Chair Design in Seated Work Tasks", Clinical Biomechanics, Vol. 2, 1987, pp. 27-33.

[58] Na, S., Lim, S., Choi, H., and Chung, M. K., "Evaluation of driver's discomfort and postural change using dynamic body pressure distribution", International Journal of Industrial Ergonomics, Vol. 35, 2005, pp. 1085-1096.