5-1-2010

Effect of backrest angle on operator discomfort

Shaheen Ahmed

Recommended Citation

Ahmed, Shaheen, "Effect of backrest angle on operator discomfort" (2010). *Theses and Dissertations*. 1640.
https://scholarsjunction.msstate.edu/td/1640

EFFECT OF BACKREST ANGLE ON OPERATOR DISCOMFORT

By

Shaheen Ahmed

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Industrial Engineering
in the Department of Industrial and Systems Engineering

Mississippi State, Mississippi

May 2010

EFFECT OF BACKREST ANGLE ON OPERATOR DISCOMFORT

By

Shaheen Ahmed

Approved:

Kari Babski-Reeves
Assistant Professor of Industrial and
Systems Engineering
(Director of Thesis)

Royce. O Bowden
Professor and Head of Industrial and
Systems Engineering

Lesley Strawderman
Assistant Professor of Industrial and
Systems Engineering
(Committee Member)

John M. Usher
Professor and Graduate Coordinator of
Industrial and Systems Engineering

Mingzhou Jin
Associate Professor of Industrial and
Systems Engineering
(Committee Member)

Sarah A. Rajala
Dean of the Bagley College of
Engineering

Name: Shaheen Ahmed

Date of Degree: 52BMay 2010

Institution: Mississippi State University

Major Field: Industrial Engineering

Major Professor: Dr. Kari Babski-Reeves

Title of Study: Effect of backrest angle on operator discomfort

Pages in Study: 86

Candidate for Degree of Master of Science

An optimal automotive seat backrest angle has not been identified, and currently, no universal method for analyzing sitting discomfort exists. The purposes of this study were to: (1) identify an optimum seat backrest angle or range of angles based on objective and subjective discomfort measures, and (2) evaluate existing methods for analyzing sitting discomfort data. Eight participants (4 male 4 female) completed three, two hour test sessions in a driving simulator. Results showed that subjective and objective measures were moderately correlated. The 120° seat backrest angle (measured from horizontal) resulted in less discomfort than the 105° and 135° seat backrest angles. Time weighted subjective discomfort ratings were the most effective subjective measure of sitting discomfort. Results also indicated that participants were able to identify discomfort differences for few body regions.

Keywords: discomfort, sitting, pressure, driving, backrest angle, seat, automotive

DEDICATION

I would like to dedicate this research to my mother, Shamsia Khanom, and youngest sister Lucky

ACKNOWLEDGEMENTS

The Department of Industrial and Systems Engineering (ISE) and the Center for Advanced Vehicular Systems (CAVS) are acknowledged for their support for this study. In addition, I would like to thank Mr. John McGinley at the Human Systems Laboratory, CAVS; for assisting in the set up of the driving simulator used in this study. Special thanks to my supervisor, Dr. Kari Babski-Reeves; there is no way I can explain her splendid supports. I highly appreciate the constructive feedback from my committee members, Dr. Lesley Strawderman and Dr. Mingzhou Jin. I also like to thank Mr. David R. Close who helped me recruit participants, and Mr. L. Carl Brown for his continuous support. I would like to thank Mr. Jihun Kang, and all my colleagues for their helpful suggestions. Special thanks to Mr. Ralf Rosenburg and my examiner Dr. Anna-Lisa Osvalder, Chalmers University of Technology, Sweden.

TABLE OF CONTENTS

Page

APPENDIX

LIST OF TABLES

Table Page

LIST OF FIGURES

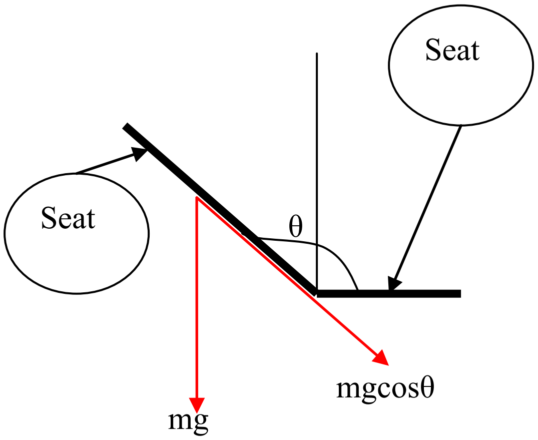
CHAPTER I

INTRODUCTION

According to the Bureau of Transportation Statistics (BTS, 2008), there are more than 247 million registered vehicles on the road today in the United States. Daily travel in the United States totals approximately 4 trillion miles, approximately 14,500 miles per person per year on average (BTS, 2008). Studies have shown that prolonged seating in vehicles leads to subjective perceptions of discomfort (e.g. Falou et al., 2003; Moes, 2005, pp 200-203). Changes in seating design adjustment parameters may result in reduced feelings of discomfort, and reduce biomechanical loads on the back contributing to the development of back pain (Kelsey and Hardy, 1975).

One way to minimize static loading on the lower back during prolonged seating is frequent posture changes. However, the ability of drivers to assume modified seating postures is limited due to the task itself. For example, drivers must have the right leg in contact with the gas pedal unless cruise control is engaged. Further, limitations on back and seat pan angle adjustments are driven by viewing requirements, eye strain, neck strain, and other parameters, such as driver anthropometry.

Static loading on the spinal column resulting from the upper body mass is one reason for developed back pain while seated. Changing the back angle can allow for the backrest to support some of the upper body mass, thereby reducing spinal column loading (Figure 1).



θ = seat backrest angle

m = upper part body mass

Figure 1 Representative free body diagram for loading on the spinal column while seated.

In sitting discomfort studies, many discrepancies exist in study lengths, data collection methods (e. g. repeated or end of the sessions, etc.) and the discomfort measures (e. g. average, peak, or time, etc.). Because of these differences, it is hard to generalize findings from a single study to multiple scenarios. Also, it is unknown if one subjective measure of discomfort is more appropriate for specific situations.

Statement of the Problem

Seating posture in a vehicle mainly depends on the seat design and the seating environment (gear shift, steering wheel, other interacting components, etc.). It is observed that, as the height of the vehicle increases, the backrest tends to become more vertical (Kyung, 2008). For example, long haul drivers usually sit in a more vertical position, while seating design in compact cars forces drivers to assume a more tilted posture (i.e., the backrest angle is angled more towards to back of the vehicle) (Chaffin et al., 2000; Hanson et al., 2006; Park et al., 2000; Reed et al., 2000). Since seat design is the main factor affecting seating posture, it is important to find an optimum seat orientation to prevent back pain and injuries due to prolonged seated postures that is not based on trial and error methods currently used in the automotive industry (Taboun and Kolich, 2004).

Buttock pressure is one of the most significant factors contributing to driver discomfort while seated (Looze et al., 2003). Research has shown that to relieve buttock pressure, individuals will shift their posture. However, in many cases, particularly during driving, posture changes are limited and awkward due to task and environment constraints. Cushioning then becomes important to decrease peak buttock pressure. Since pressure is force divided by contact area, increasing the contact area will more evenly distribute pressure across the buttocks and upper thighs, thereby reducing peak buttock pressure (Dhingra, Tewari, and Singh, 2003). However, pressure relief may not be possible if the cushion is too soft (Akerblom, 1948; Grandjean 1980; Defloor and Grypdonck, 2000). Cushioning can reduce peak buttock pressure by distributing the pressure among a wide range of ischial tuberosities; however it does not address biomechanical loading on the spine or decrease the component of pressure associated with upper body weight.

To date, data collection and analysis methods for sitting discomfort are not well defined. For example, study lengths have ranged from 15 minutes (e.g., Kyung et al., 2008) to a few hours (e.g., Looze et al., 2003). Some researchers have assessed discomfort for a few body parts (Kyung et al., 2008), while others have assessed as many as 32 body parts (Falau, 2003).

Objectives of the Study

The objectives of this study were (1) to determine the optimum seat backrest angle, or ranges of backrest angles to minimize seated discomfort, (2) to evaluate methods for sitting discomfort data analysis. Specific hypotheses tested included:

Specific hypotheses include:

1. Subjective measures of discomfort for individual body regions (except neck) will decrease as the backrest angle increases.
2. Whole body discomfort will be affected by backrest angle.
3. Buttock pressure and movements metrics will decrease as the backrest angle increases.
4. Pressure measurements for other body regions (e.g., upper back, lower back) will not be affected by backrest angle. Moreover, there will be no significant difference in pressure measurements with respect to gender.
5. Pressure measures and subjective discomfort ratings will be correlated.
6. In comparison to all other measures, time weighted discomfort will be the most effective measure of sitting discomfort.
7. Adjacent body parts will experience similar discomfort which will make logical body part groupings.

Scope and Limitation of the Study

This study used a driving simulator to simulate driving tasks and a prolonged driving environment. The simulator allowed for the control of several extraneous variables that can impact results (such as weather, time of day, traffic levels, car type, seat design, etc.). Aspects of driving that may also affect discomfort, such as vibration, were not considered in this study. Further, this study only investigated the effect of back angle changes on the dependent variables selected for study. The use of a low fidelity driving simulator did not allow for the investigation of all possible interactions of interior design on the dependent variables, or how backrest angle affected usage of other car functions. Also, as vehicle type (e.g., truck vs. sedan) affects seat design and ultimately backrest angle, it would be of interest to assess various backrest angles across different vehicle types. However, the simulator for this study was for a small sedan, and therefore, other vehicle types were not investigated.

Because this study assessed extreme backrest angles, the potential for driver error and accidents is increased. Therefore, a field study was deemed infeasible. While the use of a low fidelity driving simulator reduces realism in the driving environment, it allowed for the assessment of participant perceptions in discomfort. Further studies based on assessing optimum backrest angles without the increased potential for driver error would require a change in automotive design beyond the car seat (e.g., the dashboard) to allow for viewing of the environment.

Application of the Study

Although office seat/chair design has received marked attention in ergonomics research, automotive seat design has received less attention (Reed at al. 1994). Further, approaches to automotive seat design may not have been as scientific as they have for office seat/chair design. This study investigated various backrest angles for small sedan cars to identify a potential range of optimum backrest angles. Other components such as instrument panel, dashboard, radio, windshield angle, can be redesigned based on the sitting position. Also, evaluation of various subjective discomfort measures may allow for increased integration of study results.

References

Akerblom, B. (1948). *Standing and sitting posture with special reference to the construction of chairs*. Doctoral Dissertation. A.B. Nordiska Bokhandeln, Stockholm: Karolinska Institutet.

Bureau of transportation statics (BTS). (2008). Retrieved January 19, 2009, from World Wide Web: http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html

Chaffin, D. B., Faraway, J. J., Zhang, X., & Woolley, C. (2000). Stature, age, and gender effects on reach motion postures. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 42*(3), 408-420.

Defloor, T., & Grypdonck, M. H. F. (2000). Do pressure relief cushions really relieve pressure? *Western Journal of Nursing Research, 22*(3), 335 – 350.

Dhingra, H. S., Tewari, V. K., & Singh, S. (2003). Discomfort, pressure distribution and safety in operator's seat – a critical review. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Invited Overview Paper. V.* July 2003.

Falou, W. E., Duchene, J., Grabisch, M., Hewson, D., Langeron, Y., & Lino, F. (2003). Evaluation of driver discomfort during long-duration car driving. *Applied Ergonomics, 34*(3), 249-255.

Grandjean, E. (1980). *Sitting posture of car drivers from the point of view of ergonomics*. Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 205-213). New York: Academic Press.

Hanson, L., Sperling, L., & Akselsson, R. (2006). Preferred car driving posture using 3-D information. *International Journal of Vehicle Design, 42*(1-2), 154-169.

Kelsey, J. L., & Hardy, R. J. (1975). Driving motor vehicles as a risk factor for acture herniated lumber intervertebral discs. *American Journal of Epidemiology, 102*(1), 63-73.

Kyung, G. (2008). *An integrated human factors approach to design and evaluation of the driver workspace and interface: driver perceptions, behaviors, and objective measures.* Doctoral Dissertation, Blackburg, Virginia, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University.

Looze, M. P. D., Kuijt-Evers, L. F. M., & Dieen, J. V. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics, 46*(10), 985 – 997.

Moes, N. C. C. M. (2005). *Analysis of sitting discomfort, A review*. *Contemporary Ergonomics,* Hatfield, UK: Taylor and Francis. 200 – 203.

Park, S. J., Kim, C.-B., Kim, C. J., & Lee, J. W. (2000). Comfortable driving postures for Koreans. *International Journal of Industrial Ergonomics, 26*(4), 489-497.

Reed, M. P., Manary, M. A., Flannagan, C. A. C., & Schneider, L. W. (2000). Effects of Vehicle Interior Geometry and Anthropometric Variables on Automobile Driving Posture. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 42*(4), 541-552.

Taboun, S. M., & Kolich, M. (2004). Ergonomics modeling and evaluation of automobile seat comfort. *Ergonomics, 47*(8), 841 – 863.

CHAPTER II

OPTIMIZATION OF SEAT BACKREST ANGLE(S) FOR AUTOMOTIVE DRIVER'S SEAT BASED ON BOTH SUBJECTIVE AND OBJECTIVE MEASURES OF SITTING DISCOMFORT

Abstract

Identification of optimal automotive seating backrest angles is lacking. The purpose of this study was to identify an optimum backrest angle, or range of backrest angles, for automotive driver's seat based on simulated driving tasks. Discomfort for three seat backrest angles; 105°, 120°, and 135°; was quantified objectively (pressure measurement and movement type) and subjectively. Eight participants (4 males and 4 females) completed three, two hour test sessions. Peak buttock, left buttock, and right buttock pressures were significantly correlated with corresponding subjective body part discomfort ratings. Perceived discomfort levels for the buttock, left buttock, right buttock, lower back, and upper back decreased with backrest angle, neck discomfort increased with backrest angle, and total number of movements decreased as backrest angle increased. Results indicated that a backrest angle of 120° resulted in less discomfort than the other angles studied.

Introduction

Anatomical Basics

To prevent injury to the spine, it is very important to maintain its natural curvature. However, during prolonged seating (e.g., during driving), the natural shape of the spine tends to be flattened due to shifts in the pelvic region from changes in upper leg angle. Flattening of the spinal column may create pressure on the intervertebral discs, and can lead to injury, such as disc herniations, and low back pain (Keegan, 1953). Lumber support has been developed to maintain neutral spinal shape; however excessive lumber support creates discomfort (Akerblom, 1948; Grandjean, 1980; R32Argent, 2006).

Most automotive seating comes with standard lumber adjustment. While drivers can affect the amount of lumber support provided by the seat, there is no such adjustment for the height (or the location) of the lumbar support. This can lead to under usage, or misusage, of this protective mechanism. Therefore, users cannot rely on lumbar support to eliminate or reduce back pain, and other mechanisms by which to reduce back pain during driving needs to be considered.

Physiological Basics

Buttock pressure due to seating mostly develops in the region of ischial tuberosities due to its inverted pyramid shape (Figure 2) (Reed at al. 1994). Pressure levels can be changed or reduced by changing posture (e. g., bending leftward while driving, bending forward, tilting back, etc.). However, in the case of driving, posture changes are limited by space constraints, driver anthropometry, and the task itself. As a result, there are physiological changes associated with prolonged seating that are of particular concern, specifically changes in the bones and soft tissue of the buttocks and spine (Lueder & Noro, 1994, p. 224):

- Tissue immediately around the blood vessels thickens, as pressure inhibits blood flow.
- Lactic acid concentration in the muscles increases.
- Water builds up in subcutaneous tissue under the skin.
- Ischial bursae thicken to provide a cushion below the bone and, very importantly, as a result of tissue damage caused by shear, first locally, and then symmetrically.
- Pressure below 0.73 psi may be tolerated, however, pressure greater than 1.7 psi lead causes skill cell death.

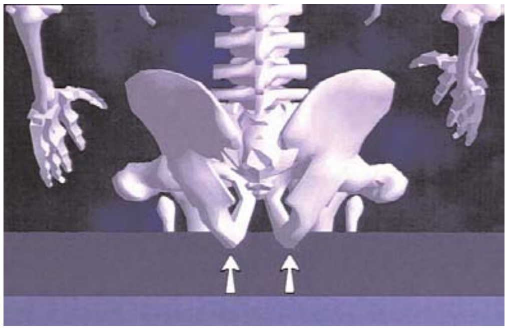


Figure 2 Ischial Tuberosities (www.ergocentric.com, 2008).

Buttock pressure during seating results from the weight of upper body, and studies have found an association between buttock pressure and seating discomfort (e.g. Kyung & Nussbaum; 2007; Porter et al., 2003). As pressure is a function of load and contact area, there are three primary actions that can be taken to reduce buttock pressure while seated:

1. Decrease the load associated with the weight of the upper body;
2. Increase the buttock contact area to avoid localized stress concentration and ensure the load is evenly distributed; or
3. Do both.

