An Integrated Model For Predicting Driver's Discomfort While Interacting With Car Seat And Car Controls

Der Fakultät für Ingenieurwissenschaften, Abteilung Maschinenbau und Verfahrenstechnik der

Universität Duisburg-Essen

zur Erlangung des akademischen Grades

einer

Doktorin der Ingenieurwissenschaften

Dr.-Ing.

vorgelegte Dissertation

von

Nor Kamaliana binti Khamis
aus
Perlis, Malaysia

Tag der Einreichung: March 2018

An Integrated Model For Predicting Driver's Discomfort While Interacting With Car Seat And Car Controls

Von der Fakultät für Ingenieurwissenschaften, Abteilung Maschinenbau und Verfahrenstechnik

der

Universität Duisburg-Essen

zur Erlangung des akademischen Grades

einer

Doktorin der Ingenieurwissenschaften

Dr.-Ing.

genehmigte Dissertation

von

Nor Kamaliana binti Khamis
aus
Perlis, Malaysia

Referent : Prof. Dr.-Ing. Dieter Schramm und Prof. Dr. Baba Md Deros
Korreferent : Associate Prof. Dr Mohd Zaki Nuawi
Tag der mündlichen Prüfung: 24.01.2018

ACKNOWLEDGEMENT

First and foremost praise be to Almighty God for all his blessings for giving me patience and good health throughout the duration of this PhD research.

I would like to offer my sincere gratitude to my supervisors Prof. Dr-Ing Dieter Schramm, Prof. Dr Hj Baba Md Deros and Associate Prof Dr Mohd Zaki Nuawi for the continuous support of my PhD study, for their patience, motivation, support, and massive knowledge. Their guidance has really helped me to complete this study. I could not have imagined having a better supervisor and mentor for my PhD study.

Besides my supervisors, I would like to express my gratitude to the rest of my research group committee: in UDE, Germany, particularly Dr-Ing Benjamin Hesse, Dr-Ing Niko Maas, Dr-Ing Martin Koppers, Dr-Ing Sebastian, Dr-Ing Rudi, Mr Fauzi, Dr-Ing Tobias Bruckmann, Ms Iris Steiner, Ms Fichera, Ms Sara and Ms Mira and also in UKM, Malaysia particularly Dr Ahmad Rithaudeen, Ms Darliana, Dr Dian Darina Indah, Mr Faizul, Dr Ezrin Hani, Dr Nur Syazwani, Ms Shukriah, Ms Roslizawati, Ms Rusalbiah, and for sharing their knowledge, encouragement and stimulating discussions during my study.

My sincere thanks also goes to all the test subjects, both in UKM and UDE for supporting me by participating in the experiments and also the development of the questionnaire. Without all of you, I could not have provided all these data.

I would also like to express my appreciation to Prof Dr Andanastuti Muchtar who continually encouraged me to study abroad, Head of Department and colleagues at Mechanical Engineering Programme (formerly known as Department of Mechanical and Materials Engineering), Faculty of Engineering and Built Environment, UKM. I gratefully acknowledge the financial support provided by MOHE under SLAB/SLAI programme and UKM.

Last but not the least, I would also like to thank my family: my parents; my Abah, Hj Khamis Hamzah and my Mama, Hjh Fatimah Abd Halim, for giving birth to me at the first place and supporting me spiritually throughout my life. My light in the dark; my precious daughter and son, Zaira Soffiya and Zuhayr Safiy, all my siblings, my relatives and my friends for their continuous support and guidance. Thank you again.

ABSTRACT

A driving task requires physical demands from the driver to operate car controls, while sitting on the car seat. The near static seated posture in a confined space may causes discomfort and fatigue. In Malaysia, fatigue is the third highest contributing factors to road accident, accounting for 15.7%. Fatigue can interfere with concentration while driving the car. When the driver is getting fatigue, it may reduce the performance, and hence increase the risk of road accident. This show that fatigue effect can cause danger to the driver. The four main objectives of this research are: (1) to evaluate driver's discomfort and performance while engaged with the car seat and car controls based on subjective assessment.; (2) to analyse the pressure interface on the car seat based on different driving positions.; (3) to evaluate the SEMG surface electromyography (SEMG) signal for the muscle activity based on different driving positions and actions.; and (4) to develop integrated model to predict driver's discomfort while engaged with the car seat and car controls. Eleven test subjects participated in this experiment. The data for this research were collected by using mixed method approach, comprising of the subjective (Visual Analogue Scales, VAS) and objective assessment methods (SEMG and pressure measurement). The VAS was the subjective assessment method used for measuring the car driver's discomfort perception while engaging with car seat and car controls, namely steering wheel, manual gear and accelerator pedal. The SEMG was used to measure muscle activity for Deltoid Anterior (DA), Gastrocnemius Medial (GM) and Tibialis Anterior (TA) involving two different positions, the closest seated position to the car controls (Position A) and the further seated position from the car controls (Position B). Having done that, the data were analysed by using Temporal and Amplitude Analysis based on Maximal Voluntary Contraction. The SEMG analysis was in accordance to the SEMG for the Non-Invasive Assessment of Muscles recommendation. The pressure mat was used to measure the pressure distribution of the car seat. In addition, the body measurement, consisting of anthropometric dimension and the joint angle were measured in this study. Referring to VAS assessment, subjects feel more discomfort at Position B while operating the steering wheel at 45 turning degree and gear during changing the gear to gear 1. For pedal control, the subjects experienced discomfort at Position A particularly when releasing the pedal. The SEMG's findings for the steering wheel task showed the DA at Position B with 45 turning degree showed a higher muscle contraction. Changing the gear to Gear 1 at Position B demonstrated the highest Amplitude at the DA. For pedal control, TA depicted the highest muscle contraction in releasing action at Position A, while the GM showed the highest muscle contraction in pressing action at Position B. In terms of pressure distribution measurement, the buttocks part at Position A depicted the highest mean pressure. The regression test was used to determine the level of significance whether the coefficient of working muscle activity can be used as characteristics and predictors for driver's discomfort. From the results, the prediction model could be developed. The results indicated that integration between the body measurement and pressure interface or muscle activity show a higher R^2; car seat (R^2 = 0.952), steering (R^2 = 0.983), gear (R^2 = 0.980), and pedal (R^2 = 0.911 and 0.952). Thus, it can be concluded that the prediction on drivers' discomfort when driving in different conditions produces better results when incorporating the body measurement that is related with the car seat and car controls.

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

LIST OF ACRONYM

B	Biceps Brachia
B/SM	Body or seat mapping
BLUE	Best Linear Unbiased Estimator
BMD	Body Map Discomfort
BP	Blood Pressure
BUT	Break-up Time
CAE	Computer Aided Engineering
CFCL	Chair Feature Checklist
CLRM	Classical Linear Regression Model
COG	Centre of Gravity
DA	Deltoid Anterior
DBQ	Driving Behavior Questionnaire
DI	Discomfort Index
DV	Dependent variable
EC	European Commission
ECG	Electrocardiogram
EEG	Electroencephalogram
EO	External Oblique
EOG	Electro-Oculogram
EPS	Epworth Sleepiness Scale
ER	Extensor Carpi Radialis
ES	Erector Spinae
FEM	Finite Element Method

FP	Full-press
G1	To gear 1
GCR	General Comfort Rating
GCR	General comfort rating
GM	Gastrocnemius
GN	To gear N
GR	Right gastrocnemius
HP	Half-press
HR	Heart level
HRV	Heart Rate Variation
IV	Independent variable
KSS	Karolinska Sleepiness Scale
L10	10 degree left turn
L45	45 degree left turn
LBP	Lower back pain
LD	Latissimus Dorsi
LDR	Local Discomfort Rating
M	Mid turn
MDF	Median Frequency
MIROS	Malaysian Institute of Road Safety Research
MPF	Mean Power Frequency
MSD	Musculoskeletal disorders
MVC	Maximal Voluntary Contraction
NEMG	Needle Electromyography
OLR	Ordinal Logistic Regression
OLS	Ordinary Least Square

PCL	Pressure Comfort Loss Index
R	Release
R10	10 degree right turn
R45	45 degree right turn
RA	Ractus Abdominis
RMS	Root mean square
S	Soleus
SC	Splenius Capitius
SCR	Skin Conductance Response
SEMG	Surface electromyography
SENIAM	Surface Electromyography for the Non-Invasive Assessment of Muscles
SPS	Samn-Perelli fatigue scale
SSS	Standford Sleepiness Scale
ST	Sternocleidomastoid
SWA	Steering wheel angle
TA	Tibialis anterior
TB	Triceps Brachia
TR	Right tibialis anterior
VAS	Visual Analogue Scale
VDV	Vibration Dose Value
VLD	Variation of Lane Deviation
VN	Vibration Number
WBV	Whole body vibration

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

This chapter provides a general overview of this study. Section 1.2 explains the background of this study. Subsequently, the reason behind this study is explained in the problem statement in the Section 1.3. Based on the issues highlighted in the problem statement, research questions are presented in the Section 1.4, while the objectives of this study are explained in Section 1.5. Additionally, the research framework, including the research hypothesis and the scope of this study is described in Section 1.6 and 1.7. Section 1.8 presents the organisation of this thesis, starting from Chapter I to Chapter VI.

1.2 BACKGROUND OF THE STUDY

A driving task requires physical demands from the driver to operate the car controls while sitting on the car seat. In this case, car controls refer to the steering wheel, the gear, and the car pedal. The driving task may affect the driver's condition, which it can be determined through sign of discomfortness and also from performance perspectives including alertness level as well as fatigue level (Bittner et al., 2002; Constantin et al., 2014; Davenne et al. 2012; Durkin et al., 2006; Fatollahzadeh 2006; Kyung & Nussbaum 2008; Philip et al. 2005). There are a lot of interacting factors that contribute to discomfort while driving, such as from physiological factor (related to body system), psychological or cognitive ergonomics factor (related to mental and emotional condition) and also physical ergonomics factor (Abdul Majid et al. 2013; Abbink et al. 2011; Brookhuis & deWaard 2010; de Looze 2003; de Waard 1996; Durkin et al.2006; Fu et al., 2011; Fuller 1984; Gao et al. 2014; Gupta et al., 2010; Hansson et al. 1991;

Healey & Picard 2005; Hurts, Angell & Perez 2011; IEA 2017; Jagannath & Balasubramanian 2014; Johnson et al., 2011; Kyung et al. 2008; Lal & Craig 2001; Mascord & Heath 1992; Miyagi, Kawanaka & Oguki 2009; Shahidi et al. 1991; Son et al., 2011; Wilson, Caldwell & Russell 2007; Zeier 1979). In addition, the road condition, the driving duration, and driving position also influence the driver's condition (Bella 2008a, El Falou et al., 2005; Ismail et al., 2010; Larue, Rakotonirainy & Pettitt 2011; Mansfield, Sammonds & Nguyen 2015; Mohamad et al. 2016; Otmani et al. 2005; Schmidt et al. 2014).

Issues pertaining to driver's condition, particularly on discomfort has been the focal point especially in the automotive industries, where driving comfort is among the top priorities in the design and manufacturing of automobiles. Numerous researches have been conducted on driver's condition in the past decades (Adler 2007; Anund, Fors & Ahlstrom 2017; Auberlet et al. 2012; Brookhuis & de Waard 2010; Connor et al., 2002; Hiemstra-van Mastrig et al., 2017; Kramer 1990;; Rumschlag et al., 2015; Walton & Thomas 2005; Xiao, Bao-Cai & Yan-Feng 2007; Yusoff et al., 2016; Zeier 1979). However, in spite of the vast studies carried out pertaining to this issue, there are still many unanswered questions and unresolved problems on driver's condition. This may be because there is not enough emphasis given on the driver's condition in the past and existing studies. In addition, the findings from studies conducted thus far were not clearly elaborated and addressed comprehensively.

Assessments on driver's condition, according to driving tasks and positions are essential to ensure a safe and comfortable driving experience while operating the car controls. In order to develop more effective methods of evaluating driver's condition, a thorough analysis of the following is required: 1) the interrelationships among driver's perception and objective measures, 2) relevant factors that influence driving condition, and 3) whether current assumptions regarding driver's condition, and methods employed to specify driver's condition are valid for the design and evaluation. Therefore, this study addresses these topics by conjoining driver's perspectives through subjective and objective measures to establish integrated models for predicting driver's condition. The following section gives a detailed explanation of this study.

1.3 PROBLEM STATEMENT

Driver's condition has gained a lot of attention especially among interested parties due to multi-component and complexity in driving task. In this case, multi-component and complexity refer to numerous tasks and activities performed by the driver. This is because while driving, the driver has to maintain the eye as well as a near static head and neck posture, gripping action on the steering wheel, and foot to accelerate and decelerate the pedal and braking. Prolonged sitting coupled with a near static seated position and posture can impose restrictions on the driver which may potentially lead to musculoskeletal disorders (MSDs) such as low back pain (LBP), neck pain and shoulder pain (Andersson 1980; Caffin et al., 2000; Tewari & Prasad 2000). Notably, this is due to the driver's body weight exerting significant pressure, which is forced directly on the muscle areas of the body which are presently functioning in an anaerobic manner. Due to the compressive force imposed on the driver's body and the seat interface, the blood flowing through large vascular blood vessels to the lower part of the anatomy will be obstructed. Consequently, this will lead to insufficient oxygen supply to the body, resulting in discomfort, fatigue and in the longer term, will convert into severe pain and possible injury if untreated (Lueder 2004; Mastright et al., 2017; Ng, Cassar & Gross 1995; Wilke et al., 1999; Yamazaki, 1992). In fact, there is a link between driver's discomfort, performance and fatigue (Hirao et al. 2006; Mohamad et al. 2016; Williamson et al., 2011). Fatigue can also be described as the impairment of alertness and tendency to feel sleepy and drowsy. According to Malaysian Institute of Road Safety Research (MIROS, 2012), fatigue is one of ten factors that contributes to road accidents. Fatigue may distract the driver and may cause the driver to lose control of the vehicle which in many cases leads to road accidents and injury. Road accidents may cause tragic loss of human life and the driver may have to bear the cost of hospitalisation, vehicle repair and maintenance and a long time to recover from the injury.

As mentioned in Section 1.2, there are many factors that affect the driver when driving. Interaction between the driver and the car controls operation, will influence the driving posture and position throughout the driving activity. It happens due to the changes of driver's body movement in car controls operation while sitting on the car seat (Adler 2007; Lueder 2004; Mansfield et al., 2017; Tanaka et al., 2009). A study conducted by Fatollahzadeh (2006) showed that the steering wheel position and the car pedal location are highly correlated to the driver’s preferable posture and the corresponding comfort. In fact, driving position is one of the factors leading to driver’s fatigue and health risks mostly concentrated on the upper extremities and also the lower back (Costanzo et al., 1999; Gyi, Porter & Robertson 1998; Hirao et al., 2006; Mohamad et al., 2016; Porter & Gyi, 1995). Hence, the driving position with regards to the driving task, should be given the utmost consideration in improving the car design and driver’s condition.

Numerous studies were conducted on the driving position in the past. In past studies, mixed method tools were widely used to evaluate driver’s condition. However, the vast majority of the studies did not comprehensively addressed the effects of driver’s condition while interacting with the car seat and car controls (Andreoni et al., 2002; Hermanns et al., 2008; Hirao et al., 2006; Kyung & Nussbaum, 2008; Na et al., 2005; Porter & Gyi 1998). Therefore, identifying which position and tasks that contribute to the discomfort and fatigue has become the focal point in monitoring driver’s condition when driving. Apart from that, the selection of a suitable mixed method tools in monitoring driver’s condition is also another issue to be solved in this study.

In addition, the driving task while engaged with the car seat and car controls can influence the driver’s perception on the level of discomfort. Subjective assessment is useful to evaluate the level of discomfort among drivers (Constantin et al., 2014; Helander & Zhang, 1997; Kyung & Nussbaum, 2008). Physiological factors and ergonomics environmental factors can influence the driver’s perception on the discomfort. Physiological factors can be referred to as muscle activity, and sensors, while ergonomics environment can be referred to temperature, humidity, noise, vibration and pressure (Griffin, 2012; Parsons, 2000).

Furthermore, the focus on driver’s condition among Malaysians is still at the initial phase (Daruis, 2010; Mohamad et al., 2010). With the development of anthropometric data based on Malaysian population, Mohamad et al., (2010) have recommended a preferred and comfortable angles range for driving posture. As mentioned by Daruis (2010), these angles of range are not far from the existing findings from various studies conducted by a majority of past researchers (Porter & Gyi, 2002; Park et al., 2000). This development certainly will assist future researchers, particularly to evaluate driver's condition in different driving positions. Furthermore, up till now, there is very minimal effort to determine driver's condition with regards to the existing Malaysian anthropometric data (Deros et al., 2015; Mohamad et al., 2016; Yusoff et al., 2016).

Therefore, in order to evaluate driver's condition, the driver's interaction with car seat and car controls should be continuously monitored. The interactions can be used as a guideline and reference for drivers and also other interested parties. The guideline and reference in this study can be determined by considering the relationship between driving task and driving condition based on car seat design, driving position when interacting with the car seat and car controls and also driver's charateristics. In this study, there are two different driving positions determined by the researcher. Both positions were identified based on past studies in the Malaysian context. All in all, in recognising the suitability of driving position adopted to improve driver's condition during driving, this study analyses driver's condition and provides probable solutions in minimising discomfort due to different driving positions while driving. It is very crucial to evaluate driver's condition based on different driving position because this factor significantly bring impacts to the driver's discomfort (Costanzo et al., 1999; Daruis 2010; Deros et al., 2015; Gyi, Porter & Robertson 1998; Hirao et al., 2006; Mohamad et al., 2016; Porter & Gyi, 1995; Yusoff et al., 2016).

1.4 RESEARCH QUESTIONS

In order to develop the objectives of this study, five main research questions (RQ) are considered based on reviews on past researches. Thus, it is important for these five questions to be tackled and solved in this study.

1. To what extent, does the interaction between the driver, car seat and car controls influence the driver's discomfort and performance from the subjective assessment? Is there any significant difference between the perceptions of driver's condition when interacting with the car seat and car controls?

2. To what extent, different driving positions and actions lead to impairment on driver's condition? Which driving positions and actions contribute to the driver's discomfort? Is there any significant difference between the positions and actions of the car seat and car controls?
3. What is the outcome from the pressure interface in evaluating the pressure distribution of the car seat? Is there any relationship between pressure distribution and anthropometric body measurement? Which position is the significant predictor in determining driver's pressure felt based on pressure interface?
4. What is the outcome from the Surface Electromyography (SEMG) in evaluating the muscle activity of drivers? Is there any relationship between muscle activity, anthropometric body measurement and joint angle? Which position and action are significant predictor in determining driver's discomfort based on SEMG?
5. Is the integrated model able to provide accurate results on the discomfort level while engaging with the car seat and car controls?

1.5 OBJECTIVES OF THE STUDY

There are four main objectives derived from review of past literatures and based on the requirements of this study:

1. To identify and evaluate driver's discomfort and performance while engaged with the car seat and car controls based on subjective and performance assessment.
2. To analyse the pressure interface on the car seat based on different driving positions.
3. To evaluate the SEMG signal for the muscle activity based on different driving positions and actions.
4. To develop integrated model to predict driver's discomfort while engaged with the car seat and car controls.

1.6 RESEARCH FRAMEWORK

Figure 1.1 shows the research framework for this study. This framework demonstrates the link between the driver's task while interacting with the car seat and car controls which leads to road accidents and injuries. As mentioned in Section 1.2 and Section 1.3, there are many contributing factors to driver's discomfort. In Figure 1.1, physical ergonomics and cognitive ergonomics are two main factors in this issue. Basically, physical and cognitive are subsystems in ergonomics. Most task systems integrate some level of cognitive matters with the physical subjects. Hence, physical and cognitive demand should be taken into account when evaluating any tasks related to the human (Mehta 2016). The research scope focuses only on the driver's actions and positions that lead to driver's discomfort, as shown by the broken line in Figure 1.1.

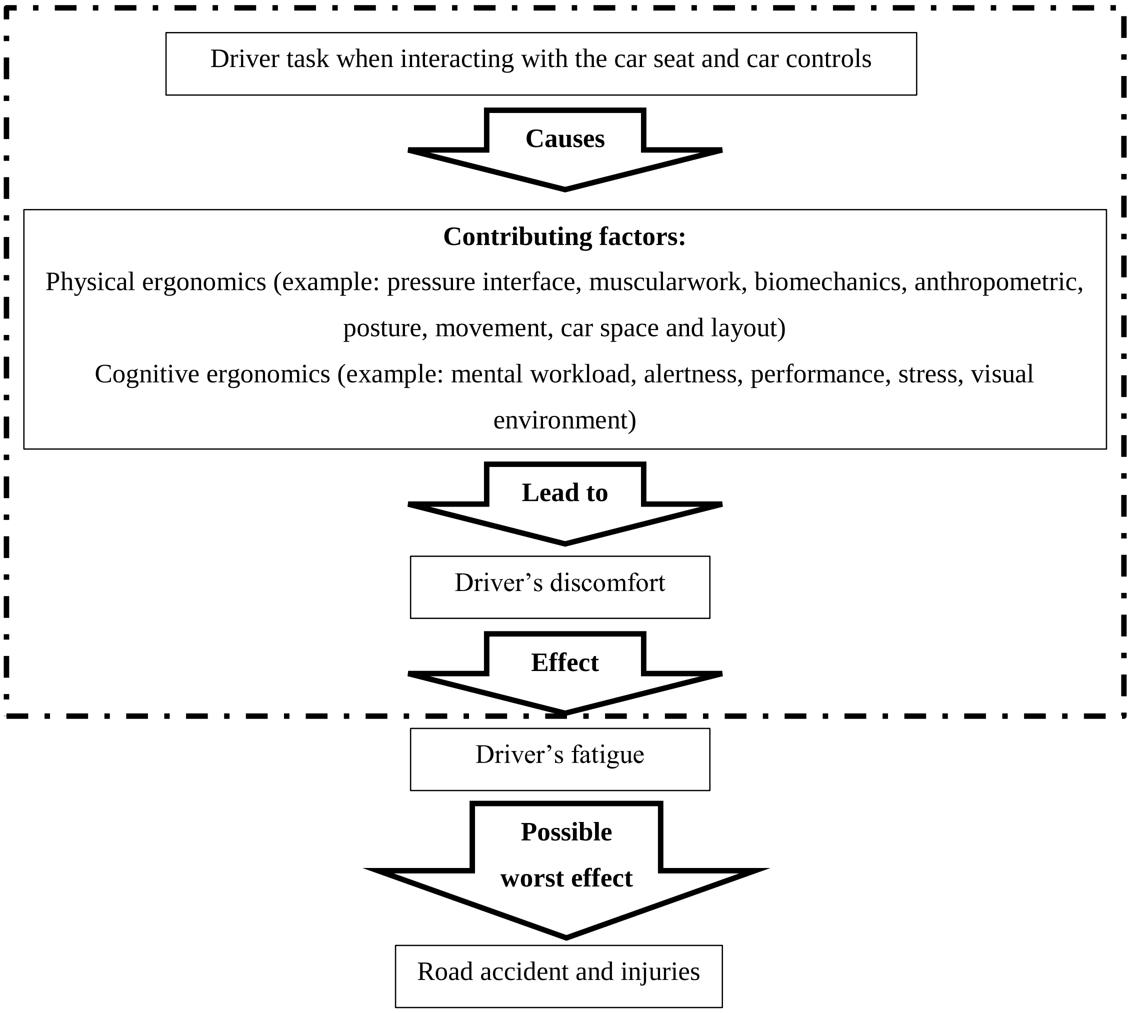


Figure 1.1 Research framework for evaluating relationship between drivers' task and the road accident and injuries

1.6.1 Research Hypothesis

Based on the extensive review of past studies, the following hypotheses are developed:

1. Comparison between actions and positions for the car controls action:

H_0: There is no significant difference between actions and positions for each car control.

H_1: There is significant difference between actions and positions for each car control.

2. Comparison between pre and post activity:

H_0: There is no significant difference between pre and post activity for each driving condition.

H_1: There is significant difference between pre and post activity for each driving condition.

3. Comparison on alertness level and cardiovascular pattern before and after driving task:

H_0: There is no significant difference between alertness level and cardiovascular pattern between two periods of time.

H_1: There is significant difference between alertness level and cardiovascular pattern between two periods of time.

4. Pressure felt level based on pressure distribution measurement:

H_0: Pressure distribution of the different body region provides no significant different effect on perceived pressure felt when engaging with the car seat.

H_1: Pressure distribution of the different body region provides significant different effect on perceived pressure felt when engaging with the car seat.

5. Discomfort level based on the muscle activity measurement:

H_0: There is no significant difference of the discomfort level between each muscle in SEMG assessment according to the car controls.

H_1: There is significant difference of the discomfort level between each muscle in SEMG assessment according to the car controls.

6. Integration between the anthropometric measurement and joint angle with the subjective perception:

H_0: Anthropometric measurement and joint angle provide no significant effects on the subjective perception.

H_1: Anthropometric measurement and joint angle provide significant effects on the subjective perception.

All these hypotheses will be tested using data obtained from experimental works and from the Regression Analysis at the significance level, $\alpha = 0.05$. If the significance level is less or equal to α, H_0 will be rejected and H_1 will be accepted.

1.7 SCOPE OF THE STUDY

The scope of research was carefully evaluated so as to achieve the objectives of this thesis. The scope of this study is as follows:

1. This study is carried out in a controlled environment using a car simulator. A monotonous road with light traffic conditions is applied in the simulator scenario. However, a validation test on the actual road is also carried out in this study to investigate the pattern of driving task according to car controls actions. In addition, the subject's task and posture are controlled, which means the subject cannot behave in the usual driving manner. The subject's head is directed towards the screen and the hands should grip the steering wheel according to instructions.
2. This research focuses on driver's posture with respect to the adjustment of the car seat before driving. In this case, the driver's position have been specified into two positions, Position A and B. These positions were considered based on the preliminary study's findings and extensive reviews from the past studies.

Perception on driving posture gathered in this study is based on the current car seat design and control in the simulator.

3. Measurement of muscle activities according to driving controls and actions is obtained using steering wheel, manual gear transmission (MT) and accelerator pedal of the car simulator. Even though the sales of automatic transmission (AT) car is higher than manual transmission (MT), MT is still produced by the local manufacturers with a AT: MT ratio of 60:40 (The Star Online 2017). In addition, MT is less pricey, compared to AT. Moreover, this is one of the research gaps that requires further analysis when considering the driver's discomfort. In fact, Zeier (1979) proved that the physiological conditions is significantly higher when driving with manual transmission, compared to automatic transmission.
4. Measurement of pressure distribution according to driving position is obtained using the car seat of the simulator.
5. The duration of the driving task is set to determine the driver's performance in a specified time.

1.8 ORGANIZATION OF THE THESIS

There are six chapters in this thesis. The organization of the thesis is as follows:

1. Chapter I provides general information on the research, including the background of the study, problem statement, research questions, objectives and scope of the study.
2. Chapter II presents literature reviews based on past studies, including definitions and concepts of past assessments regarding sitting and driving discomfort as well as driver's condition. This chapter also identifies the parameters and suitable assessments in evaluating driver's condition, performance and discomfort.
3. Chapter III explains the overall methodology used in this study to respond to the first, second and third objectives; by presenting flow charts, experiment design and procedures, and mixed method descriptions for this study.
4. Chapter IV presents the findings from both subjective and objective measurement methods used in this study with the aid of suitable statistical analysis. Hence, the first, second and third objective of this study is fulfilled through the analysis of the data from the subjective and objective measurement methods.

5. Chapter V describes the development of a few integrated models by incorporating the subjective and objective measurement to predict driver's condition, whereby integrated models of driver's discomfort are produced to satisfy the last objective in this study.
6. Chapter V1 provides a summary on the findings from Chapter IV and Chapter V. In addition, it also presents the contribution from this research, recommendations and suggestions for future research.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

Chapter II provides a fully-referenced review from relevant literature. There are seven sections in this chapter and Section 2.2 presents theories and related assessments on sitting discomfort. Then, issues on car drivers are explained in Section 2.3 while explanations on the interactions between drivers and cars are mentioned in Section 2.4. Next, Section 2.5 describes driver’s characteristics including driver’s postures as well as driver’s fatigue and well-being. In addition, assessments from past studies regarding driver’s conditions while driving are also compiled and analysed in Section 2.6. Section 2.7 provides an analysis on the research gaps based on previous studies. Overall, reviews on previous studies can provide more knowledge and insights for future researches by going through the gaps and main issues on driver’s conditions while driving.

2.2 CAR DRIVERS IN RECENT YEARS

In recent years, cars have become one of the must-have items especially for those who are just started working on jobs that require them to take long trips from one destination to another. A car is deemed necessary as the public transportation system in Malaysia is not very efficient compared to other developed countries such as Europe and Japan. In addition, based on the feedbacks from Malaysians, public transport is not their preferred mode of transport due to the erratic schedule, low availability of public transports and the difficulty to go to the main station, which is far away from their home and workplace (Ismail et al. 2012; Nurdden, Rahmat & Ismail 2007).

The problem of public transport results in a great escalation of private car registration in Malaysia, which in turn give rise to other problematic issues such as traffic congestion and frequency of accidents and injuries. Panou, Bekiaris and Papakostopoulus (2007) stated that road users are the contributing factor in the majority of the road accidents. Therefore, it is very vital to concentrate on driver's condition and issues when handling the car. Numerous attempts were made to evaluate the prominence of the driver's characteristics as accident contributor (Michon 1985; Panou, Bekiaris & Papakostopoulus 2007). As a result, automotive manufacturers put extraordinary efforts in the designs of their cars particularly the interior components. The high interest for driver's comfort is principally motivated by the practical concern for the safety and well-being of the driver. Moreover, with the high expectation and preference of the customers on comfort and safety of the car, driver comfort has become one of the main elements in choosing the right car (Brook et al. 2009). Customer satisfaction is vital to ensure their core business is sustained.

Issues related to drivers are the subject of interest not only to automotive manufacturers but also to researchers from various institutions where efforts are made to study the driver's well-being when handling the car. In Malaysia, for example, the Malaysian Institute Road Safety Research (MIROS) is one of the institutes which is concerned on any issues on road safety and provides safety intervention (MIROS, 2016).

According to Panou, Bekiaris, and Papakostopoulus (2007), driving task can be categorized into three different levels of demands: strategic level, tactical level and control level. At the strategic level, the driver evaluates the route, cost and duration of the journey. At the tactical level, the driver has to perform manoeuvres, for example turning at an intersection or estimating a gap. Finally, at the control level the driver has to execute action patterns, which together form a manoeuvre, for instance, changing the gear and turning the steering wheel. To further discuss about these levels of demand, Section 2.4 explains the interaction between the driver and the car, particularly on driver's control while handling the car.

2.3 SITTING DISCOMFORT

Prolonged sitting and near static seated posture while driving impose restrictions on the drivers which may lead to increased risks of musculoskeletal disorders (MSDs) such as low back pain (LBP), neck pain and shoulder pain (Andersson 1980; Chaffin et al. 2000; Tewari & Prasad 2000). This is due to the high pressure of the driver's body weight, which increase the force on the muscles which are functioning in an anaerobic setting. Due to this compressive force on the driver and seat interface, the blood flow through the large vessels to the lower part of the body will be obstructed. Consequently, it leads to oxygen deficiency, resulting in discomfort and fatigue. In the long run, it will turn into pain and injury (Andersson et al. 1975; Graf et al. 1995; Graf, Guggenbiihl & Krueger 1993; Gross et al. 1994; Lueder 2004; Ng, Cassar & Gross 1995; Wilke et al. 1999; Yamazaki 1992). As mentioned by Hostens and Ramon (2005), drivers are exposed to more back pain due to the vibration factor in long driving duration in dynamic condition.

Sitting comfort can be defined as a combination of appreciating condition from the physiological, psychological and physical point of view between the sitter and the environment (Kyung, 2008; Slater 1985). Meanwhile, discomfort is defined as the unpleasant condition between the sitter's body with its environment (Vink & Hallbeck 2012). Comfort of drivers while driving is very subjective and it is influenced by common driving practices and activities of the drivers. As an example, drivers can adjust their car seat position and steering wheel's height according to their own preference and comfort to obtain better driving position. A good driving position can actually help prevent accidents, improve safety, and increase driving comfort. However, comfort also depends on the driving duration and the road conditions (Oliver 1970). Porter and Sharp (1984) reported in their study, the subjects started to report a whole body discomfort after an average of 21 minutes driving duration particularly among elder subjects (50 years and above). A majority of them started to feel discomfort at specific body parts (i.e. thigh) as early as 30 minutes after sitting at the driver seat. Another study shows that some seats are considered uncomfortable after approximately 15 minutes of sitting (Porter, Gyi & Tait 2003). In addition, Adler (2007) stated that the driver takes up to 15 minutes to adopt his final position while driving. Helander and Zhang (1997) clearly mentioned that there is a gap between comfort and discomfort scales. Meanwhile, De Looze et al. (2003) model suggests adding the physical dimension to the discomfort definition.

2.3.1 Assessment of Sitting Discomfort

Up to this date, there have been substantial researches carried out to measure sitting discomfort. Generally, two types of measuring methods are normally used in past studies, subjective and objective methods. Subjective methods are the most direct evaluation, due to the subjective perceptions regarding comfort or discomfort (Richards 1980). In contrast, objective methods require the use of specific equipment to measure the comfort condition. Nevertheless, objective methods produced more advantages compared to subjective methods, among which, it requires less time on observation and test subjects, less bias and measurement errors and can produce quick relevant information for the design process (Lee et al. 1993). Objective methods provide value of condition, by measuring and collecting data mostly in numbers. The objective methods are beneficial when they are integrated with subjective methods, provided there is a relationship between them (de Looze, Kuijt-Evers & van Dieën 2003). Helander and Zhang (1997) cited the causes of sitting discomfort being mainly influenced by biomechanical causes. The causes of sitting discomfort are listed in Table 2.1. For example, vehicle specification such as vehicle cost also influence sitting discomfort. In this case, branded cars always have a great place in the user mind even though the cost of the car is quite expensive. Aaker (2012) revealed that popular and known brand are always offering vehicles of good quality and performance. Therefore, the user will feel more comfortable when sitting and driving in this type of car.