Tilting and reclining (Figure 1) facilitates transferring some weight of the upper body to the backrest, however titling the backrest has a negative effect on respiratory function (Leuder & Noro, 1994. p 222). Moreover, excessive tilting may affect a person's ability to interact with other functions in the car cab (e. g., geat shift, instrument panel, etc.) and may result poor driving performance. The range of acceptable backrest angles associated with driver discomfort and performance levels is unknown. Therefore, studies are needed to quantify the range of acceptable backrest angles that reduce discomfort and while at least maintaining driving performance.

Several seat pan designs have been investigated to determine optimum designs for distributing pressure (Vos et al., 2006). Wheelchair seat pans are known as the total contact seat and have been shown to result in buttock contact pressure measurements as low as 0.5 psi (Lueder & Noro, 1994). It is important to note that body weight has little effect on peak buttock pressure due to the fact that persons with larger body mass/shapes may have a larger vertical force component which is counterbalanced by a larger contact area.

Sitting Comfort and Discomfort

Most of the widely used dictionaries, such as Random House Unabridged Dictionary (www.dictionary.com, 2008), The American Heritage Dictionary (www.dictionary.com, 2008), the Marriam-Webster's Dictionary (www.marrian-webster.com, 2008), define discomfort as the opposite of comfort. However, it has been posited that the lack of discomfort does not imply comfort, nor does a lack of comfort imply discomfort. Several studies have quantified and defined these terms separately, (Bishu et al., 1991; Zhang et al., 1996; Looze et al., 2003; Smith et al., 2006; Zenk et al., 2007), and have found that comfort and discomfort result in a different concepts (Kyung et al., 2007). Though there is still debate in defining seating comfort and discomfort, the following three things are not in debate regarding seating comfort (Looze et al., 2003):

- comfort is a subjectively-defined personal state;
- comfort is a function of physiological and psychological factors; and
- comfort is a function of the environment.

Measurement of Sitting Comfort and Discomfort

Several methodologies have been developed to measure subjective and objective sitting (dis)comfort. Since sitting (dis)comfort are subjective perceptions which incorporate a wide range of factors; emotional, psychosocial, physical, etc.; no single measurement of sitting (dis)comfort has been widely accepted. Subjective assessments using questionnaires are common (Wachsler & Learner, 1960; Shackel et al., 1969; Oliver 1970; Oborne & Clarke 1975; Habsburg & Mittendorf, 1977; Drury & Coury 1982; Smith et al., 2006). Some objective measures of (dis)comfort have included posture and movement quantification, electromyography, pressure distribution, spinal load, etc. Pressure distribution measurement at the buttocks has been found to be associated with subjective perceptions of discomfort (Looze et al., 2003), though Kyung & Nussbaum (2007) found pressure measurements to be more closely associated with subjective perceptions comfort for driving tasks lasting a short period of time. However, from an aesthetic point of view, the Design & Emotion Society (2008) and Halender (2003) defines these two terms in a different ways – sitting "discomfort" refers to physical experiences and "comfort" refers to mental impressions of seats. This society also states that, "The human body is very adaptive and not sensitive enough to distinguish variations in seats. The most important factor for assessing discomfort is time."

Optimizing Backrest Angle

One of the earliest works in optimizing seat back angle was done by Anderson et al. (1974). He found the lowest level of back muscle activity was recorded at a backrest inclination angle of 120^{o}, horizontal lumber support of 5 cm, and seat pan inclination of 14^{o}. Hosea et al. (1986) found that back muscle activity decreases with increased seat backrest inclination. Fubini (1997) presents a detailed technical requirement considering only safety and comfort. Reed et al. (1994) presented seating guidelines for automotive drivers' seat, though guidelines were provided for seat backrest angle. Given these discrepancies in the literature and the lack of literature on optimum backrest angles for driving tasks, further study is warranted.

Summary

Automotive seat design has not received the same attention as office seating, in terms of information available in the public domain. Many of the strategies users typically employ to reduce discomfort and pain during prolonged sitting in the office work arena cannot be employed during driving due to environmental and task constraints. Current adjustability in automotive seating is also limited in range and may vary across vehicle type. Increasing the range of backrest tilt may be a viable mechanism for reducing biomechanical loads imposed on the spine and buttocks during prolonged sitting, though no studies were found in the public domain that have quantified the range of acceptable backrest angles that minimize discomfort.

Methodology

Design of Experiment

A repeated measures design was used to assess the effect of backrest angle (3 levels) on subjective and objective measures of discomfort. Participants completed the study in two orders: 105°-120°-135° and 105°-135°-120°. The 105° angle was introduced first to minimize any training effects associated with the use of the simulator, though a separate familiarization session was also provided.

Independent Variables

Two independent variables were investigated: backrest angle and gender. Backrest angle had three levels: 105°, 120°, and 135° measured counter clock wise from the horizontal line (Figure 3). These angles were chosen to fit within the simulator's backrest range-of-motion, and to accommodate human vision requirements. The simulator used in this study had the driver seat for a Dodge Neon. This seat was attached to a platform that allowed for the seat to be rotated to the specified backrest angles. To limit the confounding effect of seat pan angle, a single seat pan angle of 15° counter clock wise from the horizontal line (X-axis) was used (Figure 3).

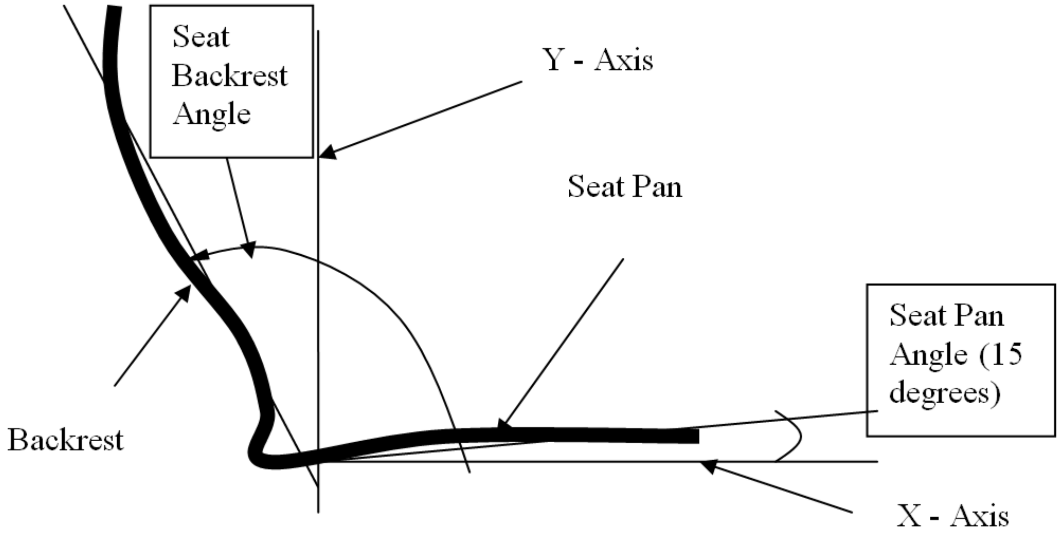


Figure 3 Seat backrest, seat pan, seat angle, etc.

Dependent Variables

Several subjective and objective dependent variables were collected, and they were associated with subjective discomfort ratings for various body regions, body movement metrics, and interface pressure measurements for different body regions. Since comfort is more related to aesthetic perception (Helander & Zhang, 1997), the measurement of comfort was considered beyond the scope of the study. Details for each dependent measure are provided below.

Measurement of Discomfort

A modified Borg CR – 10 Perceived Level of Exertion Scale (Borg, 1962; Borg & Borg, 2001; Borg & Borg 2002; Borg, 2007) was used to measure subjective sitting discomfort. Participants verbally indicated their discomfort rating every 15 minutes. The researcher orally asked participants their discomfort level for each body part (lower back, upper back, buttocks, left buttock, right buttock, eyes, neck, shoulder and thigh and whole body), and the order of the body parts was randomized at each assessment point. A total of 8 Borg assessments were taken for each body part. Rate of change in discomfort rating for each body region, the maximum discomfort rating reported, time to reach maximum discomfort rating, time to initiate discomfort rating and time weighted discomfort rating were used in the analysis. Rate of change in discomfort was measured over time meaning that change in discomfort per minute. Maximum discomfort was measured the maximum rating given by the participants for the entire test session. Time to reach the maximum discomfort rating was determined by selecting the assessment time period corresponding with the first instance of the maximum rating. For example, the maximum rating for a specific angle may have been reported at the 30 minute assessment period, and the 60 minute assessment period, with a lower discomfort rating at the 45 minute assessment period. The time to maximum discomfort rating for this instance would be 30 minutes. If the participant did not report a discomfort rating (a rating of zero was provided for the entire session), then 120 minutes was used. Time to initiate discomfort was calculated by the time taken to reach first perceived discomfort rating other than zero. Time weighted discomfort (TWD) rating was calculated by using:

$$TWD = \frac{\sum_{i=1}^{n} d_i t_i}{T} \tag{1}$$

where,

n = total number of assessment taken for each participant;

T = total time for each session (120 minutes);

d_i = perceived discomfort at i^{th} observation; and

t_i = time between $(i-1)^{th}$ and i^{th} observation.

Measurement of Interface Pressure

Two force sensitive application (FSA) pressure maps (FSA, model no. 477, Vista Medical, Winnipeg, Manitoba, Canada) was used to collect interface pressure at the seat pan and seat back interfaces. This clinical tool allows one to evaluate interface pressure between a person and the support they are sitting/lying on. The maps were secured to the simulator seat, and participants seated themselves on the map, making sure there were minimal creases in the maps. Based on previous research, peak pressure is the key variable of interest (Hermann and Bubb, 2007; Reed et al., 1994). Peak pressure for the left and right sides of the legs and back, and the upper and lower back were collected. The sampling rate was set to 5 Hz. Individual cell pressure was averaged over the entire test session, and the cell with the peak average value for a region (left, right, etc.) was selected and used in the analysis.

Measurement of Movement

Frequency counts for various movement types (move forward, move backward, leg movement, whole body movement, left leg movement, stretching, and shoulder movement) were collected during testing and through the use of redundant video analysis. In addition to analyzing the total number of these types of movements, the total number of movements, regardless of type, for the test session were also computed and analyzed. Time weighted movement (calculated based on equation 1) also analyzed to determine the changes of movements over time.

Task

Participants performed a driving simulation at each backrest angle (105^{o}, 120^{o} and 135^{o}), for two hours until reaching a discomfort level of 7, or until they wished to stop the study.

The Driving Simulator

HyperDriver software (DriveSafeety, Inc., Murray, UT) was used to provide the driving simulation environment. The simulator included a Dodge Neon car seat with manual controls for adjustment, steering wheel, CRT (Cathode Ray Tube) monitor (19-inch) for presenting driving scenarios, dashboard, turn signal, and brake and gas pedal. The driving simulator utilizes various built-in driving landscapes produced from the Hyper-Drive software around which traffic flows can be constructed. It has two speakers, one on each side of the monitor, to produce simulated sound.

Driving Scenarios

Highway driving scenarios were created to simulate prolonged driving tasks. Driving environments; such as traffic flow, over take, different types of vehicles, etc.; were continuously changed to make the scenarios as natural as possible. A single scenario was used for each test session to minimize effects due to varied cognitive load. As the scenarios were 2 hours in length, driver knowledge of the scripting was expected to be minimal. Scenarios were the same for all participants.

Participant

Eight participants (4 male and 4 female) completed this study (Table 1). Participants were excluded if they had a history of chronic or acute injuries as measured by the modified Standardized Nordic Questionnaires for the analysis of musculoskeletal symptoms (Kuorinka, 1987). Participants had to have at least three years of driving experience and were required to present a valid US driver's license upon arrival to the study. Participants were required to have at least 20/20 vision (natural or corrected), and were required to avoid prolonged driving the day prior to testing (no travel of 2 hours or greater, in total). No other inclusion/exclusion criteria existed.

Table 1 Participant Demographic Information

Demographics	Total		Male (n=4)		Female (n=4)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Age (yrs)	21.00	1.07	21.50	0.58	20.50	1.29
Weight (lbs)	145.88	20.61	160.50	16.76	131.25	11.81
Height (in)	67.38	4.21	70.50	2.89	64.25	2.63
Driving Experience (yrs)	4.88	1.46	5.50	1.73	4.25	0.96

Procedure

Participants first received a verbal and written description of the project and its objectives and procedures, completed informed consent documents approved by the Mississippi State University IRB, and completed a short demographic questionnaire including questions pertaining to inclusion/exclusion criteria for the study. Participants completed a 15 minute familiarization session at a random backrest angle, then began the test session at the prescribed backrest angle following a 10 minute rest period. Subjective assessments were taken every 15 minutes, and the session continued for 2 hours, until participants indicate a discomfort rating of 7, or until participants indicated they wished to stop testing. Participants completed three sessions on three different days at approximately the same time of the day. There were at least 48 hours between sessions to minimize any residual discomfort. Participants were provided a head rest support for the largest back angle 135^o to aid in viewing and were allowed to talk, listen to music, etc. during sessions to make the environment as natural as possible.

Data Analysis

Appropriate descriptive statistics were computed for all dependent variables (means, standard deviations, frequency counts, etc). Mixed factors ANOVAs were used to determine if backrest angle, gender, or the backrest angle by gender interaction affected the dependent variables. Slope parameters (or rates of change) were computed using regression analysis. Tukey's Post Hoc tests were used where appropriate. Spearman correlations between significant dependent variables were calculated to assess the relationship between the various dependent measures. Data trend analyses were also performed for the significant variables versus seat backrest angle to determine the functional relationships between them. All findings were considered significant at a 0.05 level of significance. All statistical analyses were performed using SAS (Version 9.1).

Results

Descriptive Statistics

In general, descriptive statistics showed that buttock pressure decreased as backrest angle increased, upper back pressure increased as backrest angle increased, and there were no noticeable changes in discomfort slope (discomfort/time in degree/minute) except for the neck which showed a sharp increase as backrest angle increased (Table 2).

No noticeable changes were observed for the number of reported "No Discomfort" ratings for the buttock and thigh at 105° and 120° backrest angle. However, the number of "No Discomfort" ratings did increase at the 135° backrest angle (Table 3). "No Discomfort" rating numbers appeared to increase as backrest angle increased for the lower back, and decreased sharply for the neck. "No Discomfort" rating reports for the shoulder and eyes remained unchanged across backrest angles, and were highest for the whole body at the 120° backrest angle (Table 3).

Table 2 Descriptive Statistics

		Backrest Angle					
		105^{o}		120^{o}		135^{o}	
		Mean	Stdv.	Mean	Stdv.	Mean	Stvd.
Pressure Measurements (mmHg)	B	124.46	37.08	100.65	32.40	79.07	18.80
	RB	93.36	13.81	84.48	18.52	72.85	20.88
	LB	123.63	38.02	99.07	33.13	77.25	18.04
	UB	46.28	13.24	69.27	38.26	105.39	62.15
	LoB	48.57	20.36	49.85	18.32	48.11	8.77
Discomfort Ratings Slope (Borg/min)	B	0.34	0.68	0.53	0.67	0.26	0.63
	LB	0.45	0.63	0.52	0.70	0.13	0.27
	RB	0.32	0.34	0.33	0.49	0.26	0.63
	Thigh	0.05	0.34	0.10	0.20	0.04	0.12
	LoB	0.97	1.43	0.36	0.45	0.38	0.47
	UB	0.16	0.31	0.15	0.24	0.23	0.41
	Shoulder	0.24	0.36	0.12	0.33	0.31	0.48
	Neck	0.06	0.12	0.33	0.53	0.67	0.62
	Eye	-0.01	0.48	-0.04	0.40	-0.05	0.13
	WB	0.45	0.42	0.42	0.56	0.40	0.51
	Movement*	2.43	4.97	1.93	2.62	0.48	2.50
Maximum Rating (Borg)	B	1.06	1.29	1.00	1.12	0.69	1.30
	LB	1.06	1.29	1.00	1.12	0.44	0.68
	RB	1.00	1.12	0.75	0.83	0.69	1.30
	Thigh	0.38	0.48	0.31	0.66	0.06	0.17
	LoB	2.56	2.23	1.00	1.12	0.88	1.02
	UB	0.50	0.87	0.38	0.48	0.69	0.83
	Shoulder	0.56	0.68	0.38	0.48	0.56	0.68
	Neck	0.19	0.35	0.88	0.74	1.50	1.22
	Eye	0.50	0.87	0.50	0.87	0.38	0.70
	WB	1.56	1.26	1.06	1.07	1.13	1.24
Time to Maximum Rating (min)	B	88.13	36.31	101.25	25.71	112.50	15.00
	LB	99.38	24.80	101.25	25.71	105.00	22.50
	RB	97.50	32.69	106.88	19.03	105.00	22.50
	Thigh	99.38	35.13	116.25	6.50	116.25	9.92
	LoB	86.31	44.09	90.00	35.18	88.13	29.47
	UB	112.50	19.84	108.75	24.59	108.75	20.88
	Shoulder	103.13	29.47	95.63	35.92	97.50	32.69
	Neck	120.00	0.00	76.88	34.73	86.25	28.80
	Eye	97.50	39.69	97.50	39.69	93.75	45.47
	WB	82.50	32.69	88.13	30.41	78.75	34.16
Time Weighted Discomfort Rating (Borg)	B	0.73	1.08	0.57	0.73	0.26	0.58
	LB	0.65	0.90	0.53	0.66	0.20	0.41
	RB	0.58	0.83	0.48	0.69	0.26	0.58
	Thigh	0.13	0.21	0.17	0.44	0.02	0.07
	LoB	1.47	1.17	0.67	0.77	0.57	0.78
	UB	0.16	0.36	0.17	0.31	0.30	0.50
	Shoulder	0.23	0.35	0.23	0.31	0.27	0.37
	Neck	0.02	0.05	0.45	0.48	0.95	1.07
	Eye	0.30	0.59	0.26	0.48	0.28	0.70
	WB	1.06	0.96	0.70	0.76	0.70	0.82
Types of Movement	Move Forward	35	3.2	1	0.4	0	0
	Move Backward	98	15	1	0.4	0	0
	Leg Dancing	30	4.4	67	15	11	2.3
	Whole Body	26	3.3	25	4	18	2.3
	Left Leg Movement	306	34	194	23	195	22
	Hand Movement	83	11	75	9.7	53	7
	Stretching	28	3.9	16	2.9	13	3
	Shoulder Movement	17	3.1	13	1.2	2	0.7

B = Buttock, LB = Left Buttock, RB = Right Buttock, UB = Upper Back, LoB = Lower Back, WB = Whole Body. *Movement slope is an estimate of the rate of change in total number of movements made per 15 min interval

Table 3 Frequency Counts for Discomfort Rating Categories for each Body Region and Backrest Angle

Type of Discomfort	Angle	Buttock	Left buttock	Right buttock	Thigh	Lower back	Upper back	Shoulder	Neck	Eye	Whole Body
None	105	43	43	42	54	21	57	48	62	54	23
	120	41	42	42	54	35	51	48	37	50	30
	135	51	51	51	61	38	48	49	29	54	28
Just Noticeable	105	1	1	0	4	8	1	6	1	1	6
	120	1	0	2	2	4	4	3	8	5	10
	135	5	5	5	3	5	2	1	2	0	10
Very Low	105	3	3	10	6	7	2	8	1	2	12
	120	10	12	10	6	11	9	13	13	4	10
	135	6	6	6	0	11	10	11	18	2	17
Low	105	8	13	7	0	11	4	2	0	6	16
	120	10	8	10	2	12	0	0	6	5	12
	135	0	2	0	0	7	4	3	9	8	6
Moderate	105	9	4	4	0	12	0	0	0	0	7
	120	2	2	0	0	2	0	0	0	0	2
	135	0	0	0	0	3	0	0	0	0	1
Moderate High	105	0	0	0	0	2	0	0	0	0	0
	120	0	0	0	0	0	0	0	0	0	0
	135	2	0	2	0	0	0	0	6	0	2
High	105	0	0	0	0	2	0	0	0	1	0
	120	0	0	0	0	0	0	0	0	0	0
	135	0	0	0	0	0	0	0	0	0	0
Very High	105	0	0	0	0	1	0	0	0	0	0
	120	0	0	0	0	0	0	0	0	0	0
	135	0	0	0	0	0	0	0	0	0	0

Order Effects

Data were collected in two orders. Subjects 1, 2, 3, 4, 5, and 6 performed the study in one order and subjects seven and eight performed the study in another order. Statistical analysis showed that there were order effects. (Table 4). Participants 1 and 4 experienced very high lower back discomfort as compared to the other participants. Both participant 1 and 4 were in same group/order 1. Participant 8 experienced very high discomfort as compared to other participants. As trends in the dependent variable were inconsistent across groupings, these findings are likely due more participant differences than study design.

Table 4 Significant Order Effect

Body Part	P-Value
Maximum Buttock Discomfort	0.0388
Whole Body Maximum Discomfort	<0.0001
Time to reach Maximum Discomfort for Shoulder	0.0237
Time weighted Discomfort for Lower Back	0.0128
Time weighted Discomfort Whole Body	<0.0001

Discomfort Ratings

Backrest angle significantly affected discomfort slopes, maximum discomfort rating, time weighted discomfort rating, time to reach maximum discomfort rating for the neck, and time to reach maximum discomfort rating for the buttock (Table 5). For all variables, post hoc analyses indicated that the 105° backrest angle differed significantly from the 135° backrest angle (Table 6). Neck maximum discomfort rating was significantly higher at the 105° backrest angle. Time to reach maximum discomfort rating for the buttock was faster for the 105° backrest angle than for the 135° backrest angle. For the neck, the time to reach maximum at the 105° backrest angle was slower than for the other two backrest angles. A backrest angle by gender interaction effect was found for maximum discomfort rating for the left buttock. Maximum ratings for males at the 105° backrest angle were greater than the maximum rating for males at the 135° backrest angle. No gender differences were found. Time weighted discomfort rating for left buttock, males and lower back was significantly higher at 105° seat backrest angle as compared to 135° seat backrest angle.

Movement Results

Eight different types of movement were identified. “Move forward” and “move backward” were significantly affected by the backrest angles (Table 7). Total number of movements and time weighted movement were also affected by the backrest angles (Table 7). The number of movements was significantly higher for the 105^0 seat backrest angle position as compared to the 120^0 and 135^0 seat backrest angle positions (Table 8). However, there were no significant differences observed between 120^0 and 135^0 seat backrest angle positions (Table 8). Moreover, statistical mean comparison showed that total number of movements made by left leg was significant higher as compared to any other types of movements (Table 9).

Table 5 Mixed Factors ANOVA Results for Discomfort Rating Dependent Variables

Dependent Variable	Body Region	Backrest Angle	Gender	BA by G
Slopes	Buttock	0.3563	0.1322	0.9055
	Left Buttock	0.1029	0.0536	0.2454
	Right Buttock	0.9417	0.1583	0.8154
	Thigh	0.8690	0.8820	0.1926
	Lower Back	0.3565	0.2165	0.7610
	Upper Back	0.7873	0.1985	0.6565
	Shoulder	0.6624	0.8013	0.8501
	Neck	**0.0309**	0.6239	0.1108
	Eye	0.9908	0.3203	0.9905
	Whole Body	0.9365	0.3495	0.4659
Maximum Discomfort Rating	Buttock	0.5415	0.0893	0.3896
	Left Buttock	0.0671	0.0717	**0.0371**
	Right Buttock	0.8072	0.1394	0.9897
	Thigh	0.3252	0.2528	0.4869
	Lower Back	0.0536	0.3154	0.5288
	Upper Back	0.5709	0.2378	0.1686
	Shoulder	0.7737	1.0000	0.7737
	Neck	**0.0203**	0.8015	0.3231
	Eye	0.396	0.1366	0.3966
	Whole Body	0.2367	0.7231	0.6974
Time to Maximum Discomfort Rating	Buttock	**0.0191**	0.2869	0.3633
	Left Buttock	0.9056	0.5122	0.8329
	Right Buttock	0.7300	0.1789	0.1719
	Thigh	0.1725	0.4021	0.8004
	Lower Back	0.9721	0.3077	0.1075
	Upper Back	0.9137	0.4265	0.3400
	Shoulder	0.8886	0.4747	0.2750
	Neck	**0.0020**	0.1966	0.2032
	Eye	0.6610	0.1340	0.6610
	Whole Body	0.6918	0.4085	0.2383
Time Weighted Discomfort Rating	Buttock	0.0960	0.0705	0.0901
	Left Buttock	**0.0254**	0.0565	**0.0259**
	Right Buttock	0.4140	0.0893	0.5736
	Thigh	0.5669	0.3514	0.3925
	Lower Back	**0.0315**	0.4057	0.6038
	Upper Back	0.7057	0.2575	0.6767
	Shoulder	0.9507	0.8270	0.5690
	Neck	0.0434	0.7092	0.2823
	Eye	0.9467	0.1682	0.9467
	Whole Body	0.2078	0.7492	0.7767

Note: Bolded values indicate significant findings, BA by G = backrest angle by gender interaction and the last three columns contain p-value of the test.

Table 6 Tukey's Pair-wise Comparison for Discomfort Rating Significant Results

Dependent Variable	Angle	Mean	Tukey Grouping	Dependent Variable	Angle by Gender	Mean	Tukey Grouping
Neck Discomfort Slope	105	0.001	A	Left Buttock Max Discomfort Rating	105, F	0.125	A B
	120	0.006	A B		120, F	0.250	A B
	135	0.012	B		135, F	0.250	A B
Neck Max Discomfort Rating	105	0.186	A		105, M	2.000	A
	120	0.875	A B		120, M	1.750	A B
	135	1.500	B		135,M	0.625	B
Buttock Time to Max Rating	105	88	A	Neck Time to Max Rating	105	120	A
	120	101	A B		120	77	B
	135	113	B		135	86	B
Time weighted Left Buttock discomfort	105	0.648	A	Time weighted Left Buttock Discomfort Rating	105, F	0.015	A B
	120	0.531	A B		120, F	0.125	A B
	135	0.195	B		135, F	0.031	A B
Time weighted Lower Back Discomfort	105	1.469	A		105, M	1.281	A
	120	0.671	A B		120, M	0.937	A B
	135	0.570	B		135, M	0.359	B
Time weighted Neck Discomfort	105	0.953	A				
	120	0.453	A B				
	135	0.023	B				

Max = Maximum

Table 7 Movement vs. Angle & Gender Results

Dependent Variable	Movement Types	Backrest Angle	Gender	BA by G
Types of Movement	Move Forward	**0.0008**	0.4128	0.6241
	Move Backward	**0.0325**	0.6860	0.8630
	Leg movement	0.2421	0.6023	0.8105
	Whole Body	0.7389	0.2708	0.2472
	Left Leg movement	0.0679	0.2640	0.1213
	Hand Movement	0.6920	0.4538	0.9144
	Stressing	0.4808	0.1984	0.0687
	Shoulder Movement	0.1416	0.2948	0.2635
Total Number of Movements	All types of movement were added	**0.0221**	0.4774	0.9002
Rate of Change of Movements	Movements per 15 minutes	0.5947	0.8529	0.4855
Time Weighted movement	Calculated based on equation 1	**0.0221**	0.4774	0.9002

Bolded values indicate significant findings and the last three columns contain the p-value of the test.

Table 8 Tukey’s Pair-wise Comparison for Significant Movement Types

Dependent Variable	Angle	Mean	Tukey Grouping	Dependent Variable	Angle by Gender	Mean	Tukey Grouping
Move Forward	105	35	A	Move Backward	105	98	A
	120	1	B		120	1	B
	135	0	B		135	0	B
Total Number of Movements	105	85	A	Time weighted Movement	105	11	A
	120	50	B		120	6	B
	135	42	B		135	5	B

Table 9 Comparison among Different Types of Movement

Types of Movement	Mean number of Movement	Standard Deviation	Tukey Grouping
Move Forward	1.50	2.72	A
Move Backward	4.13	10.14	A
Leg dancing	4.50	9.31	A
Whole Body Movement	2.88	3.18	A
Left Leg movement	28.96	26.73	B
Head Movement	8,79	8.91	A
Stressing	2.38	3.24	A
Shoulder Movement	1.33	2.06	A

Pressure Results

Backrest angle was found to affect overall buttock, left buttock, right buttock and upper back peak pressure measurements (Table 10). For the overall buttock, left buttock, and upper back, the 135^{o} backrest angle was found to be significantly lower than the other angles studied (Table 11). The 105^{o} backrest angle for the right buttock was found to be significantly higher than the 135^{o} backrest angle. A gender effect was found for the right buttock, with males having significantly higher pressure measurements. No backrest angle by gender interaction effects were found.

Table 10 Mixed Factors ANOVA Results for Pressure Variables

Factor	Overall Buttock	Left Buttock	Right Buttock	Lower Back	Upper Back
Backrest angle	**0.0005**	**0.0009**	**0.0324**	0.9400	**0.0206**
Gender	0.0664	0.0634	**0.0213**	0.3607	0.2613
BA x G	0.3307	0.3624	0.7647	0.1867	0.6459

Bolded values indicate significant findings and the last five columns contain the p-value of the test.

Table 11 Tukey's Pair-wise Comparison for Significant Results

Dependent Variable	Angle	Mean	Tukey Grouping	Dependent Variable	Angle	Mean	Tukey Grouping
Overall Buttock	105	124.46	A	Right Buttock	105	93.36	A
	120	100.65	B		120	84.48	A B
	135	79.07	B		135	72.85	B
Left Buttock	105	123.63	A	Upper Back	105	46.28	A
	120	99.07	B		120	69.27	A B
	135	77.25	B		135	105.39	B
	Gender	Mean	Tukey Grouping				
Right Buttock	F	84.18	A				
	M	118.61	B				

Correlations

All of the buttock correlations were found to be highly significant, though the strength of those correlations are fair or moderate (0.40 – 0.75) (Table 12). A complete correlation matrix (Table 13) between all dependent variables was not completed, as a number of the dependent variables were not significant. Correlation coefficients were computed between the significant dependent variables. Strong (0.9787-0.7792) and highly significant (p-value < 0.0001) correlations were found between the slope, maximum discomfort, time weighted discomfort and time to reach maximum discomfort for neck. Moderate (0.62-0.61) significant (p-value = <0.0001) correlations were found for time to reach maximum buttock discomfort with overall buttock pressure, left buttock pressure, right buttock pressure. Strong (0.98-0.81) highly significant (p-value < 0.0001) correlations were found between overall buttock pressure, left buttock pressure, right buttock pressure. Strong (0.99-0.89) and highly significant (p-value < 0.0001) correlations were found between the time weighted left buttock discomfort and left buttock maximum discomfort, and time to reach maximum buttock discomfort. Strong (0.98-0.78) and highly significant (p-value < 0.0001) were found between time weighted neck discomfort and neck discomfort slope, and time to reach maximum neck discomfort. Time weighted total number of movements was found moderate (0.64) and highly significantly (p-value = <0.0001) correlated with time weighted neck discomfort.

Table 12 Correlation between Pressure and Maximum Discomfort, Time Weighted Discomfort and Time to Reach Maximum Discomfort for Specific Body Regions

		Buttock	Left Buttock	Right Buttock	Lower Back	Upper Back
Maximum Discomfort	Spearman's Rho	**0.711**	**0.701**	**0.652**	**0.426**	-0.051
	p-value	**<0.0001**	**0.0001**	**0.0005**	**0.0378**	0.8137
Time weighted Discomfort	Spearman's Rho	**0.708**	**0.699**	**0.693**	**0.462**	-0.003
	p-value	**0.0001**	**0.0002**	**<0.0001**	**0.0232**	0.9889

Table 13 Correlation matrix for significant dependent variables

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13
x1	1.0000	**0.8678**	**0.9904**	-0.1574	-0.3298	**0.7181**	-0.2408	**-0.6228**	0.0705	**0.7167**	**0.4227**	-0.2110	-0.0640
		<.0001	**<.0001**	0.4626	0.1155	**<.0001**	0.2571	**0.0012**	0.7435	**<.0001**	**0.0396**	0.3222	0.7665
x2		1.0000	**0.8304**	-0.0200	-0.3225	**0.6738**	-0.2517	**-0.6062**	0.0056	**0.6707**	**0.4700**	-0.2101	-0.0731
			<.0001	0.9261	0.1243	**0.0003**	0.2354	**0.0017**	0.9793	**0.0003**	**0.0205**	0.3243	0.7342
x3			1.0000	-0.1722	-0.3582	**0.7014**	-0.2636	**-0.6111**	0.0817	**0.6992**	0.3887	-0.2436	-0.0644
				0.4211	0.0857	**0.0001**	0.2133	**0.0015**	0.7044	**0.0001**	0.0605	0.2514	0.7650
x4				1.0000	0.1638	-0.0842	0.2645	0.0107	-0.3897	-0.0716	-0.3007	0.2992	-0.2607
					0.4445	0.6956	0.2117	0.9603	0.0598	0.7396	0.1534	0.1556	0.2186
x5					1.0000	-0.3697	**0.8213**	0.2963	-0.3263	-0.3496	-0.0599	**0.7792**	0.1479
						0.0754	**<.0001**	0.1597	0.1197	0.0940	0.7809	**<.0001**	0.4905
x6						1.0000	-0.1562	**-0.8544**	-0.0863	**0.9922**	0.3367	-0.1026	-0.1174
							0.4660	**<.0001**	0.6883	**<.0001**	0.1077	0.6332	0.5848
x7							1.0000	0.3151	**-0.7205**	-0.1922	-0.0429	**0.9787**	0.1178
								0.1337	**<.0001**	0.3684	0.8423	**<.0001**	0.5837
x8								1.0000	-0.1839	**-0.8941**	-0.2273	0.2725	0.0361
									0.3898	**<.0001**	0.2854	0.1977	0.8670
x9									1.0000	-0.0165	0.1799	**-0.7970**	0.1378
										0.9389	0.4004	**<.0001**	0.5208
x10										1.0000	0.3415	-0.1412	-0.1226
											0.1025	0.5106	0.5681
x11											1.0000	-0.0762	**0.5261**
												0.7236	**0.0083**
x12												1.0000	0.1011
													0.6384
x13													1.0000

x1 = Overall Buttock Pressure, x2 = Right Buttock Pressure, x3 = Left Buttock Pressure, x4 = Upper Back Pressure , x5 = Neck Discomfort Slope , x6 = Left Buttock Maximum Discomfort, x7 = Neck Maximum Discomfort, x8 = Time to Reach Maximum Buttock Discomfort, x9= Time to Reach Maximum Neck Discomfort, x10= Time Weighted Left Buttock Discomfort, x11 = Time Weighted Lower Back Discomfort, x12 = Time Weighted Neck Discomfort, x13 = Time Weighted Number of Movement. .For each variable (e.g. x1) upper row contains correlation and lower row contain p-value

Trend Analyses for Significant Variables

Trend analyses for significant variables were statistically quantified at each backrest angle (Table 15). The trend in neck discomfort slope, neck maximum discomfort, time weighted neck discomfort, time weighted lower back discomfort, time weighted movement, buttock pressure, right buttock pressure, left buttock pressure, and upper back pressure was adequately explained by a linear function of seat backrest angle. A quadratic relationship was found between time to reach maximum neck discomfort and seat backrest angle.