Table 2.1 Causes of sitting discomfort

Human experience mode	**Biomechanical**		**Seat/environment source**
	Physiological cause	**Engineering cause**	
Pain	Circulation occlusion	Pressure	Cushion stiffness
Pain	Ischemia	Pressure	Cushion stiffness
Pain	Nerve occlusion	Pressure	Seat contour
Discomfort	-	Vibration	Vehicle ride

To be continued…

…continuation

Perspiration	Heat	Material	Vinyl upholstery
Perception	Visual/auditory/tactile	Breathability Design/vibration	Vehicle cost

Source: Viano & Andrzejak 1992

Sections 2.3.1 to Section 2.3.4 describe the assessments of sitting discomfort based on the compilation of past studies.

a. Subjective measurement to evaluate sitting discomfort

Subjective assessment on the subjects is the only way to explore their perception and detect changes in comfort and pain (Vergara & Page 2002). There are various subjective tools used to evaluate comfort or pain conditions, however only four tools are frequently used in past studies: body mapping and seat mapping (B/SM), checklist (C), comfort rating scales (G) and questionnaires (Q) which will be explained in this chapter. Table 2.2 demonstrates the usage of these subjective method tools in past studies. O in Table 2.2 are referred as others (usage of objective methods tools, such as vibration, pressure and thermal) and N is not mentioned in past studies.

Table 2.2 Sitting discomfort assessments in past studies

Authors	Purpose	B/SM	C	G	Q	O	N	Findings	Remarks for future study
Shackel, et al. (1969) in Lee, Schneider & Ricci (1990)	Evaluate the seating comfort of upright chairs	x	x	x		x		There was a clear trend of decreasing comfort rating with time. The poorer ratings of the two worst chairs were obvious from the start, but the others only seemed to separate clearly after 1 to 1.5 hours.	Evaluate 10 chairs by using 5 different methods and tried to correlate all methods, but not mentioned which method is the best.
Habsburg & Middendorf (1977) in Lee, Schneider & Ricci (1990)	Find a good estimate of seat comfort	x	x	x				Functional interactions of the seat determine the seat comfort.	Recommend further study to clarify the relationship between seat dimensions and corresponding comfort factors in a dynamic seat evaluation study.
Porter & Sharp (1984) in Lee, Schneider & Ricci (1990)	Examine influence of subject variables upon subjective evaluation	x						Sitting comfort assessment is not critically dependent upon the age, gender or back pain experience.	Subjects adopted normal posture when travel as car passenger in the same seat (one type of seat) for 2 ¼ hours, but not in the car environment.
Kozawa et al. (1986) in Lee, Schneider & Ricci (1990)	Develop new portable ride comfort meter and new index, known as Vibration Number (VN)						x	Ride comfort is correlated with acceleration of the seat cushion, seat back, the foot, etc. The VN index is strongly correlated with the subjective rating.	Developed new measurement methods to evaluate WBV instead of using ISO 2631.
Lee et al. (1993)	Measure seat comfort			x		x		The best 6 seats rated subjectively were the 6 seats with the lowest neck muscle activation. There is no correlation between pressure data and comfort data.	Findings contradict with another study regarding correlation between pressure and comfort.

To be continued…

…continuation

Graf et al. (1993)	Measure seat comfort		x		x	The only significant effect on discomfort was the effect of seat shape on the shoulder, indicated from high muscle activation.	Compared only two types of seat pan shape.
Jianghong & Long (1994)	Evaluate the comfort of a passenger seat for a new type of bus	x	x	x		This evaluation was done in a static condition, and the result seems to suggest that the subjects did not feel any particular sensation of discomfort.	Evaluate discomfort in dynamic study.
Bovenzi & Betta (1994)	Study the relationship between WBV dose, perceived postural load and low-back complaints among the tractor drivers			x	x	The prevalence of lower back pain (LBP) was found to be greater in the tractor drivers than in the controls. There is significant correlation between LBP, vibration dose and postural load. Back accidents and age correlate well with LBP.	More epidemiological and exposure data are needed in order to improve the knowledge of the dose-effect relationship between WBV exposure and LBP.
Wilder et al. (1994)	Measure comfort and muscle fatigue between the seat		x		x	No significant differences in comfort or muscle fatigue between the seats.	More studies should be conducted to prove this findings.
Ng, Cassar, & Gross (1995)	Evaluate the effect of an intelligent seat system		x		x	Subjects felt significantly more comfortable in the baseline seat after the Intelligent System was installed.	Used microprocessor based interactive seat to assess comfort on standard seat as a baseline.
Thakurta et al. (1995)	Compare subjective assessment of short and long duration sitting comfort			x	x	There is a correlation between variation of seat pressure and seat comfort.	More studies should be conducted to prove this findings.
Zhang et al. (1996)	Identify factors related to sitting comfort and discomfort			x		The findings have similarities with job satisfaction.	Test the models found in this study by studying the effects of different chairs and the effects of the day time.

To be continued…

…continuation

Nilsson et al. (1997)	Investigate how long subjects can drive before they feel fatigue and want to stop driving		x					Sore feet, tired eyes and feeling drowsy are significant predictors to determine level of fatigue	Test in the actual road.
Shen & Parsons (1997)	Test the validity and reliability of several rating scales				x			The CP-50 was found to be highly reliable and most valid for rating pressure intensity and perceived discomfort and more preferred by respondents.	Test CP-50 for another intensity ratings and subjective constructs.
Fernandez & Poonawala (1998)	Determine the optimum time in an 8 hours work day for evaluating the comfort rating of chairs			x				The comfort rating obtained at the end of the third hour of work was not significantly different from that obtained at the end of 8 h of work.	Test this theory for only 3 hours of work.
Udo et al. (1999)	Compare a fixed seat and a rocking seat					x	x	Most of the subject preferred the rocking condition, it can reduced back and LBP due to its tilting capability.	Respondents should sit more than 1 hour to see the discomfort pattern.
Goonetilleke & Feizhou (2001)	Propose methodology to determine the optimal seat depth for a target population		x					A seat depth of approximately 31-33cm is suitable for the South China region Chinese population in contrast to the ANSI standard of 38-43 cm for the US population.	Five minutes of sitting need to be investigated further. Is it enough for subjective evaluation?
Vergara & Page (2002)	Analyse the causes of lumbar discomfort while sitting on a chair	x		x		x		Cause of short-term lumbar pain is due to adopting lordosis and forward pelvic mean postures.	Investigate changes in variety of posture for the future studies with more respondents.
Grabisch et al. (2002)	Modelling the subjective sensation of sitting discomfort				x			The proposed methodology is more flexible, and provides information on interaction among variables. Also, the obtained model is easy to interpret due to the clear meaning of the notion of interaction.	Test the proposed modelling in another experiment setup.

To be continued…

…continuation

El Falou et al. (2003)	Study the driver fatigue, discomfort and performance when driving for long duration, both with or without vibration	x			x	x	x	Respondents became increasingly uncomfortable during the 2.5 hours trial period. Performance was reduced when subjects were in an uncomfortable seat in the presence of vibration.	There was no evidence of an associated change in surface electromyography (SEMG) parameters when compared to changes in questionnaire response. Further investigation need to be done.
Philip et al. (2003)	Identify risk factors of performance decrement in automobile drivers					x	x	Age and duration of driving were the main factors associated with decreased performance.	Measure alertness/ sleepiness in this study during driving.
Kolich (2003)	Challenge ergonomics criteria related to anthropometry					x		There are divergences between published anthropometric criteria and user preferences related to the height of the apex of the lumbar contour, seatback width, cushion length, and cushion width.	The interdependence of various seat comfort aspects should be investigated as part of future research.
Thiffault & Bergeron (2003)	Evaluate the impact of the monotony of roadside to the driver fatigue					x	x	Fatigue appears when driving in low demanding road environments.	Future research should evaluate the interruption of monotony impacts.
Kolich et al. (2004)	Compare two types of analysis model in determining seat comfort				x	x		The neutral network approach is more superior to predict subjective perceptions of comfort.	Future research should understand the time dependency associated with seat-interface pressure measures.
Hostens & Ramon (2005)	Determine if the muscles would undergo any physiological change due to the repetitive work					x	x	For 1 hour drive with many actions to be performed, signs of fatigue were present in the muscles.	Future studies should involve more muscle measurements in order to see if the task distribution changes, if the same results can be obtained and what is the effect of longer periods of driving.

To be continued…

…continuation

Na et al. (2005)	Investigate the relationships among the pressure distribution and postural changes and discomfort				x		x	There is high correlation between the body pressure change variables and subjective discomfort ratings.	The proposed new model can be used in the future to evaluate driver discomfort in the actual road.
Solaz et al. (2006)	Evaluate the static comfort evolution of users while seated on second row van seats	x			x			Although static comfort data have been used, these techniques can be immediately transferred to analyse discomfort data from real vehicle tests or simulation in dynamic platforms.	Focus on functional data analysis.
Fatollahzadeh (2006)	Create and construct a mathematical model which clarifies and predicts the drivers' comfortable sitting posture and position	x			x	x		Drivers preferred to sit in the rearmost position and at a rather high level relative to the rest of the available and adjustable area.	The investigation of a complete assessment of comfort in the future should be supplemented with an analysis of how many truck drivers are satisfied with the comfort in the end.
Kong (2006)	Study the static and dynamic characteristics of a bus passenger seat for comfort	x			x		x	The passenger posture and size and road conditions have effects on the pressure distribution and SEAT data.	Improve the seat parameters and compare with the previous result.
Parakket et al (2006)	Develop objective methods for determining and predicting human tolerance of prolonged sitting in various seat cushions				x		x	There is correlation between subjective measures and objective parameters for the static cushions. Peak seat pressure =1.22 to 3.22 pound per square inch. Oxygen saturation and subjective comfort levels decreased over 8 hours. Muscle fatigue increased throughout 8 hours.	These results will be used to develop cushion design guidelines.
Cengiz & Babalik (2007)	Evaluate thermal comfort in an extended road trial for three cover materials, velvet, jacquard and micro fiber					x	x	There is small difference in respondent feedback on thermal sensation between the three seats. According to objective measurement results, all seat cover materials have the same degree of thermal comfort. On the road the participants feel warmer around their waist than any other area of the body.	More experiment time with more participants in the future will be better for thermal comfort determination.

To be continued…

…continuation

Tsutsumi et al. (2007)	Evaluate the car cabin environment on the driver's comfort and fatigue		x		The performance decrease when the break up time (BUT) of the respondent’s eye gets shorter due to indoor environment. BUT at low humidity was shorter than at high humidity. There is no significant difference between eye dryness sensation and visual fatigue.	Car cabin found to affect driver’s comfort, performance and fatigue.
Zenk et al. (2007)	Identify a close interconnection between the seat pressure and the human discomfort	x	x	x	The seat position with the pressure distribution corresponding to the most comfortable posture the pressure in the intervertebral disc is lowest. The pressure in this position is 0.5 bar, while in the upright seated position the pressure is 1.6 bar.	Identification of a close relationship between the pressure on the seat and the discomfort felt by the person sitting.
Bush & Hubbard (2008)	Compare different type of office chairs		x	x	There are significant differences between chairs relative to head and hand motions.	Main focus is on objective assessment. Future study in real working environment for extended periods.
Newell & Mansfield (2008)	Investigate the influence of sitting in different working postures on the reaction time and perceived workload of subjects exposed to WBV			x	Twisted posture is the factors contribute to workload demand. The armrest usage may improve performance and reduce the workload demand experienced by operators.	Used older subjects for next studies and investigate the use of joystick-type controls and the differences between mounted to the seat and mounted to the floor.
Kyung (2008)	Investigate the efficacy of several perceptual ratings in evaluating driver workspace and interface design and clarify relationship between ratings and interface pressure		x	x	Comfort ratings were more effective at differentiating among interface designs, in contrast to the current common practice of using discomfort ratings for designing and evaluating interface designs	Limitation: (1) genders were confounded with the stature groups, (2) appearances of car parts could be a confusing factor, (3) historical driving experience with specific vehicle classes could affect subjective responses.

To be continued…

continuation

Cengiz & Babalik (2009)	Investigate the thermal comfort effects of ramie blended seat cover (RBSC) material on drivers					x	x	There is strong correlation between subjective and objective measures. Back and waist areas are the most sensitive on the human body. The RBSC was a good balancer at high temperature.	Further studies required to determine the long term effects of seat cover material on thermal comfort.
Deros et al. (2009)	Develop a local vehicle seat discomfort survey that is reliable and valid which could be applied together with objective measurements				x	x		The new survey showed a good correlation between the two surveys by Smith et al. (2006) and Kolich & White (2004). It is easier for respondents to understand.	Further test would be pairing the assessment tool with objective measures in both static and dynamic environment.
Groenesteijn et al. (2009)	Investigate the influence of chair characteristics on comfort, discomfort, adjustment time and seat interface pressure				x	x	x	There is no significant differences for seat design comfort and discomfort, first impression and peak interface pressure.	Investigate in the future about the hypothesis highlighted in this study.
Tan et al. (2010)	Examine the seat discomfort and travel time factors for Dutch truck driver seat	x				x		The truck seat discomfort is associated with travel duration. The analytical results showed that buttock is the most uncomfortable body part for truck driver over time. It was followed by lower back and neck.	Investigate the impact break time in between the driving duration.
Daruis et al. (2010)	Identify the vibration characteristics transmitted to the human in real vehicle conditions or field tests					x	x	Steven Power Law equation was able to relate discomfort and whole-body vibration using VDV or RMS significantly. From the objective measurement and subjective evaluation, the exponent β was 1.24 if VDV was used and 1.25 if RMS was used in the equation.	This test was performed on passenger not a driver.

To be continued…

…continuation

Openshaw (2011)	Predict and quantify office worker seated comfort and discomfort using linear and neural network modelling				x	x		Neural network shows good prediction compared to linear modelling. (2) There was no significant difference between genders when evaluating comfort/discomfort. (3) Discomfort increased over time and comfort ratings decreased over time.	At least 45 minute comfort testing is needed to understand subjects' comfort/discomfort in a particular office chair.
Lanzotti et al. (2011)	Validate a new statistical index (Weighted Pressure Comfort Loss, WPCL)			x	x	x		Ordinal logistic regression model (OLR) identifies peak pressure and Pressure Comfort Loss Index (PCL) as the two parameters that are significantly associated to perceived comfort.	Further studies should consider a refinement of the index.
Kamp (2012)	Define the comfort experience of the new seat with respect to other available seats				x	x		Hard seats with rather high side supports are rated sporty, seats that are softer are rated more luxurious.	Participants only had to sit in each seat for several minutes and that they could not adjust their seat.
Beard & Griffin (2013)	Quantify the extent to which the discomfort caused by lateral oscillation in the range 0.2-1.0 Hz	x				x		Low frequency lateral acceleration can cause less discomfort when sitting with a backrest than when sitting on the same seat without a backrest	Different prediction between current standard and findings.
Mansfield et al. (2017)	Develop objective measures system to determine discomfort	x	x		x			Camera based system can be one of the tool to detect motion related to discomfort	Additional of camera (different angle)

i. Body mapping and seat mapping

Tan et al. (2008) mentioned that body mapping technique is one of the most common subjective measures used in discomfort studies. A respondent is required to rate the discomfort in certain body areas according to a given scale. Besides that, seat mapping is also another subjective method, where the seat is divided into different areas and subjects, and the respondent is asked to rate the comfort level based on a given scale. Overall, both mapping techniques use similar approaches.

ii. Check list

Checklist is another common subjective evaluation tool used in studies on comfort. Usually the respondents are required to respond to a given list of statements and rate them according to a given scale, such as dichotomous, continuous or Likert scale.

iii. Comfort rating scale

There are some important guidelines that need to be considered when using this tool. As quoted by Shen and Parsons (1997), and Pitrella and Kippler (1988), there are 14 rating scale design principles, which are: (1) the use of continuous scale rather than category scale formats; (2) the use of both verbal descriptors and numbers in scale points; (3) the use of descriptors in all major scale markings; (4) the use of horizontal rather than vertical scale formats; (5) the use of either extreme or no descriptors at end points; (6) the use of short and precise descriptors; (7) the use of empirically determined rank-ordered descriptors; (8) selecting and using equidistant descriptors; (9) the use of psychologically scaled descriptors; (10) using positive numbers only; (11) having desirable qualities increase to the right; (12) the use of descriptors that are free from evaluation demands and biases; (13) using 11 or more scale points as available descriptors permit; and (14) minimizing the subject workload with appropriate aids. In previous studies, local discomfort ratings (LDR) is used to measure the sitting discomfort of a subject. Normally, the LDR scale is rated on a scale from 1 to 10 or -10 to 10. Another rate similar to LDR is Visual Analogue Scale

(VAS) which is used to rate comfort or discomfort level when sitting in a continuous scale (Wilder et al. 1994).

iv. Questionnaires

Questionnaire is a research instrument consisting of a series of questions to gather specific information from subjects. A researcher is required to ask the right questions and validate the questionnaire with the experts before distributing it to the respondents.

Apart from these common methods, there are other subjective methods used in previous studies. Hence, the next subsection of this chapter will deliberate on the numerous methods and their applications based on past studies. The purpose of this review is to observe the existing and present subjective assessments in the recently published studies related to sitting discomfort and to find the gap between each study so that they can be applied in future researches.

a. Objective measurement to evaluate sitting discomfort

There are numerous objective measurements being applied in evaluating sitting discomfort up to this date. According to past studies, pressure distribution, vibration and surface electromyography (SEMG) methods are among the popular techniques used in researches related to sitting discomfort (Tan et al. 2008). In addition, de Looze, Kuijt-Evers and van Dieën (2003) mentioned that the pressure distribution data correlated well with the subjective ratings. Overall, as mentioned earlier in Section 2.4.1, objective measures are reliable tools which can provide additional data to the subjective measures.

b. Mixed approach to evaluate sitting discomfort

By combining the available methods in evaluating fatigue, the researcher can be ensured of gaining robust and reliable findings. Table 2.2 highlights the review of 45 published studies and based on these reviews, it is clear that the majority of past studies used multiple assessment tools to evaluate sitting discomfort. Hence, a correlation between multiple variables or parameters and relationships between each method can be observed.

i. Single subjective assessment

Subjective assessment is known as one of the quickest, cheapest and simplest ways compared to objective measurement (Johns 2014; Kowalski et al. 2012). Porter and Sharp (1984) used Body Map Discomfort (BMD) with five point scale ratings after 15, 45, 75, 105 and 135 minutes of sitting. A video monitor is used to reduce boredom and to ensure that the respondents constantly focus in one direction for the whole duration. Analysis of variance is then carried out on the comfort data, by averaging 14 body areas. Nilsson et al. (1997) used the checklist tool to identify the actual fatigue symptoms during driving. There are 18 recognized symptoms in this checklist with four points Likert Scale (1=not, 2=uncertain, 3=somewhat and 4=definite). The ratings are taken verbally and then recorded by the researcher every 20 minutes.

ii. Combination of subjective assessment tools

Shackel et al. (1969) used a combination of subjective assessment tools to assess the sitting comfort of ten chairs: General Comfort Rating (GCR), Body Area Comfort Ranking, Chair Feature Checklist (CFCL), Direct Ranking and Body Posture Change Frequency. In GCR, a respondent is instructed to rank 20 statements using 11 point scale (example: I feel completely relaxed, comfortable, cramped, pain, etc); about comfort and select responses that gave the most constant equal interval scale. In CFCL, a respondent is required to provide feedbacks regarding height, length, width, shape, slope, back support, backrest shape and curvature of a selected chair. Habsburg and Middendorf (1977) employed various subjective and physiological methods such as blood flow and total segmentation accumulation to determine a good estimation of seat comfort for 20 different seats. This evaluation took around 15 minutes for each respondent.

iii. Mixed approaches: objective and subjective assessment

A combination of different approaches is more favourable to evaluate human discomfort in several areas. Past studies showed that objective measures provide reports that are more reliable compared to subjective measures. However, it is more time consuming and sometimes difficult to install the equipment to fit the respondents (Kowalski et al. 2012). Hence, the combination of subjective measures will help to cover the shortcomings of each approach in conducting the experiment. The following subsection provides four examples of mixed approaches used in past studies.

- Vibration and subjective assessment

Bovenzi and Betta (1994) evaluated whole body vibration (WBV) and postural stress of 1155 tractor drivers and 220 office workers. A standardized questionnaire is used in this study to obtain information on low back (LB) symptoms, as well as work and individual related risk factors. Vibration measurements are performed on selected respondents. Vibration magnitude and duration of exposure are used to calculate the vibration dose for each tractor driver.

- Thermal and subjective assessment

Cengiz and Babalik (2007, 2009) investigated the thermal comfort effect of different seat materials such as ramie blended, velvet, jacquard and micro fibre during different road trials. In their studies, measurements on respondents' skin temperatures and moisture are taken and recorded. In addition, a respondent is required to give a response based on the questionnaire provided after each session.

- SEMG and subjective assessment

Lee and Ferraiuolo (1993) used 16 car seats with various foam thickness and hardness to measure seat comfort and discomfort. General and local comfort or discomfort with ten point scale is used with the combination of SEMG measure and pressure map distribution. For SEMG, an investigation was carried out on the neck, shoulder, back, upper leg, and lower leg muscle activation.

Graf et al. (1993) carried out a study to determine the presence of discomfort in standard and modified shapes of seat pan by using SEMG and local discomfort rating. Wilder et al. (1994) also used a similar method in their study where a VAS is used to rate comfort or discomfort level when sitting on two types of truck seats with steel spring or gas spring.

El Falou et al. (2003) performed a study on two types of car seat; with and without vibration among 11 subjects using SEMG, performance task, and questionnaire on 36 body zones. A respondent is required to rate the local discomfort based on a 10 point scale (0=no discomfort to 10=unbearable) and answer general questions on the discomfort condition after the experiment.

Hostens and Ramon (2005) conducted a one hour driving test in a simulator using SEMG and questionnaire. All respondents are required to position their seat that provide good reachability for the pedals and steering wheel, but the angle setting of the back portion of the seat and pan must be at 110^0. Then, the respondents are required to indicate their fatigue status in general and possible pain spots in a questionnaire before and after the test.

- Pressure distribution and subjective assessment

Several studies combined subjective assessment tools such as comfort rating with pressure distribution data. Past studies showed that there is good correlation between pressure distribution data and seat comfort rating. Ng, Cassar & Gross (1995) conducted another study with the same approach by developing an intelligent seat system based on the pressure data adjustment on the seat. Subjective comfort ratings (from 1=very poor to 10=very good) and anthropometric measurements are also carried out in this study where 20 respondents are asked to simulate driving position in a seat buck. Thakurta et al. (1995) compared subjective assessment of short and long driving on 80 mile highway. Thirty six respondents provide evaluation on five small cars by using comfort assessment questionnaire and mapped the pressure distribution before and after driving.

2.4 INTERACTION BETWEEN DRIVER AND CAR

Some people see driving as a fun and pleasurable activity. However, driving may not be pleasurable anymore, particularly when one has to face traffic congestion and if the journey is too long. The driving task is physically demanding to drivers as they have to maintain their posture in a confined space (Baldauf, Burgard & Witmman 2009; Fu et al. 2011; Jagannath & Balasubramanian 2014). Throughout the driving activity, drivers have direct physical contacts with the car seat, steering wheel, gear and pedals (Yusoff et al. 2016). Restricted driver workspaces may hinder drivers from adopting their preferred driving postures (Kyung 2008). When driving, it is essential for all the necessary parts of the car such as steering wheel, gear shift and pedals to be within easy reach so that drivers are able to fulfil the driving task. In addition, drivers are required to pay extra attention to the road to ensure the ride is safe. Overall, the driver's task when driving is very complicated and multitasking. Due to the confined space and unexpected situations that may occur while driving, many unwanted effects may subsequently appear. Each driver has his or her own specific style in adapting to the driving conditions, however a good set up of seat adjustment, steering wheel, gear or lever shifting and pedal can provide a comfortable journey (Vilimek, Horak, & Petr 2011). Table 2.3 shows 21 studies with different objectives conducted from 1979 to 2017 on the interaction between the driver and the car. Based on Table 2.3, the car seat and steering wheel are two popular car components that frequently studied by the researcher. In addition, only four research tasks are related to the gear shift.

Table 2.3 Investigation on car-driver interaction

No	Reference	Main components				Aim
		Seat	Steering	Gear	Pedal	
1	Zeier (1979)			x		Physiology
2	Qiu & Griffin (2003)	x				Vibration
3	Giacomin et al. (2004)		x			Vibration

To be continued…

…continuation

4	Walton & Thomas (2005)		x			Behaviour
5	Hostens & Ramon (2005)		x	x		Muscle fatigue
6	Adler (2007)	x				Comfort
7	Bougard, Moussay, & Davenne (2008)	x				Dynamic comfort
8	Kyung (2008)	x				Mixed method
9	Astrom et al. (2009)		x		x	Vibration
10	De Waard, Van den Bold & Lewis-Evans (2010)		x			Behaviour
11	Fouladi, Inayatullah, & Ariffin (2011)	x				Vibration
12	Döring et al. (2011)		x			Gestural interaction
13	Vilimek, Horak, & Petr (2011)			x		Optimum posture
14	Auberlet et al. (2012)		x		x	Road environment
15	Kamp (2012)	x				Design
16	Yusoff et al. (2012)				x	Vibration
17	Maël, Etienne, & Vincent (2013)	x				Vibro-acoustic comfort
18	Rudin-Brown, Edquist, & Lenné (2014)		x	x	x	Road environment
19	Mossey et al. (2014)		x			Behaviour
20	Yusoff et al. (2016)				x	Muscle activity
21	Mansfield et al. (2017)	x				Behaviour system

2.4.1 Driver and Car Seat

From the ergonomics perspective, the car seat is defined as one of the main workstations where the driver performs the driving task. This component is close to the driver and passengers in the car. Briefly, the car seat itself supports the head, upper and lower back, buttock and also thigh and provides space for the driver and passengers. Table 2.3 shows that the majority of past studies on seat comfort use different approaches which will be explained in Section 2.6. As stated earlier in Section 2.2, the sitting position may influence how the body adapts to the driving task. In relation to the driving task, Section 2.5.1 will explain the functional factors of sitting and its relation with the driver.

2.4.2 Driver and Steering Wheel

The steering wheel is the main controller of the car as its function is to manoeuvre the vehicle towards the intended direction. As mentioned by Liu et al. (2014), vehicles are generally operated in a closed loop, and thus the dynamic characteristics of the driver's steering is important in order to optimize the dynamic behavior of the vehicle. There are many styles of hand grip used when driving, depending on the preference of the drivers. Figure 2.1 shows the hand positions on the steering wheel by referring to the clock's number. Normally, drivers tend to put their hand at 9 and 3 or 10 and 2 positions (De Waard, Van den Bold & Lewis-Evans 2010; Klein 2009; Mossey et al. 2014; Walton & Thomas 2005).

Figure 2.1 Hand position on the steering wheel

Source: BC Driving Blog, 2016

In laboratory research, normally, a car simulator is used to replicate the scenario of the actual road condition (Blana, 1996). The present state of driving simulator technology makes it possible to incorporate human factors to simulate actual driving conditions. In addition, using a simulator or performing a field work in the laboratory gives the researcher extra advantage because the researcher has the ability to control the environment and it is less hazardous (Arezes et al. 2013). By using a driving simulator, all the seasonal features, day or night cycles and weather conditions can be recreated easily. The road models and traffic behaviors can be modified according to the desired study parameters by programming the vehicle dynamics element and road vibration into the scenario. Furthermore, all hazards and accidental risks associated with driving on an open road and highways can be eliminated.

With regards to steering wheel control in the simulator, its frequency and styles of movement are recorded to determine the lane deviation of the car on the road. It can indicate the performance of the driver (Gastaldi, Rossi, & Gecchele, 2014; Rossi, Gastaldi, & Gecchele 2011; Thiffault & Bergeron, 2003). Moreover, the steering wheel control can determine driver's alertness when dealing with different road scenarios and environments which is mostly indicated by the line crossing (Davenne et al. 2012).

Instead of controlling just the direction, a steering wheel nowadays also has numerous touch buttons on its surface for different functions. Döring et al. (2011) investigated the interaction of visual demand with the usage of multi-touch steering wheel which has twenty commands with two main applications, music player interaction and map interaction. The findings showed that a multi-touch steering helps to reduce visual demand up to 80%. This means the driver can drive the car without affecting the driving performance by ensuring their hand reaches the radio or navigation systems while still in their preferred driving positions.

2.4.3 Driver and Gear Shift

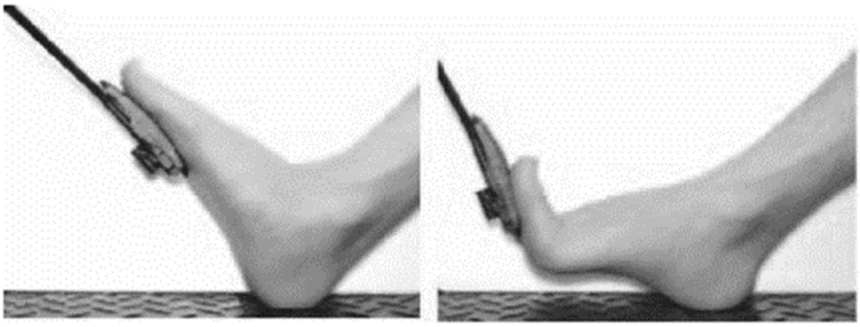
From Table 2.3, it can be seen that there are very few studies conducted on the gear shift. However, there are some researchers in the past who conducted studies to determine the relationship of the gear shift with car driver and passenger. For instance, Zeier (1979) compared driver and passenger reactions in vehicles with manual and automatic transmission by measuring the physiological conditions such as, skin conductance, electromyography (EMG), urine intake and heart rate measures (HR). The findings showed that the rate of adrenaline excretion, skin conductance activity, heart rate and heart rate variability (HRV) are significantly higher when driving with manual transmission, compared to driving with automatic transmission. With respect to the interaction between the car driver's seat and driver, there is an increment on the disc pressure in the car driver's seat when dealing with gear shifting and clutch pedal depressing (Andersson et al. 1975). In addition, when the gear is shifted, there is also an increase in myoelectric activity.

Vilimek et al. (2011) presented the relationship between the position of manual shift lever and muscular activity of upper extremities, including brachioradialis, biceps brachii, triceps brachii and deltoid. Based on this study, the deltoid is the dominant muscle in gearing action particularly during the pushing task. On the other hand, elbows flexors play an important role in the pulling task. Moreover, based on findings from this study, it is recommended to have the elbow angle below 1000 when driving the car. Okunribido, Magnusson, and Pope (2006) studied the frequency of the LBP due to vehicle gearing. Based on this study, 46% of LBP occurence is due to the automatic gear while the mechanical gear is nearly 49%.

In terms of the reaction time in gearing task, Hostens and Ramon (2005) found that the average time between two gear actions is between 14 and 28 seconds for all subjects. Moreover, based on two driving periods on the same day, a trend towards faster driving and faster gearing is clearly seen at the end of the driving task but this trend is not significant. In addition, drivers tend to change gear less in fatigued conditions (Chakrabarty, 1992; Mittal, Chakrabarty & Sarin, 2004).

2.4.4 Driver and Car Pedal

Car pedals can be categorized into two or three functions, based on the type of transmission. The automatic transmission has only two pedals which are the accelerator and the brake, while there is an additional pedal to the manual transmission which is known as the clutch. Even though there are two different transmissions, the car pedal is one of the main components to control the car mainly in speeding and braking task (Wang, Le Breton-Gadegbeku, & Bouzon, 2004; Yusoff et al. 2016). Throughout the journey, drivers are required to interact with the car pedals frequently due to unexpected traffic and road conditions as well as the environment. According to Tanaka et al. (2009), there are two types of contact conditions in pedalling between the foot-sole and pedal-pad, either in releasing action (Figure 2.2(a)) or in pressing action (Figure 2.2(b)). The effects when the foot touches the heel of the foot pedal and the floor of the car will cause discomfort to the driver while driving.



(a) (b)

Figure 2.2 Contact conditions changes in the pedal operation

Source: Tanaka et al. 2009

Brook et al. (2009) developed an ergonomic data measurement system for driver-pedals interaction particularly on the right leg, which integrates five objective methods: an electro goniometry system and a pressure-pads system to monitor driver's positioning and movements, an EMG system to observe the muscular activity of the lower leg, the vehicle on-board diagnostic system, a global positioning system (GPS) system and an audio-visual system to provide environment and driving situation information. A series of test drives confirmed that this system is capable to differentiate data based on different postures and styles. The next section discusses driver's characteristics and assessment on the driver's condition according to researches to date.

2.5 DRIVER CHARATERISTICS

Driving task requires patience of the driver. With unexpected incidents occurring from different angles of condition and environment while driving (eg: unanticipated road users' behavior, poor weather, bad road conditions), drivers still need to concentrate on the road and bear with their driving fatigue in order to ensure they arrive at their destination safely. However, driver's well-being explicitly in term of behavior and health condition cannot be controlled due to their limited capacity as humans. Yet, throughout the journey in the confined space, the driver must ensure his driving position is in a relaxing posture to prevent discomfort and fatigue at the early stage of driving. During a long drive, the discomfort may turn into injury or pain due to incorrect driving position. Up until now, there are numerous studies carried out on the driving position and driver's fatigue which is further elaborated in Section 2.6. These studies were either carried out in the laboratory or in an actual conditions. According to Adler (2007), the total subjects' capacity and load can only be evaluated consistently if the driver's characteristics such as posture, fatigue and personal background are considered. All in all, driver's behaviors and his characteristics can be assessed using various indirect and direct methods. In this section, the background on the driver's posture and fatigue with regards to different styles of driving and conditions are briefly explained before going into the details in Section 2.6.