Table 14 Trend Analyses for Significant Depended Variables against the Three Levels Seat Backrest Angle.

Independent Variable	Dependent Variable	Significant Trend	P-value
Seat Backrest Angle (three levels)	Neck Discomfort Slope	Linear	0.0165
	Neck Maximum Discomfort	Linear	0.0115
	Time to Reach Maximum Buttock Discomfort	No significant trend, but close to linear	0.1025
	Time Weighted Lower Back Discomfort	No significant trend, but close to linear	0.0727
	Time Weighted Neck Discomfort	Linear	0.0141
	Time to Reach Maximum Neck Discomfort	Quadratic	0.0318
	Time Weighted Movement	No significant Trend, but close to linear	0.0648
	Buttock Pressure	Linear	0.0022
	Right Buttock Pressure	Linear	0.0125
	Left Buttock Pressure	Linear	0.0022
	Upper Back Pressure	Linear	0.0128

Discussion

The purpose of this study was to quantify the effect of backrest angle on various objective and subjective discomfort measures during simulated driving tasks. By using both subjective and objective discomfort measures for different body regions, those body regions most affected by changes in backrest angle were able to be identified. Discomfort rating data, measured using a Modified Borg CR-10 scale, was not sensitive to changes in backrest angle for many of the body regions studied. Neck discomfort was found to be significantly affected by backrest angle, and discomfort increased with increases in backrest angle. This is due to the need for participants to assume more flexed neck postures to maintain eye contact with the road. These more flexed neck postures resulted in higher maximum ratings of discomfort for the higher backrest angles, as well as a reduction in the time needed to reach that maximum rating. It has been posited that any non-neutral posture is harmful and may cause musculoskeletal injury (McAtamney and Corlett, 1993). Ironically, there is very little research pertaining to neck discomfort as it relates to automotive seating. A wealth of literature exists on neck discomfort and typing tasks, though the generalizability of these findings to the driving environment is somewhat questionable due to the variation in arm postures and the dynamics of the driving task. Further research is needed to quantify neck discomfort during driving and effective interventions for reducing this discomfort, in addition to the current focus of reducing buttock and back pain.

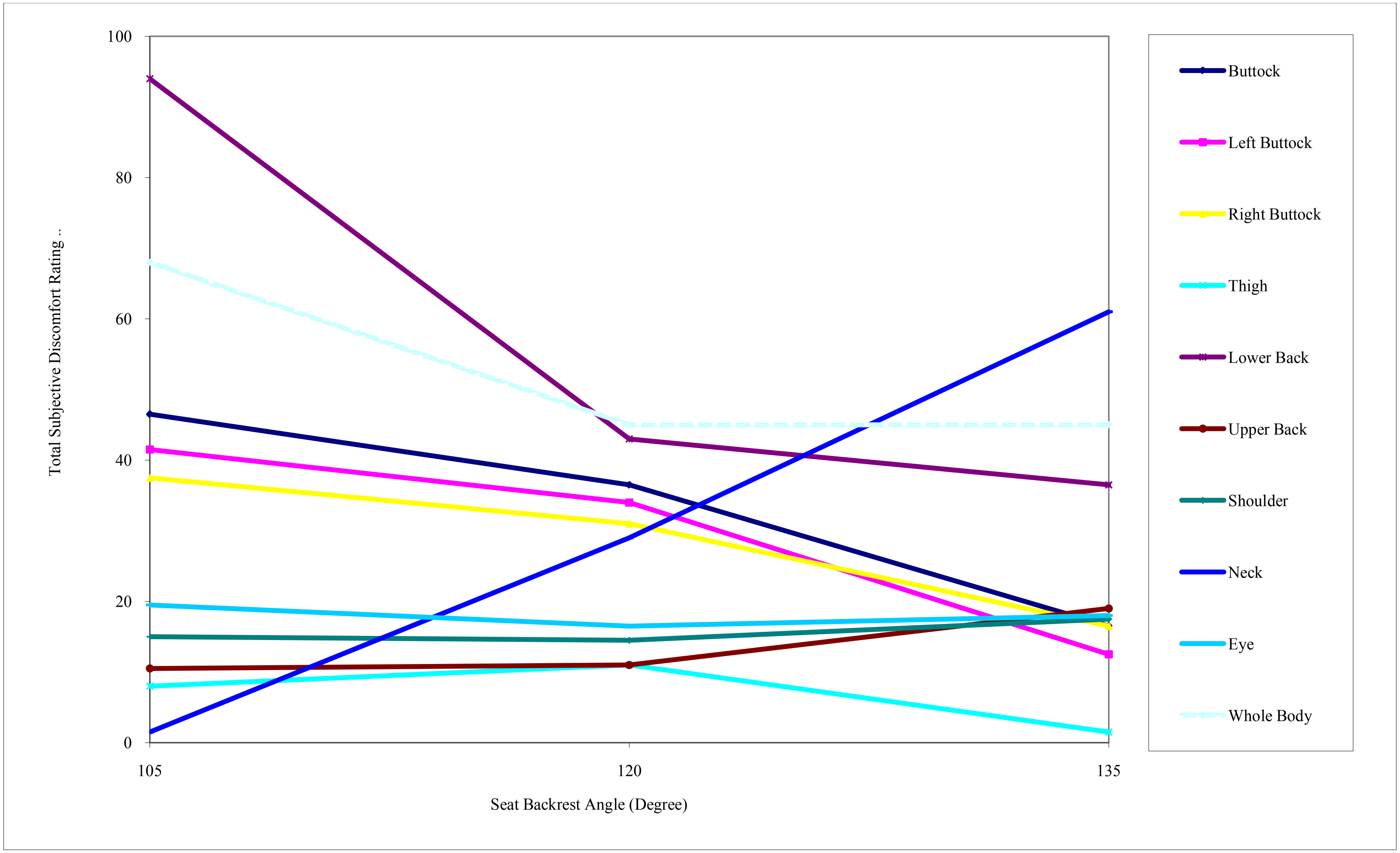


Figure 4 Total perceived level of discomfort rating plotted against backrest angle.

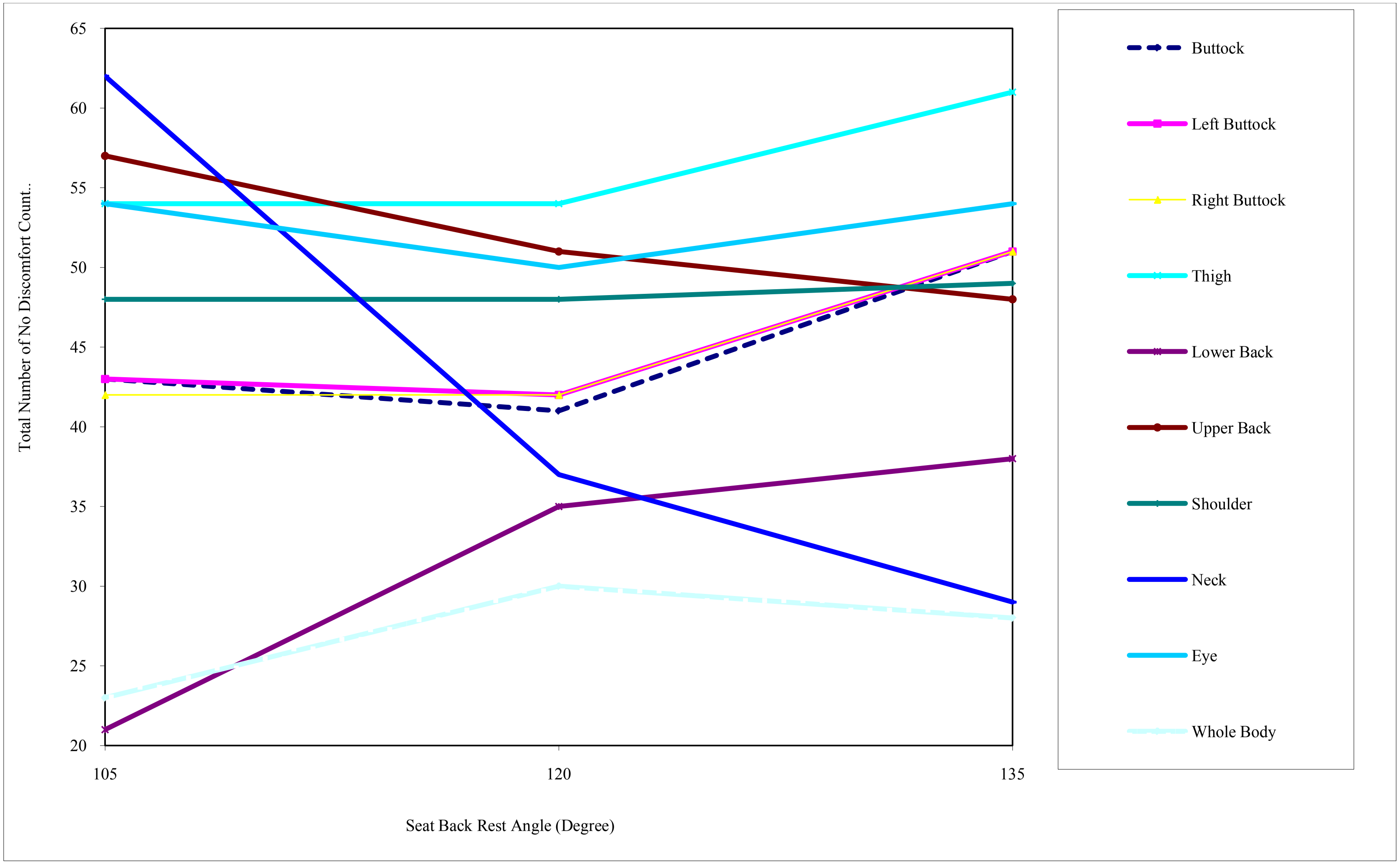


Figure 5 No discomfort counts versus seat backrest angle.

Discomfort for overall buttock, left buttock, and right buttock, lower back, decreased as seat backrest angle increased (Figure 4). Similar findings were found in previous research (e.g. Akerblom, 1948; Andersson et al., 1974; Hosea et al. 1986) by using myoelectric back muscle activities, assuming that less myoelectric activity contributes less discomfort. No trends were found for many of the body regions studied (e.g., thighs, eyes, shoulder, etc.). Future studies will be able to focus more specifically on body regions that are grossly affects by changes in backrest angle, since it is difficult for humans to perceive small or slight differences (Ahmed and Babski-Reeves, 2009). It is interesting to note in Figure 4 the trade-off between neck discomfort and back discomfort. Using the data from this Figure, backrest angles of approximately 120° are most effective at minimizing both neck and back discomfort simultaneously. This finding, again, provides support for previous studies that have identified a backrest angle of 120° as optimum (Akerblom, 1948; Andersson et al., 1974; Hosea et al. 1986).

A recommendation for a backrest angle of 120° is further supported. If one sums the discomfort ratings for all body parts, for all participants at each backrest angle, the total discomfort sum for the 105° angle is quite a bit larger than the other two angle, and the sum is lowest at 120° (Figure 5). Further, increased movement is a clear indication of discomfort, as found in previous studies (Akerbloom, 1948; Andreoni et al., 2002; Dhingra et al., 2003; Jenny et al., 2001). When looking at the total number of movements made at each angle for all participants, then again, backrest angles of approximately 120° impose less discomfort (Figure 6).

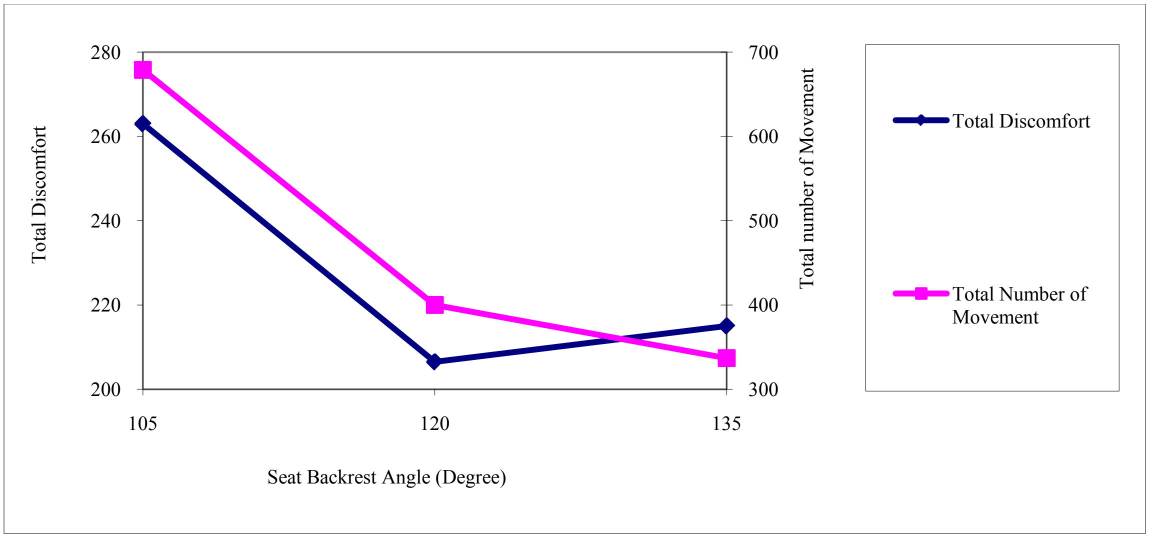


Figure 6 Total discomfort and total number of movement changes with respect to the seat backrest angle.

A single interaction effect (backrest by gender) was found for left buttock maximum discomfort rating. Upon further analysis, this interaction was constrained to males, with higher buttock pressure recorded at the 105^o backrest angle than at the 135^o backrest angle. Research has shown that sitting preference varies from subject to subject (Chaffin et al., 2000; Hanson et al., 2006; Park et al., 2000; Reed et al., 2000), that there are gender difference in sitting preferences (Park et al., 2000), and that driving postures are not always symmetric (Andreoni et al., 2002; Hanson et al., 2006). Results from this study support these previous findings.

In this study, it was found that buttock pressure decreased, in general, as backrest angle increased. At higher backrest angles, some body weight is transferred from the buttocks to the backrest, resulting in observable and measureable reductions in buttock pressures. The results of this study found that most of the redistribution is through the upper back, not the lower back, and this also explain why the upper portion of the “s” in normal spinal alignment is flattened during prolonged sitting.

Past studies have claimed that pressure measures can be used to quantify discomfort (Hermann and Bubb, 2007; Reed et al., 1994). Results from this study are in line with past research. Further, the correlations between buttock pressure measurements and maximum discomfort ratings were significant, providing additional support that pressure can be used to quantify discomfort. However, these correlation coefficients were moderate at best, implying that pressure is measuring more than just discomfort, or that the relationship between the variables is more complex.

No-discomfort-counts were plotted against the seat backrest angle to observe the trend in absence of discomfort. Some body parts such as thigh, eye, upper back, shoulder, had higher no-discomfort-counts (Figure 6). These body parts experienced less discomfort as compared to the other body parts. No-discomfort-counts for neck sharply decreased with increased backrest angles. In contrast to neck, no-discomfort-counts for lower back increased sharply from 105^o to 120^o sitting positions and it was flatten after 120^o sitting position. These findings indicated that 105^o and 135^o sitting position were less acceptable due to the less no-discomfort-counts for lower back and neck respectively. Moreover, the no-discomfort-counts for whole body were highest at 120^o seat backrest angle driving position as compared to the 105^o and 135^o seat backrest angle positions (Figure 6). Many studies (Akerblom, 1948; Andersson et al., 1974; Hosea et al. 1986) claim that 120^o seat backrest angle can be used as the optimum backrest angle for small cars.

Several studies claimed that movement is an objective measure of sitting discomfort. Higher number of movements indicates higher discomfort. However, the quantification of movements that are associated with discomfort is difficult to determine in a car driving context. All movements are not necessarily created by discomfort. Eight different types of movement were determined. In this study the 105o angle resulted in more movements than the others. Most movements were associated with the left leg and the head. However, these two body parts are free to move and to say these movements were a result of discomfort is questionable.

Statistical trend analysis confirmed that neck maximum discomfort, time weighted neck discomfort and upper back pressure increased linearly as the backrest angle increased (e. g.) and overall buttock pressure and time weighted lower back discomfort decreased linearly as the backrest angle increased (Figure 8). So, the lower body parts such as buttock and lower back of the body suffers if seat backrest angles are close to vertical position whereas upper body part such as neck suffers if the seat backrest angles are more tilted backwards. According to the data trend analysis, it can be statistically inferred that the seat backrest angle 120^{o} was optimum for small cars such as coupe, sedan, hatch back, station wagon, etc.

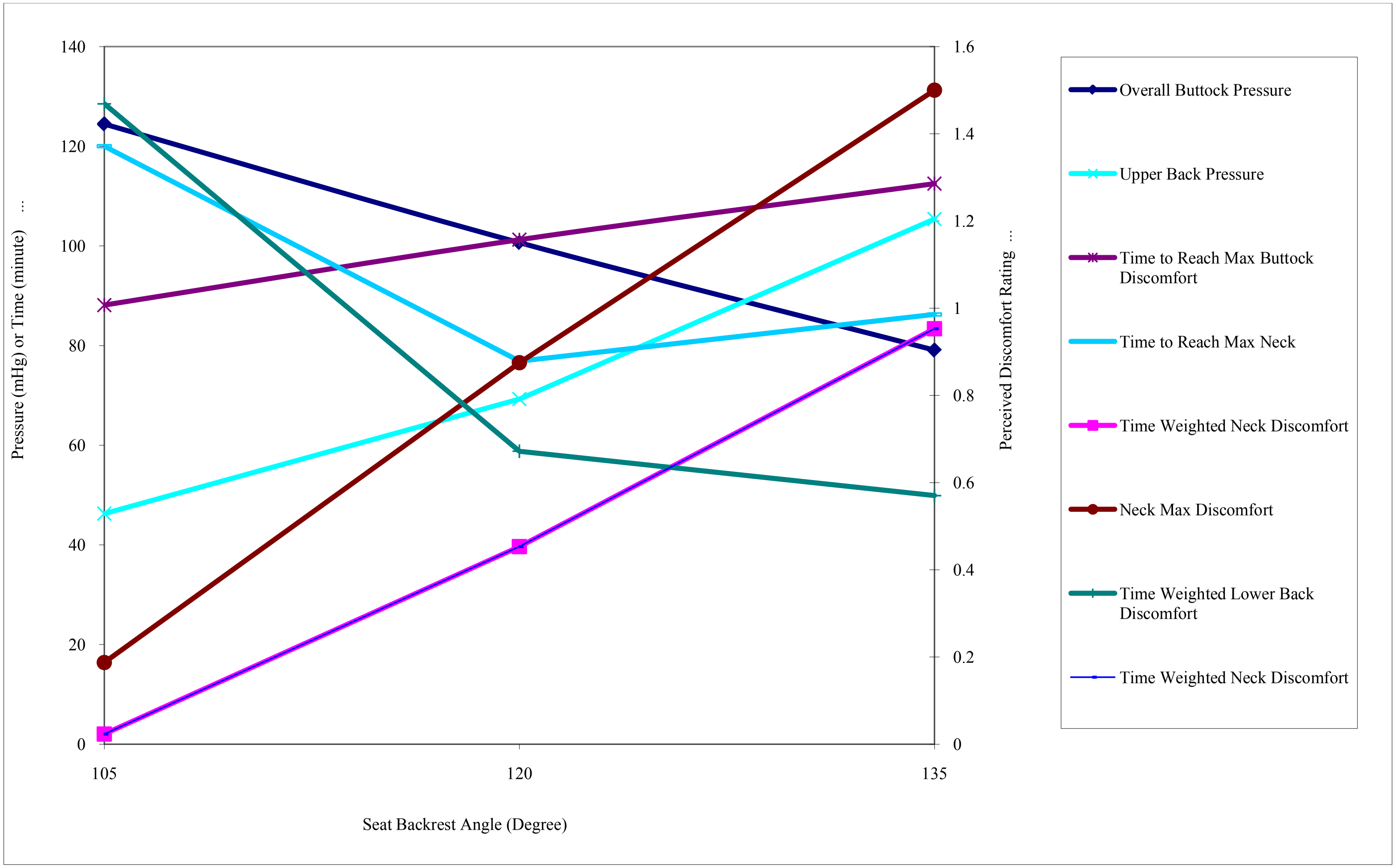


Figure 7 Trend analysis graphical representation (Primary Y axis on the left contains two parameters: Pressure and Time, Secondary axis on the right contains only discomfort.

References

Ahmed, S. and Babski-Reeves, K. (2009). Analysis of Subjective Body Discomfort Ratings during Simulated Prolonged Driving Tasks: What Measures are most Effective? *Proceeding of the Human Factors and Ergonomics Society, 53nd Annual Meeting-2009*. San Antonio, Texas, October 19-23, 2009, USA: Human Factors and Ergonomics Society

Akerblom, B. (1948). *Standing and sitting posture with special reference to the construction of chairs*. Doctoral Dissertation. A.B. Nordiska Bokhandeln, Stockholm: Karolinska Institutet.

Andersson, B. J. G., Ortengren, R., Nachemson, A., & Elfstrom, G. (1974). Lumbar disc pressure and myoelectric back muscle activity during sitting. IV studies on a car driver's seat. *Scandinavian Journal of Rehabilitation Medicine, 6*(1), 28 – 33.

Andreoni, G., Santambrogio, G. C., Rabuffetti, M., & Pedotti, A. (2002). Method for the analysis of posture and interface pressure of car drivers. *Applied Ergonomics*, 33(6), 511-522.

Bishu, R. R., Hallbeck, M. S., & Riley, M. W. (1991). Seating comfort and its relationship to spinal profile: a pilot study. *International Journal of Industrial Ergonomics*, 8(1), 89 – 101.

Borg, E. (2007). On perceived Exertion and its Measurement. Doctoral dissertation, 2007, Department of Psychology, Stockholm University, Sweden.

Borg, E., & Borg, G. (2002). A comparison of AME and CR100 for scaling perceived exertion. *Acta Psychologica, 109*(2), 157 – 175.

Borg, G. (1962). *Physical performance and perceived exertion*. Studia Psychologica et Paedagogica, Series altera, Investigationes X1. Lund, Sweden: Gleerup

Borg, G. & Borg, E. (2001). A new generation of scaling methods: Level-anchored ratio scaling. Psychologica, 28, 15 – 45.

Bureau of transportation statics (BTS), (2008). Retrieved January 19, 2009, from World Wide Web: http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html

Design and Emotion Society. (2008). *Tools to measure SENSORY characteristics* Retrieved February 20, 2008, from World Wide Web: http://www.designandemotion.org/society/knowledge_base/tools_methods.html?showcase=1&category=4.

Discomfort. (n.d.). *Dictionary.com Unabridged* (v 1.1). Retrieved March 21, 2008, from World Wide Web: http://dictionary.reference.com/browse/discomfort

Discomfort. (n.d.). *The American Heritage® Dictionary of the English Language, Fourth Edition*. Retrieved March 21, 2008, from World Wide Web: http://dictionary.reference.com/browse/discomfort

Discomfort. (n.d). *www.merriam-webster.com* . Retrived March 21, 2008, from World Wide Web: http://www.merriam-webster.com/dictionary/discomfort

Drury, C. G., & Coury, B. G. (1982). *A methodology for chair evaluation, Applied Ergonomics, 13*(3), 195 - 202.

England, M. A., & Wakely, J. (2006). *Color atlas of the brain and spinal cord: An introduction to normal neuroanatomy*. Philadelphia, PA: Mosby Elsevier. pp. 223.

Ergocentric.com, (2008). *The anatomy and Biochemistry of the human body in the seated posture*. Retrieved April 11, 2008, from World Wide Web: http://www.ergocentric.com/pdfs/in_the_seated_position.pdf

Fubini, E. (1997). The interaction between technical requirements and comfort in car seating. *Coil Anthropol, 21*(4), 05-27.

Grandjean, E. (1980). *Sitting posture of car drivers from the point of view of ergonomics. , Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour*, New York: Academic Press, pp. 205-213

Habsburg, S., & Middendorf, L. (1977). *What really connects in seating comfort? Studies of correlates of static seat comfort.* SAE paper no. 770247.

Helander, M., (2003). Forget about ergonomics in chair design? Focus on aesthetics and comfort! *Ergonomics 46*(13/14), 1306–1319.

Helander, M., & Zhang, L., (1997). Field studies of comfort and discomfort in sitting. *Ergonomics 40* (9), 895–915.

Hermann, S. & Bubb, H. (2007). Development of an objective measure to quantify automotive discomfort over time. *Industrial Electronics, 2007, IEEE International Symposium on, Vigo, Spain, June 4-7, 2007.* Spain IEEE, pp 2824-2830.

Hosea, T. M., Simon, S. R., Delatizky, J., Wong, M. A., & Hsieh, C., C. (1986). Myoelectric analysis of the paraspinal musculature in relation to automobile driving. *Spine, 11*(9), 28-36.

Keegan, J. J. (1953). Alterations of the lumber curve related to posture and seating. *Journal of Bone and Joint Surgery, 35*, 589-603.

Kyung, G. (2008). *An integrated human factors approach to design and evaluation of the driver workspace and interface: driver perceptions, behaviors, and objective measures*. Doctoral Dissertation, Blackburg, Virginia, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University.

Kyung, G., & Nussbaum, M. A. (2007). Driver sitting comfort and discomfort – part 2: Relationships with and prediction from interface pressure. *Journal of Industrial Ergonomics, 38*(5-6), 526-538.

Kyung G., Nussbaum, M. A., & Babski-Reeves, K. (2007). Driver sitting comfort and discomfort (part 1): Use of subjective ratings in discriminating car sets and correspondence among ratings. *Journal of Industrial Ergonomics,* 38(5-6), 516-525.

Kourinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G., & Jorgensen, K. (1987). Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms, *Applied Ergonomics, 18*(3), 233–237.

Leuder, R., & Noro, K. (Eds.). (1994). *Hard facts about soft machines: the ergonomics of seating. "the genesis of chair and sitting is not know………..".* : London & N.Y., Taylor & Francis, pp. 222.

Looze, M. P. D., Kuijt-Evers, L. F. M., & Dieen, J. V. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics, 46*(10), 985 – 997.

McAtamney L and Corlett EN (1993). RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics, 24(*2), 91-99.

Oliver, RJ. (1970). *A study of the comfort characteristics of production car seats*. MIRA Report, no. 197W12

Oborne, D.J., & Clarke, M.J. (1975) Questionnaire surveys of passenger comfort. *Applied Ergonomics*, 6(2), 97-103

Porter, J. M., Gyi, D. E., & Tait, H. A. (2003). Interface pressure data and the prediction of driver discomfort in the road trials. *Applied Ergonomics, 34*(3), 207-214.

R32Argent. 2006. R 32 Gallary Updated, May 10, 2006. Retrieved April 24, 2008 from World Wide Web: http://r32argent.blogspot.com/2006/05/r32-gallery-update_10.html

Reed, M. P., Manary, M. A., Flannagan, C. A. C., & Schneider, L. W. (2000). Effects of Vehicle Interior Geometry and Anthropometric Variables on Automobile Driving Posture. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 42*(4), 541-552.

Reed, M. P., Schneider, L. W., & Ricci, L. L. (1994). *Survey of auto seat design recommendations for improved comfort*. Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Shackel, B.; Chidsey, KD., & Shipley, P. (1969). The assessment of chair comfort. *Ergonomics, 12*(2), 269 – 306.

Smith, R. D., Andrews, D. M., & Wawrow, P. T. (2006). Development and evaluation of the automotive seating discomfort questionnaire (ASDQ). *International Journal of Industrial Ergonomics, 36*(2), 141 – 149.

Spineuniverse.com (March 25, 2008). Your Healthy Spine. Retrieved March 25, 2008, from the World Wide Web: http://www.spineuniverse.com/displayarticle.php/article1296.html

Tekscan, Inc. Automotive Seating Application with the *BPMS*TM System (2008). Pressure measuring device for automotive seat. Retrieved March 21, 2008, from World Wide Web: http://www.tekscan.com/industrial/app-seating.html .

The Society of Design & Emotion, (2008). Perceived Comfort Assessment. Retrieved May 1, 2008, from World Wide Web: http://www.designandemotion.org/society/knowledge_base/template.html?item=141

U. S. Department of Transportation, Research and Innovation Technology Administration, Bureau of Transportation Statistics (2008). *Number of U. S. Aircraft, Vehicles, Vessels, and other Conveyances*, Retrieved April 8, 2008, from World Wide Web: http://www.bts.gov/cgi-bin/breadcrumbs/PrintVersion.cgi?date=09010438

U. S. Department of Transportation, Research and Innovation Technology Administration, Bureau of Transportation Statistics (2008). Number *of U. S. Aircraft, Vehicles, Vessels, and other Conveyances*, Retrieved April 8, 2008, from World Wide Web: http://www.bts.gov/publications/highlights_of_the_2001_national_household_travel_survey/html/section_02.html

Vos, G. A., Congleton, J. J., Moore, S., Amendola, A. A., & Ringer, L. (2006). Postural versus chair design impacts upon interface pressure. *Applied Ergonomics, 37*(5), 619 – 628.

Wachsler, R. A., & Learner, D. B. (1960). An analysis of some factors influencing seat comfort. *Ergonomics, 3*(4), 315 – 320.

Zenk, R., Mergl, C., Hartung, J., & Bubb, H. (2007). Predicting overall seating discomfort based on body area ratings. *SAE World Congress & Exhibition, April 2007,* Detroit, MI, USA.

Zhang, L., Helander, M. G. & Drury, C. G. (1996). Identifying factors of comfort and discomfort in sitting, *Human Factors*, *38*, 377 – 389.

CHAPTER III

ANALYSIS OF SUBJECTIVE BODY DISCOMFORT RATINGS DURING SIMULATED PROLONGED DRIVING TASKS: WHAT MEASURES ARE MOST EFFECTIVE?

(Reprinted with approval by the Society of Human Factors & Ergonomics)

Abstract

Subjective discomfort ratings are a common assessment technique in human factors and ergonomics, and there exist a number of different methods for analyzing ratings (e.g., mean, median, maximum rating, etc.). The objective of this research was to evaluate multiple methods for analyzing body discomfort ratings. Perceived discomfort of eight participants was measured across ten body parts (buttock, left buttock, right buttock, lower back, upper back, neck, shoulder, eye, thigh and whole body) during 2-hour simulated driving tasks at 3 backrest angles (105^o, 120^o, 135^o). Discomfort ratings were collected every 15 minutes using a modified Borg CR- scale. The time weighted discomfort (TWD) average of was found to be more sensitive to backrest angle changes than other measures considered. In addition, factor analysis revealed different methods provided different groupings of body parts, and the method selected for analyzing subjective discomfort ratings should be selected based on the objective of the study.

Introduction

A widely accepted definition for seated comfort/discomfort does not exist (Looze et al, 2003). Some researchers believe that seated comfort is a psychological phenomenon, and as such is difficult to measure (Helander & Zhang, 1997). Seated discomfort is typically considered as a physical phenomenon (Halander, 2003; Schifferstein & Hekkert, 2008; Design & Emotion Society, 2008), and may be instantaneously perceived (Mansfield et al., 2007). Although there are no unified thoughts about seated (dis)comfort definitions, many researchers believe that sitting discomfort and comfort should be considered separately (Bishu et al, 1991; Zhang et al, 1996; Looze et al, 2003; Smith et al, 2006; Zenk et al, 2007). Research has shown that comfort during driving activities disappears quickly (Fai et al., 2007), and therefore, during prolonged driving tasks, discomfort assessment are more applicable.

Most studies of seated discomfort during simulated or actual driving collected ratings at the conclusion of the test session regardless of test session duration (e. g. Kyung et al, 2008; Falou et al, 2003; Na et al, 2005). While for extremely short test durations this may be appropriate, collecting discomfort ratings at the end of a long test session may result in lost information. For example, a participant may have the same final discomfort rating for two conditions, but reach that final rating in drastically different ways. For one test session, the participant may remain at a low level of discomfort for most of the session and increase to the final rating within one assessment period. For the second test session the participant may reach the final discomfort rating quickly within the test session.

Several measures for discomfort ratings exist (mean rating, median rating, maximum rating, time to peak rating, time weighted average, etc.). However, it is unclear if one of these measures is more useful in representing discomfort data collected throughout test sessions. Therefore, the objective of this study was to determine which discomfort data representation method is most appropriate measure of sitting discomfort in prolonged simulated driving task (e.g., mean rating, time weighted average, time to reach peak rating, etc.). The methods selected for testing were chosen to be representative of those commonly used in automotive discomfort studies. Moreover, discrepancy exists in terms of the number of body parts considered ranging from a few (e.g., Kyung et al, 2008) to many (as high as 32) (e. g. Falau, 2003). A secondary objective of the study was to determine appropriate body parts that humans are capable of discriminating between in discomfort assessments.