2.5.1 Driver's Posture

As shown in Table 2.4, when the driver is reaching for something during his or her task, the sitting posture will change, caused by the angle of certain body parts (eg: trunk-thigh angle). Consecutively, it will affect the comfort of the driver even though the driver is still on the same seat. In the case of driving task, the driver adapts his or her posture by ensuring the upper and lower extremities reach his or her targets (eg: steering wheel, gear, car pedal, or foot rest). Sometimes, the driver will adjust the body position to reduce the driving discomfort or fatigue. As a result, it will change the body angle with respect to all the targets mentioned earlier. According to Adler (2007), body posture can be directly inferred from observation (from video recording or self-assessment), body angle measurement (using goniometer or inclinometers) and sonometry. Apart from direct methods, indirect methods such as EMG and pressure profiles can be used to analyse the body posture.

Table 2.4 Functional factors in sitting

The task	The driver	The seat
Seeing	Support weight	Seat height
Reaching (arm and leg)	Resist acceleration	Seat shape

To be continued…

…continuation

Under-thigh clearance	Backrest shape
Trunk-thigh angle	Stability
Leg loading	Lumbar support
Spinal loading	Adjustment range
Neck/arm loading	Ingress/egress
Postural change	
Long-term use	
Acceptability	
Comfort	

Source: Lee, Schneider, & Ricci 1990

Generally, the adaptation of body posture while performing a task, mostly depends on the seat adjustment and anthropometry of the driver (Adler, 2007). According to Mohamad et al. (2010), changes in the knee angle can indicate the changes to driver's posture during driving. When the driver is in an uncomfortable posture, it may affect his driving, for instance when the driver is operating and controlling the accelerator. In addition, Majid et al. (2013) found that various seat adjustments, for example seat back inclination provides complex influences on the muscle activation and spinal joint of the human body. As mentioned by Kyung et al. (2008), seat and package geometries as well as driving postures, will likely affect the pressure distribution interface.

In addition, the gender of the driver also determines the body posture variation. Women prefer to sit and drive closer to the steering wheel, while men prefer different positions (Helander & Zhang, 1997; McFadden et al., 2000; Zhang et al. 1996). With regards to body size, 95% of big-sized subjects prefer to sit farther back from the steering wheel; meanwhile smaller-sized subjects which make up 5% of the subjects tend to sit closer to the steering wheel with a greater trunk-thigh angle. Since there are numerous postures that can be adopted by drivers, evaluating these postures is important to determine driver's condition and well-being. Incorrect driving posture may result in body muscles not functioning properly and consequently will cause fatigue to the driver (Schmidt et al. 2014). In the long run, drivers risk pain and injury.

2.5.2 Driver Fatigue and Well-being

Fatigue can be described as an experience of tiredness, boredom, and unwillingness to continue a task. The progression of fatigue interacts with other factors which influence driver's condition in general (Brookhuis 1995). According to Brookhuis and de Waard (2010) and Heinze et al. (2013), human performance can be measured by monitoring the conditions of the human while reacting and responding to the task demand. In general, fatigue level will change according to a specific condition and can be reflected by performance impairment and declination. Performance can be impaired during fatigue where an individual performs an activity continously (Brown 1994). As an example, fatigue increases with time spent when driving (Fuller 1984; Williamson, Feyer, & Friswell 1996). As mentioned in Chapter I, fatigue may occurred due to prolonged sitting in the constrained space and restricted posture, resulting to insufficient oxygen supply to the body. This condition may lead to discomfort and fatigue. In the longer term, it will convert into severe pain and possible injury if untreated. In fact, there is a link between fatigue, human performance impairment and safety (Williamson et al. 2011). Past studies indicated a major concern in this area where mental and physical fatigue can cause health problems such as musculoskeletal disorders (MSDs). In addition, it can cause a reduction in health level, impair efficiency, performance and alter cardiovascular functions (Bonnet, 1985; Lal & Craig 2001; Okogbaa et al. 1994; Schliefer & Okogbaa 1990).

From the perspective of road safety and transportation, driving fatigue is one of the main reasons behind fatal crashes and injuries (Campagne et al. 2004; Connor et al. 2002; Gander et al. 1993; Hakkanen & Summala 2000; Haworth et al. 1989; Mackie & Miller 1978; Philips et al. 2005; Tijerina et al. 1999; Torsvall & Åkerstedt 1987). This is due to the fact that driving a car requires substantial cognitive effort and attention from the brain. In addition, numerous attempts were made to correlate various measures of driving to drowsiness. Variations in keeping to the lane, steering inputs, and speed maintenance are regarded as functions of fatigue level (Wierwille & Eggemeier 1993, 1994).

It is simply impossible to directly measure fatigue and performance. Thus, past studies used measurable indicators to determine the fatigue level of the driver and monitor performance condition while driving (Charlton et al. 2003). Psychophysiological methods are one of the main measurable indicators used to quantify fatigue level. Another approach proposed by researchers is performance test such as lane keeping ability and speed control. Normally, this approach is combined with psychophysiological methods to obtain reliable findings related to fatigue. A variety of psychophysiological measures to detect fatigue level such as electrocardiogram (ECG), EMG, electroencephalogram (EEG) and electrooculogram (EOG), respiratory measures, and electro dermal measures were used in previous studies (Kramer 1990; Wierwille & Eggemeier 1993). Other than using equipment to detect and determine driver's condition, subjective methods are also among popular tools used in evaluating driver's condition. This section provides description on several subjective methods based on the compilation of several studies from 1997 regarding driver's fatigue and well-being. The reason to elaborate on the subjective method in evaluating driver's condition in this study is because the standard subjective methods are varied and improvised from time to time, where it is revised and modified based on the requirement of the research. Some of these subjective methods will be used in this research. Chapter III explains the usage of selective subjective methods in this research.

a. Standardised subjective methods to determine driver's fatigue and well-being

Figure 2.3 shows subjective method to determine driver's condition. In past studies, performance test is a popular subjective method used for evaluating fatigue. Three popular subjective methods used to measure alertness are standardised subjective fatigue or sleepiness, checklist, and performance test. Subjective scales are more demanding than filling in the checklist, but can usually be completed in a shorter time. Performance test is usually based on the response and behavior of the respondents during the experiments. Some past studies used a combination of several measuring scales and subjective methods to evaluate human fatigue.

Based on Figure 2.3, there are five standardized and well developed subjective fatigue or sleepiness methods employed to study human fatigue or sleepiness. They are Stanford Sleepiness Scale (SSS), Karolinska Sleepiness Scale (KSS), VAS, Samn-Perelli seven-point fatigue scale (SPS) and Epworth Sleepiness Scale (EPS) (Kecklund & Akerstedt, 1993; Pilcher et al. 2003; Shahid et al. 2012; Short et al.,2013; Wewers & Lowe 1990; Wright & Lack 2014;). Details of each measuring scale are tabulated in Table 2.5.

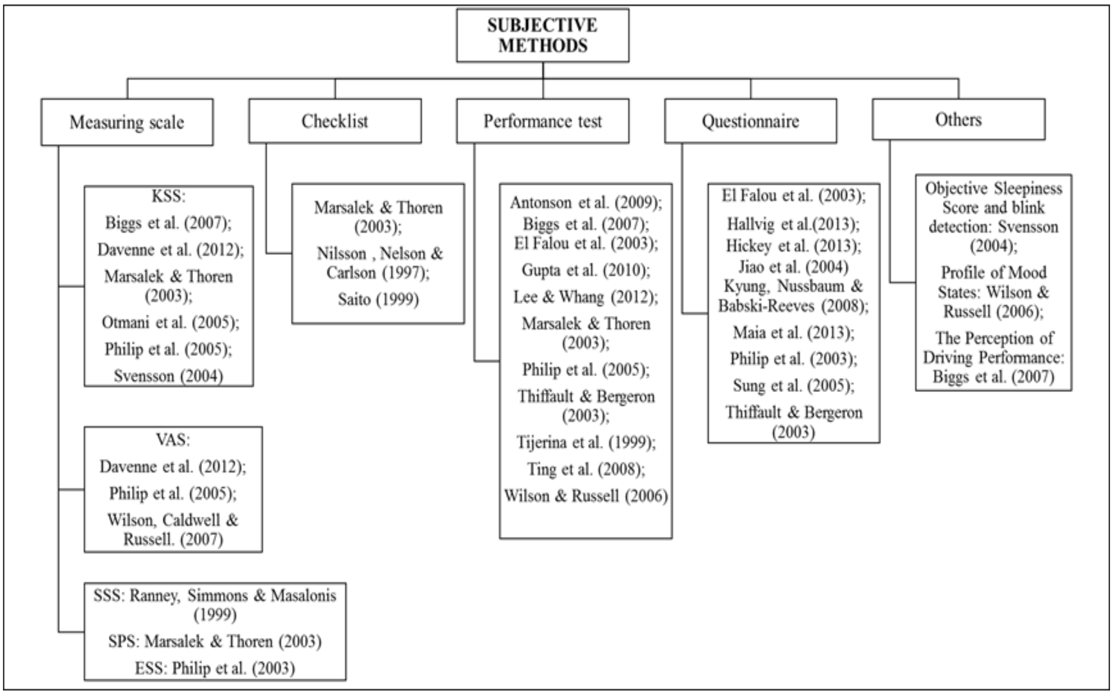


Figure 2.3 Subjective methods to evaluate driver's condition

Table 2.5 Standard scales

Scale	Description
SSS	Based on seven statements that describe his/her feelings and alertness level at the time.
KSS	A 9-point scale (1 = extremely alert, 2=very alert, 3 = alert, 4=rather alert, 5 = neither alert nor sleepy, 6=some signs of sleepiness, 7 = sleepy, but no difficulty remaining awake, 8=sleepy but some difficulty to keep awake, and 9 = extremely sleepy, great difficulty to keep awake, fighting sleep).
VAS	A horizontal line 100 mm long across a page, anchored by word descriptors at each end.
SPS	Consists of seven numbered descriptors, ranging from 1=fully alert, wide awake to 7=complete exhausted, unable to function.
EPS	A self-administered eight item questionnaire that is summed to give an overall score of daytime sleepiness.

b. Checklist

Checklist is another well-known tool used in fatigue and sleepiness study. Many past studies used this method to identify feelings and symptoms related to the presence of drowsiness or fatigue at a particular time. Nilsson et al. (1997), for instance, developed Fatigue Checklist to determine the alertness level in their study. Another example is Marsalek & Thoren (2003), who developed a fit-for-driving checklist, which is a form that documents facts relevant to driver's fatigue.

c. Performance test

Decrement in performance is highlighted by the significant increase in mean reaction time, increase in heart IBI and HRV. Physiological and behavioral measures provide complementary evidence for the detection of fatigue effects (Mascord & Heath 1992). According to Arun, Sundaraj & Murugappan (2012) who cited from several past studies (Akin et al. 2008; Charlton, 2009; Engstrom et al. 2005; Healey & Picard 2005; Kawakita et al., 2010; Kokonozi et al. 2008; Liu et al. 2009; Miyaji, Kawanaka & Oguri 2009; Smith, Shah & Vitoria, 2003; Victor et al. 2005; Xiao, Bao-Cai, & Yan-Feng 2007), there are three main measures of drowsiness or inattention, as tabulated in Table 2.6 below.

Table 2.6 Performance parameters

Measures	Parameters	Advantages	Limitations
Vehicle based measure	Deviation from the lane, deterioration in acceleration pressure, loss of control over the steering wheel turning	Nonintrusive	Unreliable, depends on the study design
Behavioral Measures	Yawning, eye closure, eye blink, head pose	Non intusive Ease of use (only use video camera)	Lighting condition Background
Physiological measures	Statistical & energy features derived from ECG, EOG, EEG, EMG etc.	Reliable, accurate	Intrusive

Overall, this section provides a brief view on driving position with regards to different styles of driving and driver's fatigue and well-being in general. As mentioned earlier, Section 2.6 will further elaborate on past researches related to driver's condition in various issues.

2.6 PAST RESEARCH RELATED TO THE DRIVER'S CONDITION

There are substantial researches carried out in the past which focused on the driver in different input of road scenarios, either in the actual road setting or in the laboratory using an advanced system or a complete set of car simulator. Up to this date, automotive researchers particularly in the areas of human factors have investigated the driver's physiological responses with regards to different pattern of driving styles and its effects by integrating various visual input, task demand, hazard, and scenarios. Numerous objectives and subjective measures were used to find and determine the output based on the aim of the research. A list of articles in English dating as far back as 1979 was compiled from Science Direct and Google Scholar. "Discomfort", "fatigue", "sleepiness", "automotive seat", "car", "simulator" and "driver" were among the main keyword search terms used to review the issues and findings of past studies. In addition, a secondary search was performed by using bibliography of retrieved articles in order to support the initially retrieved papers. Table 2.7 shows a compilation of past studies on the driver's condition from 1979 to 2017. In Section 2.7, gaps analysis on all these past studies is presented with detailed explanations based on this analysis.

According to Table 2.7, the following symbols are used; L=lab, S=Simulator, A=Actual, NA=Not available, and U=Unsure. Furthermore, there are numerous other methods used in past studies. In the Table 2.7, it refers to: oxygen saturation level, vibration measurement, blood pressure, Computer Aided Engineering (CAE), Finite Element Methods (FEM), camera image, image analysis, thermal and humidity, ECG, muscle force, skin conductance and subjective methods.

Table 2.7 Compilation of past studies in evaluating driver's condition

No	Authors	Experiment			Methods							
		Subject	**Place**	**Distance/ Duration**	**EMG**	**EEG**	**EOG**	**HR**	**Eye / Face**	**Behaviour**	**Pressure**	**Others**
1	Zeier (1979)	12 subjects	A	14 km	X			x				x
2	Grandjean (1980) in Lee, Schneider & Ricci (1990)	NA	NA	NA								x
3	Hubbard & Reynolds (1984) in Lee, Schneider & Ricci (1990)	NA	NA	NA								x
4	Hartley et al. (1994)	2 truck crews	A	25, 35 hours						x		x
5	Nilsson et al. (1997)	80 drivers	S	2.5 hours								x
6	Coelho & Dahlman (1999)	4 subjects	S	50 minutes per seat							x	x
7	Wu, Rakheja & Boileau, (1999)	6 subjects	L	NA							x	
8	Tijerina et al. (1999)	10 drivers	A	NA					x	x		
9	Lal & Craig (2000)	35	S	U		x		x	x			
10	Oron-Gilad & Shinar 2000	314 army truck drivers	A	NA								x
11	Porter & Gyi (2002)	600 subjects	A	15 minutes								x
12	Andreoni et al. (2002)	8 subjects	L	1 minute							x	x
13	Porter, Gyi & Tait (2003)	18 drivers	A	2.5 hours							x	x
14	Qiu & Griffin (2003)	12 subjects	S,A	1 minutes								x
15	El Falou et al. (2003)	11 subjects	L	150 minutes	x					x		
16	Chieh et al. (2003)	NA	L	NA								x

To be continued…

…continuation

17	Svensson (2004)	20 subjects	S	U		x	x		x			x
18	Jiao et al. (2004)	60 subjects	S	90 minutes				x				x
19	Na et al. (2005)	16 subjects	S	45 minutes							x	x
20	Hostens & Ramons (2005)	22 drivers	A	30 minutes (2 periods)	x							
21	Shiomi et al. (2005)	12 subjects	S	12 minutes								x
22	El Falou et al. (2005)	11 subjects	L	150 minutes	x							
23	Otmani et al. (2005)	20 drivers	S	NA		x				x		x
24	Philip et al. (2005)	22 drivers	A	105 minutes						x		x
25	Sung et al. (2005)	10 drivers	S	2 hours						x		x
26	Atieh et al. (2005)	NA	L	NA	x							
27	Verver et al. (2005)	NA	L	NA								x
28	Durkin et al. (2006)	8 drivers	S	1 hour	x							
29	Wilson, Caldwell & Russell (2007)	9 subjects	S	U		x			x	x		x
30	Adler (2007)	U	A, S	Near 3 hours								x
31	Biggs et al. (2007)	12 drivers	S	30 minutes						x		x
32	Balasubramanian & Adalarasu (2007)	11 subjects	S	15 minutes	x	x	x	x				x
33	Hatfield & Chamberlain, (2008)	16 and 28 subjects	A, S	NA						x		x
34	Brook et al. (2009)	3 subjects	A	NA	x						x	x
35	Cengiz & Babalık (2009)	10 subjects	A	1 hour								x
36	Morad et al. (2009)	29 army truck drivers	L	30 s.		x	x	x		x		

To be continued…

…continuation

37	Antonson et al. (2009)	18 drivers	S	35 km						x		x
38	Deros et al. (2009)	22 subjects	NA	NA								x
39	Stephens & Groeger (2009)	48 drivers	S	10.2 mile						x		x
40	Grujicic et al. (2010)	NA	L	NA								x
41	Ismail et al. (2010)	U	A	U								x
42	Mohamad et al. (2010)	45 subjects	A	NA								x
43	Larue, Rakotonirainy & Pettitt (2011)	25 subjects	S	40 minutes				x	x	x		x
44	Johnson et al. (2011)	24 drivers	S,A	Various				x				x
45	Daruis et al. (2011)	11 subjects	A	1 hour							x	x
46	Trutschel et al. (2011)	16 subjects	S	40 minutes		x	x		x	x		x
47	Franz et al. (2011)	20 subjects	A	2 hours	x							x
48	Döring et al. (2011)	12 subjects	S	30 minutes						x		x
49	Vilimek, Horak & Petr (2011)	NA	NA	NA	x							x
50	Son et al. (2011)	30 male subjects	S	37 km				x		x		x
51	Zhao et al. (2012)	13 subjects	S	90 minutes		x		x				x
52	Coelho & Dahlman (2012)	12 subjects	L	NA								x
53	Auberlet et al. (2012)	42 drivers	S	NA						x		
54	Davenne et al. (2012)	34 drivers	S,A	2, 4, 8 hours						x		
55	Yusoff, Deros & Daruis (2012)	U	A	NA								x
56	Abdul Majid et al. (2013)	U	L	NA								x

To be continued…

…continuation

57	Heinze et al. (2013)	5 subjects	S	55 minutes			x		x	x
58	Arora & Grenier (2013)	10 drivers	S	45 minutes	x					
59	Dixit et al. (2013)	132 subjects	S	NA					x	
60	Merat & Jamson (2013)	33 drivers	S	U				x	x	
61	Ronen & Yair (2013)	45 drivers	S	30-40 minutes			x		x	
62	Kumbhar (2013)	NA	L	NA						x
63	Hallvig et al. (2013)	10 drivers	S, A	60, 90 minutes		x			x	x
64	Ünal et al. (2013)	47 subjects	S	30 minutes			x		x	x
65	Antonson et al. (2014)	18 drivers	S				x			x
66	Dong et al. (2014)	17 subjects	A	1 minute	x					x
67	Jagannath & Balasubramanian (2014)	20 drivers	S	60 minutes	x	x	x			x
68	Gastaldi, Rossi & Gecchele (2014)	10 drivers	S	40 minutes					x	x
69	Gao et al. (2014)	NA	L	NA	x					x
70	Liu et al. (2014)	5 drivers	A	NA	x					x
71	Rudin-Brown, Edquist & Lenne (2014)	29 drivers	S	U						x
72	Mossey et al. (2014)	32 male subjects	A	NA						x
73	Smith et al. (2015)	12 drivers	S	60 minutes					x	x
74	Mansfield, Sammonds & Nguyen (2015)	U	S	Up to 60 minutes						x
75	Rumschlag et al. (2015)	50 subjects	S	U					x	x
76	Pandis, Prinold & Bull (2015)	8 subjects	S	NA						x
77	Deros et al. (2015)	100 subjects	L	NA						x

To be continued…

..,continuation

78	Ba et al. (2016)	84 subjects	S	NA							x
79	Gruevski et al. (2016)	14 subjects	S	2 hours					x		x
80	Yusoff et al. (2016)	12 drivers	A	1 minute	x						
81	Saxby, Matthews & Neubauer (2017)	U	S	NA				x			
82	Chai et al. (2017)	43 subjects	S	U		x					
83	Filtness & Naweed (2017)	28 drivers	A	NA				x			
84	Anund, Fors & Ahlstrom (2017)	16 subjects	S	150 km			x	x			
85	Li et al. (2017)	NA	S	90 minutes				x			
86	Mansfield et al (2017)	10 subjects	S	90 minutes				x		x	

2.6.1 Application of Driving Simulator in Determining Driver's Condition

A driving simulator was used to gain reliable information on driver's behavior and it is easy to control (Bella 2008a, 2008b; Bittner et al. 2002; Blana 1996; Godley et al. 2002; Hallvig et al. 2013; Johnson et al. 2011; Kawamura et al. 2004; Klee et al. 1999; Kaptein et al. 1996; Mayhew et al. 2011; Rossi et al. 2011). Methods and findings from several past studies are explained in detail in this section.

Combining available methods in evaluating fatigue is one of the ways to ensure researchers gain robust and reliable findings. For example, Jagannath and Balasubramanian (2014) evaluated driver's fatigue with the use of EMG, EEG, seat interface pressure, blood pressure (BP), HR, and oxygen saturation level among 20 subjects. The subjects were required to drive in the static simulator for 60 minutes. The static driving simulator comprises of a steering wheel with force feedback, gear shift lever, foot pedals and a projection of the driving environment for visual feedbacks. The findings show that there is a significant physical fatigue in the back and shoulder muscle groups based on the EMG measurement. According to the EEG result, when the subjects drive in a monotonous condition, there is a significant increase of alpha and theta activities while beta activity decreases. Meanwhile the HR decreases significantly from 76.6 to 69.2 beats per minute during driving. In addition, in terms of seat interface pressure, the systolic pressure decreased from 107.4 mmHg (before driving) to 103 mmHg (after driving) while the diastolic pressure is reduced from 72 mmHg to 68.6 mmHg due to the driving activity. Furthermore, there is a significant change in the bilateral pressure distribution on the thigh and buttock. There are no significant changes recorded when controlling oxygen saturation. Furthermore, the majority of subjects experienced discomfort at the shoulder, middle back and low back areas. It can be concluded that this study provides multiple views of fatigue condition by utilizing various methods. It is clear from these studies that fatigue increases with the increase in test duration.

However, some researchers choose to observe human fatigue by using just one or two methods and apparatus. It is because they have specific focus of certain body parts to enable them to arrive at a conclusion. Arora and Grenier (2013), for example, investigated the trunk muscle by using SEMG. In this study, 10 subjects were asked to drive a whole body vibration (WBV) simulator and control the steering wheel and accelerator and brake pedals. All these setups are required to simulate driving posture during exposure sessions. The findings show that EMG latency increased more in the vibration condition compared to while in sitting without vibration. In addition, there is a possibility of recovery from acute effects of WBV with sufficient rest period. Otmani et al. (2005) investigated the effect of partial sleep deprivation and driving duration on subsequent alertness and performance in car drivers by using EEG and KSS. Findings showed that there is a correlation between sleep deprivation and KSS. However, no significant correlation is observed between driving performance indices and EEG data either in control group subjects or sleep deprived subjects.

Observation study applying different environment and road signs were also conducted in simulator studies to evaluate driver’s fatigue. Antonson et al. (2009), for example, evaluated how three Swedish landscape types (open, forested, and varied) affect driver’s behavior. Eighteen subjects were selected and the study was carried out under controlled conditions in the driving simulator. Qualitative (questionnaires) and quantitative (simulator measurement) data were obtained. The findings indicated that the drivers are affected by different landscape types. Based on the observation, the subjects drove faster and did not drive as close to the centre of the road, and grasped the steering wheel more often while simultaneously experiencing less stress in the open landscape.

Ronen and Yair (2013) examined the relationship between the subjects’ subjective sensation of acclimation and objective driving performance measures using a simulator. Based on this study, curved roads induced longer need for adaptation compared to the other types of road. In addition, deterioration of performance was observed towards the end of the drive.

Some researchers tried to find the factors which can be associated to human fatigue. For instance, Biggs et al. (2007) studied the effects of caffeine on sleepy driver's ability to monitor his or her simulated driving performance. Based on this study, caffeine provided positive improvements in driving for all measures.

A simulator was also used to compare the results obtained from the actual road study. For instance, Hallvig et al. (2013) in their study compared the driving performance between simulator and actual driving by using EEG, ECG and subjective sleepiness. Their findings showed that simulated driving results in higher levels of subjective and physiological sleepiness compared to actual driving. However, in both actual and simulated driving, the response to night driving appears to be rather similar for subjective sleepiness and sleep physiology.

In general, as mentioned by Hallvig et al. (2013), the comparative validity of simulators is adequate for many variables. However, occasionally simulators cause higher sleepiness levels than actual driving. Therefore, a comparison between actual and simulated driving should be performed to validate the findings.

2.6.2 Other Findings from the Past Studies

Abdul Majid et al. (2013) and Grujicic et al. (2010) developed human models using Computer Aided Engineering (CAE) method. For instance, Abdul Majid et al. (2013) evaluated the influence of different sitting postures and environment on muscle activity. In addition, they also investigated the effects of back rest inclination, seat pan inclination and accelerator pedal’s spring stiffness on muscular activity and spinal joint forces during driving. Findings indicated that a slight backward inclination of the seat-pan and back-rest may reduce the muscle fatigue of a driver. Furthermore, by adding a spring to the accelerator pedal, helps to minimize the muscle activity and spinal joint forces.

Tijerina et al. (1999) investigated drowsiness period and inattention and documented it for public education and outreach program. Their study used the drowsy driver detection algorithms developed by Wierwille et al. (1994) in a simulator environment. Results showed the importance of lane keeping variation as a key predictor variable for detecting drowsiness while driving.

Overall, considerable researches regarding human fatigue were carried out. The current fatigue evaluation study promises a potentially good approach for human fatigue management and detection. Some studies combined objective and subjective measures to evaluate human fatigue, while some either use various objective methods or subjective methods only. Based on this review, observation on performance is a popular means used to evaluate human fatigue. Previous studies showed that human performance and alertness decrease with the increase in task duration. Besides that, variations in the surrounding environment such as the road condition, the weather, road marks input and the road surrounding also influence human response while driving. In addition, the application of driving simulators has been widely recognized as one of the main apparatus to evaluate driver's behavior. In fact, the simulator can provide enormous possibilities to analyse the driving behavior by setting risky scenarios without compromising the driver's safety. Control and safety issues are important factors that need to be considered in experiments involving humans as subjects. It can be concluded that the combined methods used to evaluate human fatigue is more robust and reliable because researchers can observe the fatigue pattern from a wider viewpoint and solid findings can be gathered based on these results.

2.7 GAPS ANALYSIS

In Section 2.6, a compilation of past studies comprising 86 articles were reviewed. Section 2.7 provides a thorough analysis on previous studies which is beneficial in determining the research focus in this study, as indicated in Table 2.8. This section provides detailed explanations on several topics such as study or simulator design, driver posture and muscle part applied in past studies

Table 2.8 Gaps analysis

No	References	Important remarks (assessment findings)	Gap
1	Zeier (1979)	The vehicle variables were speed, operation of clutch (on the car with manual transmission), foot and hand brake, position of the gear lever (or selector lever), and automatic gear shifting for the car with the automatic transmission. When driving with manual transmission, rate of adrenaline excretion, skin conductance activity (SCR), HR and HRV were significantly higher than when driving with automatic transmission.	Study design: Focus on comparison between automatic and manual transmission. Posture: No specific posture. Muscle part: at the middle of each eyebrow over the frontalis muscle
2	Grandjean (1980)	A comfortable body posture (angles) according to this study are, ankle (90-110), knee (110-130), arms (20-40), hip (100-120) and head-neck axis to trunk axis (20-25).	Study design: Focus on seat parameters (side support, lumbar support, inclination of seat surface, profile and shape of seat surface, and comfortable body posture
3	Hubbard & Reynolds (1984)	Three different body size groups (small female, average male, and large male) and two different driving postures (erect and reclined) were defined. Important body parts for automotive seat design are the femur, pelvis, spinal column (lumbar, thoracic, and cervical), and head.	Study design: Focus on important features in seat design.
4	Hartley et al.(1994)	All measures changes over the course of journey.	Study design: Focus on truck drivers
5	Nilsson et al. (1997)	Driver tend to feel fatigue at the end of driving, no matter how long the drive before wanting to quit.	Study design: Focus more on investigation of fatigue symptoms by using subjective methods.
6	Coelho & Dahlman (1999)	Investigate on 3 seat factors, the cover's friction properties, the distance between the opposing side supports and the side support's size at the hip-lower torso level with four test seats.	Study design: Focus on car seat side supports.
7	Wu, Rakheja & Boileau, (1999)	Evaluate elastic car seat under vertical vibration by using seat interface pressure. Maximum variations in the ischium pressure. The maximum ischium pressure and elective contact area on a soft seat tend to increase considerably with increase in the magnitude of vibration excitation.	Study design: More focus on seat material, instead of driving position and styles.
8	Tijerina et al. (1999)	Lane keeping variation can predict drowsiness among driver.	Study design: Focus on eye condition and performance. Posture: No specific posture.
9	Lal & Craig (2000)	Delta and theta activity from EEG data increased when fatigue feel. Fast eye movements and conventional blinks during wakefulness were replaced by no eye movements and small fast rhythmic blinks during drowsiness.	Study design: Only cover on effects of EEG, HR, and eye blink parameter. Posture: No specific posture.
10	Oron-Gilad & Shinar (2000)	Sleep deficit issue.	Study design: among military truck drivers

To be continued…

…continuation

11	Porter & Gyi (2002)	Occupational drivers have more risk to feel LBP compare to those who work in sitting (not driving) and standing. It is increased with the duration and mileage. Car drivers with more adjustable driving packages had fewer MSD complaints.	Study design: More on survey on prevalence of MSD among car drivers
12	Andreoni et al. (2002)	Acquisition of driving posture and pressure map: Posture and pressure measure recording was taken when the subject put his/her right foot on the accelerator while the left foot on the clutch.	Study design: No driving activity Posture: Driving position is not fixed and same to all subjects. Subjects choose the most comfortable sitting position on the car seat.
13	Porter, Gyi & Tait, (2003)	Clear differences were identified between the cars with respect to reports of discomfort on foot-calf angle, arm flexion, elbow angle, knee angle and thigh angle from the horizontal. However, no clear relationship was found between interface pressure data and reported discomfort.	Study design: Use three left-handed cars from the same class, measure on-road. Posture: No specific posture. Driving position was measured according to the type of the car.
14	Qiu & Griffin (2003)	Correct vibration input spectra and the correct subject posture can be used in a field test, whereas a higher coherency can be obtained using the laboratory test.	Study design: Focus on transmission of fore-aft vibration to a car seat
15	El Falou et al. (2003)	Performance was significantly worse for seat Uncomfortable with vibration. The median frequency of SEMG signals did not change between experimental conditions or across time.	Study design: No driving activity, just sit to two different seats and two different vibration intensity, no car simulator Posture: Subjects sit based on their comfort perceptions, no specific posture. Muscle parts: From cervical erector spinae and external oblique muscles
16	Chieh et al. (2003)	Used a smart sensor.	Study design: Focus more on the development of steering grip force monitoring system.
17	Svensson (2004)	The results show a possibility to detect drowsiness by analysing blink behaviour changes, but that inter-individual differences need to be considered.	Study design: Focus on EEG and blink behaviour changes. Posture: No specific postures.
18	Jiao et al. (2004)	The drivers' fatigue ratings were associated with vibration frequencies in simulated driving.	Simulator design: Focus on the effect of different vibration frequencies by modifying simulator input and examine the HR. Posture: No specific posture

To be continued…

…continuation

19	Na et al. (2005)	Close relationship between body pressure change and subjective comfort. The trunk angle of shorter subjects decreased as lumbar support prominence increased and trunk angle of taller subjects increased as lumbar support prominence increased.	Simulator design: Road scenes are two straight parts and two curved parts. Posture: Seat back angle was fixed at 115^0, use the mean trunk-thigh angle of Korean male 115.9 =/-7.63^0.
20	Hostens & Ramon (2005)	For a 1-h drive with many actions to be performed, signs of fatigue were present in the muscles. Only for the active parts a significant decrease of the MF was seen. But also the EMG amplitude decreased significantly.	Study design: Focus on the muscle activation only by means of EMG assessment. Posture: Restricted posture for seat pan and seat back angle=110^0, but do not controlled the knee-trunk angle (based on their reachability for pedal and steering wheel), drivers free to drive according to their best capabilities Muscle Part: Deltoid (L&R), Trapezius (L&R)
21	Shiomi et al. (2005)	Speech processing.	Study design: No physiological measures use, only spoken voice.
22	El Falou et al. (2005)	Elimination of non-postural surface EMG segments by the use of a segmentation approach enabled muscular fatigue to be identified in signals that contained no evidence of fatigue when analysed using traditional methods	Study design: Focus more on segmentation approach Muscle part: Cervical erector spinae (CES), ES, External oblique (EO), Tibialis anterior (TA)
23	Otmani et al. (2005)	EOG and KSS findings had been reported. Time on driving task alone had a significant effect on driving performance; the sleep restriction having only an effect on one of the performances indices studied: the number of right edge-line crossings.	Study design: Focus on sleep deprivation and sleep duration
24	Philip et al. (2005)	Performance degradation was associated with sleepiness and not fatigue. Sleepiness combined with fatigue significantly affected reaction time.	Study design: Focus more on sleep restriction.
25	Sung et al. (2005)	Results showed by lowering the oxygen rate, fatigue level will deteriorate severely.	Study design: Focus on relationship between oxygen rate, fatigue and performance.
26	Atieh et al, (2005)	EMG signal can provide data to determine the most comfortable car seat, based on variation of frequency.	Study design: More on EMG signal techniques from data mining and statistical techniques, no discussion on task part.
27	Verver et al. (2005)	Seat modelling for seating comfort analysis	Study design: Focus on seat modelling

To be continued…

…continuation

28	Durkin et al. (2006)	There are no significant differences between each seat, based on Mean EMG for continuous EMG. The variability in seat positions between subjects may also have contributed to the small differences detected between seats.	Simulator design: No manual gear changes Posture: No specific driving posture, respondents were required to sit based on their comfort perception on static simulator, where can adjust horizontal seat position (A); anterior seat tilt (B); vertical seat height (C); backrest recline (D); lumbar support (E); and vertical headrest position (F). Muscle parts: From the right and left thoracic and lumbar ES musculature
29	Wilson, Caldwell & Russell (2007)	EEG, ECG and pupil area were recorded during task performance. Performance decrements were found at the next to last and/or last testing session.	Study design: Focus on aviation.
30	Adler (2007)	Driver posture changes over time. Driver takes up to 15 minutes to adopt his final position.	Study design: Develop Sonosens Monitor to measure driver posture. Posture: No specific posture.
31	Biggs et al. (2007)	Sleep restriction and caffeine have effects on performance.	Study design: Focus on effect of sleep restriction and caffeine
32	Balasubramanian & Adalarasu (2007)	Two groups of professional and non-professional drivers participated in this study. There is significant change in muscle activity is found in both the groups during a short duration of gaming.	Simulator design: Do not use proper car simulator and car seat, just office chair. Without gear changes Posture: No specific posture, choose their own preferred posture. Muscle parts: Deltoid (L&R), Trapezius (L&R), Splenius capitis (L&R):
33	Hatfield & Chamberlain (2008)	Drivers pay attention to displays in neighbouring vehicles and it provides influences to the performance.	Study design: Focus on visual display
34	Brook et al. (2009)	Preliminary analysis of data collected from the validation test-drives was able to determine the differences between drivers in terms of their position/posture, leg movements and joint angles by integrating five subsystems: EMG, electro-goniometer, pressure-pad systems, vehicle on-board diagnostic system, GPS system and audio-visual system.	Study design: Focus in particular on the actuation of the acceleration and brake pedals Posture: Limitation was imposed on the height adjustment of the seat, i.e. the subjects could only adjust the fore-aft seat position and seat recline Muscle part: lower leg

To be continued…

…continuation

35	Cengiz & Babalik (2009)	Investigation on the effects of ramie blended seat cover.	Study design: Focus on seat material effect on the drivers' comfort.
36	Morad et al. (2009)	Investigation on ocular parameter and a few parameters.	Study design: Focus on truck drivers, not car driver.
37	Antonson et al. (2009)	Driver is affected by different landscape types. In the open landscape, subjects drove faster, did not drive as close to the centre of the road, and grasped the steering wheel more often while simultaneously experiencing less stress.	Study design: Focus on the effects of three Swedish landscapes on driver behaviour.
38	Deros et al. (2009)	Evaluate on the car seat.	Study design: Subjective method (questionnaire) only.
39	Stephens & Groeger (2009)	Anxiety-prone drivers tend to find difficulty to evaluate the subjective rating and generally drove more cautiously. Anger-prone drivers showed higher ratings of anger and frustration, but their evaluations and anger tendencies were unrelated to their general driving behaviours.	Study design: Focus on the influence of the anger and anxiety traits on driver evaluations and behaviour.
40	Grujicic et al. (2010)	Various seat adjustments, driver's back supports and the nature of seat upholstery provide complex influence on the muscle activation, joint forces, soft-tissue contact normal and shear stresses influence driver's perception on comfort and fatigue.	Study design: Focus on seat adjustment, but no specific parameters.
41	Ismail et al. (2010)	Daily Exposure to Vibration A(8) and the Vibration Dose Value (VDV) increased with the driving duration and magnitude of the vibration exposure.	Study design: Focus on vibration measurement.
42	Mohamad et al. (2010)	Taller subject preferred a driving posture with their arms outstretched in order to achieve comfort, subject with bigger body dimension have a tendency to sit further back from the steering wheels and smaller subject prefer to sit closer to the steering wheels with a slightly greater trunk thigh angle.	Study design: Focus on development of a range of comfortable angles of driving posture based on Malaysian population.
43	Larue, Rakotonirainy & Petttitt (2011)	During periods of hypo vigilance, the driving performance impairment affected lane positioning, time to lane crossing, blink frequency, HRV and non-specific electro dermal response rates.	Simulator design: No manual gear changes Posture: No specific posture.
44	Johnson et al. (2011)	The changes of all measures are similar between simulated and on-road condition, however, the HR value pattern is quite different.	Simulator design: No gear shift. Posture: No specific driving position.
45	Daruis et al. (2011)	Developed integrated model that combines static condition and dynamic condition of the car users.	Posture: Fixed seat back at 110^0, can adjust the distance between seat and steering wheel, refer to knee angle.
46	Trutschel et al. (2011)	Combined a few methods: KSS, Variation of lane deviation (VLD), EEG, EOG, eye blink, and behaviour analysis.	Study design: Focus more driver alertness Posture: No specific posture.