Methodology

Experimental Design

A repeated measures design was used to assess the effect of backrest angle (3 levels: 105°, 120°, and 135°) on several subjective measures of discomfort. All participants were exposed to the 105° backrest angle initially, and exposure to the remaining backrest angles was balanced. The 105° angle was introduced first to minimize any training effects associated with the use of the simulator, despite the use of a familiarization session.

Independent Variable

Three seat backrest angles (105°, 120°, and 135°) measured counter clock wise from the horizontal line (Figure 3) were studied. These angles were chosen to fit within the simulator's backrest range-of-motion, and to accommodate human vision requirements. The simulator used in this study had the driver seat for a Dodge Neon. This seat was attached to a platform that allowed for the seat to be rotated to the specified backrest angles. To limit the confounding effect of seat pan angle, a single seat pan angle of 15° counter clock wise with the horizontal line (X-axis) was used (figure 1). It was also of interest to determine if backrest angle affected the type of discomfort measure that was most appropriate.

Dependent Variables

A modified Borg CR – 10 Perceived Level of Exertion Scale (Borg, 1962; Borg & Borg, 2001; Borg & Borg 2002; Borg, 2007) was used to measure subjective sitting discomfort, where the scale ranged from 0 = no discomfort to 10 = maximal discomfort. Participants verbally indicated their discomfort rating every 15 minutes. The researcher orally asked participants their discomfort level for each body part (lower back, upper back, buttocks, left buttock, right buttock, eyes, neck, shoulder and thigh and whole body), and the order of the body parts was randomized at each assessment point. A total of 8 Borg assessments were taken for each body part. Since comfort has been linked to aesthetic perception (Helander & Zhang, 1997), the measurement of comfort was considered beyond the scope of the study.

Rate of change in discomfort ratings for each body part, maximum discomfort rating reported, time to initiate discomfort, time to reach maximum discomfort rating, and time weighted discomfort rating were computed and used in the analysis. Rate of change in discomfort was computed using simple linear regression, and the slope parameter used in the analysis. Maximum discomfort rating was defined as the largest discomfort rating reported regardless of at what time that rating occurred. Time to reach maximum discomfort rating was determined by selecting the assessment time period corresponding with the first instance of the maximum rating. If the participant did not report a discomfort rating (a rating of zero was provided for the entire session), then 120 minutes was used as the time to maximum discomfort rating. Time to initiate discomfort was calculated by the time taken to reach first perceived discomfort rating other than zero. Time weighted discomfort (TWD) rating was calculated by using:

$$TWD = \frac{\sum_{i=1}^{n} d_i t_i}{T} \tag{2}$$

Where,

n = total number of assessment taken for each participant;

T = total time for each session (120 minutes);

d_i = perceived discomfort at ith observation; and

$_{\mathrm{ti}}$ = time between (i-1)th and ith observation.

The unit of TWD is discomfort rating.

Task

At each backrest angle (105°, 120° and 135°, participants performed a two-hour simulated driving task, until they wished to stop the study or reached Borg scale rating seven (7).

The driving simulator. The simulated driving tasks were created using Hyper Driver software (DriveSafety, Inc., Murray, UT). The simulator had a Dodge Neon car seat, steering wheel, and cathode ray tube 19-inch monitor, dashboard, turn signal, and brake and gas pedal. There were many built-in scenarios available in the hyper drive software. To simulate the real world car driving sound, the simulator also had two speakers both sides of the monitor to introduce realistic driving sounds.

Driving scenarios. To simulate prolonged driving tasks, highway driving scenarios were used. Scenarios were made as natural as possible (such as traffic flows, vehicles, animals crossing the highways, houses, schools, etc.) that changed continuously throughout the test session. A single scenario was used for each test session to minimize scenario complexity differences. As the test session was two hours in length, learning of the scenario was expected to be minimal.

Participants

Four males and four females were recruited for the study from a university undergraduate population (Table 1). The Standardized Nordic Questionnaire was used to exclude participants from the study if they had any injury that would affect the task (Kuorinka, 1987). Participants having less than three years of experience and less than 20/20 (or corrected to) eye vision were excluded from the study. They were also asked not to drive for more than a total of 2 hours the day before each test session to minimize residual fatigue and discomfort.

Procedure

Participants completed informed consent procedures approved by the Mississippi State University IRB prior to data collection, followed by a demographic questionnaire, and the Nordic questionnaire. On the first day of testing, participants were trained on the use of the Borg scale by holding a weight in their hand with their shoulder flexed at 90 degrees. Participants walked through the scale until reaching a value of 10. They also received a short 15-minute familiarization session with the simulator prior to their test session. Participants were seated in to the simulator and allowed to adjust the simulator features (except the seat back and seat pan angles). The simulation began, and discomfort ratings were collected every 15 minutes until the session ended or were terminated. Sessions were at least 48 hours apart to minimize residual effects. Listening to music and talking were permitted throughout the sessions to make the driving task as natural as possible.

Data Analysis

Factor analysis was used to determine which body regions were considered the same by participants, and to determine which groupings were logical for each of the subjective rating analysis methods. Those that did not create logical factors were considered to be less accurate and less sensitive to test conditions. Both principal component analysis and the maximum likelihood method were used. Varimax rotation (an orthogonal transformation method which reduces the information overlap) was applied to both methods to redistribute the variation. Any factor with an Eigen-value greater than 1 was retained. Cumulative variance explained/accounted by factors is a measure of the amount of information lost by the analysis. If the cumulative variance accounted by the factors was less than 90 percent, then addition factors were considered even if the Eigen-value was less than 1 (Johnson & Wichern, 2007). For the maximum likelihood method, a significance level of 0.05 was used to determine the number of factors. All statistical analyses were performed using SAS (Version 9.1).

Results

Table 15 provides the results of the factor analyses. It should be mentioned here that both factor analysis methods provided identical results. Different subjective rating methods resulted in different factor groupings. For TWD, a logical body part grouping was observed and the body regions identified (or the factors identified) were:

Factor 1: Buttock Discomfort

Factor 2: Lower Back Discomfort

Factor 3: Upper Body Part Discomfort

Factor 4: Thigh Discomfort, and

Factor 5: Eye Discomfort

Figures 4 and 5 show that not all body parts were impacted by this driving task (namely the thigh, eye, shoulder, and upper back). The analysis was rerun with the remaining six body parts (Table 15). All methods resulted in the same three factors except for discomfort slope. The three factors identified for the majority of the discomfort measures were:

Factor 1: Buttock Discomfort

Factor 2: Lower Back Discomfort, and

Factor 3: Neck discomfort

Discussion

This study evaluated various methods for analyzing discomfort data collected at multiple time points in a test session. It was expected that adjacent body parts would form a single factor (Hughes et al., 2004), however, only TWD produced this expected result when all body parts were considered. This finding illustrates that humans are not sensitive enough to differentiate discomfort between adjacent body parts (e.g., left vs right buttock), as has been found in previous research (Hughes et al., 2004). This is because adjacent body parts are exposed to similar loads, and in the case of driving tasks, similar postural constraints. Additionally, research has found that discomfort is distributed to from one body part to adjacent body parts (England, & Wakely, 2006).

Results of this study indicated that different methods for representing discomfort data resulted in significantly different factor groupings. This is likely due to the intent of the discomfort analysis method. For example, discomfort slope will indicate which body parts have more rapid or slower changes in discomfort regardless of their location on the body; whereas TWD will more likely result in logical groupings as discomfort will be relatively uniform for specific regions of the body (as discussed previously).

However, consistent factor results were observed when unimportant variables were deleted from the analyses. This implies that most any discomfort analysis method is appropriate as long as only impacted body parts are assessed. Therefore, researchers need to consider the type of task they are assessing and carefully select the body parts/regions they collect data from. However, it is difficult to know the appropriate body parts prior to data analysis. However, given that the TWD analysis method resulted in logical groupings, even in the presence of relatively unaffected body parts, this analysis method is a more reliable method than the others considered here.

Table 15 Factor analyses for time weighted discomfort, maximum discomfort, time to reach maximum discomfort, time to initiate discomfort and discomfort slope

	Using discomfort rating for all body parts									
	Factor 1		Factor 2		Factor 3		Factor 4		Factor 5	
	Variable	Correlation	Variable	Correlation	Variable	Correlation	Variable	Correlation	Variable	Correlation
Time Weighed Discomfort	Buttock Left Buttock Right Buttock	0.89556 0.93213 0.75188	Lower Back Whole Body	0.94858 0.67335	Upper Back Shoulder Neck	0.74298 0.67690 0.66255	Thigh	0.58747	Eye	0.70646
Maximum Discomfort	Buttock Left Buttock Right Buttock Thigh Upper Back	0.93854 0.91094 0.82727 0.45762 0.48144	Lower Back Whole Body	0.55861 0.80369	Shoulder	0.83727	Eye	0.96008	Neck	0.85861
T to Reach Maximum Discomfort	Buttock Left Buttock Right Buttock Upper Back	0.84071 0.68627 0.74513 0.70214	Eye Whole Body	0.98147 0.50765	Thigh Shoulder	0.54204 0.95363	Lower Back	0.89036	Neck	0.70753
D Slope	Neck Eye Whole Body	0.79456 0.94095 0.87546	Buttock Right Buttock Shoulder	0.66996 0.70416 0.79399	Lower Back Upper Back	0.63797 0.92178	Left Buttock	0.99022	Thigh	0.69717
T to Initiate Discomfort	Shoulder Whole Body	0.93067 -0.95645	Buttock Left Buttock	0.99625 0.99625	Thigh Neck	0.80996 0.94331	Upper Back Eye	0.90799 0.63928	Lower Back	0.76535

	Excluding thigh, eye and shoulder and upper back (lower discomfort body parts)					
	Factor 1		Factor 2		Factor 3	
	Variable	Correlation	Variable	Correlation	Variable	Correlation
Time Weighted Discomfort	Buttock, Left Buttock Right Buttock	0.93683 0.94862 0.91715	Lower Back Whole Body	0.91950 0.82125	Neck	0.99531
Maximum Discomfort	Buttock, Left Buttock Right Buttock	0.96109 0.94375 0.90813	Lower Back Whole Body	0.94568 0.66312	Neck	0.99039
Time to Reach Maximum Discomfort	Buttock, Left Buttock Right Buttock	0.87194 0.85072 0.80840	Lower Back Whole Body	0.81691 0.73578	Neck	0.97206
Discomfort Slope	Neck Whole Body	0.94615 0.90334	Buttock Right Buttock	0.86482 0.78721	Left Buttock Lower Back	0.88849 -0.63648
Time to Initiate Discomfort	Buttock Left Buttock	0.99523 0.99523	Whole Body Lower Back	0.89223 -0.85871	Neck	0.98600

References

Bishu, R. R., Hallbeck, M. S. & Riley, M. W. (1991). Seating comfort and its relationship to spinal profile: a pilot study. *International Journal of Industrial Ergonomics, 8*(1), 89 – 101.

Borg, E. (2007). On perceived Exertion and its Measurement. Doctoral dissertation, Department of Psychology, Stockholm University, Sweden.

Borg, E., & Borg, G. (2002). A comparison of AME and CR100 for scaling perceived exertion. *Acta Psychologica, 109,* 157 – 175.

Borg, G. (1962). Physical performance and perceived exertion. *Studia Psychologica et Paedagogica,* Series altera, Investigationes X1. Lund, Sweden: Gleerup.

Borg, G. & Borg, E. (2001). A new generation of scaling methods: Level-anchored ratio scaling. *Psychologica, 28,* 15 – 45.

Design & Emotion Society. (2008). Tools to measure SENSORY characteristics. Retrieved February 20, 2008, from World Wide Web: http://www.designandemotion.org/society/knowledge_base/tools_methods.html?showcase=1&category=4.

England, M. A., & Wakely, J. (2006). *Color atlas of the brain and spinal cord: An introduction to normal neuroanatomy*. Philadelphia, PA: Mosby Elsevier. pp. 223.

Falou, W. E., Duchene, J., Grabisch, M., Hewson, D., Langeron, Y. & Lino, F. (2003). Evaluation of driver discomfort during long-duration car driving. *Applied Ergonomics, 34*(3), 249-255.

Helander, M. (2003). Forget about ergonomics in chair design? Focus on aesthetics and comfort! *Ergonomics 46*(13-14), 1306–1319.

Helander, M., & Zhang, L. (1997). Field studies of comfort and discomfort in sitting. *Ergonomics 40* (9), 895–915.

Hughes, L. E., Babski-Reeves, K, Nussbaum, Maury, & Smith-Jackson, T. (2004). Effects of time pressure and mental workload on physiological risk factors for upper extremity musculoskeletal disorders while typing. M. Sc. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Johnson, R. A., & Wichern, D. W. (2007). *Applied multivariate statistical analysis*. Upper Saddle River, N.J.: Pearson Prentice Hall. Chapter 9 and Chapter 10, pp. 481 – 574.

Kourinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G., & Jorgensen, K. (1987). Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms, *Applied Ergonomics, 18*(3), 233–237.

Kyung G., Nussbaum, M. A., & Babski-Reeves, K. (2007). Driver sitting comfort and discomfort (part 1): Use of subjective ratings in discriminating car sets and correspondence among ratings. *Journal of Industrial Ergonomics, 38*(5-6), 516-525.

Looze, M. P. D., Kuijt-Evers, L. F. M., & Dieen, J. V. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics, 46*(10), 985 – 997.

Mansfield, N. J. MacMull, S. J. Singla, G & Rimell, A. N. (2007). Relative influence of sitting duration and vibration magnitude on sitting discomfort in a car seat. *42nd United Kingdom Conference on Human Responses to Vibration*. ISVR, University of Southampton, Southampton, England, September 10 – 12, 2007.

Na, S. Lim, S., Choi, H. S., & Chung, M. K. (2005). Evaluation of driver's discomfort and postural change using dynamic body pressure distribution. *International Journal of Industrial Ergonomics*, *35*(12), 1085–1096.

Schifferstein, H., & Hekkert, P. (2008). *Product experience*. San Diego, CA: Elsevier, pp. 459.

Smith, R. D., Andrews, D. M., & Wawrow, P. T. (2006). Development and evaluation of the automotive seating discomfort questionnaire (ASDQ). *International Journal of Industrial Ergonomics, 36*(2), 141 – 149.

Zenk, R., Mergl, C., Hartung, J., & Bubb, H. (2007). Predicting overall seating discomfort based on body area ratings. *SAE World Congress & Exhibition, April 2007,* Detroit, MI, USA.

Zhang, L., Helander, M. G. & Drury, C. G. (*1996*). Identifying factors of comfort and discomfort in sitting, *Human Factors, 38*(3), 377 – 389.

CHAPTER IV

LIMITATIONS AND CONCLUSION

Limitations

Due to safety hazards, it was infeasible to conduct this study using real automobiles. Therefore, a low fidelity driving simulator was used. While many of the aspects of driving are common between the simulator and the real-world, the lack of realism may limit the results. For example, participants may be willing to accept more discomfort in the simulator sitting, because there is no risk of injury. However, if the experiment were conducted in the real world, perceptions of discomfort may be affected by perceived risk or hazard. The simulator did allow for the controlling of confounding variables (such as weather and time of day) which may have impacted results.

Research shows that sitting discomfort is a function of time (Helander and Zhang, 1997). Despite the amount of literature available for evaluating seating discomfort, no guidelines or standards were found regarding specific testing times for assessing discomfort. Study times have ranged from a few minutes to several hours. Two specific studies of discomfort assessment in the automotive setting used a 1 hour test session (Uenishi et al., 2000), though 2 hour test sessions have been recommended (Gyi and Porter, 1999). A 2-hour test session was used for this study. However, as mentioned previously, many of the dependent variables were not sensitive to changes in backrest angle. Therefore, this time period may need to be increased. Likely, a change in the way discomfort is assessed subjectively is needed to capture micro-changes in discomfort. Any changes will need to be reflective of the human system, and it is likely that humans are not sensitive to micro-changes in our discomfort (Ahmed & Babski-Reeves, 2009). Rather, we transverse quickly from a state of “comfort” or “no discomfort” to a state of “discomfort” rapidly, at least perceptually.

Human perceptions change with age; older people are more sensitive to perceive discomfort. In this study, some subjects were not sensitive enough to notice changes of discomfort and no subjects did reach the discomfort rating to 7 (very very high discomfort) except one subject rated 7 for lower back at 105°. Due to the subjects with young age used in the study, most of the ratings reached maximum 4 (moderate discomfort). So, the testing time can be increased for this study if younger participants are used.

The driver’s seat for dodge neon was used in this study, so the results may be changed if the seat is changed to hard cushion from soft cushion. In the future study, different types of seat can be tested to make a generalized conclusion on backrest angle.