To be continued…

…continuation

47	Franz et al. (2011)	The comfort was higher, and the EMG was significantly lower in the trapezius area while driving with the lightweight massage system (LWMS), in a car seat.	Study design: Focus on influence of LWMS. Muscle part: trapezius
48	Döring et al. (2011)	Driver’s visual demand is reduced significantly by using gestural interaction on the multi-touch steering wheel.	Study design: Focus on driver distraction and gestural input on steering wheel. Simulator design: Emphasise on multi-touch on steering wheel.
49	Vilimek, Horak, & Petr (2011)	Deltoid is highly activated when pushing the gear.	Study design: Focus on automatic gear action only, but do not provide the value in rms. Muscle parts: brachioradialis, biceps, brachialis, triceps and deltoid.
50	Son et al. (2011)	HR and skin conductance increased with each different delayed auditory recall tasks. There is small different on the effect of these different tasks with the speed and standard deviation of lane position.	Study design: Focus on the effect of different level of demand on tasks during driving towards performance.
51	Zhao et al. (2012)	EEG alpha and beta, the ECG, and the lower and upper bands of power of HRV are significantly different before and after finishing the driving task.	Study design: Focus more on driver’s mental fatigue. Posture: No specific posture during driving.
52	Coelho & Dahlman (2012)	Compared between two types of seat.	Study design: Focus on car seat design.
53	Auberlet et al. (2012)	The context of this study is the need to inform drivers more effectively about the risk of losing control on rural roads.	Study design: Focus on the usefulness of current simulator design and input with filed test. Simulator design: Use a complete set of driving simulator, but no explanation on instruction given. Posture: No specific posture indicated in this study.
54	Davenne et al. (2012)	Real and simulated driving conditions had an identical impact on fatigue and sleepiness during extended periods of nocturnal driving.	Study design: Focus on the usefulness of current simulator design and input to determine drivers’ fatigue and sleepiness.
55	Yusoff, Deros & Daruis (2012)	Compared between three difference sizes of pedal-pads-small, medium and large.	Study design: Focus on vibration transmissibility of foot when handling accelerator pedal.

To be continued…

…continuation

56	Abdul Majid et al. (2013)	Examine the influence of different car seat adjustments and the accelerator pedal's spring stiffness on muscular activity and spinal joint forces during driving. An optimal adjustment for the car-seat is proposed, i.e. the backrest inclination is 10° and the seat-pan inclination is between 0º to 5 º using AnyBody Modeling System.	Study design: Focus on influence of seat adjustment but no specific instruction has been given in this article. Only focus on modelling system.
57	Heinze et al. (2013)	An overnight driving simulation scenario with partial sleep deprivation was utilized to induce driver performance impairment.	Study design: Focus more on the effect of HR measures on the driver performance.
58	Arora & Grenier (2013)	EMG latency was increased more in the vibration condition than in sitting without vibration. Significant effects with respect to directionality were observed in ES muscles. The EMG latency reduced from the effect of perturbation after a 20 s rest period. Even though the EMG latency did not fully return to its Pre-test condition, the present results still show that recovery from the acute effects of WBV is possible with a rest period.	Study design: Focus on the effect of vibration on the seat to the muscle latency. Muscle parts: RA, ES, EO
59	Dixit et al. (2013)	Subjective perception on risk is change with experience. In the task and drivers' skill.	Study design: Focus on risk attitudes in accidents.
60	Merat & Jamson (2013)	There is difference in these measures between drivers' baseline (not fatigued) and experimental (fatigued) visits. There were also some reductions in lateral deviation and eye closure (as measured by PERCLOS) when the treatments were encountered	Study design: Focus on engineering treatment variable message signs, chevron and rumble strip in the simulator study.
61	Ronen & Yair (2013)	Roads with different characteristics require different time for adaptation. For example, the curved road required longer adaptation times and showed the need for improvement in more performance.	Study design: Focus on the adaption period to different characteristic of the road scenes.
62	Kumbhar (2013)	Human body response depends on the dynamic properties of seat suspension and cushion.	Study design: Focus more on vibration measurement on the car seat.
63	Hallvig et al. (2013)	The usage of simulators is acceptable for many variables, but that in absolute terms simulators cause higher sleepiness levels than real driving.	Study design: Focus on driving sleepiness.
64	Unal et al. (2013)	There is no impairment on driving performance when listening to music based on variety of measured in this study. Drivers' lateral control is better when listening to music compared not listening.	Study design: Focus on the effect of music on driving performance.

To be continued…

…continuation

65	Antonson et al. (2014)	Objects close to the road affected the drivers' choice of' lateral position. No significant differences could be observed concerning the test drivers' gaze between old or modern objects, but a significant difference was observed between the test drivers' gaze between road stretches with faraway objects and stretches without objects. No meaningful, significant differences were found for the drivers' stress levels as measured by HR.	Study design: Focus more on road landscape effects on performance and perception.
66	Dong et al. (2014)	Mean frequency decreases with the increase of the fatigue intensity.	Study design: Focus on the effect of working time with muscle fatigue. Muscle parts: bicep, deltoid anterior (DA), triceps
67	Jagannath & Balasubramanian (2014)	Results from EMG showed significant physical fatigue in back and shoulder muscle groups.	Simulator design: Not used proper car seat and no gear shift Posture: No fixed posture. Muscle parts: extensor carpi radialis (ECR), bicep, detoid medial, trapezius medial, S, LDM and ES
68	Gastaldi, Rossi & Gecchele (2014)	The duration of driving tasks and circadian effects on driving performance, increasing the likelihood of "near misses" and accident	Study design: Focus on driving performance and crash risk. Posture: No specific posture and speed limit, suit to normal driving.
69	Gao et al. (2014)	Scapular portion of the deltoid, infraspinatus, latissimus dorsi, subscapularis, triceps long head and triceps lateral head were significantly activated. Latissimus dorsi and subscapularis were activated during the whole process while sternal portion of pectoralis major was activated when the wheel approached the center position, which enhanced the stability of the glenohumeral joint. The rest of the muscles are activated depending on the direction of steering wheel rotation.	Study design: Focus on steering activity only and upper limb only. Muscle parts: deltoid, infraspinatus, latissimus dorsi, subscapularis, triceps
70	Liu et al. (2014)	Different drivers will present different co-contraction magnitudes in similar steering tasks.	Study design: Focus on steering activity only and upper limb only. Muscle part: Triceps, pectoralis major, deltoid anterior, deltoid posterior, teres major (both sides)
71	Rudin-Brown, Edquist, Lenne (2014)	Driving experience and low sensation-seeking tendencies may be associated with an enhanced ability to appropriately assess the demands of the road environment.	Study design: Focus on driver behaviour and landscape.

To be continued…

…continuation

72	Mossey et al. (2014)	Driver preference was assessed by combining driver hand placement and anthropometric data. In this study most people believed that the most comfortable position to grip the steering wheel was symmetrically (75.8%) and/ or on the top half of the steering wheel (79.7%), while only 10.9% reported that two hands on the bottom of the wheel would be most comfortable.	Study design: Focus on hand placement on the steering wheel n four different vehicles in static environment. No driving activity required between two groups of ages.
73	Smith et al. (2015)	Compare two driving positions; elevated (seat is higher than standard, about 400-800mm displacement) driving position and standard posture. The elevated position did not, in general, show more discomfort than the standard position. There were no adverse effects shown for emergency stop reaction time or for driver headway for the elevated posture compared to the standard posture. The only body part that showed greater discomfort for the elevated posture compared to the standard posture was the right ankle.	Simulator design: Two types of seat. Posture: No specific posture. Focus is more on comparison between two seats.
74	Mansfield, Sammonds, & Nguyen (2015	There is an acute step change in discomfort complaint when vibration exposure starts or stops. Small changes in seat foam affects the overall discomfort, but it is significant after 40 minutes.	Simulator design: No gear shift. More focus on seat foam composition and vibration input.
75	Rumschlag et al. (2015)	Texting impairs driving simulator performance. Moreover, the present study demonstrates that for highly skilled texters, the effects of texting on driving are actually worse for older drivers	Study design: Focus on effect of texting on performance.
76	Pandis, Prinold & Bull (2015)	Statistically significant and large differences are shown to exist in the joint and muscle forces for different driving positions as well as steering with one or both hands (up to 46% bodyweight glenohumeral joint force).	Simulator and study design: Do not used proper car seat, just office chair, no gear action (focus on steering activity). Posture: 4 conditions, I Comfortable seated position, both hands on wheel, II Comfortable seated position, single hand on wheel, III Distant seated position, and both hands on wheel and IV Close seated position, both hands on wheel.
77	Deros et al. (2015)	The dimensions of the new driver's seat were determined: 520mm cushion width; 380mm cushion length, 480mm backrest width, 407.5mm backrest height and 180mm adjustability for Malaysian population.	Study design: Focus on the dimensions of seat design for Malaysian population based on anthropometry data in Malaysia.

To be continued…

…continuation

78	Ba et al. (2016)	High-risk drivers with more Go decisions showed more violations, in both simulator tasks and real road driving, as well as higher scores of Driving Behaviour Questionnaire (DBQ) violations and more Balloon Analogue Risk Task (BART) pumps. These high-risk drivers also showed different behavioural patterns in simulator driving, moderated by the specific driving situations (e.g. scenario and scene). Several behaviour assessments were consistently distinct in all tested situations, qualified as robust indictors to predict risk-taking in more general driving situations.	Study design: Focus on driver behaviour when driving. Posture: No specific posture.
79	Gruevski et al. (2016)	The postures in the thoracic support condition were more similar to non-occupational driving without occupational equipment than the Crown Victoria Inceptor (new design of seat) seating condition. The reduction in pressure area at the low back with the thoracic support has the potential to reduce discomfort reporting in officers compared to a standard vehicle package.	Study design: Use the new seat. Posture: No specific posture.
80	Yusoff et al. (2016)	TA muscle contraction on driver's posture based on knee angle less than 101° showed muscle contraction occurred in the release pedal position. When the knee angle decrease, the TA muscle contraction will increase.	Study design: Use actual car pedal, focus on leg position when depressing and pressing the car accelerator, and no driving activity. Posture: Knee angle less than 101 degree, but not mentioned the back rest angle, or either the subject lean comfortably on the back rest. Muscle part: TA
81	Saxby, Matthews & Neubauer (2017)	Conversation while driving do not reduce fatigue and alertness even using hands-free device.	Study design: Focus on driver behaviour when in multi-tasking.
82	Chai et al. (2017)	Focus on classification algorithm.	Study design: Focus on classification algorithm by using EEG.
83	Filtness & Naweed (2017)	Improvement on organisational culture such as shift swapping.	Study design: Focus on train's driver behaviour.
84	Anund, Fors & Ahlstrom (2017)	Day-time line crossing based on KSS and blink duration is less associated compared to night-time. Night-time produce more high levels of KSS.	Study design: Focus on driver behaviour.
85	Li et al. (2017)	Steering wheel angle (SWA) signals helps to prevent road accident by detecting driver's fatigue.	Study design: Focus on driver behaviour when interacting with steering wheel.

To be continued…

…continuation

86	Mansfield et al. (2017)	Movement analysis to indicate discomfort in vehicle seats	Study design: Focus on the algorithm to determine discomfort. Posture: No specific posture

As shown in Table 2.7 and Table 2.8, a vast majority of past studies combined and integrated multiple methods in their studies to determine the discomfort level among drivers in both static (only sitting on the car seat) and dynamic (performing driving task) conditions. Hence, based on the limitation and gap analysis from existing studies, this research is focused on several issues aimed at evaluating driver's condition in different driving conditions. Explanation on this research focus is presented below:

- Study design: As mentioned in Chapter I, this research is aimed at determining the driver's condition pattern based on different driving actions and positions. In fact, findings from previous studies as depicted in Table 2.2, Table 2.7 and Table 2.8, suggest that the integration of a several physiological parameters and methods would be useful to record meaningful data which can differentiate various driving styles. Based on Table 2.7 and Table 2.8, 51 studies used mixed method in their research. In terms of investigation on car components, 25 studies were related to car seat, 11 studies related to steering wheel, two studies related to gear and three studies related to car pedal. Furthermore, only 36 studies were investigated driver's condition by considering alertness, drowsiness and sleepiness factors.

- Different driving position: According to the theory on driving position, changes in the knee angle can describe the changes to driver's posture during driving (Mohamad et al. 2010). Only a few past studies concentrated on the effect of different driving position with regards to certain body parts or seat adjustment. So far, a study conducted by Pandis, Orinold and Bull (2015) applied different seat positions. However, simulator design is missing in their study where an actual car seat is not used and no gearing action is required. In addition, different method was used in this study, which is force assessment. Based on the study conducted by Pandis, Prinold and Bull (2015), different shoulder position extension while driving may produce different force. In this study, two different positions are evaluated using a car simulator with a complete set of car controls; steering wheel, gear and pedal. The reason behind the investigation of these two positions is explained in the Chapter III.

- Different driving action: Up to this date, only Yusoff et al. (2016) and Yusoff (2017) investigated different actions regarding car pedal control. However, there is still lack of findings and improvement that can be made in this current research work. Yusoff (2017) and Yusoff et al. (2016) did not investigate the effect of half-pressing action towards the driver. In addition, this study did not evaluated the impacts of other car controls such as steering wheel and manual gear towards the driver. Furthermore, seat design and position parameters such as the seat distant, particularly for position A and back rest inclination for this study were not fixed for all the test subjects. Majid et al. (2013) found that various seat adjustments, for example the back rest inclination provides complex influences on the muscle activation and spinal joint of the human body.

- Integration method: Based on past studies, SEMG and pressure profiles measurements are the two commonly used method in investigating different driving positions (Adler 2007). SEMG is useful in observing muscular activity and action on the body part and provides accurate indication of muscles' tension while performing the task (Brook et al. 2009; Zeier 1979). Meanwhile, a pressure distribution system plays an important role in monitoring driver's positioning and movement. In addition, the pressure distribution system produced high correlation with subjective measures and provides early prediction of body part discomfort. HR or BP may provide valuable information on driver's condition before and after driving. Other than HR or BP data, output from the simulator, may also be useful to determine driver's condition by evaluating the variation of lane deviation or line-crossing when driving. Therefore, in this study, a combination of physiological measures namely pressure distribution, SEMG, HR or BP and driver's performance based on simulator activity as well as subjective method through self-assessment is applied. Furthermore, the relationship between subjective and objective methods with the body measurement was not frequently studied in the past research. Up to this date, according to Table 2.8, there were several studies performed the integration of subjective or objective method with body measurement. For instance, Ng, Cassar & Gross (1995) evaluated the new design of seat system based on the anthropometric data, subjective rating and pressure distribution pattern. Mossey et al. (2014) explored the link between steering wheel and anthropometric data, particularly data for hand placement and driver grip design preferences. Yusoff et al. (2016) found that there was a correlation between knee angle less than 101^0 and TA muscle activation. Nevertheless, the relationship mentioned in the studies are only relevant for the certain car component and controls.

- Simulator design: The majority of past studies concentrated on steering manoeuvre task when driving and the instruction given for each task is quite unclear. In addition, most of the SEMG data collection focused on the upper limb activity, when engaging with steering wheel. In reality, drivers do not only sit and grasp the steering wheel while driving, but they also interact with the gear and car pedal. According to Brook et al. (2009), there is a lack of research in past studies on the assessment and prediction of comfort of the lower leg, associated with operation of the pedals. Therefore, in this study, a combination of steering wheel rotation, manual gear action and accelerator pedal based on different postures and actions are examined using the actual car seat in the simulator.

The next subsection provides an overview on all the measures stated in the preceding paragraph while details of the process flow is explained in Chapter III.

2.7.1 Pressure Distribution Measurement

Pressure distribution measurement is known as a remarkable and useful technique to predict driver discomfort during the early stage of design process. Therefore, most automotive manufacturers tend to use this method in their designing stage due to its ability to give quick information (Gyi, Porter & Robertson, 1998). As mentioned in previous sections, pressure distribution is identified as one of the objective measures that correlates well and has a high association with subjective measures (de Looze et al. 2003; Mehta & Tewari 2010; Na et al. 2005; Thakurta et al. 1995; Vergara & Page

2000). Ergic, Ivandic & Kozak (2002) in their study produced pressure distribution data based on the transmission of the human body's weight by sitting over sitting bones (tuberosis ischii) and the surrounding soft tissue on the seat. This transmission develops a change in the soft tissue and skeleton due to the seat's pressure, which can be seen on the bulk muscular and bulk bones. Normally, this distribution can be clearly seen in the lower back and buttock area, and significantly affects local discomfort (de Looze et al. 2003; Yun, Donges & Freivalds, 1992). Comfortable seats are characterized by mean pressure levels ranging from 1.4 kPa to 2.3 kPa in the lumbar region of the back rest, and by pressure levels of 5.8 kPa under the tuberosis ischii and 2.9 kPa elsewhere (de Looze et al., 2003; Kamijo et al., 1982).

The collection of pressure distribution data is very essential not only to determine the comfort level, but it can also be used in addressing other health related issues especially to avoid any undesirable consequences due to sitting condition (Dhingra, Tewari & Singh 2003). In fact, a good pressure distribution can minimize load concentrations, which affect blood circulation and nerves that caused discomfort and pain (Ng, Cassar & Gross, (1995); Porter, Gyi & Tait 2003; Thakurta et al. 1995). The pressure distribution of human seat interface of a rigid seat is affected by seat height, posture, type of cushion, frequency and vibration (Dhingra, Tewari & Singh, 2003).

a. Seat pressure measurement

Seat pressure measurements are acquired using thin flexible pressure mats made up of force-sensing resistors. These pressure mats are configured over the seat pan and seat back and do not affect the seat geometry. Details on the seat pressure measurement used in this study is explained in Chapter III. Figure 2.4 shows 12 standard regions of seat pan and back rest

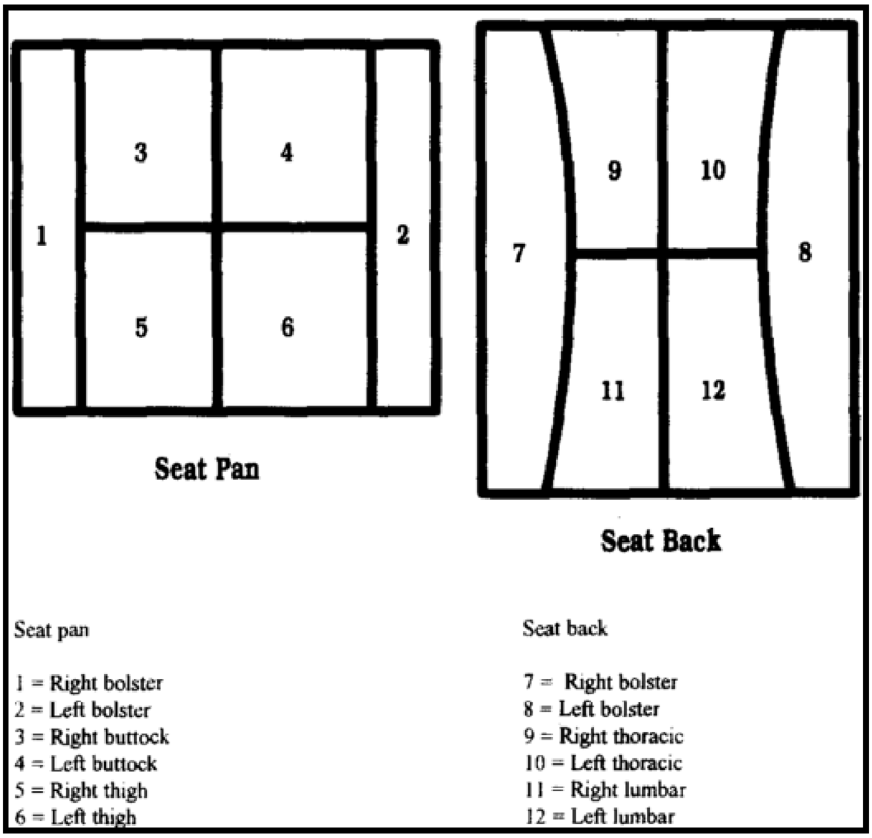


Figure 2.4 Twelve regions of seat pan and back rest

Source: Ng, Cassar, & Gross 1995

b. Relationship between pressure distribution, subjective assessment and body measurement

Past studies show that there was a good relationship between pressure distribution, subjective rating and body measurement (de Looze, Kuijt-Evers & van Dieën 2003; Ng, Cassar & Gross 1995; Zenk et al. 2007). For instance, Ng, Cassar & Gross (1995) evaluated the new design of seat system by using subjective rating, and pressure map. Furthermore, the seated anthropometric data was also collected among 20 subjects. For the seat, joint angle such as ankle angle and knee angle as well as the anthropometric measurements such as buttock-popliteal length and knee height were collected when the subjects stretched their arm to reach the steering wheel. Goonetilleke & Feizhou (2001) and Shen & Parsons (1997) also found that buttock-popliteal length was one of the main parameter for determining sitting pattern and shows good relationship with the other measurement. In the study conducted by Goonetilleke & Feizhou (2001), the buttock-popliteal length shows a linear relationship with the seat depth of the chair with R Square 99.98%. Furthermore, the buttock-popliteal length is the determinant factor to the cushion length. Based on Reed, Schneider & Ricci (1994), a cushion that is too long will lead to local discomfort due to much pressure under the thigh and restricted the blood flow to the leg.

2.7.2 Electromyography Evaluation

a. History of electromyography signal

The interpretation, decomposition and application of biological signals, such as ECG, EMG and EEG have fascinated many researchers. EMG signal is generated by skeletal muscles, the motors that allow us to move. According to Merletti and Parker (2004), the first investigator to study EMG signals was Piper from Germany who used a string galvanometer. There are two EMG techniques being used, needle EMG (NEMG) and SEMG. The difference between these two techniques is, the NEMG can detect Motor Unit Action Potential (MUAPS) in small volume near the needle tip and provide much localized information concerning either superficial or deep muscle structures. Meanwhile, SEMG can detect MUAPs in large volume and provide global information dominated by the most superficial motor units. A motor unit (MU) consists of α-motoneuron in the spinal cord and the muscle fibers it innervates. The number of MUs per muscle in humans may range from about 100 for a small hand muscle to 1000 or more for large limb muscles (Cavalcanti, Garcia & Vieira 2011; Merletti & Parker 2004).

The SEMG is the most extensively used technique to determine muscle activity. Surface electrodes are readily available and easily applied and free of discomfort. The equipment consists of individual electrodes of various diameters, electrodes of fixed inter-electrode distances, and electrodes that do or do not contain on-site pre-amplification (DeLuca 1997; Soderberg & Cook 1984; Soderberg & Knutson 2000).

Since 30 years ago, there are a lot of researches that used SEMG in their studies, however, the findings created a confusion due to lack of guidelines and standards. Therefore, in 1995, a group of researchers proposed that the European Commission (EC) sponsors a concerted action on SEMG for Non-invasive Assessment of Muscle (SENIAM). The aim of SENIAM is to enhance international cooperation and reach an acceptable level of consensus among European laboratories active in the field. Nowadays, NEMG and SEMG are complementary instruments having a correlation with one another. Both are important tools for physiological investigations. NEMG is more subtle for diagnostic applications, while SEMG is useful for biofeedback, prosthesis control, ergonomics, occupational and sport medicine and evaluation of neuromuscular applications.

b. Classification of EMG

EMG is a technique used for evaluating and recording electrical activity produced by skeletal muscles. Actually, it is an electrical signal which is stored at the muscle level (Atieh et al. 2005). According to Atieh et al. (2005), EMG signal is easier to detect compared to other signals such as nerves and brains. Therefore, this measure will be very useful to evaluate human physical fatigue in daily life. According to previous studies, the presence of muscle fatigue can be quantified through the decline in maximum physical strength, changes in SEMG signals and increase in subjective rating of discomfort (Yassierli 2005). González-Izal et al. (2012) summarized the many different types of SEMG models to assess muscle fatigue during isometric or static contraction, dynamic for non-stationary, as well as dynamic for time frequency, amplitude based parameters, and spectral parameters. Results showed that the isometric is easy to record due to the static contraction. Meanwhile, the dynamic model is relevant with daily task. Nevertheless, it is difficult to interpret the signal as it is a very complex technique because of the non-stationary characteristics.

There are several types of analysis for EMG parameters, temporal analysis, amplitude analysis, spectral analysis and time frequency (Cavalcanti Garcia & Vieira 2011; González-Izal et al. 2012; Yusoff et al. 2016). Table 2.9 shows the descriptions and related equation for each analysis. RMS and mean power frequency (MPF) or median frequency (MDF) are commonly used to describe the signal amplitude and the frequency content of the recorded SEMG signal, respectively (Basmajian & De Luca 1985; Gerdle et al. 1999; Hostens & Ramon 2005).

Table 2.9 Equations to analyse SEMG data

Analysis	Description	Equation
Temporal	Normally conducted at smoothing RMS 500ms signal, to identify the flow pattern of the muscle either at rest or during contraction and analyse visually.	-
Amplitude	Performed at time domain and the amplitude unit is microvolt (μV) with stipulated epoch.	$R.M.S = \sqrt{\frac{1}{N}\sum_{n=1}^{n} \mathrm{EMG}\,[n]^2}$ (Equation 2.1) where N is the number of data and n is the EMG data in μV.
Spectral	Frequency analysis based on Fast Fourier Transform (FFT) to derive the median (Equation 2.2) and mean frequency (Equation 2.3).	$\int_{f1}^{Fmedian} PS(f).df = \int_{Fmedian}^{f2} PS(f).df$ (Equation 2.2) $Fmean = \frac{\int_{f1}^{f2} PS(f).df}{\int_{f1}^{f2} PS(f).df}$ (Equation 2.3) where PS (f) is the sEMG power spectrum that is calculated from FFT, and f1 and f2 determine the bandwidth of the sEMG (f1=the lowest frequency, f2=the highest frequency of the bandwidth).

However, the treatment of EMG raw data is quite complicated. It needs to be filtered and smoothed using a certain frequency. Each of these factors influenced the data, and incorrect selections can lead to misrepresentation of data, which may alter the interpretations applied to either temporal or amplitude features. Examples of appropriate filter choices are given in the Journal of Electromyography and Kinesiology, which states that low-pass and high-pass filters and filter types should be specified in articles describing EMG. According to Soderberg and Knutson (2000), most of the power in the EMG signal is in the frequency range of 5 to 500 Hz. Chapter

III explains the EMG data processing which involves filtering and smoothing processes.

c. Role of muscles in driving task based on past studies

Table 2.10 shows the frequency of muscle parts selection according to past studies. Generally, the predominant muscle groups mobilized while driving are deltoids, biceps, triceps, flexor carpi radialis, trapezius, and sterno cleidomastoid (Freund, Budingen & Dietz 1998). Table 2.11 shows the function of each muscle. It covers the role of upper limb and lower limb muscle while operating the vehicle. General function for each muscle also shows in the Table 2.11.

Table 2.10 Frequency of muscle parts selection in past studies

Acronym: T=trapezius, D=deltoids, ST= sternocleidomastoid, **SC=** splenius capitius, ES=Erector spinae, LD=Latissimus dorsi medial, RA=Rectus abdominis, EO=external oblique, B=biceps, TB=triceps, ER: extensor carpi radialis, TA=tibialis anterior, S=soleus, G=gastrocnemius

References	**Shoulder / neck / head**				**Trunk / lower back**				**Arm / hand**			**Lower leg/foot**			**Other**
	T	**D**	**ST**	**SC**	**ES**	**LD**	**RA**	**EO**	**BB**	**TB**	**ER**	**TA**	**S**	**G**	
Zeier (1979)															Eye
El Falou et al. (2003)															
Hostens & Ramon (2005)					✓			✓							
El Falou et al. (2005)					✓			✓				✓			
Durkin et al. (2006)					✓										Thoracic
Balasubramanian et al. (2007)	✓	✓		✓											D medial right
Brook et al. (2009)												✓	✓	✓	
Franz (2011)	✓														
Vilimek et al. (2011)		✓							✓	✓					Brachioradialis
Arora & Grenier (2013)					✓		✓	✓							
Dong et al. (2014)	✓	✓							✓						
Jagannath & Balasubramanian (2014)	✓	✓	✓		✓	✓			✓		✓				
Gao et al. (2014)		✓				✓				✓					
Liu et al. (2014)		✓								✓					Pectoralis, teres major
Yusoff et al. (2016)												✓			

Table 2.11 Function of selected muscles in driving task

Joint	Muscle	General function	Role in driving task	Guideline
Shoulder /neck/head	T	Stabilize and move the scapula.	Hand arm vibration from steering wheel may induce muscle group	Jagannath & Balasubramian (2014): bilateral T muscle significant Jonsson & Jonsson (1975): There is no correlation between the periods of contraction and the angular movements of the steering wheel.
	D	When all its fibers contract simultaneously, the D is the prime mover of arm abduction along the frontal plane. The arm must be medially rotated for the D to have maximum effect. This makes the D an antagonist muscle of the pectoralis major and LD during arm adduction.	Steering wheel control and gear shift	Jonsson & Jonson (1975) anterior and middle portions of the D muscle work during contralateral rotation of the steering wheel, while the posterior portion does not work at all. The D muscle seems to have a purely phasic action in driving.
	ST	Flexes the neck and helps with the oblique rotation of the head.	Maintaining the head in a prone position	Jagannath & Balasubramian (2014): no effect on this muscle while driving
	SC	A prime mover for head extension.	Maintaining the head.	Balasubramanian & Adalarasu (2007): Significant change in electrical activity was found to exist when compared the beginning and end of driving in 15 minutes.
Trunk /lower back	LD	Responsible for extension, adduction, transverse extension also known as horizontal abduction, flexion from an extended position, and internal rotation of the shoulder joint	Back muscle groups need to support the body to maintain its posture during driving.	Jagannath & Balasubramian (2014): significant change in postural muscle-groups such as LD and ES during monotonous driving.
	ES	Straighten the back and provides for side-to-side rotation. Main spinal stability provider.	Forward movement.	
	RA	Lumbar spine flexion	Flexion task	Arora & Grenier (2013): Have an effect.

To be continued…

…continuation

	EO	Rotate and side bend the trunk, provide spinal stability	Flex the trunk, side bend the torso toward the same side (i.e., the side of the contracting muscle), and rotate the trunk toward the opposite side.	El-Falou et al. (2003): no significant differences in the median frequency between the four experimental conditions for any of the muscles examined in 150 minutes.
Arm /hand	B T	Helps control the motion of two different joints, the shoulder and the elbow.	Show some activity during driving during grasping steering wheel,	Jagannath & Balasubramian (2014) and Jonsson & Jonnson 1975:): did not seem to be involved in the steering activity as much as the T
	ER	Acts to extend and abduct the wrist.		Dohi, Sakuma, Liao (2008): ECR functioned during driving phase.
Lower leg/foot	TA	Responsible for dorsiflexing and inverting the foot.	Slow down the car by flexing the foot near to the leg	Brook et al. (2009) and Yusoff et al. (2016): TA involves in dorsiflexion, while G and S in plantarflexion.
	S	Plantarflexion of the foot, plays an important role in maintaining standing posture; if not for its constant pull, the body would fall forward.	Depressing a car pedal	
	G	Primarily involved in running, jumping and other "fast" movements of leg, and to a lesser degree in walking and standing.	Depressing a car pedal	

As mentioned in Chapter I and the earlier section in Chapter II, this study focuses on the interaction between the driver and car components. In this case, car components are referred to car seat and also car controls, namely the steering wheel, manual gear transmission and accelerator pedal. Based on past studies on the assessment of the driver with respect to different driving condition, assessment using SEMG technique was found to be really useful in determining muscle activity and contraction while engaging with different car controls.

Operating the steering wheel and gear requires the upper body part to move the control. As explained in Section 2.4.2, the driver has to manoeuvre the direction of the car using the steering wheel. This turning and rotating action to certain degree and direction, requires certain shoulder and arm muscles to be active. In this case, deltoid and trapezius are two active muscles activated for this control. However, according to past studies as depicted in Table 2.10 and Table 2.11, deltoid anterior (DA) is the prime mover for steering wheel control, while trapezius act as the stabilizer for this task. For gear shift, the driver is required to pull or push the gear lever to certain position based on the driving condition and speed. To move the car in the beginning, pushing activity is required for changing the gear from N to 1, while pulling activity is required when driver want to change the gear from gear 1 to N. This pulling and pushing activity requires the shoulder and lower body part to operate the gear. It requires certain muscles from the upper body part such as brachioradialis, biceps brachii, triceps brachii and DA, as well as muscles from lower body part such as TA, S and G to move the car. Based on past studies, the DA is the dominant muscle in gearing action particularly during the pushing task, while for the pulling task, elbows flexors play an important role. For accelerator pedal function in a right handed car system, right TA, S and G from the lower leg part play important roles in pressing and releasing the car pedal.

Hence, according to these findings, the shoulder and lower leg muscle are selected due to their dominant function when engaging with car controls. Deltoid from shoulder body part seems to provide clear and great activation in operating the steering wheel and gear task, while lower leg provides clear indication when performing car pedal task.

d. Range of motion for shoulder and lower leg or foot joints

According to Brook et al. (2009), there is a limitation on the joint degree and function. Table 2.12 shows the joint, measured output and range of the muscle, based on muscle principals and compilation from past studies (Ali 2013; Back et al. 1995; Brook et al. 2009; Freeman & Haslegrave 2004; Isman, Inman & Poor 1969; Medlej 2014; Smith 1995; Yusoff et al. 2016). The location of each muscle in Table 2.12 can be referred in Figure 2.7.

Table 2.12 Shoulder and foot joint

Joint	**Measured output**	**Range of motion (^{0})**	**Primary muscle**
Shoulder (Biggest range of motion due to its socket articulation)	Abduction	Up to 180	Deltoid
	Adduction	Up to 45	Pectoralis major and LD
	Vertical flexion	Up to 180	Pectoralis major, DA
	Vertical extension	Up to 60	LD, teres major
	Horizontal abduction/extension	Up to 45	LD, deltoid posterior
	Horizontal adduction/flexion	Up to 130	Pectoralis major and DA
Lower leg-Ankle/Foot (Quite similar to wrist, but with more limited range of rotation)	Plantarflexion (bring toes down)	Up to 50	Posterior leg: G, S, plantaris and tibialis posterior
	Dorsiflexion/extension (bring toes up)	Up to 20	Anterior leg: TA, extensor halluces longus, extensor digitorum longus
	Pronation (sole faces in)	Up to 30	Peroneal
	Supination (sole faces out)	Up to 20	Tibialis posterior

As tabulated in Table 2.12, both joints have diverse range of motion, depending on the joint action. Ali (2013) stated that during abducting activity, 60 to 120 degrees is known as painful arc. If the motion is outside of this range, abduction activity is painless, as shown in Figure 2.5.

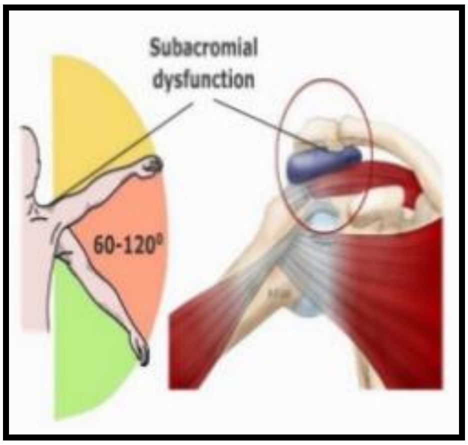


Figure 2.5 Painful arc during abducting task

Source: Ali 2013

As for foot joint, it has four degrees of severity for plantarflexion contractures, severe, moderate, mild and ideal flexion, as shown in Figure 2.6. The mild degree represents the neutral position of the foot. Moreover, there is an increment in knee extension when plantarflexion is between 10 degrees and 20 degrees with mean increase from 5 degrees to 9 degrees compared to neutral position (Leung et al., 2014). As mentioned by Cawthorn et al. (1991), the muscles that control foot inversion and eversion are most active between 10 degree dorsiflexion and 25 degree plantarflexion. In addition, the position of 10 degree plantarflexion is more preferable compared to the neutral and 10 degree dorsiflexion position in evaluating the inversion and eversion force.

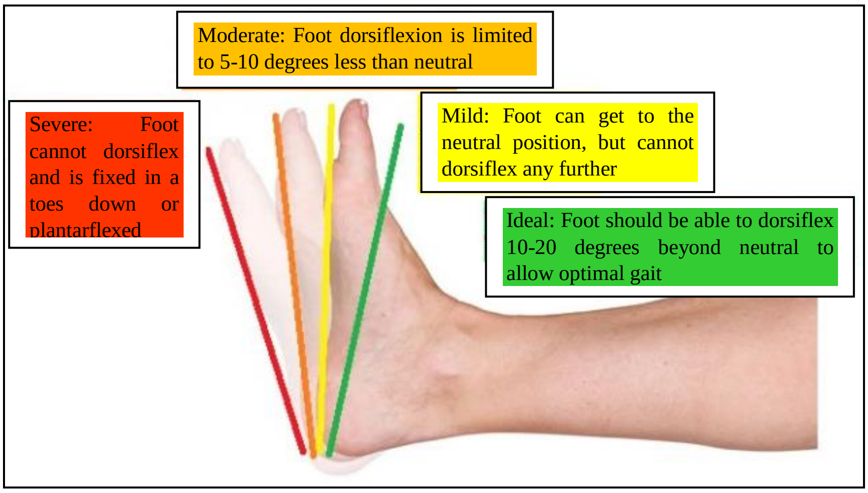


Figure 2.6 Degree of severity for foot

Source: Anon 2015

e. Muscle parts for the shoulder and lower leg

Figure 2.7 shows the whole body part, with specific muscles. In this study, only part A (involves in the steering wheel and gear activity) and part E (involves in the car pedal activity) are the research focus.

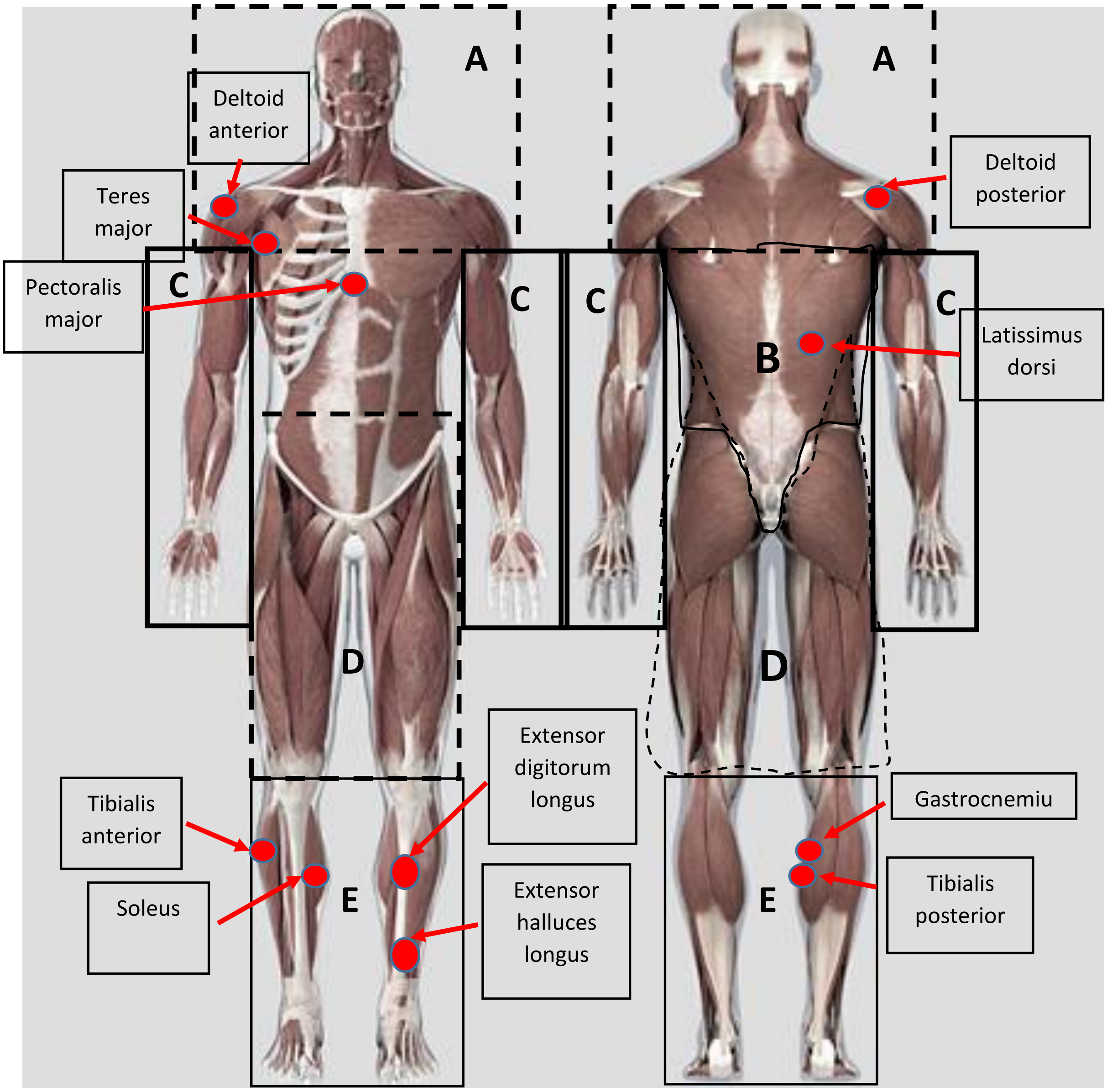


Figure 2.7 Muscle part for the whole body

Symbol: A - Shoulder or neck, B - Trunk or (lower) back, C - Arm or hand , D - Hip and upper leg, E - Lower leg and foot
Source: Surface Electromyography for the Non-Invasive Assessment of Muscles SENIAM, 2016

SENIAM has proposed recommendations for sensor locations on 30 individual muscles. For each muscle the recommendations include a description of the muscle anatomy (subdivision, origin, insertion, and function), a description of the recommendations for SEMG sensors, a description of the electrode location and orientation and a description of the starting posture and clinical test for recording the SEMG of that particular muscle. The recommendations for the individual muscles are organized according to the body parts where the muscles are located:

i. Shoulder part: Deltoid

Shoulder complex is consist of four joints. There are sternoclavicular joint, acromioclavicular joint, glenohumeral joint and scapulothoracic joint. Movements of upper extremity are inter-related within these joints in producing functional task. For example, scapular motions at scapulothoracic joint and motions of humerus at glenohumeral joint are move synchronizedly during rotating steering wheel. The synchronous motion of scapula allows muscles to move the humerus to maintain an effective length-tension relationship throughout the activity. It helps to maintain congruency between humeral head and gleniod fossa while decreasing in shear forces, subsequently will prevent mechanical loading on shoulder joint and minimize risk of MSDs with shoulder pain among driver. When arms movement is produced from synchronized motion by glenohumeral joint and scapulothoracic joint, the movements had achieved its scapulohumeral rhythm (Basmajian & De Luca 1985; Neumann 2002; Schenkman & Rugo de Cartava 1987; Smith 1995).

SENIAM proposed recommendations for sensor locations on the following shoulder muscles, trapezius and deltoid. In this study, DA is selected and explained in this section. The DA muscle is used while grasping the steering wheel and shifting the gear (Hostens & Ramon 2005; Jagannath & Balasubramanian 2014; Vilimek et al. 2011). From the biomechanics perspective, different distance from the steering wheel, will produce different muscle contraction, which is the value of joint angle. As mentioned by Kang et al. (2013), the change in the joint angle results in the change of muscle length. Hence, a variation of muscle contraction can be produced based on different joint angles. Figure 2.8 depicts the range of motion at the elbow. According to Neumann (2002), a healthy human elbow range of motion is from 5 degrees (hyperextension) to 145 degrees of flexion. In addition, the centre of gravity (COG) theory for the human body also provide additional information for the muscle activity value according to different driving position. The COG will be change according to the shoulder and hand position (Hamill & Knutzen 2006; Kumar 1999; Nordin & Frankel 2001; Schafer 1987). It determines the ability and stability of controlling the vehicle, by referring to the force value.

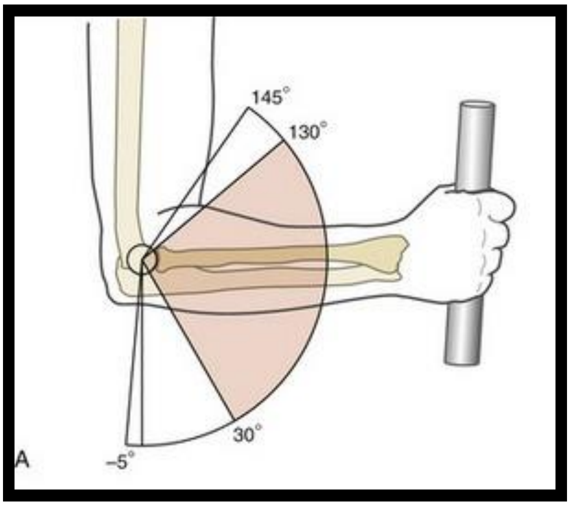


Figure 2.8 Range of motion at the elbow

Source: Neumann 2002

ii. Lower leg muscles: Tibialis anterior and gastrocnemius medialis

SENIAM also proposed some recommendations for sensor locations on the following lower leg or foot muscles, tibialis anterior (TA), peroneus longus, peroneus brevis, soleus, gastrocnemius medialis (GM) and gastrocnemius lateralis. Apart from controlling the steering wheel, driving task also requires the driver to control the speed and movement of the car at a certain force, by using his or her leg. To accelerate the car, the leg is used to press the car accelerator pedal, while to decelerate the car, the leg is released from pressing the car accelerator. This scenario is known as biomechanical movement. The biomechanical movement on human muscles is the calculation of force acting upon the muscles, working muscles and joint angle in completing the driving task (Wang, Le Breton-Gadegbeku, & Bouzon, 2004). As shown earlier in Table 2.12, there are several motions that can be performed by the foot muscle. However, with respect to the driving task, plantarflexion (referring to pressing the car pedal) and dorsiflexion (referring to releasing the car pedal) are two main measured outputs for the lower leg, concentrating on the foot muscle. In this study TA is preferred for dorsiflexion role, while soleus and GM for plantarflexion. The leg position in plantarflexion is greater than 90° from the ankle joint angle while in the dorsiflexion; it is less than 90°, as shown Figure 2.9. In addition, based on Keene (2010), the maximum ankle joint angle for dorsiflexion task is 70°, while for plantarflexion task is 140°.

(a) (b) (c)

Figure 2.9 The leg position for (a) dorsiflexion, (b) neutral and (c) plantarflexion

Source: Keene 2010

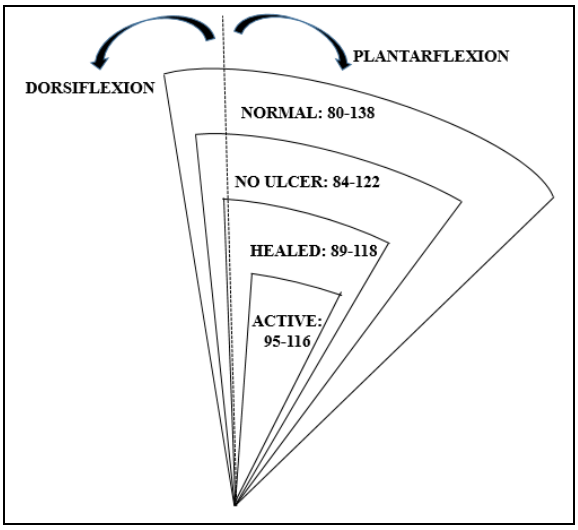


Figure 2.10 Average range of ankle motion for four groups of limbs, with regards to dorsiflexion and plantarflexion

Source: Leung et al. 2014

As depicted in Figure 2.10, there are significant differences between the four groups of limbs, normal, no ulcer, healed and active patient. The range of motion for each group is varied, with the active patients who are not yet cured from lower limb problem , has a small range of motion compared to the rest of the group. Based on Tanaka et al. (2009), there are two positions in the interactions between the foot and car pedal, pedal with the foot and pedal with the toes. In driving task, both positions will influence the position of the heels and car floor, and indirectly affect the driver's discomfort.

f. **Relationship between SEMG, subjective assessment and body measurement**

In term of relationship between subjective and objective measure by using SEMG, Franz et al. (2011) mentioned that there was a good correlation of sitting comfort and the SEMG value. Based on the study, an improvement of the seat has been conducted. It shows that as the comfort was higher, the EMG value was reduced. Instead of the subjective measure, the SEMG produces good relationship with the body measurement. Kang et al. (2013) mentioned that the change in the joint angle results in the change of muscle length. As a result, variation of muscle contraction can be produced based on different of the joint angle. In addition to muscle contraction measurement, discomfort indices based on subjective measure can also become vital parameter to determine the driver's condition. El Falou et al. (2003) highlighted that discomfort perception based on subjective measure produce better correlation with static characteristics of component compared to direct measure. Furthermore, there is other factors that may affect subjective measure of driver's discomfort, such as reach parameter to the car controls (Fazlollahtabar 2010). It refers to how the driver extend and retract their body to reach the controls, such as steering wheel, gear and accelerator pedal when driving the car. It involves the shoulder, hand and foot to reach the controls. Fore arm and shoulder grip length are two common parameters to determine the working distance and reach (Kee & Lee 2012). In Table 2.4 under subsection 2.5.1, it shows that when the driver is reaching something, it will change the posture. Therefore, the SEMG would be a great indicator to determine driver's discomfort when there are changes of driving position.

2.7.3 Cardiovascular Parameters: Heart Rate and Blood Pressure

Several studies investigated the effect of simulated environment on physiological parameters (Jorna 1993). In this study, heart rate (HR) and blood pressure (BP) are monitored to evaluate driving-induced fatigue after driving activity. Both of these parameters are known as basic cardiovascular arousal parameter in determining human condition after performing any activity (Brookhuis & de Waard 2010; Kramer, 1990; Lenneman & Backs 2010; Roscoe 1992; Veltman & Gaillard 1998; Wilson, Caldwell & Russell 2007; Reimer et al., 2011).

In this section, further analysis is performed based on past studies on HR and its correlation with driving task. All the reviewed studies discussed a few main points as listed below. Table 2.7 shows the points based on the below-mentioned lists according to the past studies.

i. HR value will be decreased after driving.

ii. Past study combines HR measures with other tools, either in subjective or objective way.

iii. There is a strong correlation between HR and KSS.

iv. There is a strong correlation between HR and lane deviation (driving performance with regards to steering wheel control).

v. There is a strong correlation between HR and multiple fatigue measures.

vi. There are significant differences between HR and different setting parameters, such as simulator setting (static/moving base), vibration frequencies, and different task while driving.

In terms of BP measures, the BP can be lowered during the course of driving (Jagannath & Balasubramanian, 2014). In a study conducted by Jagannath and Balasubramanian (2014), significant differences were detected in both systolic and diastolic BP before and after driving with a decrement in BP after the driving session. However, this findings contradicted the study carried out by Fumio et al. (2002), where they found an increment during on-road driving in city traffic. Possible assumption for this contradiction is due to the location of experiment. In this case, Jagannath and Balasubramanian (2014) performed the experiment using a simulator in the laboratory, while Fumio et al. (2002) carried out their study in the actual road condition. In addition, Jagannath and Balasubramanian (2014) and Li et al. (2004) explained the differences between both studies are possibly due to a sense of security and safety among subjects when driving on the actual road and in the simulator, where there is less stress. In addition, restricted movements in the simulator may lead to poor blood circulation. All in all, the variation in HR and BP before and after driving can be helpful to provide prediction of the driver's condition for each driving task and correlate with other measures.

Table 2.13 Summary on heart rate (HR)

Authors	**i**	**ii**	**iii**	**iv**	**v**	**vi**
Jagannath & Balasubramanian (2014)	✓	✓				
Heinze et al. (2013)		✓	✓	✓		
Hefner et al. (2009); Son et al. (2011)		✓			✓	
Ronen & Yair (2013)	✓	✓			✓	
Li, Jiao, Chen, & Wang (2004); Zhao et al. (2012)	✓	✓				
Jap, Lal, Fischer, & Bekiaris (2009); Larue, Rakotonirainy, & Pettitt (2011); Lenneman & Backs (2009)	✓					
Heinze et al. (2011)		✓		✓		
Arun, Sundaraj, & Murugappan (2012); Engström, Johansson, & Östlund (2005); Jiao et al. (2004); Reimer et al. (2011); Unal et al. (2013)						✓
Johnson et al. (2011)		✓				

2.7.4 Driver's Posture Measurement

According to Porter et al. (2003), postural angles are defined as follows, which is adapted from Grandjean et al. (1983) and Bridger (1998):

- Ankle angle: The angle between a line from the lateral condyle to the lateral malleolus and a line parallel with the foot.

- Arm flexion: The angle between the vertical and a line from the acromium (part of the shoulder) to the lateral epicondyle (part of the elbow).
- Elbow angle: The angle between a line from the acromium to the lateral epicondyle and a line from the ulnar styloid (distal end of the forearm) to the lateral epicondyle.
- Knee angle: The angle between between the thigh muscles and the kneecap of the hamstring.
- Neck inclination: The angle between the vertical and a line from the 7th cervical vertebrae to the auditory canal.

Past studies showed a variety of recommended ranges of driving posture which are suitable for the driver. However, the majority of the studies focused on Westerners, which is known to have slightly different anthropometric data, compared to Asians. Due to this issue, Daruis (2010) and Mohamad et al. (2010) suggested suitable driving positions based on the compilation of anthropometric data of Malaysians, as shown in Table 2.14.

Table 2.14 Preferred driving position among Malaysians

Body part-seat angle	**Daruis (2010)**	**Mohamad et al. (2010)**
Backrest angle	105 deg	96-123 deg
Knee angle	109-121 deg	102-143 deg
Upper arm angle	22-38 deg	-
Elbow angle	130-139 deg	100-188 deg

In this study, based on the objective stated in Chapter I, two different driving positions are investigated. Joint angle between each posture is performed to determine the relationship between driver’s discomfort and joint angle. Chapter III presents details on these measurements.

2.7.5 Simulator Output

As mentioned in the previous section, a simulator is a safe and reliable tool to replicate the actual car. In addition, it can provide numerous valuable data, derived from the car components. With regards to the steering wheel, when the turning became larger, it will indicate the drowsiness level of the driver, particularly when driving on a monotonous road (Brown 1997; Svensson 2004; Wylie et al. 1996). In addition, referring to the car pedal function, the speed variability increases and the minimum distance to any lead vehicle decreases when driver's alertness decreased. Therefore, it is very useful to integrate all these factors with the physiological measures and subjective methods as mentioned above to indicate driver's performance (Belz 2000; Kircher, Uddman & Sandin 2002).

2.8. SUMMARY OF CHAPTER II

Discomfort is a subjective experience, which results from a combination of physiological (eg: muscle activity, pressure, skin condition) and psychological processes. It is influenced by common driving practices and activities of the drivers. As described in Section 2.3, the literature review from various studies related to sitting discomfort researches showed that the combination of the objective and subjective measurement is the most common method used for evaluating sitting discomfort. Subjective methods are the most direct evaluation, while the objective methods require the use of specific equipment to measure the comfort condition. The objective methods are more valuable when they are integrated with subjective methods. Comfort rating is a popular subjective assessment tool used to gather personal perception from respondents in past studies. LDR and VAS are the common methods used to evaluate the sitting discomfort of a subject in the past studies. In term of objective measures, pressure distribution and SEMG are among the popular techniques used in research related to sitting discomfort.

In Section 2.2, Section 2.4 and Section 2.5, issues related to car drivers when engaging with the car seat and car controls were investigated. Several past research related to the car seat and car controls are summarised in Table 2.3. Based on Table 2.3, up to this date, there is no study conducted on the integration of the car seat and car controls in one research. In addition, in the past studies, there is limited studies conducted by integrating multiple assessments to evaluate driver's discomfort. In term of driving position, the driver will change his or her posture when reaching out for something while driving. Hence, the appropriate methods and measures are required to analyse the body posture and driving position. The driver's anthropometric and body measurement is also another related parameter to determine driver's condition while driving in different posture and positions. Different positions may influence driver's condition due to difference in seat distance and seat position. Based on past studies, it has an effect on COG, muscle force and stability.

Driver's fatigue is another important issue related to driving activity. Performance can be impaired during fatigue where an individual performs an activity continuously. As mentioned in Section 2.5.2, there is a link between discomfort, fatigue and performance. There are many methods to evaluate driving performance. The KSS is the popular measuring scale to determine driver's fatigue. Other than measuring scale, as listed in Table 2.6, vehicle based measure (eg: lane deviation, steering wheel control), behavioral (eg: yawn, eye blink) and physiological methods (eg: EMG, EEG) are other methods to determine driver's performance.

Section 2.6 and Section 2.7 encapsulated findings from existing studies particularly on simulator studies. Referring to this review, there is a good correlation between subjective and objective measurement methods. In addition, determination of the test subjects, test location and scope of the research are among the main issues that need to be addressed before conducting the experiment. Nevertheless, this review highlighted numerous concerns based on each study as reference for future research, either in the methodology procedures and implementation or the consistency of the findings. As explained in Section 2.7, this study focuses on certain parameters only in order to meet the objectives stated in Chapter I based on the analysis carried out in Chapter II. Therefore, with clear understanding and knowledge, hopefully this review can assist researchers to deal with sitting discomfort problems in the future. Chapter III provides explanation on the process flow for this study.

CHAPTER III

METHODOLOGY

3.1 INTRODUCTION

This chapter provides explanation in detail on the process flow of this study. Section 3.2 shows the flow chart of this study, then Section 3.3 describes the background of the subjects and apparatus used in this study. The last section explains on the statistical analysis tools to be used to analyse the findings. This research methodology was approved by The Universiti Kebangsaan Malaysia (UKM) Ethical Advisory Committee, with the reference number UKM PPI/111/8/JEP-2016-200, as shown in Appendix A.

3.2 FLOW CHART

Figure 3.1 shows the research framework used in this study to accomplish the objectives of this study, as established in Chapter I. As mentioned in previous chapters, this study focused on mixed methods to determine driver’s condition when engaging with the car seat and car controls. Furthermore, summary and explanation on the reason behind this methodology selection was described and justified in Section 2.7 in Chapter II. According to the Figure 3.1, data from subjective measure, objective measure, anthropometric measurement and joint angle were collected in this study.

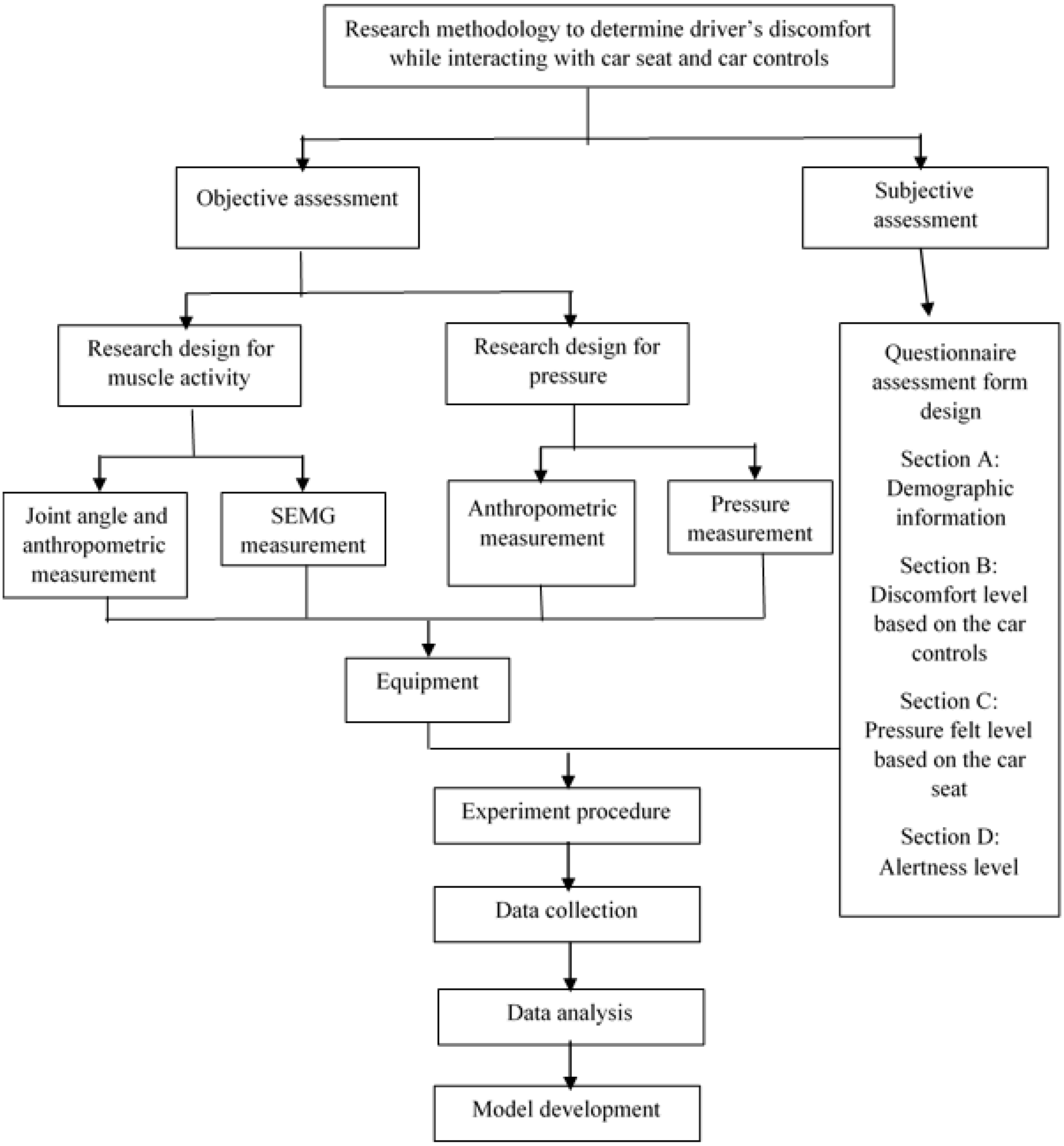


Figure 3.1 Research framework

With respect to subjective measure assessment, there were four main sections in the assessment form, consisting of the demographic information (Section A), discomfort level (Section B), pressure felt level (Section C) and alertness level (Section D). The test subjects are required to evaluate their discomfort level, pressure felt level and alertness level according to driving condition in the experiment. Alertness level was gathered before, during and after driving. Meanwhile, discomfort and pressure felt level were gathered during pre (before) and post (after) driving. For the main objective assessments, pressure interface distribution and SEMG methods were used, due to its measure outputs and functions to determine the effects of driving position to driver's condition. The output of pressure distribution was in the form of the mean pressure of the body parts. Meanwhile for SEMG measurement, muscle activity measurement of each muscle from each car controls was determined by applying Amplitude Analysis. The output value was in the form of RMS with the unit in microvolt (µV). Furthermore, cardiovascular data based on HR and BP as well as simulator output was collected to determine the driver's condition in terms of performance before and after driving.

In addition, apart from the subjective and objective measures methods used, anthropometric measurement was carried out. Based on past studies, the anthropometric measurements are good predictors to determine the condition level and the effects to the activities (McFadden et al. 2000; Chaffin et al. 2000; Wind et al. 2010; Fattahi et al. 2012; Saginus & Marklin 2013; Mohan et al. 2014; Ng, Cassar & Gross 1995; Shen & Parsons 1997). There were three anthropometric parameters to be measured in this study; buttock to popliteal length, shoulder grip length and fore arm hand length. Buttock-popliteal length is used to determine the car seat parameter, particularly on the seat pan. As mentioned in Chapter II, this parameter is useful to determine the cushion length of the seat pan and produce good correlation with buttock and thigh length. Shoulder grip and arm length are often used in defining the reach zone. In this study, factors such as seat position, seat inclination and car controls position affects driver's reach capabilities. These three parameters were selected based on the past studies that mentioned the occupant sizes can influence the posture (Porter & Gyi 1998). Furthermore, as mentioned by McFadden et al. 2000, driver characteristics may be a good indicator of sitting distance from the steering wheel. For example, these distances increased with the driver size according to the activity. The distance from the car controls may provide an effect on the driver's comfort level when driving. In addition, SAE J4004 (2008) stated that seat position determines the driver's safety and comfortability while driving.