A relatively small number of participants were used in this study. Because many of differences in discomfort are very small, a large sample size would be needed to fully understand and describe how perceived discomfort is affected by backrest angle. Additional studies are needed to investigate this hypothesis.

Only three backrest angles were studied, while there are an unlimited number of backrest angles that people employ while driving. This research illustrates that a backrest angle near 120° is optimum. However, it is impossible at this point to identify if a true optimum backrest angle is smaller or larger than this number.

Performance measures in vehicle driving are very important. Poor performance can lead to hazardous situations for example it can cause an accident. Due to the technical flaws of the simulator the performance data were not able to retrieve from the simulator. Therefore the optimum 120° seat backrest angle was determined only based on the perceived discomfort and movement data. Performance metrics will need to be added to future studies to ensure that discomfort minimization is synonymous with required performance levels.

Conclusions

The optimum backrest angle for this study is concluded to be 120°, in line with previous studies. However, other researchers have identified that when given the chance, drivers typically assume a more upright posture (Kyung, 2008). Given this, additional research into the design of the seat is needed to minimize discomfort at these more upright seated angles. Further research is needed to more directly identify the optimum seating posture for both comfort and discomfort, while also maximizing performance.

The time weighted sitting discomfort deemed to be the best measure of perceived sitting discomfort of measure. Moreover, the study found that adjacent body parts make a group in perceiving sitting discomfort, in other words, humans are not much sensitive in perceiving sitting discomfort. In future, it will be possible to focus on those body parts those are sensitive to sitting discomfort. However, further research is needed in the direction of data collection and analysis method to get the better generalizability of sitting discomfort research.

References

Ahmed, S. and Babski-Reeves, K. (2009). Analysis of Subjective Body Discomfort Ratings during Simulated Prolonged Driving Tasks: What Measures are most Effective? Proceeding of the Human Factors and Ergonomics Society, 53nd Annual Meeting-2009. San Antonio, Texas, October 19-23, 2009, USA: Human Factors and Ergonomics Society.

Gyi, D. E., & Porter, J. M. (1999). Interface pressure and the prediction of car seat discomfort. *Applied Ergonomics, 30*(2), 99-107.

Helander, M., & Zhang, L., (1997). Field studies of comfort and discomfort in sitting. *Ergonomics 40* (9), 895–915.

Kyung, G., & Nussbaum, M. A. (2007). Driver sitting comfort and discomfort – part 2: Relationships with and prediction from interface pressure. *Journal of Industrial Ergonomics, 38*(5-6), 526-538.

Kyung G., Nussbaum, M. A., & Babski-Reeves, K. (2007). Driver sitting comfort and discomfort (part 1): Use of subjective ratings in discriminating car sets and correspondence among ratings. *Journal of Industrial Ergonomics,* 38(5-6), 516-525.

Uenishi, K., Tanaka, M., Yoshida, H., Tsutsumi, S., & Miyamoto, N. (2002). *Driver's fatigue evaluation during long term driving for automotive seat development.* SAE Technical Paper Series (2002-01-0773).

APPENDIX A

PRESSURE MEASURING DEVICE

During this study a Force Sensitive Applications (FSA) pressure map was used. This Clinical tool allows one to evaluate interface pressures between a person and the support they are sitting and lying on. In the study FSA pressure map has been used to measure the amount of pressure applied to the back and the buttock of an individual while they're driving. The peak pressure that was collected which measures is the objective measure of seating discomfort. (Hermann & Bubb, 2007). The Pressure map has many different features that can be used. The product specifications are as shown below in Table 1.

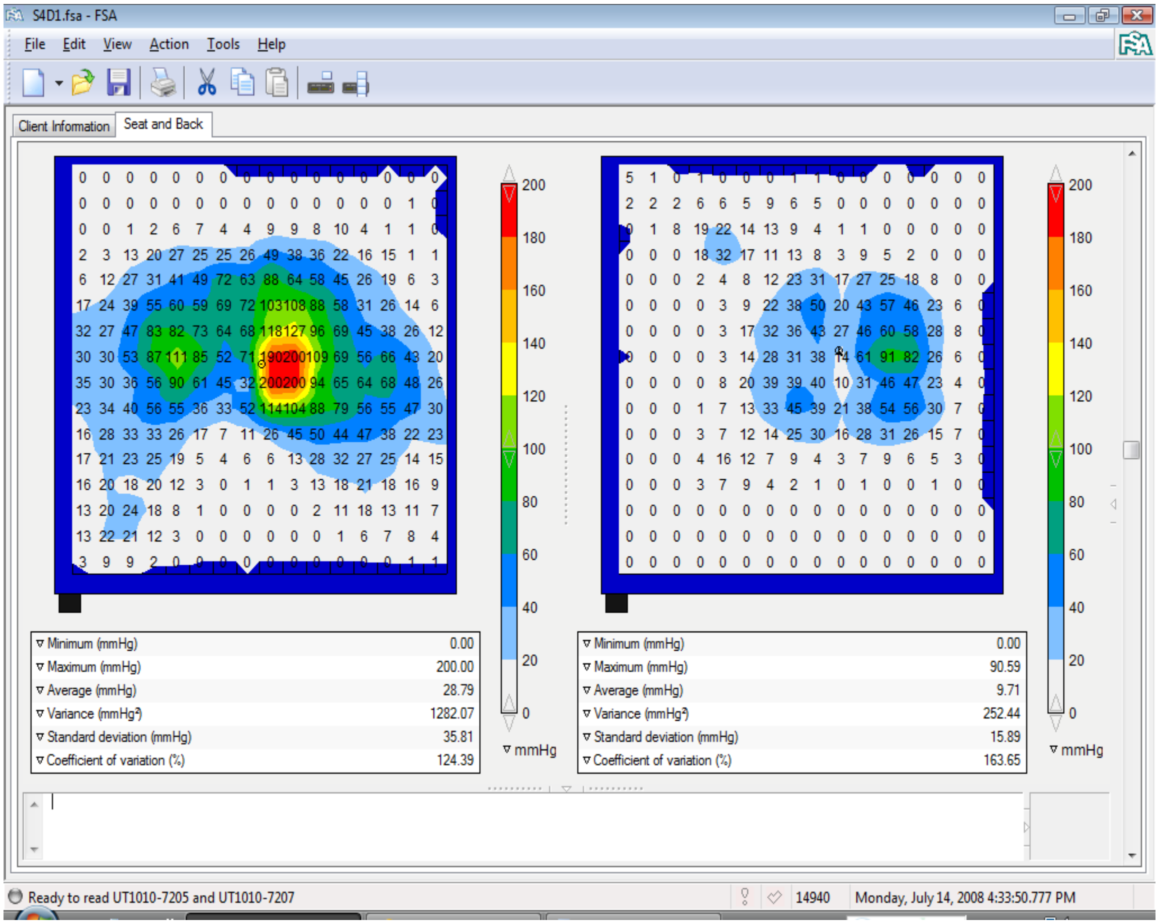
Table 16 FSA Pressure Map Specifications

FSA Mat Name	Seat 16/53
Sensing Area	430 mm x 430 mm (16.9" x 16.9")
Poly Thickness	2 mm (.080")
Sensor Dimensions	23.8 mm x 23.8 mm (15/16" x 15/16")
Sensor Gap	3.1 mm x 3.1 mm (.120" x .120")
Sensor Arrangement	16 x 16
Finished Mat	533 mm x 533 mm (21.0" x 21.0")
ISO Bag Size Required	559 mm x 610 mm (22" x 24")
Sensing Area	185,000 mm^2 (287 in^2)
Number of Sensors	256
Sensor Surface Area	566 mm^2 (.880 in^2)
Standard Calibration Range	200 mmHg (3.89 PSI

During the study the pressure map collects data that is sent to the computer as shown in Figure 1. The colored surface allows one to see the pressure points on the map. There is a color legend on the side of each map to shows the calibration unit range. The

Legend can be changed to different colors as one so chooses. Clicking the arrows at the top of the legend increases/decrease the top of the range by 10 units. By clicking the arrow at the bottom of the legend the range at the bottom is increase/decrease by 1 unit. The color legend (pressure) can be measured in six different units such as kPa, mmHg, psi, $\frac{N}{cm^2}$, $\frac{Kg}{cm^2}$, $\frac{g}{cm^2}$. In this study we used mmHg.

The Pressure map is broken up into many different cells as shown above in Figure 1. These cells display the output number of pressure being applied to a specific point on the mat. These cells are categories in alphabetical order from left to right and numerically from top to bottom. This allowed use to separate the left buttock from the right buttock and the lower back from the upper back which in turned saved time on computer work. The software also allows to export data into a Micro soft excel worksheet. The software select the data frame by frame and pastes it into an excel worksheet with the time of each frame, the minimum pressure point, maximum pressure point, the Average pressure, the Variance, the Standard deviation, Coefficient of variation, the Horizontal center, Vertical center of pressure. It also shows each cell by it categorized alphabet and number as well as the time of the experiment. Figure 2 shows a more detailed description of the excel worksheet.



0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	1	2	6	7	4	4	9	9	8	10	4	1	1	0
2	3	13	20	27	25	25	26	49	38	36	22	16	15	1	1
6	12	27	31	41	49	72	63	88	64	58	45	26	19	6	3
17	24	39	55	60	59	69	72	103	108	88	58	31	26	14	6
32	27	47	83	82	73	64	68	118	127	96	69	45	38	26	12
30	30	53	87	111	85	52	71	190	200	109	69	56	66	43	20
35	30	36	56	90	61	45	32	200	200	94	65	64	68	48	26
23	34	40	56	55	36	33	52	114	104	88	79	56	55	47	30
16	28	33	33	26	17	7	11	26	45	50	44	47	38	22	23
17	21	23	25	19	5	4	6	6	13	28	32	27	25	14	15
16	20	18	20	12	3	0	1	1	3	13	18	21	18	16	9
13	20	24	18	8	1	0	0	0	0	2	11	18	13	11	7
13	22	21	12	3	0	0	0	0	0	0	1	6	7	8	4
3	9	9	2	0	0	0	0	0	0	0	0	0	0	1	1

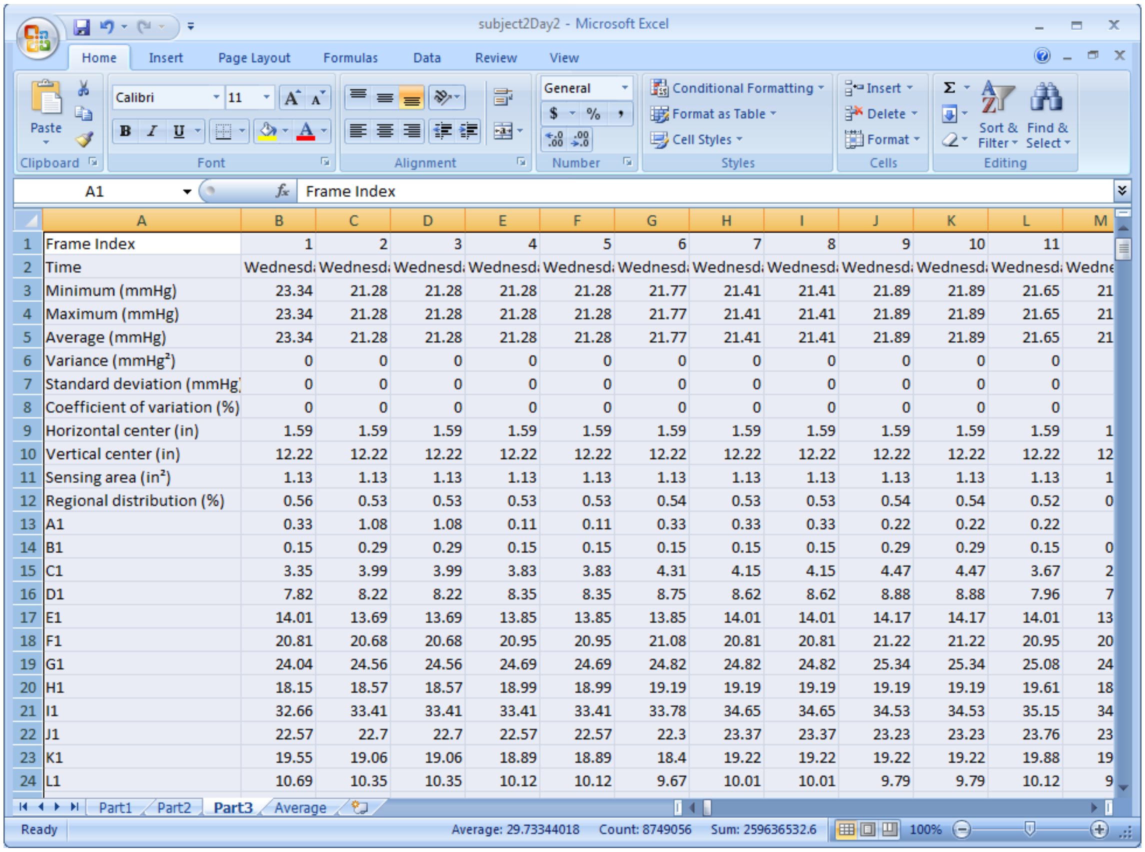
▿ Minimum (mmHg)	0.00
▿ Maximum (mmHg)	200.00
▿ Average (mmHg)	28.79
▿ Variance (mmHg²)	1282.07
▿ Standard deviation (mmHg)	35.81
▿ Coefficient of variation (%)	124.39

5	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0
2	2	2	6	6	5	9	6	5	0	0	0	0	0	0	0
0	1	8	19	22	14	13	9	4	1	1	0	0	0	0	0
0	0	0	18	32	17	11	13	8	3	9	5	2	0	0	0
0	0	0	2	4	8	12	23	31	17	27	25	18	8	0	0
0	0	0	0	3	9	22	38	50	20	43	57	46	23	6	0
0	0	0	0	3	17	32	36	43	27	46	60	58	28	8	0
0	0	0	0	3	14	28	31	38	14	61	91	82	26	6	0
0	0	0	0	8	20	39	39	40	10	31	46	47	23	4	0
0	0	0	1	7	13	33	45	39	21	38	54	56	30	7	0
0	0	0	3	7	12	14	25	30	16	28	31	26	15	7	0
0	0	0	4	16	12	7	9	4	3	7	9	6	5	3	0
0	0	0	3	7	9	4	2	1	0	1	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

▿ Minimum (mmHg)	0.00
▿ Maximum (mmHg)	90.59
▿ Average (mmHg)	9.71
▿ Variance (mmHg²)	252.44
▿ Standard deviation (mmHg)	15.89
▿ Coefficient of variation (%)	163.65

Ready to read UT1010-7205 and UT1010-7207 | 14940 | Monday, July 14, 2008 4:33:50.777 PM

Figure 8 Pressure map output.



A1 | Frame Index

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Frame Index	1	2	3	4	5	6	7	8	9	10	11	
2	Time	Wednesd	Wednesd	Wednesd	Wednesd	Wednesd	Wednesd	Wednesd	Wednesd	Wednesd	Wednesd	Wednesd	Wedne
3	Minimum (mmHg)	23.34	21.28	21.28	21.28	21.28	21.77	21.41	21.41	21.89	21.89	21.65	21
4	Maximum (mmHg)	23.34	21.28	21.28	21.28	21.28	21.77	21.41	21.41	21.89	21.89	21.65	21
5	Average (mmHg)	23.34	21.28	21.28	21.28	21.28	21.77	21.41	21.41	21.89	21.89	21.65	21
6	Variance (mmHg²)	0	0	0	0	0	0	0	0	0	0	0	
7	Standard deviation (mmHg	0	0	0	0	0	0	0	0	0	0	0	
8	Coefficient of variation (%)	0	0	0	0	0	0	0	0	0	0	0	
9	Horizontal center (in)	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1
10	Vertical center (in)	12.22	12.22	12.22	12.22	12.22	12.22	12.22	12.22	12.22	12.22	12.22	12
11	Sensing area (in²)	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1
12	Regional distribution (%)	0.56	0.53	0.53	0.53	0.53	0.54	0.53	0.53	0.54	0.54	0.52	0
13	A1	0.33	1.08	1.08	0.11	0.11	0.33	0.33	0.33	0.22	0.22	0.22	
14	B1	0.15	0.29	0.29	0.15	0.15	0.15	0.15	0.15	0.29	0.29	0.15	0
15	C1	3.35	3.99	3.99	3.83	3.83	4.31	4.15	4.15	4.47	4.47	3.67	2
16	D1	7.82	8.22	8.22	8.35	8.35	8.75	8.62	8.62	8.88	8.88	7.96	7
17	E1	14.01	13.69	13.69	13.85	13.85	13.85	14.01	14.01	14.17	14.17	14.01	13
18	F1	20.81	20.68	20.68	20.95	20.95	21.08	20.81	20.81	21.22	21.22	20.95	20
19	G1	24.04	24.56	24.56	24.69	24.69	24.82	24.82	24.82	25.34	25.34	25.08	24
20	H1	18.15	18.57	18.57	18.99	18.99	19.19	19.19	19.19	19.19	19.19	19.61	18
21	I1	32.66	33.41	33.41	33.41	33.41	33.78	34.65	34.65	34.53	34.53	35.15	34
22	J1	22.57	22.7	22.7	22.57	22.57	22.3	23.37	23.37	23.23	23.23	23.76	23
23	K1	19.55	19.06	19.06	18.89	18.89	18.4	19.22	19.22	19.22	19.22	19.88	19
24	L1	10.69	10.35	10.35	10.12	10.12	9.67	10.01	10.01	9.79	9.79	10.12	9

Average: 29.73344018 Count: 8749056 Sum: 259636532.6

Figure 9 Excel worksheet collected data.