Besides, joint angle measurements based on the elbow, toe, and knee were collected among the test subjects when performing the experiment. These joint angles were collected to find the inter-relations between different postures. In fact, based on the literature, there are significant correlations between the anthropometric measurements, the postures and joint angles (Porter & Gyi 1998; Lio & Drury 2010). In addition, as mentioned by Porter & Gyi (1998), there was a need to collect various body angles with respect to the actual postures and the range of adjustments of the car components. Any change in driving positions and posture may affect the center of gravity (COG) of the human body. When the arms are raised overhead and lowered, the COG is respectively raised and lowered within the body (Schafer 1987). A good sitting posture places the upper body's COG over the hips, supporting with muscles to balance the body. Therefore, both measurements (anthropometric data and joint angle) were performed to determine its correlation with the driving condition in this study. This study is a static field experiment which data acquired are in the quantitative form. The descriptions of each research methods were explained in Section 3.2.1 to Section 3.2.3.

3.2.1 Test Subjects

Eleven subjects (mean age = 28 ±4.83 years old, mean height = 161 ±6.38 cm, mean weight = 56 ±7.16 kg) were recruited from the staff and students population at Universiti Kebangsaan Malaysia to take part in this study. Each subject was required to attend one session, either in the morning session (from 9 am to 12 pm) or in the afternoon session (from 2 pm to 5 pm). The inclusion criteria, all the respondents must have a full Malaysia driving license, had at least three years of driving experiences, aged between 21 to 35 years old, and reporting no risk of nausea (motion sickness) while riding in a car as the driver. The constriction of the age range was proposed to reduce variations in the results due to age, since even in normal ageing, people present slight perceptive variations that have a direct attitude towards driving (Antonson et al. 2014). In addition, this study examined the driver's behaviour and well-being, therefore it is important that this study includes experienced drivers in order to avoid disorienting result due to lack of driving experience.

Moreover, all subjects were allowed to adapt with the car simulator setup and driving task before starting the experiment. The experiment started after five minutes the subject had been in the driving position to allow to adapt with the seat environment and fabrics. All subjects understood and complied with the oral and written instructions provided by researcher for this experiment: before, during and after driving. Information about the road, simulator driving procedures, and questionnaires used was included. After receiving the complete information about the study, each subject signed an informed consent as shown in Appendix B. However, before starting the experiment, the subjects were required to test the simulator in order to ensure they were familiar with the car's component; gears, steering, and acceleration as well as the simulator road condition and landscape. All subjects were instructed to drive and obey traffic rules for 15 minutes for each driving positions. The subject's answers for Section B and C were recorded twice to ensure the feedback is reliable. The seat back rest was positioned at 100^0. Figure 3.2 demonstrates the process flow of the instruction for the subject. Section 3.2.2 describes the design of the simulator setup and experiment scenario for this study.

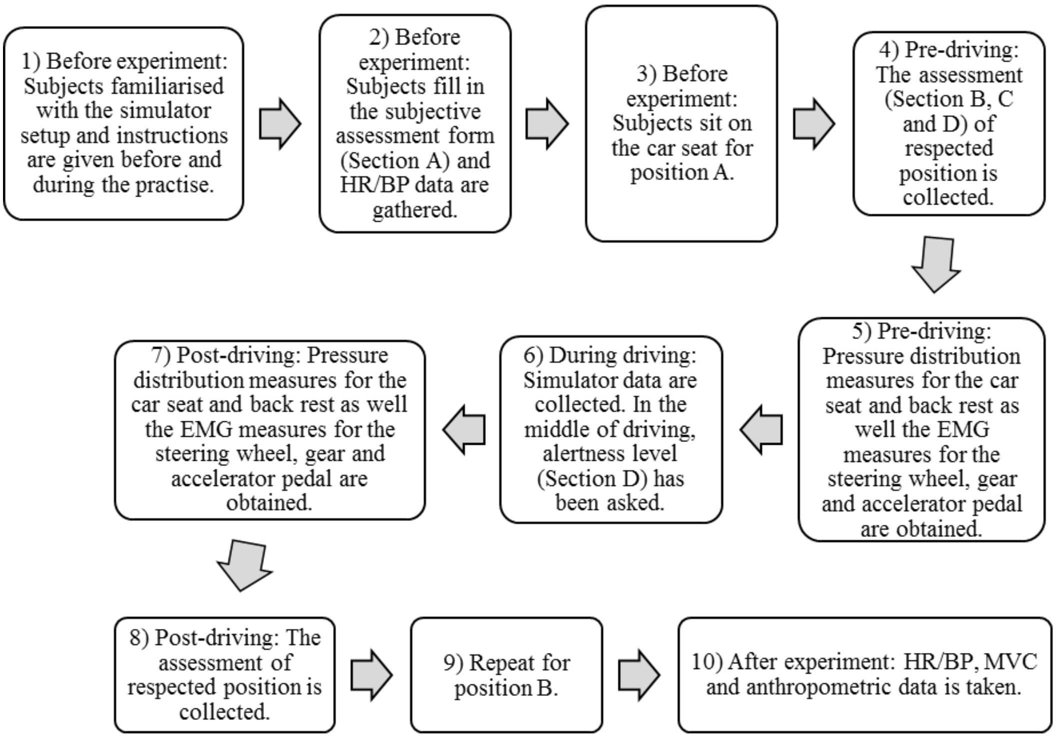


Figure 3.2 Experiment flow for each subject

3.2.2 Simulator Setup and Scenario

A simulator was used in this study as displayed in Figure 3.3. This simulator is located in the Ergonomics Laboratory, Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, UKM. The design and seat parameters of this simulator was quite similar to one of the national compact car, as shown in Appendix C. The simulator consists of an adjustable driver’s seat (back rest inclination, lower or elevate head rest, forward or backward seat), steering wheel, clutch, accelerator and brake pedals, handbrake and manual gear shift. The screen was arranged in front of the driver and have the virtual dashboard on it when using the simulator. The screen shows the simulator’s road scene and environment and the subject can see the current speed and the gear change through the virtual dashboard when using the simulator. The system also produced simulated engine noise. The simulated route and traffic signs were standardized according to national traffic law.

Figure 3.3 Simulator setup

The driving task was reduced to a lane keeping task to induce task monotony: no traffic, driving consisted in following a lane (no itinerary involved) with speed in between 50 to 70 kilometres per hour, without having to stop the car (no red traffic lights, stops) or having the need for frequent breaking intervals (no T inter-sections or perpendicular turns), or having the necessities for gear and lane changing during the driving task (only change gear to gear 5 at the beginning), as well as turn signals activation. In addition, driving at the suburban scene was selected for this experiment. The simulated driving task was designed with the following requirements: the route was simple so that the drivers could complete the task as easily as possible, there were few scenery changes, there was no inclination on driving route to reduce outside stimuli, and light curvature was chosen so that drivers should pay attention. However, there is different road characteristics along the driving journey. Some road surfaces are quite bumpy and the driver can see this changes in the scene while driving. Even there is minimal contact of the car controls, particularly in gearing and braking system, there are other factors that will influenced driver's condition such as, car seat's pressure, driving duration, driving style, driving position and driver's charateristics. In fact, these factors are in agreement with the statements by other reseachers (Adler 2007; Balasubramanian & Adalarasu 2007; Gyi & Porter 1999; Hiemstra-van Mastrigt et al., 2017; Kyung & Nussbaum 2013; Pandis, Prinold & Bull 2015; Porter, Gyi & Tait 2003). Furthermore, in this study, the research scope is concentrated on several parameters by selecting the most prominent muscle that related to car controls. In this case, DA, TA, and GM are three prominent muscles for steering wheel, manual gear and pedal control.

3.2.3 Experimental Design and Procedure

Klein et al. (2008) mentioned that a key factor in maintaining car control was the driver's manual grip of the steering wheel. Majority of the drivers tend to put their hand at the upper half and at symmetric position, for instance 10 and 2 position (Mossey et al. 2014). Past studies have recommended that the good position while in seated interface was that the elbow should be bent to 90 degree with regard to the upper arm vertical and lower arm horizontal (Sanders & McCormick 1993; Walton & Thomas 2005). However, up to this date, the majority of existing studies were focused on driver's behaviour and no fixed posture while handling the steering wheel and other car controllers, for instance gear and pedal. In addition, there was no detailed study conducted on the measurement and effect of hand placement and driving position in the past studies (Mossey et al. 2014; De Waard, Van den Bold & Lewis-Evans 2010; Walton & Thomas 2005; Klein 2009; Klein et al. 2008; Andreoni et al. 2002; Porter, Gyi & Tait 2003; Jagannath & Balasubramanian 2014).

As described in Chapter II, two different driving positions with fixed back rest position at 100^0 were carried out in this study, as depicted in Figure 3.4 (a) and (b). Two different driving position were: i) Position A: the closest seated position to the car controls and ii) Position B: the further seated position from the car controls, as long as the test subjects could operate the car controls and sat leaning against the back rest of the car seat. These positions were chosen in this study because the highest discomfort rate was obtained in the preliminary study, which will be explained in Section 3.3.2.

(a) Position A

(b) Position B

Figure 3.4 Driving position

Hand position was recorded in 10 and 2 o'clock as shown in Figure 3.5. In addition, as mentioned in Section 3.2.1, each subject was required to drive the simulator for 15 minutes. As mentioned by Porter, Gyi & Tait (2003), some seats are considered uncomfortable after approximately 15 minutes. In addition, Balasubramanian & Adalarasu (2007) found that, there is significant change in muscle activity during 15 minutes of driving task in simulated condition. Furthermore, it can determine the onset or early stage of discomfort among drivers. Therefore, 15 minutes of driving task for each driving position should be enough to investigate the driver's condition pattern in simulated condition. In addition, based on preliminary study's findings that will be explained in Section 3.3.2, there is significant difference pattern based on the subjective assessment. This pattern can be seen from measurement and assessment on pre (before) and post (after) driving activity.

Figure 3.5 Hand placement and coordination

As mentioned in Figure 3.2, two time periods (pre and post activity) taken for the subjective and objective methods. The purpose of gathering data from pre and post activity was to determine any significant difference between both periods of time according to driving posture and task. Referring to subjective methods, the test subject was required to determine discomfort and pressure felt level according to driving condition. Meanwhile in objective method, pressure interface and SEMG measurement were recorded.

During the pressure interface measurement for pre and post driving, the subject need to ensure the right leg at the car pedal, while the left leg at the car simulator floor, near to the clutch pedal. Moreover, the test subject was required to sit on the car seat with hand at position 10-2 o'clock. The seat pan measurement was recorded first, then followed by the back rest measurement.

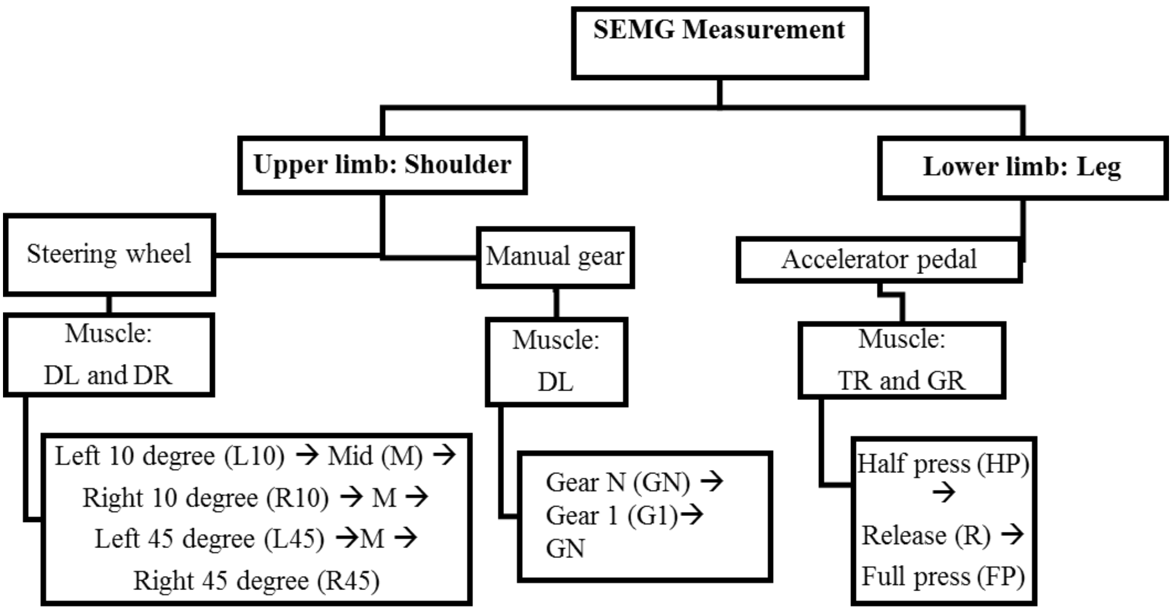
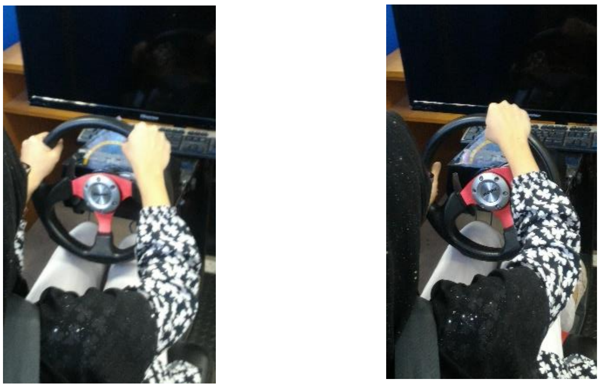


Figure 3.6 Recorded SEMG data according to car controls

SEMG measurement involved recording data from three main controls; steering wheel, manual gear transmission and accelerator pedal, as depicted in Figure 3.6. Each controls have several actions that need to be performed during experiment. Data acquisitions for pre and post driving taken for three tasks with each completed task is from 10 to 40 seconds. All the test subjects should follow all the following points for each action in the experiment. For steering wheel control, an angular ruler was used in this study to indicate the turning degree as illustrated in Figure 3.5.

- Steering wheel: Turning the steering wheel to the left 10 degree (L10), to the mid (M), to the right 10 degree (R10), to the left 45 degree (L45), to the M, to the right 45 degree (R45), and to the M according to the researcher instruction, which each turn is taken for 5 to 10 seconds. Figure 3.7 shows the example of actions for the steering wheel operation.
- Manual gear transmission: Changing the gear from gear N to gear 1 (G1), and from gear 1 to gear N (GN), which each shift is taken for 3 to 5 seconds. Figure 3.8 shows the example of actions for the gear operation.
- Accelerator pedal: Half press (HP), release (R), full press (FP), release (R), which each pedal activity is taken for 5 to 7 seconds. Figure 3.9 shows the example of actions for the pedal operation.



(a) Turning at 10 degree (b) Turning at 45 degree

Figure 3.7 Steering wheel action

Figure 3.8 Manual gear action

(a) Release (b) Half press

Figure 3.9 Accelerator pedal action

3.3 MIXED METHOD MEASUREMENTS

As shown in Figure 3.1, four main data acquisition apparatus which included objective and subjective assessments were used in this study. Section 3.3.1 to Section 3.3.6 describes detailed information on these measurements.

3.3.1 Driving Position, Anthropometric Data and Joint Angle Measurement

Figure 3.10 shows the joint angle measurement by using the goniometer. Ankle angle, elbow angle and knee angle were measured with the test subjects adopting to the instructed driving position in each of the right-hand drive cars. Measurement of these angles were taken by using a goniometer as depicted in Figure 3.11. Three sticker markers were positioned on anatomical landmarks on the right side of the body (at toe joint, elbow joint and knee joint) to aid measurement through clothing.

Figure 3.10 Joint angle measurement

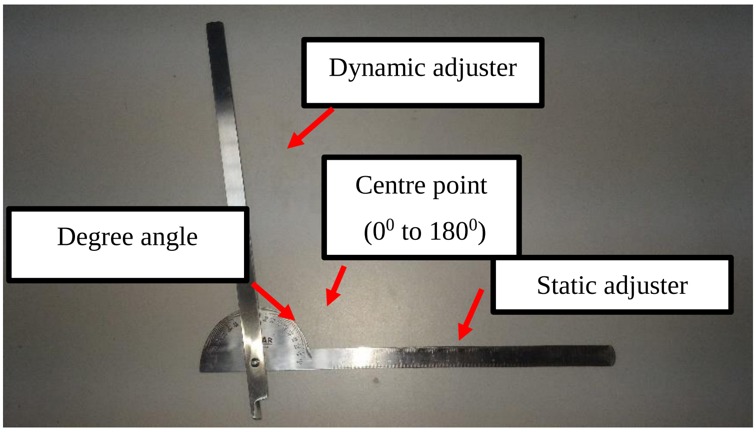


Figure 3.11 Goniometer

In addition, the anthropometer (Figure 3.12) was used to collect the anthropometric data of the buttock-popliteal length, shoulder grip length and fore arm length. Figure 3.13 shows the body landmark for the buttock-popliteal length (a), shoulder grip length (b) and the fore arm length (c) (Vaghefi e al. 2014). Chapter IV produces the findings for this measurement.

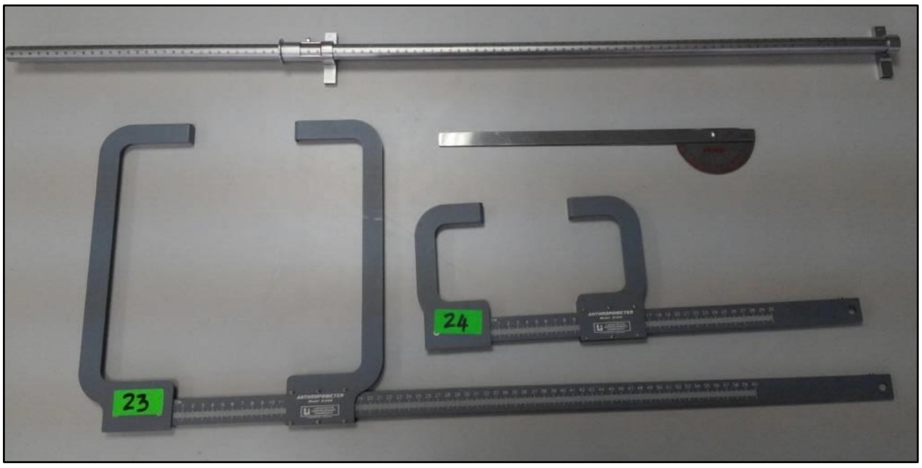
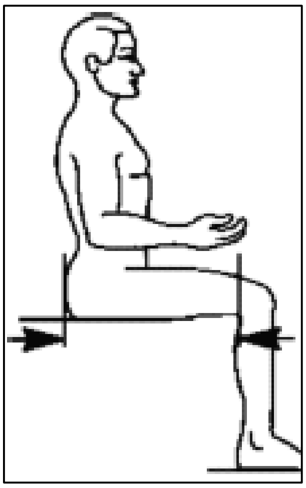
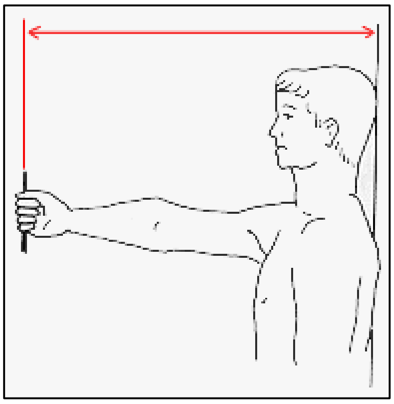


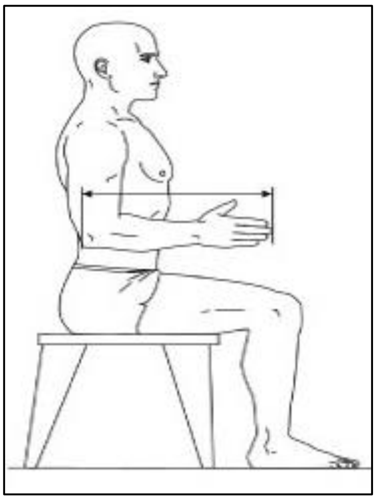
Figure 3.12 Anthropometer



(a) Buttock-popliteal length



(b) Shoulder grip length



(c) Fore arm length

Figure 3.13 Body landmark

3.3.2 Subjective Assessment: Questionnaire Form Design

Subjective methods can provide additional information on driver's perception regarding discomfort and their condition when driving. The main objective of using these methods was, to determine the relationship of different driving condition with driver's condition. The questionnaire was carefully designed to ensure that this study would attain its main objective.

a. Subjective assessment form development

The questionnaire design was developed based on the requirements and practices in existing empirical studies (Biggs et al. 2007; Davenne et al. 2012; de Looze et al. 2003; Deros, Daruis & Mohd Nor 2009; Grabisch et al. 2002; Hallvig et al. 2013; Hefner et al. 2009; Heinze et al. 2013; Kee & Lee 2012; Kyung, Nussbaum, & Babski-Reeves 2008; Kyung & Nussbaum 2008; Millar 2012; Openshaw 2011; Philip et al. 2005; Shen & Parsons, 1997). The draft of the assessment consisted of four main sections, which consists of the general information on the subjects (Section A), discomfort level according to driving positions (position 1=knee angle less than 110 degree, 2=knee angle between 110 and 129 degree and 3=knee angle above 130 degree) by using the Likert Scale of five rating scale (1=very uncomfortable to 5=very comfortable) (Section B), for 10 body parts at left and right, namely neck, shoulder, upper back, arm, low back, buttock, thigh, knee, calf, and feet. Section C was regarding the pressure felt level by using the Likert Scale of five rating scale (1=no pressure felt, 2=a little pressure felt, 3=significant pressure felt, 4=extreme pressure felt, 5=very extreme pressure felt) and the alertness evaluation (Section D) by using Karolinska Sleepiness Scale (KSS). Data from pre and post activities for Section B, C and D were collected based on this assessment.

b. Expert validation and pilot study protocol

Throughout the subjective assessment development, discussions were held with the research team to ensure the clarity of questions and the appropriateness of the proposed scale. The pilot study was performed to obtain the feedback from them regarding this questionnaire design (N=32 subjects). Furthermore, the pilot study has been conducted to ensure that the questionnaire design and its contents are understandable by the subjects. A briefing on the questionnaire design was given before all subjects agreed to participate in this pilot study. All subjects were required to attend this pilot study for two times by using the similar simulator setup. Based on the findings from this pilot study, the reliability analysis has been carried out with the Cronbach's alpha is significant with $\alpha > 0.7$ as shown in Appendix D. Cronbach's alpha coefficient used to determine the perceived usefulness and perceived ease of the subscales of the instrument (Hendrickson, Massey & Cronan, 1993). After gathering the feedback from subjects and reviewed them with the research team, the final questionnaire design has been modified based on the final experimental setup. In addition, some modifications on the questionnaire in terms of its wording selection, scale selection and explanation of each section has been made. Furthermore, a separate study was performed to investigate the general driving pattern among the drivers. In this study, the respondents (N=42) were asked regarding their favourable driving style and position when interacting with the car controls. Basically, one of the reasons behind implementation of the pilot study and investigation regarding preferable driving pattern was to assist the researcher in determining the research parameters (hand position and seat position) in this research. The researcher can determines driver's perception regarding driving position and styles. According to both studies, majority of the respondents were operating the steering wheel at 10 and 2 hand position. In addition, the closest seated position (position 1) and the far distant seated position (position 3) are two positions that the respondents feel discomfort.

c. Final subjective assessment form design

The final assessment form used in this study had four main sections. Appendix E shows the subjective assessment used in this study. Section A required the subject to provide the information regarding age, gender, height, weight, caffeine intake, food intake, sleep duration and driving experience. Section B required the subject to identify the body part discomfort level according to driving positions and task. The Visual Analogue Scale (VAS) was used in this questionnaire with the scale 0 (very comfortable) to 10 (very uncomfortable). There were three main subsections for Section B: Section B1, B2 and B3. Section B1 was regarding the evaluation on the steering wheel control according to five actions, L10, M, R10, L45 and R45. In addition, the subject was required to evaluate the discomfort level according to the muscle involved for this control. In this case, it referred to DL and DR muscle. Section B2 was regarding the evaluation on the gear control with respect to two actions, G1 and GN. Only DL muscle was evaluated for Section B2. Section B3 was regarding the evaluation on the accelerator pedal control according to three actions, HP, R and FP. For this section, TR and GR muscle have been evaluated for the pedal control. Section C required the test subject to identify their perception on pressure felt level based on driving position. Two parts being assessed for this section, seat part and back rest part. Each part had two segments; seat part (buttock and thigh) and back rest part (upper back and lower back). Similar to Section B, this section used the VAS for perception on pressure felt. However, the indication for each point scale was different from the Section B's scale. In this section, 0 was referred as no pressure felt, and 10 referred to as extreme pressure felt. The final section, Section D was regarding the assessment on test subjects' alertness by using KSS scale. As stated in Chapter II, the KSS scale used nine points of scale which each point had different definition and indication. Based on the feedback from the subjects in pilot study, this scale has been categorized into three main category, to assist the test subjects in evaluating their alertness based on this category. In this case, point 1 to 4 were categorised as alert category, 5 was the middle category, while 6 to 9 were categorised as sleepy category. Figure 3.14 shows the flow chart for the subjective assessment development.

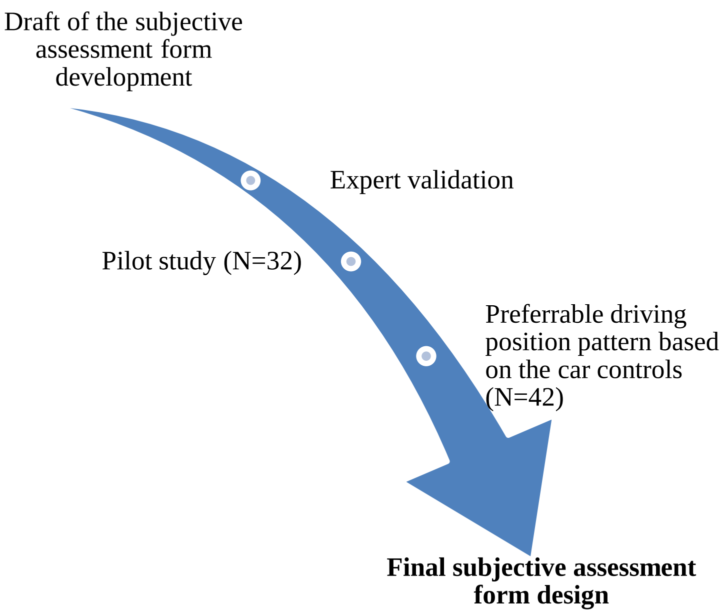


Figure 3.14 Flow chart of the subjective assessment development

3.3.3 SEMG Measurement

SEMG measurement was used in this study to investigate the muscle activity according to the different styles of driving positions. A Trigno™ Personal Monitor with Parallel-Bar Sensors from Delsys Incorporation was used to collect these analog data of muscle activity with sample rate up to 1000Hz interfaced with 5-channel signal amplifier. Figure 3.15 illustrates the Trigno™ Personal Monitor with Parallel-Bar Sensors.

Figure 3.15 A Trigno™ Personal Monitor with parallel-bar sensors

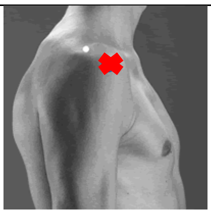
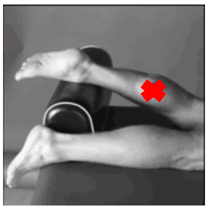
Source: Delsys Inc. 2016

The surface myo-electrical signal was converted to the analog data which later converted to digital data at the signal analysis personal computer interface. SEMG measurement was performed by placing electrodes on the skin's surface and electrical activity of the deltoid anterior (DA) at the left and right side, right Tibialis Anterior (TR) and right gastrocnemius medial (GM) underneath was recorded. The data collection procedure on the selected muscle was according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations. This section provides details on SEMG measurement used in this study.

a. EMG data collection preparation based on SENIAM recommendation

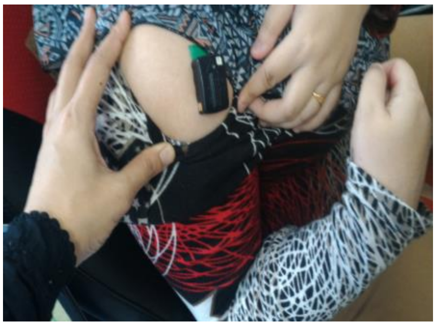
Skin inspection was performed prior to the electrodes placement to reduce the skin impedance and avoid noises on the EMG readings. Proper skin preparation was required to improve the electrode-skin contact. All subjects shaved at the selected muscle belly, cleaning with alcohol, rubbing with gel and abrasion with an abrasive cream such as NuPrep (Florimond, 2009). The EMG electrodes were pasted directly on the selected muscles belly after careful palpation and parallel to its muscle fibers. The procedure of electrodes placement such as body posture, location of electrodes, orientation, clinical test and task for selected muscle are depicted in Table 3.1. The cross symbol in the figures inside the Table 3.1 indicates the selected muscle.

Table 3.1 Identification of selected muscle and electrode placement position based on SENIAM recommendation

Muscle	Starting posture	Electrode placement	Clinical test	Orientation	Task
Deltoid anterior (DA)	Sitting with the arms hanging vertically and the palm pointing inwards	The electrodes need to be placed at one finger width distal and anterior to part of shoulder.	Shoulder abduction in slight flexion, with the humerus in slight rotation. In the erect sitting position it is necessary to place the humerus in slight lateral rotation to increase the effect of gravity on the anterior fibres. The anatomical action of the anterior deltoideus entails slight medial rotation while pressure is applied against the antero medial surface of the arm in the direction of adduction and slight extension.		Steering wheel and gear
Tibialis anterior (TA)	Supine or sitting	The electrodes need to be placed at 1/3 on the line between the tip of the fibula and the tip of the bump on the inner side of the ankle joint.	Support the leg just above the ankle joint with the ankle joint in dorsiflexion and the foot in inversion without extension of the great toe. Apply pressure against the medial side, dorsal surface of the foot in the direction of plantar flexion of the ankle joint and eversion of the foot.		Accelerator pedal
Gastroc nemius medial (GM)	Lying on the belly, the knee extended and the foot at the end of the table.	Electrodes need to be placed on the most prominent bulge of the muscle.	Plantar flexion of the foot with emphasis on pulling the heel upward more than pushing the forefoot downward. For maximum pressure in this position it is necessary to apply pressure against the forefoot as well as against the calcaneus.		Clutch and accelerator pedal

Source: SENIAM 2016

After the electrodes were placed and fixed, the electrodes could be connected to the SEMG equipment and a clinical test could be performed to test whether the electrodes have been placed properly on the muscle and connected to the equipment so that a reliable SEMG signal can be recorded. Recovery time was required before performing the next tasks (Son et al. 2011). The rest period of five minutes between the two periods of driving tasks is required in this experiment because it can influence the EMG parameters due to recovery (Hostens & Ramon, 2005). Figure 3.16 shows example of sensor's assembly on the skin based on assigned muscle. In Figure 3.16 (a), it shows that the electrode was placed at the DA muscle, while in Figure 3.16 (b), the electrode was place at the TR muscle.



(a) (b)

Figure 3.16 Sensor's assembly on the selected muscle

b. SEMG data analysis

Figure 3.17 shows the flow chart of SEMG data analysis. In this study, the signal processing of the SEMG data was not conducted using Delsys software since the data collection and analysis were in accordance with SENIAM recommendation and standard. Matlab and Microsoft Excel software are two main operators in processing and analysing EMG data in this study. All data should be gathered in 1000 Hz frequency. Before starting the experiment, the signal from the selected muscle should be tested to determine whether the muscle is working properly according to the driving activity. The muscle signal is displayed in the Delsys EMGworks Acquisition software. If the muscle works as predicted, then the experiment can be started. All raw data from the Delsys software are in the form ASCII file. These file need to be transferred to the Matlab software for further analysis as shown in Figure 3.17.

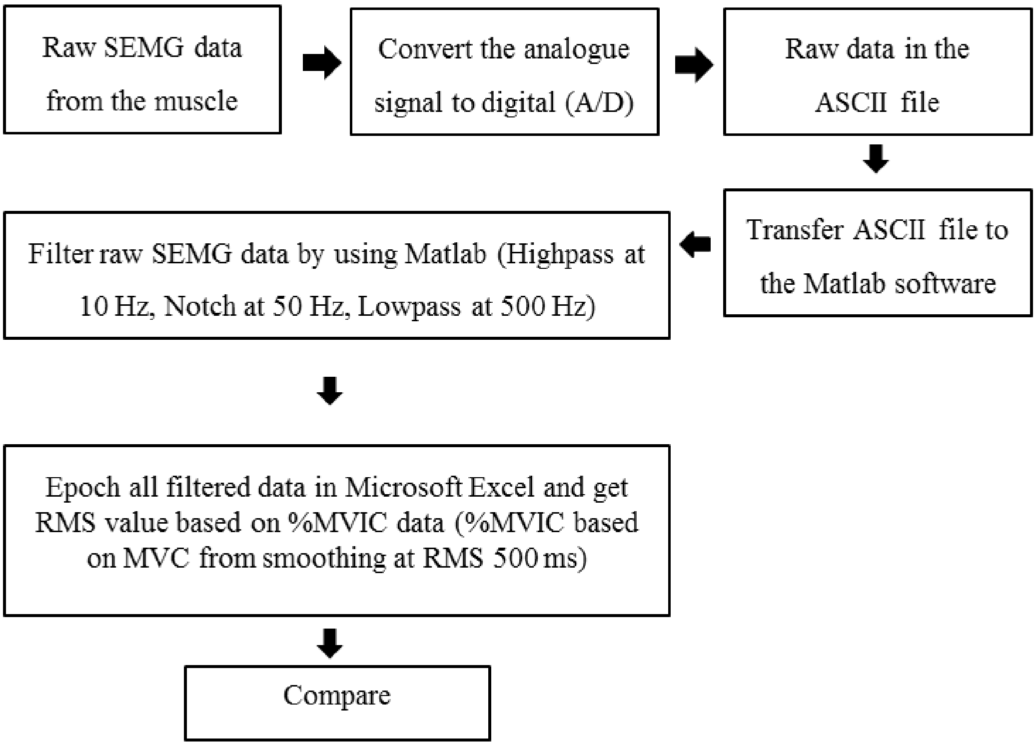
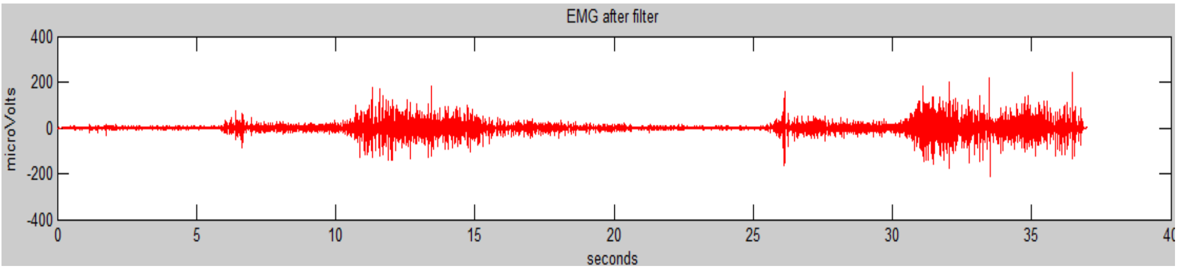


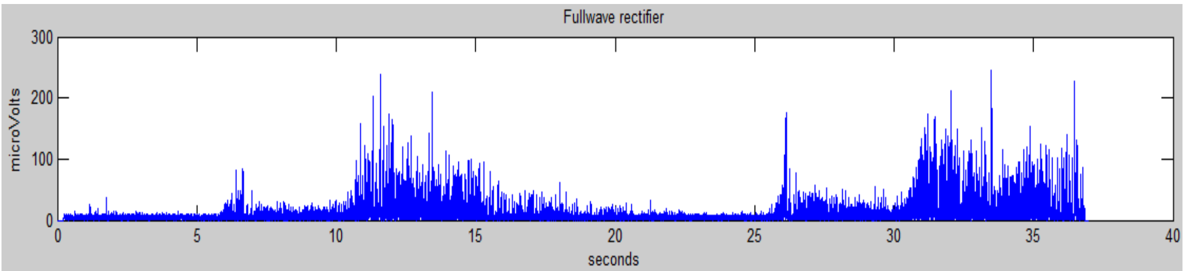
Figure 3.17 Flow chart of EMG data analysis

All data should be filtered since the raw data has unnecessary noise and artefact from movement of the electrode. All raw SEMG signal were filtered via the band pass and notch filter process. Most of the power in the EMG signal is in the frequency range of 5 to 500 Hz (Soderberg & Knutson, 2000; Hermens et al. 2000). This filter setup was based on recommendation from SENIAM and past studies. There were two types of band pass filter, namely high-pass and low-pass Butterworth filter. It was used to reduce the source of SEMG signal noise. In this study, the high-pass and low-pass Butterworth filters of the fourth order were used at cut-off frequencies of 10 Hz and 500 Hz respectively, while the notch filter was set at 50 Hz. Ten Hertz was setup as cut off frequencies at the high-pass to ensure the signal was adjusted to zero line first. Consequently, it can reduce the unwanted noise and artefact. Meanwhile, 500 Hz was the next setup as cut-off frequency at the low-pass. This frequency was used to reduce the biological artefact such as from the body fat which cannot be recognized by the EMG signal. Therefore, according to SENIAM recommendation, this setup was necessary to reduce the noise due to this type of artefact. Then, 50 Hz was the setup for the notch filter. This frequency was used to reduce the noise signal from any electrical device such as computer or hand phone that had been used near to the experiment location. Figure 3.18 (a) depicts the example of EMG signal after filtering process.

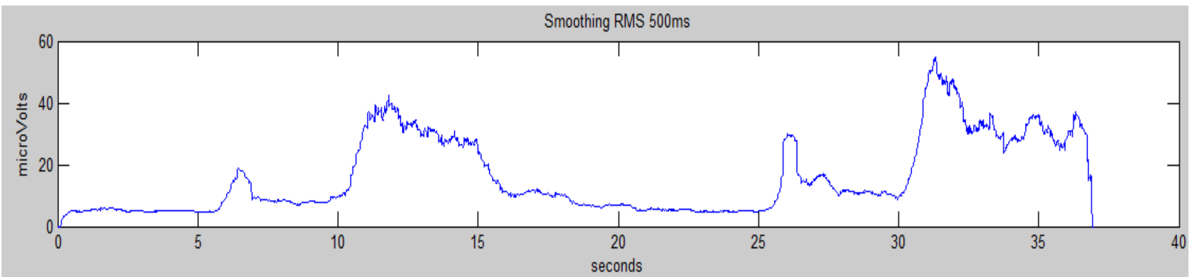
After the filtering process, the filtered SEMG signals were transferred to full-wave rectified signal for Temporal Analysis. Temporal Analysis was conducted to investigate the pattern of muscle when controlling and interacting with certain task in driving. This analysis will be discussed in Chapter IV. Figure 3.18 (b) illustrates the signal pattern after conducting this process. Next after the full wave processing, the signals were smoothened at RMS 500 ms as shown in Figure 3.18 (c). All these processes as shown in Figure 3.18 had used the Matlab processor. Appendix F depicted the programming code to produce this cleaned signal.



(a) After filtering process



(b) After performing full wave



(c) After smoothing process

Figure 3.18 EMG signal pattern after certain process

Then, all signals were epoched in every segment. Epoch is referred as segmentation in stipulated time used for analysis. With regards to this study, epoch was obtained at one second for one segment for each activity. After the epoch process, percentage of Maximum Voluntary Isometric Contraction (% MVIC) analysis was required to compare the driving tasks between each subject and each muscle. The purpose of conducting MVIC is to generate maximum voluntarily muscle during isometric muscle contraction. In the MVIC research design, respondents were required to perform pre-determined activities, as shown in Table 3.1 under clinical test. The MVIC reference value is divided by SEMG value which will give the normalized MVIC percentage value. The Microsoft Excel was used for this process. Basically, the Amplitude Analysis was gathered based on this value. Chapter IV presents the %MVIC and Amplitude Analysis based on driving condition. Equation (3.1) shows the % MVIC.

$$\% \, MVIC = \frac{IMVC}{MVC} x100 \qquad (3.1)$$

In short, as mentioned in Chapter II (Table 2.9), Amplitude Analysis was carried out to determine muscle activity according to driving condition, either in contraction form or rest form. The value of muscle activity is in Root Mean Square (RMS). If the RMS of muscle activity is below 5 microvolt (μV), it means that the muscle is in the rest form (Florimond 2009). Basically, the Amplitude Analysis was performed at time domain and the amplitude unit is in μV. Amplitude analysis was conducted at the stipulated epoch (Basmajian & De Luca, 1985; Gerdle et al., 1999; Hostens & Ramon, 2005). The RMS equation in discrete time is defined in Equation (3.2).

$$R.M.S = \sqrt{\frac{1}{N} \sum_{n=1}^{n} EMG\,[n]^2} \qquad (3.2)$$

where N is the number of data and n is the EMG data

3.3.4 Pressure Distribution

Pressure distribution pattern can demonstrate and predict the sitter's discomfort. Pressure measure is sensitive to postural changes of varied angulation and has good correlation with subjective comforts, by determining the maximum pressure, average pressure ratio and maximum pressure gradient (de Looze, Kuijt-Evers, & van Dieën, 2003; Shen & Galer, 2015). In this study, the Tactilus® pressure mapping from Sensor Products Incorporations (SPI) was used as shown in Figure 3.19. System includes 22 x 22 sensor pad calibrated 0 to 5 pound per square inch (psi) with 32 x 32 sensor matrix. The interface pressure use thin and flexible sensor arrays. By scanning the grid and measuring the electrical resistance at each grid point, the pressure distribution on the sensor's surface can be determined. The scanning electronics are packaged in a handle assembly that clips onto the sensor's interface tab and provides the electrical connection to each sensing cell.

Figure 3.19 Tactilus® pressure mat

Outputs from this equipment are in the form of minimum, maximum, average and standard deviation of pressure in the unit of psi, percentage of variation coefficient and regional distribution, horizontal and vertical center in inch as well as sensing area as demonstrated in Figure 3.20. It produces different colours to indicate the pressure range for each body part distribution.

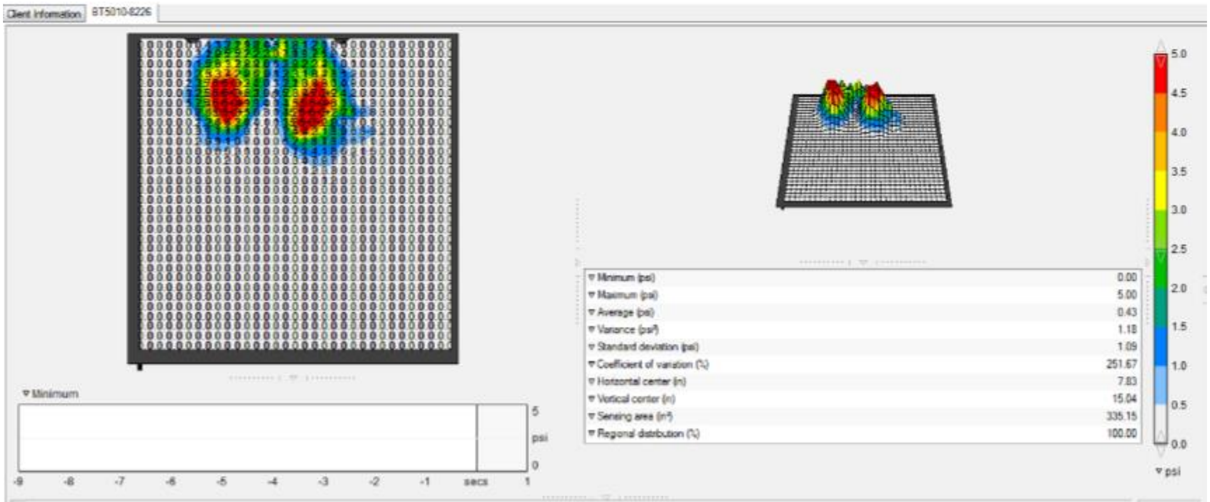


Figure 3.20 Example of pressure distribution data

a. Pressure distribution measurement procedure

All subjects were requested to wear suitable clothes for driving but without heavy seams, buttons or pockets to ensure that there was minimal effect on the pressure readings. This requirement is necessary to avoid false seat or back rest interface pressure readings. These mats were securely attached to the seat using strips of masking tape. Care was exercised to ensure that the mats were placed in a consistent location from subject and the seat pan or the back rest. Subjects adopted the driving positions for this measurement (i.e. semi-depressing the accelerator, hands on the steering wheel and looking ahead), held for 30 s. Then, the pressure distribution measurement of pre and post driving for the car seat and back rest was taken about one minute for each positions. The mats were removed and the occupant was asked to re-enter the seat in order to complete the survey without interference from the mats. The reason behind this instruction was, subjects have difficulty to rate the appearance of the seat if they were sitting on it.

b. Pressure distribution analysis

All raw data in the Tactilus software were then converted manually to Microsoft Excel, provided by SPI for further analysis. The average of the pressure was used in this study to compare between each subject. Figure 3.21 shows the findings after conversion in Microsoft Excel format.

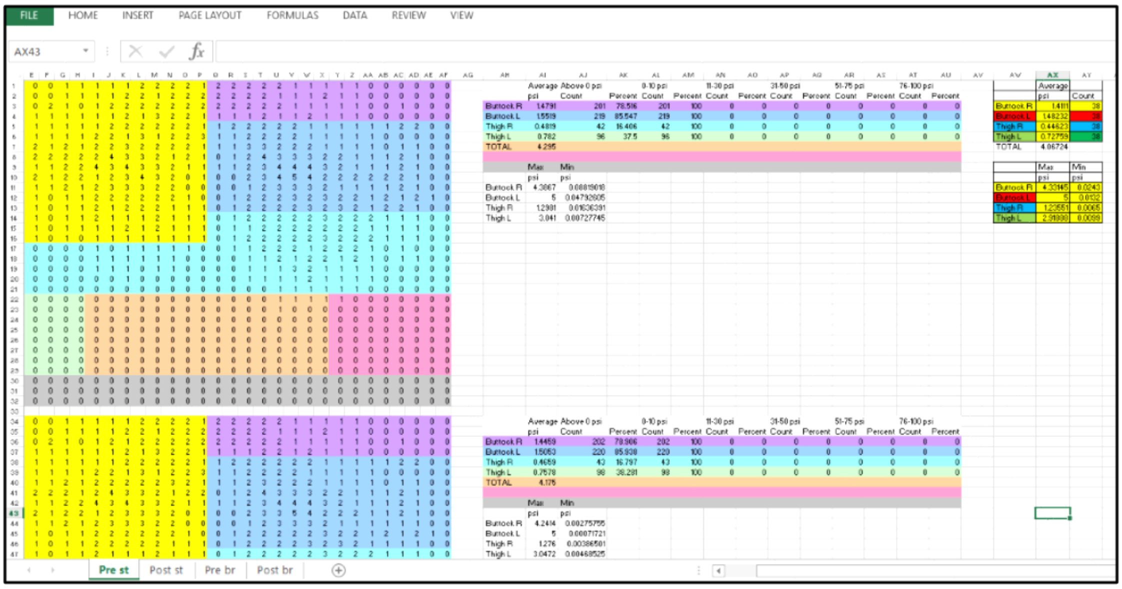
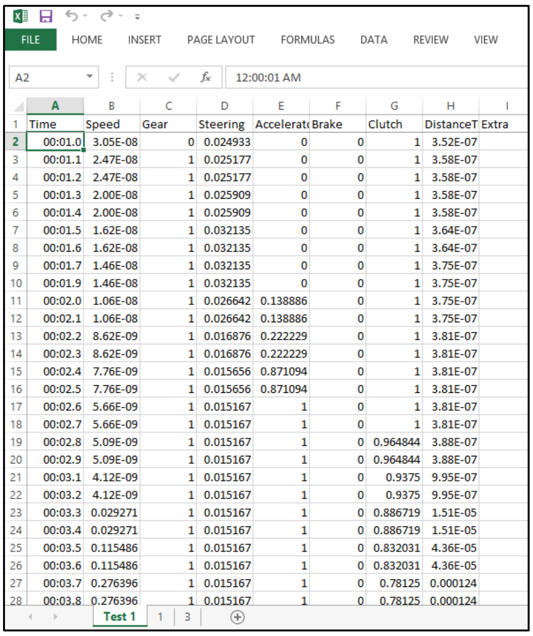


Figure 3.21 Pressure distribution value based on conversion in Microsoft Excel

3.3.5 Simulator Output

As mentioned in Chapter II, the simulator in this study can record the usage of the gear, the pedal and steering wheel during driving. The steering wheel rotation parameter was used to indicate lane deviation and degree of turning of each subject, while the pedal data can be used to determine the frequency of braking, changing gear, accelerating and decelerating during driving. The task of keeping a vehicle between the lines of a lane, to brake or to accelerate are largely a psychomotoric task involving eye, hand and leg coordination (de Waard 1996). Figure 3.22 shows the example of parameters from simulator, while Figure 3.23 depicts the example of simulator output that had been converted to Microsoft Excel for more analysis. Based on Figure 3.22, the speed, gear, steering, accelerator pedal, brake and clutch pedal were recorded as the simulator output. Gear parameter was based on the manual gear shift. In this case, zero (0) was equal to gear N, one (1) was equal to gear 1. Similar value as gear 1 was applied for gear 2, 3, 4 and 5. Apart from that, steering wheel's parameter was shown in positive and negative value. It was referred according to direction and degree of turning. Meanwhile, accelerator, clutch and brake pedal was measured according to percentage of pressing action from neutral position (pedal in the rest form).

Figure 3.22 General output from simulator



	A	B	C	D	E	F	G	H	I
1	Time	Speed	Gear	Steering	Accelerat	Brake	Clutch	DistanceT	Extra
2	00:01.0	3.05E-08	0	0.024933	0	0	1	3.52E-07	
3	00:01.1	2.47E-08	1	0.025177	0	0	1	3.58E-07	
4	00:01.2	2.47E-08	1	0.025177	0	0	1	3.58E-07	
5	00:01.3	2.00E-08	1	0.025909	0	0	1	3.58E-07	
6	00:01.4	2.00E-08	1	0.025909	0	0	1	3.58E-07	
7	00:01.5	1.62E-08	1	0.032135	0	0	1	3.64E-07	
8	00:01.6	1.62E-08	1	0.032135	0	0	1	3.64E-07	
9	00:01.7	1.46E-08	1	0.032135	0	0	1	3.75E-07	
10	00:01.9	1.46E-08	1	0.032135	0	0	1	3.75E-07	
11	00:02.0	1.06E-08	1	0.026642	0.138886	0	1	3.75E-07	
12	00:02.1	1.06E-08	1	0.026642	0.138886	0	1	3.75E-07	
13	00:02.2	8.62E-09	1	0.016876	0.222229	0	1	3.81E-07	
14	00:02.3	8.62E-09	1	0.016876	0.222229	0	1	3.81E-07	
15	00:02.4	7.76E-09	1	0.015656	0.871094	0	1	3.81E-07	
16	00:02.5	7.76E-09	1	0.015656	0.871094	0	1	3.81E-07	
17	00:02.6	5.66E-09	1	0.015167	1	0	1	3.81E-07	
18	00:02.7	5.66E-09	1	0.015167	1	0	1	3.81E-07	
19	00:02.8	5.09E-09	1	0.015167	1	0	0.964844	3.88E-07	
20	00:02.9	5.09E-09	1	0.015167	1	0	0.964844	3.88E-07	
21	00:03.1	4.12E-09	1	0.015167	1	0	0.9375	9.95E-07	
22	00:03.2	4.12E-09	1	0.015167	1	0	0.9375	9.95E-07	
23	00:03.3	0.029271	1	0.015167	1	0	0.886719	1.51E-05	
24	00:03.4	0.029271	1	0.015167	1	0	0.886719	1.51E-05	
25	00:03.5	0.115486	1	0.015167	1	0	0.832031	4.36E-05	
26	00:03.6	0.115486	1	0.015167	1	0	0.832031	4.36E-05	
27	00:03.7	0.276396	1	0.015167	1	0	0.78125	0.000124	
28	00:03.8	0.276396	1	0.015167	1	0	0.78125	0.000124	

Figure 3.23 Simulator output in Microsoft Excel

3.3.6 Cardiovascular Pattern based on HR and BP

As explained in Chapter II and Section 3.2, HR/BP data was recorded before and after all driving tasks were performed. The trend of HR and BP was analysed and compared between each subject. The purpose of gathering HR and BP data was, to identify pattern of HR and BP value between these two periods and to determine if there was any significant difference between these periods.

3.4 STATISTICAL ANALYSIS METHOD

This section explains the method used in this study. There are six main parts in this section.

3.4.1 Suitable Statistical Analysis

To respond on the first, second and third objectives and all hypothesis of this study, suitable statistical analysis was conducted based on selected parameters. The fundamental steps before performing this analysis, the researcher should recognise the category of raw data, either it was in nominal form, ordinal form, interval form or ratio form. In this study, data for subjective measures, particularly from Section B and C were in ordinal variable form, because the data was gathered by using VAS. It was in continuous scale from 0 to 10 points and each point indicated a different definition of driver's condition. For objective measures, the data was also in continuous form. Then, to compare between variables, all data should fulfil this major fundamental requirement, the data is normally distributed. This action is required to determine whether the data will be undergoing parametric or non-parametric test. In order to determine whether the data is normally distributed or not, the Shapiro-Wilk will provide the value. If $p < 0.05$, the, it shows the data is not normally distributed. Hence, the non-parametric test by using Wilcoxon signed-rank (if variables are less than two group) or Friedman test (if variables more than two group) should have been conducted for next analysis. On the other hand, the parametric test by using T-test (if variables are less than two groups) or One Way ANOVA (if variables more than two groups) should have been used if the data is normally distributed. Then, the Dependent variables (DVs) and Independent variables (IVs) for each comparison analysis should be identified. The results for normality test can be found from Appendix G.

3.4.2 Sample Size Selection and Validation

The sample size for this study was 11 test subjects. Suitable sample size selection is one of the frequent issue in performing the regression tests. It is better to have large sample size selection. However, in the actual experiment, there is limited numbers of sample size that can be handled by the researcher due to experimental condition (Sekaran 2013). Therefore, Sekaran (2013) has recommended the minimum number of sample size which is in between 10 to 20 samples that is appropriate for the study based on the experimental works. Furthermore, this fact was in line with another recommendation by Harrell (2015) that stated 10 subjects are the minimum number of a sample size for multiple regression test to ensure the prediction test is correct. Earlier chapter demonstrated the number of subjects used in the past studies, as shown in Table 2.7 (Chapter II). The minimum number of subjects that has been used in the past studies for research works were 2 subjects (a study conducted by Hartley et al. (1994) due to long hours of travel distance), and 3 subjects (a study conducted by Brook et al. (2009) due to preliminary study to validate the system). About thirty past studies in Table 2.7 conducted the research by using in between 10 to 20 test subjects. In addition, based on the past researchers, the example of minimum sample sizes number to develop the regression analysis model were: 4 samples (Daruis 2010), 5 samples (Liu et al. 2014); 6 samples (Vergara & Page 2002; Yadav & Goel 2008), 9 samples (Morioka & Griffin 2015), 10 samples (Amarantini & Bru 2015; Gazendam & Hof 2007; Gimmon et al. 2011;; Tijerina et al. 1999), 11 samples (Barry, Hill & Im 1992; El Falou et al. 2005), and 12 samples (Kolich, Seal & Taboun 2004; Morioka & Griffin 2009; Yusoff et al. 2016).

However, all these findings were incomplete without the proof from any relevant method to support the suitable sample size selection. Estimated sample size for regression is based on statistical power analysis (Aktas & Keskin 2013). The statistical power is originally developed by Jerzy Neywman and Egon S. Pearson as they introduced this concept in 1928 (Cohen 1990). In the regression analysis, the dependent variable (Y) is closely related to the independent variable (X_1, X_2 ... X_k). The power level is identified for the number of independent variables (k) and R Square, R^2 to verify the selected sample size is sufficient or not. The selection of a good minimum sample size to make predictions in the multiple regression test proposed by Knofczynski and Mundfrom (2008) is 7 samples with R^2 is 0.9. If there is any reduction in R^2 values, the addition of sample size should be performed (Knofczynski and Mundfrom 2008). Therefore, to verify whether the sample size selection used in this research is sufficient or not, G * Power software is used to identify the effect sizes by referring to the power level and effect of sample size. G * Power Software is a unique power analysis program for statistical tests commonly used in the research (Faul et al., 2007, Faul et al. 2009).

3.4.3 On-road Validation

On-road validation was conducted to determine the pattern of driver's condition when interacting with car seat and car controls based on the actual road condition. In addition, it was conducted to prove the pattern of the highest muscle activation and pressure distribution are similar with the simulated condition. In this case, it refer to the results based on different positions. Five subjects were using the actual national car, which has a quite similar specification and design as mentioned in the Section 3.2.2 and Appendix B. Instructions for the on-road test was similar with the simulator test. The subjects were required to drive the car near to Desa Pinggiran Putra and Putrajaya area for approximately fifteen minutes, as shown in Figure 3.24. This road was chosen due to lack of traffic and therefore, the road scene is quite similar to the simulator scene. This can be proven by making comparison between the pictures, as depicted in Figure 3.25 and Figure 3.26 (a) to (d). All measurements such as pressure interface distribution, SEMG and subjective evaluation were collected during the on-road test.

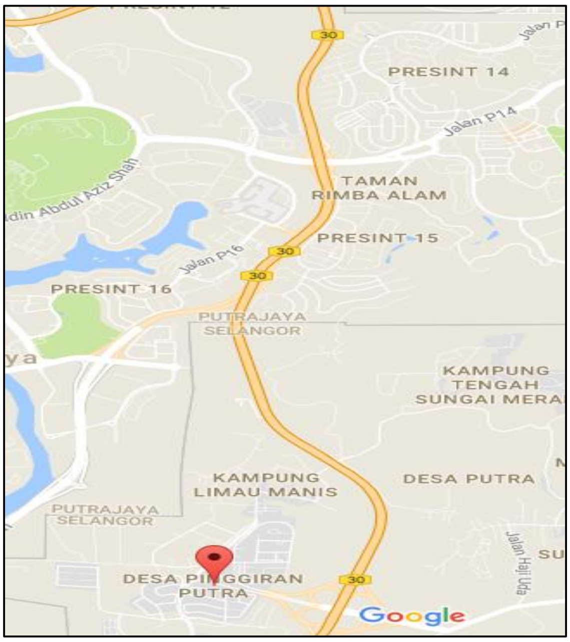


Figure 3.24 Road selection for the on-road test

(a) simulator: straight road without car

(b) actual road: straight road without car

(c) simulator: light curvature road without car

(d) actual road: light curvature road without car

Figure 3.25 Road scene without car

(a) simulator: straight road with car

(b) actual road: straight road with car

(c) simulator: light curvature road with car

(d) actual road: light curvature road with car

Figure 3.26 Road scene with car

3.4.4 Model Development

Figure 3.27 shows the Dependent Variables (DVs) and Independent Variables (IVs) according to the data from the research works to develop the linear model in this study. Based on Figure 3.26, the DVs were indicated with a broken line (subjective measure: discomfort level and pressure felt level), while the IVs were indicated with a continuous line (anthropometric and joint angle: shoulder grip length, fore arm length, buttock popliteal length and knee angle as well as objective measure: mean score from SEMG and pressure distribution measurement). Furthermore, the green color refers to the variables for car controls activities, while red colors refers to the variables for car seat.

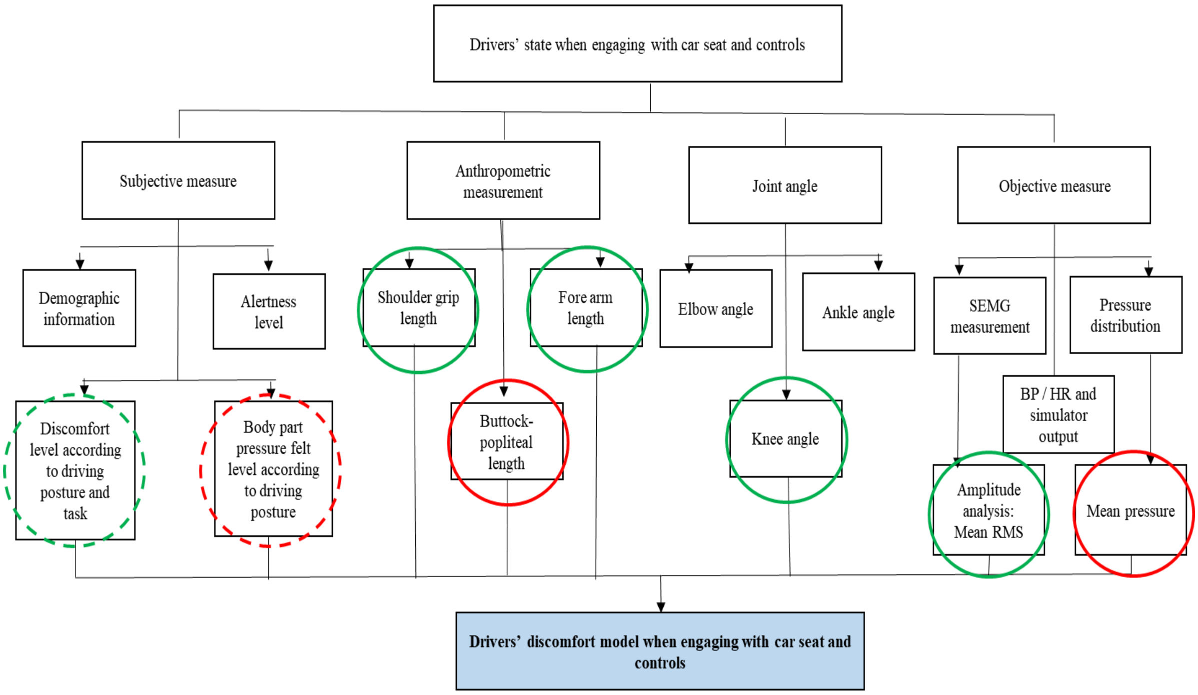


Figure 3.27 The DVs and IVs framework

As stated in Figure 3.27, the final objective of this study is to develop an integrated model to determine driver's discomfort according to different styles of driving conditions. This model can predict the condition of each driver when they are adopting different positions and actions while driving. In fact, linear models have been widely used by past researchers in predicting parameters influenced comfort and discomfort (Yusoff et al. 2016; Openshaw 2011; Daruis 2010; Wang, Le Breton-Gadegbeku & Bouzon 2004; Kolich 2003). Therefore, suitable analysis by using statistical methods is required in order to produce accurate and reliable output. As mentioned by Kolich, Seal, & Taboun (2004), statistical methods are adequate to predict seat comfort perceptions. In general, linear model is the basis for statistical analysis. Linear Regression Analysis is a common method to develop linear models. Based on Rencher & Schaalje (2008), Linear Regression is used to determine relationship between DV and IV in a linear form. Basically, there were several Regression Analyses that have been applied in the existing studies, Simple Regression, Logistic Regression and also Multiple Regression. In this study, Multiple Regression has been used to determine relationship between variables. Chapter V explaines in detail the steps in determining relationship between DV and IV according to driving condition. In this study, all statistical analyses were performed in Statistical Package for Social Science (SPSS) version 10. Based on this method, it can determine the regression co-efficient (K), regression constant (c), multiple correlation coefficient (R), coefficient of determination (R^2) and significance level (p). In general, if R value is more than 0.70, it shows that there was strong correlation between the variables (Piaw 2006). The acceptance or rejection of the null hypothesis (H_0) for this study can also be determined based on the new developed model. The H_o can be rejected if the p value is low ($p < 0.05$). As a result, it can estimate the driver’s condition based on these integrated assessment methods. In other words, a predictor that has a low p-value is likely to be a significant predictor to the model because changes in the predictor's value are connected to changes in the response variable. From the regression result, the Ordinary Least Square (OLS) will be used to develop the linear model equation. The OLS technique is used to determine the linear line that is quite similar to all data points obtained from the experimental works. The linear equation used is demonstrated in Equation (3.3).

$$Y = K_1X_1 + K_nX_n + c \qquad (3.3)$$

Where;

Y = Dependent variable (DV)

K = Regression coefficient as the contributor factor towards independent variable

X = Independent variable (IV)

c = Regression constant

3.4.5 Model Validation

In order to validate the linear model for this study, the assumptions related to classical linear regression model (CLRM) should be performed. These assumptions are required to show that the estimation technique, OLS, could validly be conducted. The Best Linear Unbiased Estimator (BLUE) criteria should be fulfilled in this case. There are five tests that should be performed in the CLRM (Lim & Salleh 2007; Gujarati & Porter 2003):

a. Normality test

The normality test is performed to determine whether the data is normally distributed or not. All data for the CLRM should be normally distributed. As mentioned in the previous paragraph, the normality value is based on the Shapiro-Wilk. If the significance value, p is more than 0.05 ($p>0.05$), the data is normally distributed.

b. Linearity test

Linearity determines the relationship between the IV and DV, whether it is in the linear or non-linear characteristics. In this case, the linearity test can be investigated by referring to correlation coefficient (more than 0.5) based on Pearson correlation and scatter plot methods (visually linear, either positive or negative). According to Cohen (1992), association between variables can be interpreted either very strong, strong, moderate or weak based on the correlation coefficient, r as shown in Table 3.2.

Table 3.2 Correlation coefficient interpretation

Correlation coefficient value (r)	**Association**
-0.3 to +0.3	Weak
-0.5 to -0.3 or 0.3 to 0.5	Moderate
-0.9 to -0.5 or 0.5 to 0.9	Strong
-1.0 to -0.9 or 0.9 to 1.0	Very strong

If the investigation for both methods are within the specification of linearity, the assumption can be made that there is a linear relationship between the DV and the IV.

c. Auto correlation test

Auto correlation test is used to determine whether there is any correlation or relationship between the variables in the regression model. A good regression model should not have any auto correlation between each variable. The Durbin-Watson (DW) statistic is a number that tests the autocorrelation for the model. It refers to the upper Durbin (d_u) and the lower Durbin (d_l) from the DW table at significance level 0.05 (refer to sample size, n and number of IV, k). In this case, the d_l value is 0.66 and d_u is 1.60 (n=11, k=2). If the DW value is in between d_u =1.6 < DW < (4- d_u), there is no auto correlation. Otherwise, if the DW value is in between d_l and d_u as well as (4- d_u) and (4-d_l), Runs test should be performed. The runs test can be used to decide if a data set is from a random process. In this case Asymp. Sig. (2-tailed) should be greater than 0.05, to ensure there is no auto correlation symptoms.

d. Heteroscedasticity test

Heteroscedasticity is useful to check whether there is a difference in the residual variance of the observation to the regression model. A good regression model should not have any heteroscedasticity problem. Glejser technique can examine the heteroscedasticity problem if the significance level is p>0.05, assumption can be made, that there is no heteroscedasticity.

e. Multicollinearity test

Multicollinearity test is used to identify if there is a strong relationship between IVs in the regression model. A good regression model should not have any auto correlation between each variable. Tolerance and Variance Inflation Factor (VIF) are used to determine multicollinearity. Tolerance should be > 0.1 (or VIF <10) for all variables.