This pressure map has two different frequencies it runs. It has a scanning frequency and a Remote frequency. Both frequencies are defaulted at 5 Hz, but the max frequency is 40 Hz. One can only obtain this value when running at high speed, which the computer is interface module is reading at approximately 10000 sensors per second. We ran our study at 5 Hz for both of the settings; we collected 5 reading per second. Due to the nature of the study it is not necessary to use the high frequency rate; which would otherwise make wastage of CPU power.

The FSA a mat also has these following features:

- Comparison View
- Time Plot Display
- The Statistics Display
- Note area
- Video Window
- Remote Download
- Exporting Graphics
- Windows XP, Vista Compatible
- Real time viewing
- Template Creator
- Senor Array
- One mat 32 x32 array
- Two mats 16 x 16 array
- Sapling Rate 0- 40 Hz
- Sensor are comfortable and durable

Each FSA system comes with a system Base that includes the following:

- FSA 4D Software
- Dual Port Serial / USB Interface Module
- Trigger, Battery Pack and Belt for Mobile Use
- Comprehensive User Manual
- Standard and Extension Cables

- Universal AC Power Supply
- FSA High Strength Transport and Storage Tube
- 1 Year limited Warranty

APPENDIX B

DATA COLLECTION SHEET

1. Subject Number:________

Backrest Angle	Discomfort rating for																			
	Buttock		Left Buttock		Right Buttock		Thigh		Lower Back		Upper Back		Shoulder		Neck		Eye		Whole body	
105																				
120																				
135																				

APPENDIX C

MOVEMENT DATA COLLECTION

1. Subject Number:________ 2. Seat Backrest Angle:________________

Type of movement								
	15	30	45	60	75	90	105	120
Shift left								
Shift right								
Move forward								
Move backward								
Leg movement								
Other								
Other								
Other								

APPENDIX D

DEMOGRAPHIC QUESTIONNAIRE

Subject Number:

1. Age________ 2. Gender ______Male _________Female

3. Ethnicity ________ Caucasian ________Asian __________African American

4. Weight ____________lbs

5. Height__________(inches)

6. Years of Driving Experience _____________

7. Average Number of miles/day you drive usually ___________

8. After what point in time do you begin to feel discomfort

_____________0 – 15 min_____________16 – 30 min

_____________30 – 45 min_____________ > 45 min

9. When you begin to experience disc, what do you do (check all that apply)? Please put in order of frequency all that you do.

___________Shift left

___________Lean forward

___________Shift right

___________Move legs

___________Lean back

___________others (please specify)

_____________Move forward

_____________ Move backword

_____________ Stressing

_____________ Head Movement

_____________ Shoulder

10. What type of vehicle do you typically drive?

_______2 door sedan _________ 4 doors Sedan _______Small SUV

_______SUV _________ Van _______Minivan

_______ Pickup Truck _________ other (please specify)

APPENDIX E

SCREENING QUESTIONNAIRE FOR SUBJECTS SELECTION

Subject Number:

Number of years you have driven a vehicle

Do you have at least 20/20 vision (natural or corrected by glass or contacts

____________YES____________NO

3.

Have you had Pain, Ache, Discomfort, Injuries in:	In the pas 12 months		In the last 7 days	
	When did it occur	Duration it lasted	When did it occur	Duration it lasted
Neck				
Shoulders				
Arms/Elbow/Wrist/Hands				
Upper Back/ Lower Back				
Knees / Legs				
Hips/ Thighs				
Knees/Ankles/Feet				

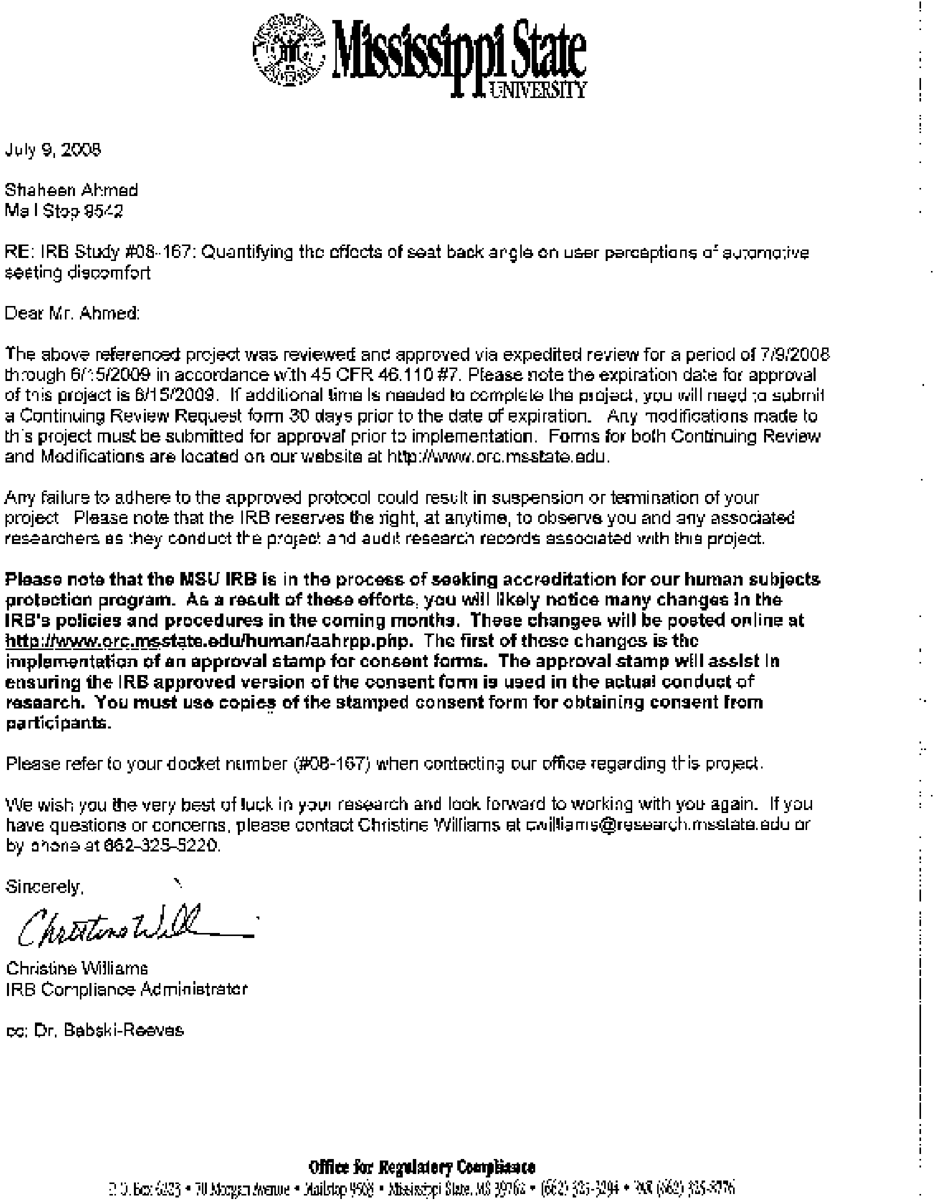
APPENDIX F

MODIFIED BORG CR-10 PERCEIVED LEVEL OF EXERTION SCALE.

Discomfort Rating	Perceived level of discomfort
0	Nothing at all
0.5	Just noticeable
0.7	Very low level of discomfort
1	Low level of discomfort
2	
3	Moderate
4	
5	High
6	Very high
7	Very very high
8	
9	
10	Unbearable discomfort

APPENDIX G

INSTITUTIONAL REVcIEW BOARD (IRB) APPROVAL



Mississippi State University

July 9, 2008

Shaheen Ahmed
Mail Stop 9542

RE: IRB Study #08-167: Quantifying the effects of seat back angle on user perceptions of automotive seating discomfort

Dear Mr. Ahmed:

The above referenced project was reviewed and approved via expedited review for a period of 7/9/2008 through 6/15/2009 in accordance with 45 CFR 46.110 #7. Please note the expiration date for approval of this project is 6/15/2009. If additional time is needed to complete the project, you will need to submit a Continuing Review Request form 30 days prior to the date of expiration. Any modifications made to this project must be submitted for approval prior to implementation. Forms for both Continuing Review and Modifications are located on our website at http://www.orc.msstate.edu.

Any failure to adhere to the approved protocol could result in suspension or termination of your project. Please note that the IRB reserves the right, at anytime, to observe you and any associated researchers as they conduct the project and audit research records associated with this project.

Please note that the MSU IRB is in the process of seeking accreditation for our human subjects protection program. As a result of these efforts, you will likely notice many changes in the IRB's policies and procedures in the coming months. These changes will be posted online at http://www.orc.msstate.edu/human/aahrpp.php. The first of these changes is the implementation of an approval stamp for consent forms. The approval stamp will assist in ensuring the IRB approved version of the consent form is used in the actual conduct of research. You must use copies of the stamped consent form for obtaining consent from participants.

Please refer to your docket number (#08-167) when contacting our office regarding this project.

We wish you the very best of luck in your research and look forward to working with you again. If you have questions or concerns, please contact Christine Williams at cwilliams@research.msstate.edu or by phone at 662-325-5220.

Sincerely,

Christine Will

Christine Williams
IRB Compliance Administrator

cc: Dr. Babski-Reeves

Office for Regulatory Compliance
P. O. Box 6223 • 70 Morgan Avenue • Mailstop 9563 • Mississippi State, MS 39762 • (662) 325-3294 • FAX (662) 325-8776

APPENDIX H

IRB APPROVED INFORMED CONSENT

INFORMED CONSENT

Title: Quantifying the effects of seat back angle on user perceptions of automotive seating discomfort

Investigators: Shaheen Ahmed, Primary Investigator, and Dr. Kari Babski-Reeves, Research Advisor

THE PURPOSE OF THIS STUDY: The objective of this research study is to look at different car seat back positions on discomfort and performance during simulated driving tasks.

PROCEDURE: As one of eight participants, you will first meet with a researcher and be asked to complete informed consent documents, and a personal information and medical history questionnaire. If you have a history of chronic or acute injury in any part of the body, you cannot participate in this research study. Also, you must be between the ages of 18 and 40 years. If cleared to participate, you will complete a 15 minute familiarization session with the driving simulator and schedule your remaining testing sessions. This first session should last no more than 30 min.

Testing sessions will last 2 hours, and you will be asked to complete three test sessions. All sessions will be at least 48 hours apart (to minimize fatigue) and occur at approximately the same time of day.

Three seat positions will be investigated: 105, 120, and 135 degrees from the y-axis (figure 1). The simulator to be used in this research study has the driver seat for a Dodge Neon. This seat will be attached to a platform that will allow for the seat to be moved to the angles identified.

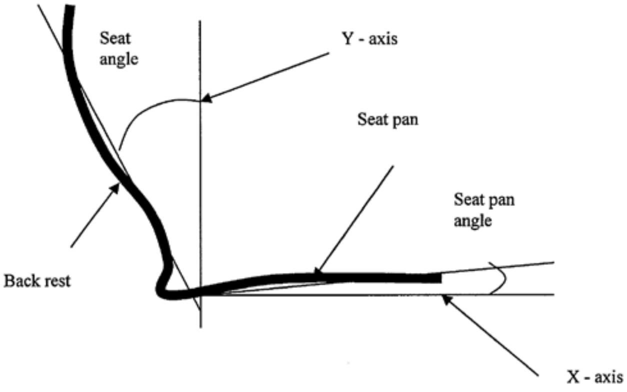


Figure 1. Seat back rest, seat pan, seat angle, etc.

A modified Borg CR – 10 Perceived Level of Exertion Scale will be used to measure your discomfort level for the back, buttocks, eyes, neck, shoulders, thighs, and whole body. You will be asked to orally state your ratings for each area every 15 minutes. If you provide a discomfort rating of 7 for any body part, the test session will be stopped.

Buttock pressure and back pressure will be measured throughout each session using pressure maps. A pressure map will be placed both on the backrest and on the seat (Figure 2). Peak pressures for different body regions

MSU IRB
Approved: 7/9/08
Expires: 6/15/09

will be collected. The pressure maps are thin and you will not notice them during testing.

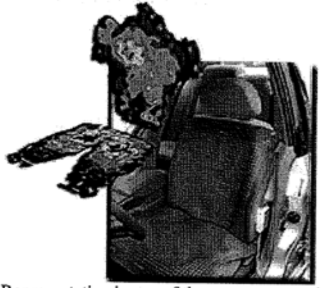


Figure 2. Representative image of the pressure mapping system

Additionally, videos will be used to collect you body movements during the session. For example, did you shift your body to the right or left, did you lean forward in the seat, and so on. The camera will be adjusted to avoid imaging of your face, though you may shift your body in such a way that your face, or part of you face is captured.

HyperDriver software (Drive Safety, Inc., Murray, UT) will be used to present the driving tasks. The simulator includes a Dodge Neon car seat with manual controls for adjustment, steering wheel, viewing monitor (19-inch) for presenting driving scenarios, dashboard, turn signal, and brake and gas pedals. Two speakers will also be used to present driving sounds.

Highway driving scenarios will be created to simulate driving tasks. The driving environment will be adjusted so that it is similar to real driving. For example, you may need to pass a car, cars may pass you, you will need to obey traffic signs (such as stop signs), etc. Scenarios will be developed in such a way that there will be quiet driving (no traffic, no obstacles, etc.) for 1-2 minutes every 15 minutes. During this period, you will be asked to provide oral responses for body part discomfort ratings.

RISK AND BENEFIT OF THIS RESEARCH: You will not receive any direct benefits other than being part of a research study. However, the results from this research study may result in changes to the adjustability features of current automotive seat designs to reduce discomfort during driving.

There is not more than minimal risk associated with this project. You may experience discomfort from performing the task, similar to what one would experience if one drives a car for two hours. However, you are encouraged to terminate the test session at any time if you feel you cannot perform the test without discomfort. You will be routinely asked (every 15 minutes) if you are experiencing any discomfort and if you wish to stop testing. The session will be stopped if you at any time provide a rating of 7 or higher.

Video images will be collected and therefore it is possible someone may recognize your face or other identifying objects (jewelry, moles, etc.). Video images will only be available to project personnel and electronic files pass-coded. Any images used in the development of progress reports, final reports, or conference/journal publications and presentations will have the images covered to preserve confidentiality.

What do I do if I am injured as a result of this research?
In addition to reporting an injury to Shaheen Ahmed (662-325-0248) or to Dr. Kari Babski-Reeves (662-325-1677) and to the Regulatory Compliance Office (662-325-5220), you may be able to obtain limited

compensation from the Sate of Mississippi if the injury was caused by the negligent act of a state employee where the damage is the result of an act for which payment may be made under 11-46-1, et seq. Mississippi Code Annotated 1972. To obtain a claim form, contact the University Police Department at MSU UNIVERSITY POLICE DEPARTMENT, Stone Building, Mississippi State, MS 39762, (662-325-2121).

COMPENSATION: There are four sessions (a 30 minute screening session and three test sessions lasting approximately 2 hours). You will be paid $10 per hour for every hour you participate, or proportionately for the amount of time you are a participant.

EXTENT OF ANONYMITY AND CONFIDENTIALITY: Individual identities will be protected and will not in any way be connected with any written summary of results that may later be published. At no time will your name be collected on any data collection forms. If video clips are used for presentations or in publications, your face and other identifying marks (such as tattoos) will be covered.

FREEDOM TO WITHDRAW: Your participation in this research study is completely voluntary. At any time, for any reason you may withdraw from this project without any penalty or loss of pay. You can also refuse to answer any question you do not wish to answer without providing a reason.

APPROVAL OF THIS RESEARCH: The research project has been approved by the Institutional Review Board at Mississippi State University for projects involving human participants. The IRB approval number is 08-167.

PARTICIPANT RESPONSIBILITIES: You should notify the researcher at any time about a desire to discontinue participation or of any medical conditions that may interfere with results or increase of the risk of injury or illness. If you have any questions, please ask them now.

PARTICIPANT'S PERMISSION: If you have read the description of the research study, understand the nature of the research, are 18 years old or older and agree to participate, please sign below,

Signature, Printed name and Date:____

*For further information please contact: Shaheen Ahmed, Department of Industrial and Systems Engineering, Mississippi State University, Starkville, MS 39759 (662) 325-0248, sa293@msstate.edu

*If you have additional question regarding your rights as a human participant in this research, you may contact the Mississippi State Regulatory Compliance Office at (662) 325-5220. You will be given a copy of this form for your records.