In this study, five multiple regression models have been developed. The results for these validation tests can be found from Appendix H. There are:

1. Linear model to predict pressure felt level with integration of the subjective, objective and anthropometric measurement

2. Linear model to predict discomfort level for steering wheel task with integration of the subjective, objective and anthropometric measurement

3. Linear model to predict discomfort level for gear task with integration of the subjective, objective and anthropometric measurement

4. Linear model to predict discomfort level for pedal task based on TR muscle with integration of the subjective, objective and joint angle measurement

5. Linear model to predict discomfort level for pedal task based on GR muscle with integration of the subjective, objective and joint angle measurement

3.4.6 Discomfort Index

In order to determine the discomfort level while engaging with the car seat and car controls, the Discomfort Index (DI) has been developed. The DI is used to be the reference point to evaluate the driver's discomfort level with regards to the pressure distribution and muscle activity measurement based on the car seat and car controls activities. Table 3.3 shows the DI for the drivers when engaging with the car seat as well as the steering wheel, gear and accelerator pedal.

Table 3.3 Discomfort Index

Discomfort Index	**Discomfort Level**
≤ 2.0	Very comfortable
2.1-4.0	Comfortable
4.1-6.0	Neutral
6.1-8.0	Uncomfortable
8.1-10.0	Very uncomfortable

The DI was developed by referring to five regression models as described in Chapter V. In addition, the scale for each discomfort index was developed based on the VAS value, which has been used in the subjective assessment form. Table 3.4 shows five regression models that have been elaborated in Chapter V.

Table 3.4 Five regression models

Car component	Equation	Dependent variable (Y)	First independent variable	Second independent variable
Car seat	$Y_1 = 31.518x_1 - 0.270x_2 + 12.936$.	pressure felt level at the buttock in position A	Buttock's pressure measurement at position A	buttock-popliteal length
Steering wheel	$Y_2 = 0.073x_3 + 0.098x_4 + 0.384$	discomfort level based on muscle activity in position B	muscle activity for 45 turning degree action	arm length
Manual gear	$Y_3 = 0.09x_5 - 0.191x_6 + 15.756$	discomfort level at position B	muscle activity for G1 action	shoulder grip length
Car pedal (TR)	$Y_4 = 0.229x_7 + 0.167x_8 -10.914$	discomfort level at position A	muscle activity for releasing action	knee angle at position A
Car pedal (GM)	$Y_5 = 0.126x_9 + 0.123x_{10} - 10.491$	discomfort level at position B	muscle activity for full-pressing action	knee angle at position B

3.5 SUMMARY OF CHAPTER III

This chapter explained the methodology that has been used in this study. In this chapter, there were five main sections, starting from flow chart in Section 3.2. The framework of methodology for this thesis was illustrated in Figure 3.1. Based on this figure, mixed method assessment are used to determine driver's condition based on different driving condition, comprising of subjective and objective assessment. The VAS was the subjective assessment method used for determining the driver's condition perception while interacting with the car seat and car controls. Meanwhile, the two objective assessment methods used in the study were pressure interface and SEMG equipment. The pressure mat was used to compute the pressure distribution of the car seat, consisting of the seat pan and the back rest. The SEMG was used to compute muscle activity for DA, GM and TA. Having done that, the data were analysed by using Temporal and Amplitude Analysis based on Isometric Maximal Voluntary Contraction. The SEMG analysis was in accordance to the SENIAM recommendation. There were two different driving positions in this study, the closest seated position to the car controls (Position A) and the further seated position from the car controls (Position B). In addition, the body measurement, consisting of anthropometric dimension and the joint angle were measured in this study.

In terms of driving action, it is depending on the car control operation. In this study, there were three main controls, steering wheel, gear and accelerator pedal. Steering wheel and gear control required upper body part, particularly shoulder to operate these controls, while pedal control required lower body part, particularly lower leg to operate this control. Suitable statistical analysis is performed on the data obtained. The analysis will be explained in Chapter IV. Sample size and model validation will be carried out by using suitable tool and test that will be described in Chapter V.

CHAPTER IV

RESULTS AND ANALYSIS

4.1 INTRODUCTION

Chapter IV presents findings from the experiment assessments mentioned in previous chapters. Section 4.2 provides a description on the subjective measurement analysis, particularly on test subjects and their perceptions regarding their condition during the driving task and the trend of cardiovascular parameters before and after the experiments. Section 4.3 explains the results on pressure distribution assessment, while Section 4.4 describes the outputs from the SEMG assessment. The next section, Section 4.5 provides the analysis on simulator output. Detailed analysis for each assessment was carried out using SPSS Version 21 (IBM Corporation, New York, USA) at a significance level of $\alpha=0.05$. The final section that is Section 4.6; presents the summary of all the assessment findings.

4.2 SUBJECTIVE MEASURES ANALYSIS

Subjective measurement was conducted in order to gain feedback directly from the subjects regarding their condition when performing actions in the experiment. As described in Chapter III, the subjective assessment in the form of a questionnaire has four main sections. Section 4.2.1 presents the information collected from Section A of the questionnaire regarding subjects' demographic information. Then, Section 4.2.2 describes the findings from Section B regarding the discomfort level according to driving position and driving task. Meanwhile, Section 4.2.3 explains the results on seat and back rest pressure according to driving position. Statistical analysis based on this assessment was performed in Section 4.2.4. Section 4.2.5 and Section 4.2.6 explain the results about the driver’s condition based on each driving position, according to the Alertness Scale and cardiovascular parameter in the form of heart rate (HR) and blood pressure (BP). Section 4.2.7 summarizes the main results from this subjective assessment analysis. Appendix E shows the subjective assessment form for this study.

4.2.1 Subjects’ Demographic Information

The subjects’ demographic information was collected in Section A of the subjective assessment form, as shown in Table 4.1. Demographic data such as age, gender, weight, height, caffeine and food intake, sleep duration and driving experience were gathered in order to clarify the subjects’ background before the experiment. All subjects took light breakfast and did not drink any caffeine beverage before the experiment.

Table 4.1 Demographic information of the subjects

Subject, N	**Age (year) (mean$\pm$SD)**	**Weight (kg) (mean$\pm$SD)**	**Height (kg) (mean$\pm$SD)**	**Driving experience (year)**			
				<1	**1-3**	**3-5**	**>5**
11	28.09 (4.83)	56.36 (7.16)	161.09 (6.38)	-	-	5	6

In addition, the anthropometric data of eleven subjects were collected in this study. As mentioned in Chapter III, three parameters were measured by using an anthropometer in this study. This parameters were selected based on the function of each parameter in the past studies (Goonetilleke & Feizhou 2001; Porter & Gyi 2015; Shen & Parsons 1997). Table 4.2 shows the results based on this measurement.

Table 4.2 Anthropometric data of the subjects

Parameter	**Sample n=11 (mean$\pm$SD)**
Buttock-popliteal length (cm)	47.36 $\pm$ 1.75
Fore arm-hand length (cm)	43.18 $\pm$ 1.52
Shoulder grip length (cm)	64.03 $\pm$ 1.84

4.2.2 Discomfort Level according to Driving Position and Driving Task

The main aim of this section is to identify the body part discomfort level according to driving position and task. This section provides answers to the first objective in this study. As mentioned earlier, there are three subsections for this section which are the steering wheel control (B1), gear control (B2) and accelerator pedal (B3). In these subsections, there are two questions asked to the subjects. The first question is regarding the discomfort level based on driving position for each control, while the second question is regarding the muscle's discomfort level based on driving task and position. The measurement used in this study is in a continuous scale.

a. Steering wheel control

Figure 4.1 shows the result for the first question from subsection B1.1 (refer to Appendix E for more details). Based on Figure 4.1, position A showed the lowest mean score of discomfort level for the steering wheel action, 5.64 compared to position B at 7.64. This indicates that the subject feel more discomfort while operating the steering wheel in position B. The result obtained is in line with the preliminary study that have been explained in Chapter III (Section 3.3.2). This is in agreement with previous work conducted by Pandis, Prinold & Bull (2015) that mentioned, far distant position from the steering wheel resulted to higher muscle force. In addition, far distant position may also affects the driver's ability to control the car because the the driver's hand was in tranverse position between shoulder and steering wheel, with the mean elbow angle 148.89^0 (SD=6.00). In fact, a good position while in seated interface is when the elbow is bent to 90^0 with regards to the vertical upper arm and horizontal lower arm, which is refer to Position A (Sanders & McCormick, 1993; Walton & Thomas, 2005).

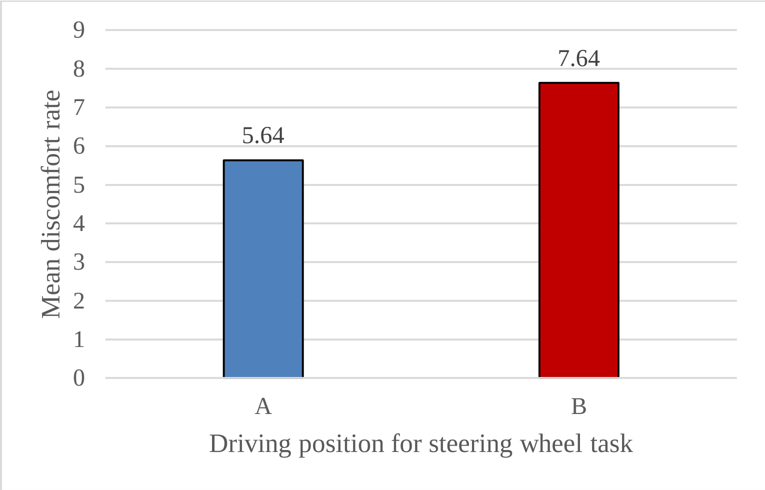


Figure 4.1 Discomfort level for steering wheel control

The findings for the second question in Subsection B1.2 are presented in Figure 4.2 to Figure 4.5. It shows the mean discomfort level based on specific task of the steering wheel for two muscles, DL and DR. Figures 4.2 and 4.3 show the findings for DL muscle based on five actions, L10, L45, R10, R45 and mid. According to Figure 4.2, based on driving action for DL muscle, R45 turning action depicts the highest discomfort level from pre to post task: from 5.99 (pre activity) to 6.56 (post activity). The lowest discomfort level is shown at L10 turning action for both periods, 2.77 (pre activity) and 3.03 (post activity). This is in agreement with the theory that explained, the combination of muscles acting during motion is dependent on biomechanical factorsto muscle size, muscle length, joint angle, and movement force. It was found that muscle function depends strongly on both steering rotation and direction (Basmajian & De Luca 1985; Neumann 2002; Schenkman & Rugo de Cartava 1987; Smith 1995).

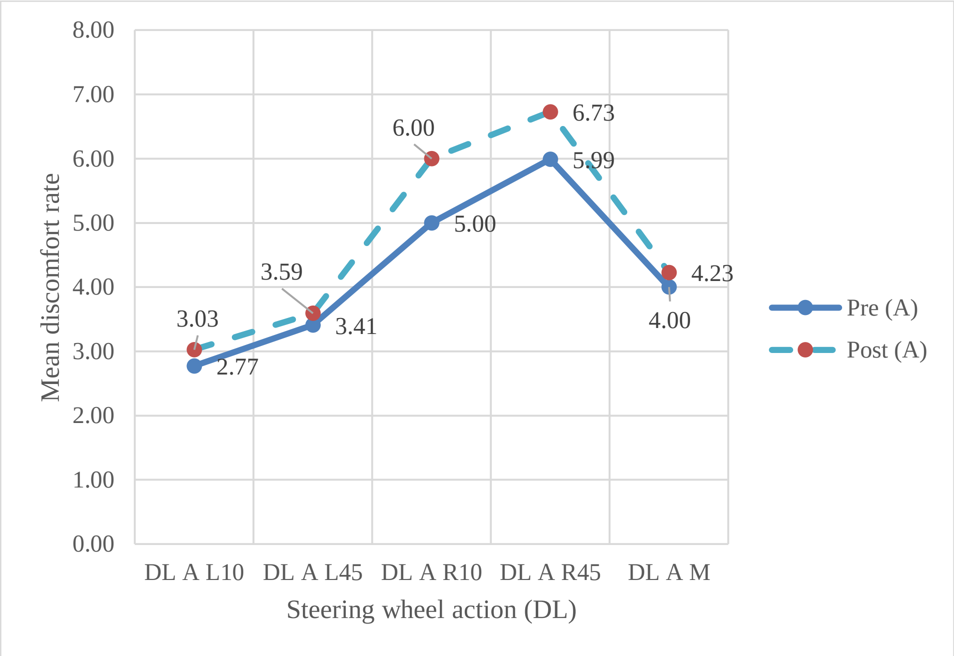


Figure 4.2 Discomfort level based on steering wheel task for position A at DL

Similar trend can be seen at Figure 4.3 based on discomfort level at position B. R45 action depicts the highest discomfort level from pre to post task: from 7.04 (pre activity) to 7.50 (post activity). The lowest discomfort level is shown at L10 turning for both periods, 4.32 (pre activity) and 4.63 (post activity).

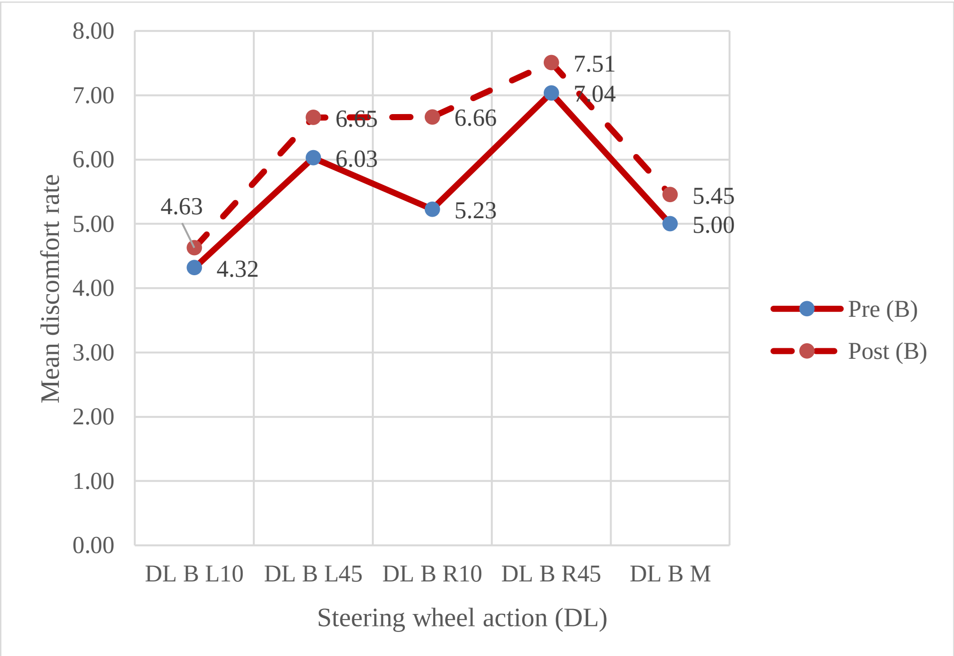


Figure 4.3 Discomfort level based on steering wheel task for position B at DL

Figures 4.4 and 4.5 show the findings for DR muscle based on five actions, L10, L45, R10, R45 and mid. According to Figure 4.4, based on driving action for DR muscle, L45 turning action shows the highest discomfort level from pre to post task: from 6.11 (pre activity) to 6.72 (post activity). The lowest discomfort level is shown at R10 turning action for both periods, 2.44 (pre activity) and 2.76 (post activity).

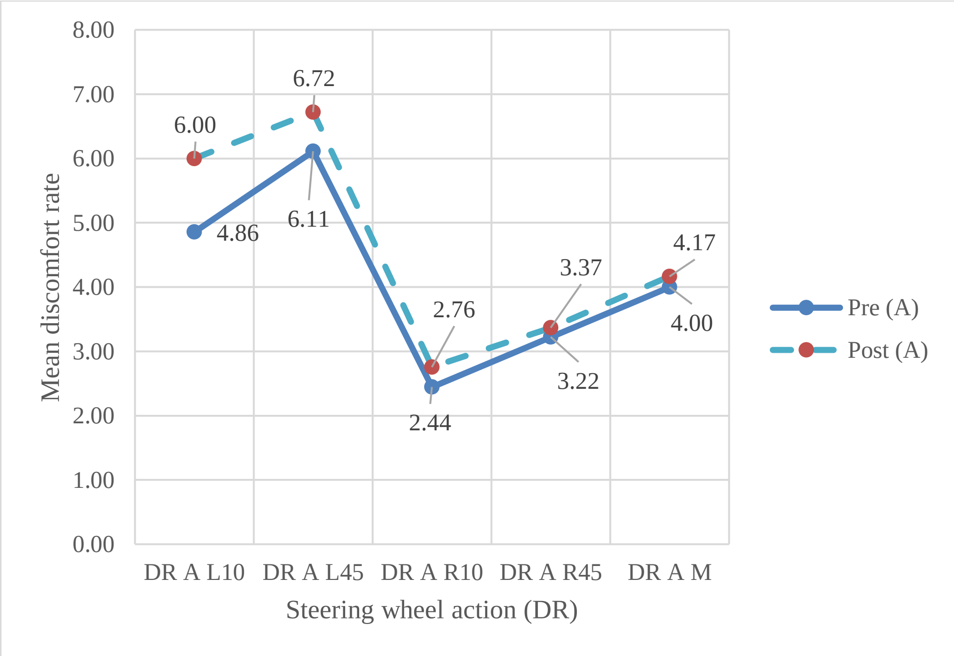


Figure 4.4 Discomfort level based on steering wheel task for position A at DR

Similar trend can also be seen at Figure 4.5 based on discomfort level at position B. L45 action shows the highest discomfort level from pre to post task: from 6.83 (pre activity) to 8.00 (post activity). The lowest discomfort level is shown at R10 turning for both periods, 4.17 (pre activity) and 4.50 (post activity).

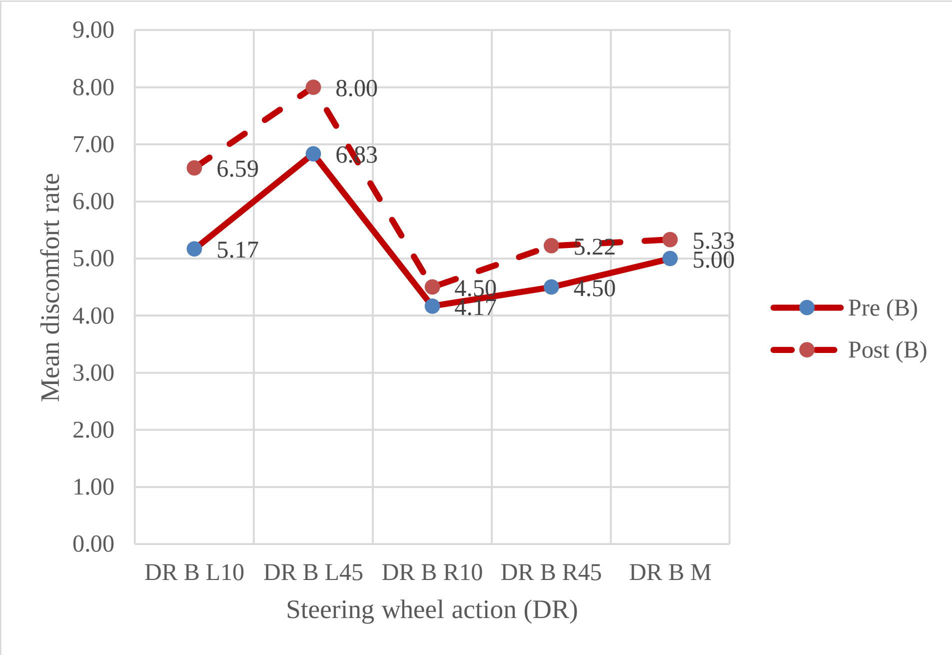


Figure 4.5 Discomfort level based on steering wheel task for position B at DR

b. Gear control

Figure 4.6 depicts the finding for the first question from subsection B2.1 (refer to Appendix E for more details). Referring to Figure 4.6, position A shows the lowest mean score of discomfort level for the gear action, 5.23 compared to position B at 6.59. It indicates that the subject feels more discomfort while controlling the manual gear in position B. The result obtained is in line with the preliminary study that have been explained in Chapter III (Section 3.3.2). In addition, far distant position may also affects the driver's ability to control the car because the the driver's hand was in tranverse position between shoulder and gear, with the mean elbow angle approximately 150^0. This is in agreement with previous work conducted by Vilimek et al. (2011) that recommended to have elbow angle below 100^0 when controlling the gear shift, which referred to position A.

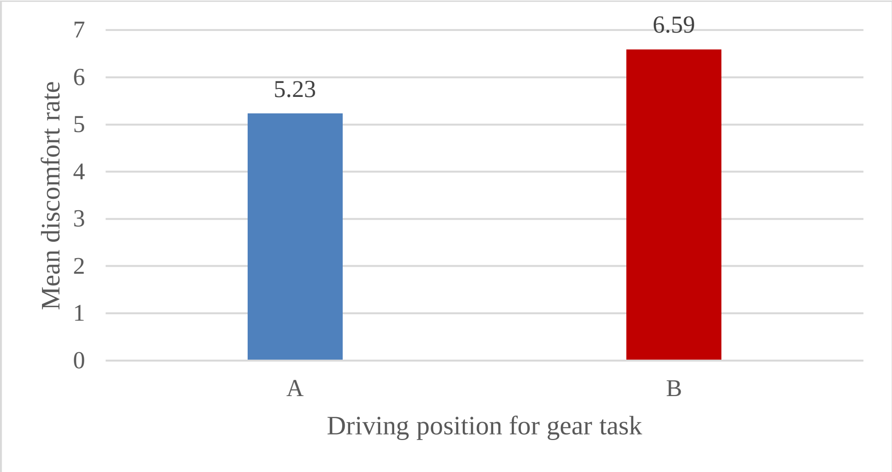


Figure 4.6 Discomfort level for gear control

The findings for the second question in Subsection B.2.2 from Appendix E are shown in Figure 4.7 and Figure 4.8. Figure 4.7 and Figure 4.8 show the mean discomfort level based on two actions of the gear task for DL muscle. According to Figure 4.7, G1 action shows the highest discomfort level from pre to post task: from 5.59 (pre activity) to 6.18 (post activity). Meanwhile, the lowest discomfort level is shown at GN action for both periods, 4.41 (pre activity) and 5.55 (post activity). It means that pushing task (from GN to G1 action) provides more discomfort to the driver compared to pulling task. This is in agreement with the finding from previous work carried out by Vilimek et al. (2011).

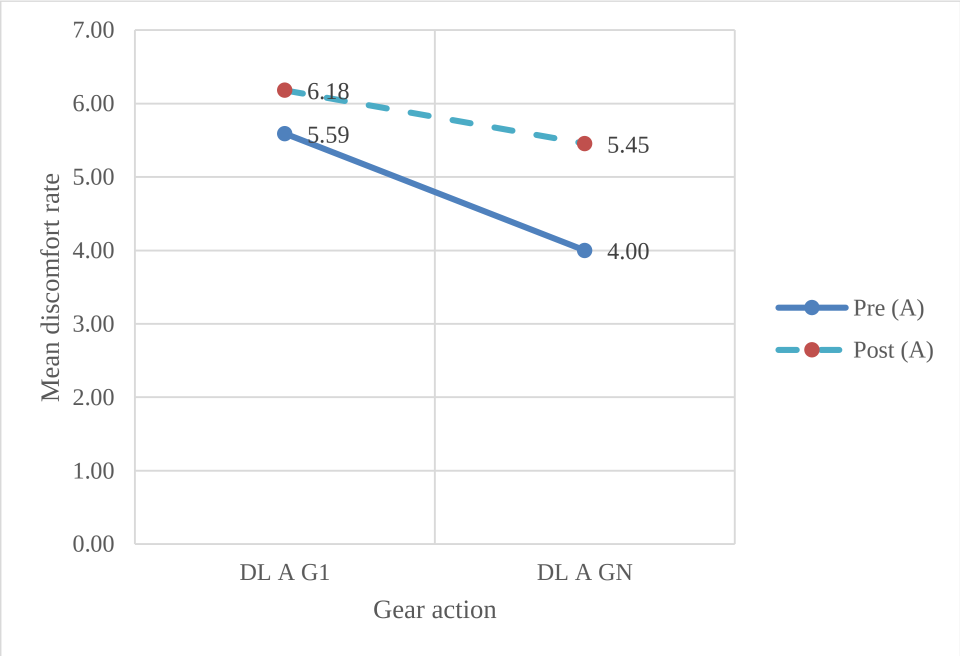


Figure 4.7 Discomfort level based on gear task for position A

Figure 4.8 shows similar trend for gear task based on discomfort level at position B. G1 action shows the highest discomfort level from pre to post task: from 6.76 (pre activity) to 7.26 (post activity). The lowest discomfort level is shown at GN for both periods, 5.00 (pre activity) and 6.00 (post activity).

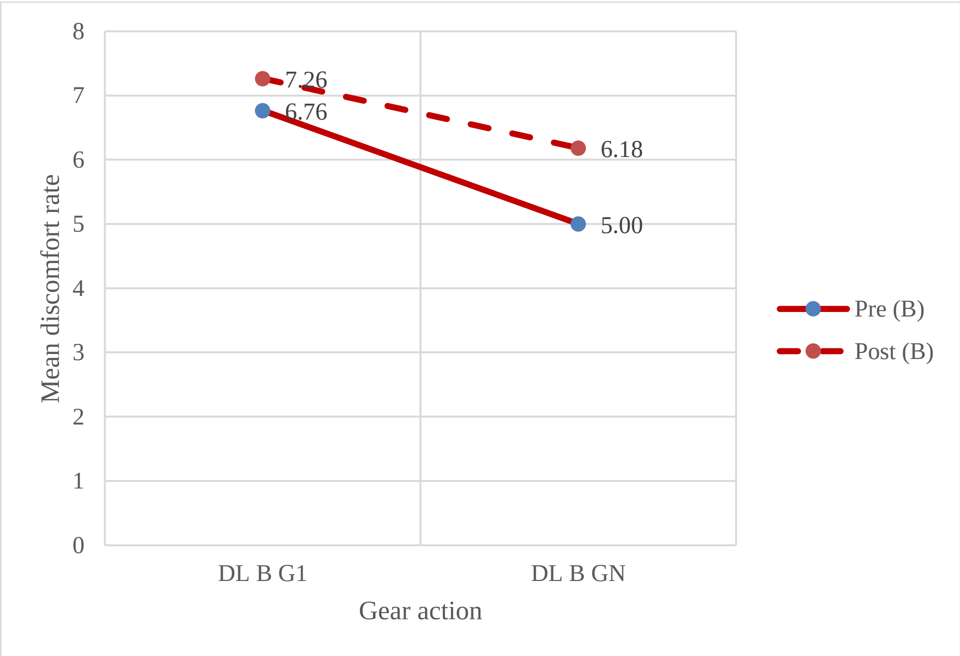


Figure 4.8 Discomfort level based on gear task for position B

c. Accelerator pedal

The output of the discomfort level for accelerator pedal is illustrated in Figure 4.9. This output is based on the first question from subsection B3.1 (refer to Appendix E for more details). According to Figure 4.9, position A shows the highest mean score of discomfort level for accelerator pedal control, 8.68 compared to position B at 5.55. It indicates that the subject feels more discomfort while operating the accelerator pedal in position A. In this study, the mean knee angle is 101.77^0 (SD=4.01) for position A and 135.09^0 (SD=4.01) for position B. It is possibly due to the lower leg produces more discomfort when driving the car, near to the pedal, which is refers to position A. The result obtained is in line with the preliminary study that have been explained in Chapter III (Section 3.3.2). In fact, Daruis (2010) revealed that Malaysian drivers prefer to drive the car with knee angle in between 109^0 to 121^0. It can be concluded that when the driver sits too close to the car controls (position A), considerable muscular discomfort is caused to the lower leg, particularly in releasing position. This is in agreement with the findings from previous studies, such as Tanaka et al. (2009), Wang et al. (2004), and Yusoff (2017).

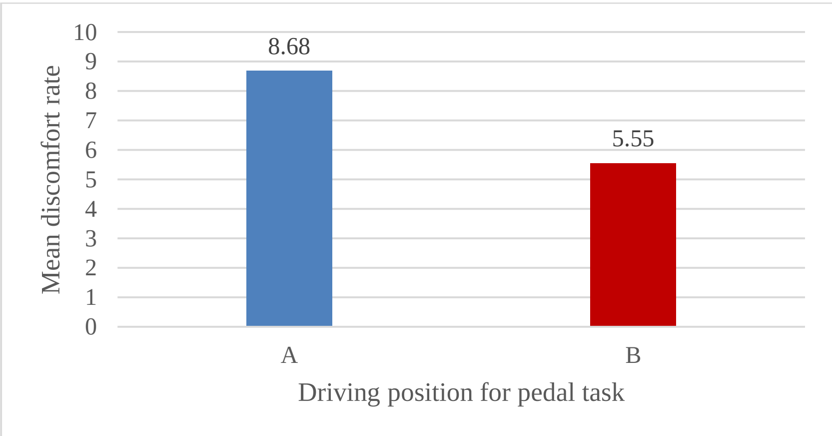


Figure 4.9 Discomfort level for accelerator pedal control

As mentioned in Chapter III, there are two muscles involved in the accelerator pedal actions, GR and TR. There are three main actions that were carried out for accelerator pedal, half press (HP), release (R) and full press (FP). Figure 4.10 and Figure 4.11 depict the results for the second question in Subsection B3.2 based on Position A and Position B for the GR muscle. Referring to Figure 4.10, FP action depicts the highest discomfort level for both periods: from 5.70 (pre activity) to 6.19 (post activity). The lowest discomfort level is shown at R action for both periods: from 5.08 (pre activity) to 5.41 (post activity). As mentioned by Tanaka et al. (2009), the effects when the foot touches the accelerator pedal and the car floor will cause discomfort to the driver while driving. In this case, the foot produces more discomfort when performing R action because restricted angle range of ankle joint in position A. In this study, the mean ankle angle is 104^0 (SD=4.00) for position A and 114^0 (SD=9.00) for position B.

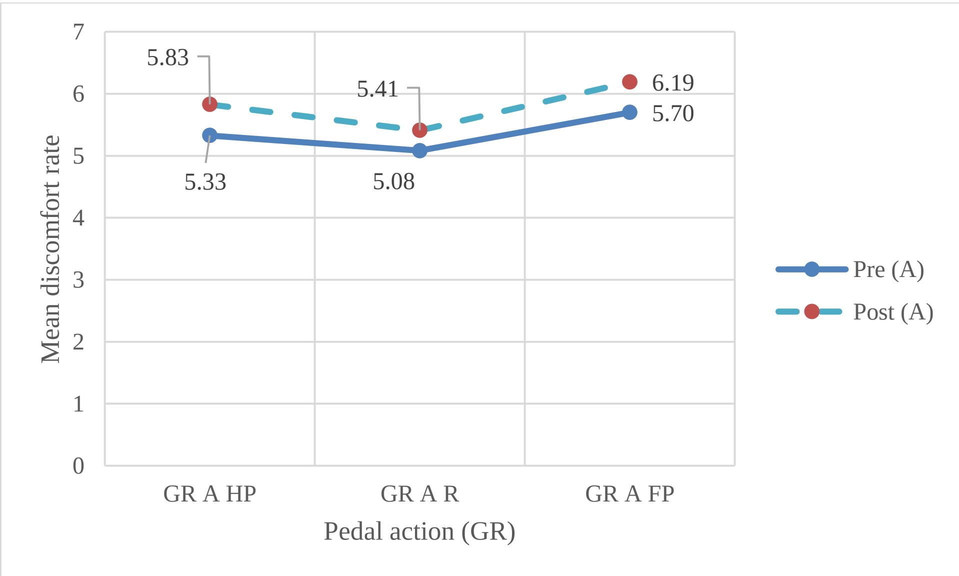


Figure 4.10 Discomfort level based on accelerator pedal task for position A at GR

Figure 4.11 depicts similar trend for pedal task based on discomfort level at position B. FP action shows the highest discomfort level from pre to post task: from 7.05 (pre activity) to 7.64 (post activity). The lowest discomfort level is shown at R action for both periods, 4.82 (pre activity) and 5.82 (post activity).

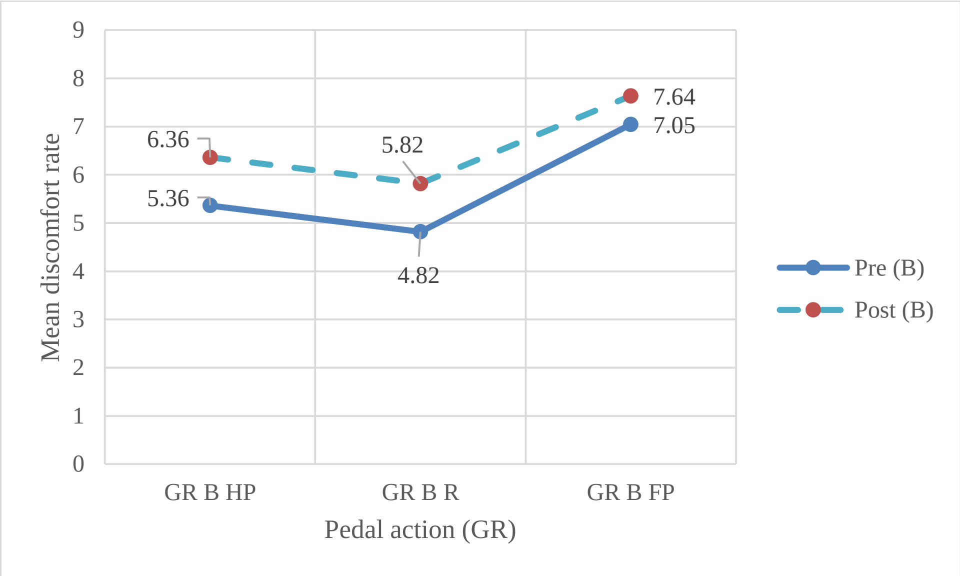


Figure 4.11 Discomfort level based on accelerator pedal task for position B at GR

Figure 4.12 to Figure 4.13 illustrate the results for the second question in Subsection B3.2 based on Position A and Position B for the TR muscle. Referring to Figure 4.10, R action shows the highest discomfort level for both periods: from 8.40 (pre activity) 8.65 (post activity). The lowest discomfort level is indicated at HP action for both periods: from 4.23 (pre activity) to 4.73 (post activity). This is in agreement with the findings carried out by Yusoff et al. (2016) that revealed pressing action produces higher muscle contraction compared to R action.

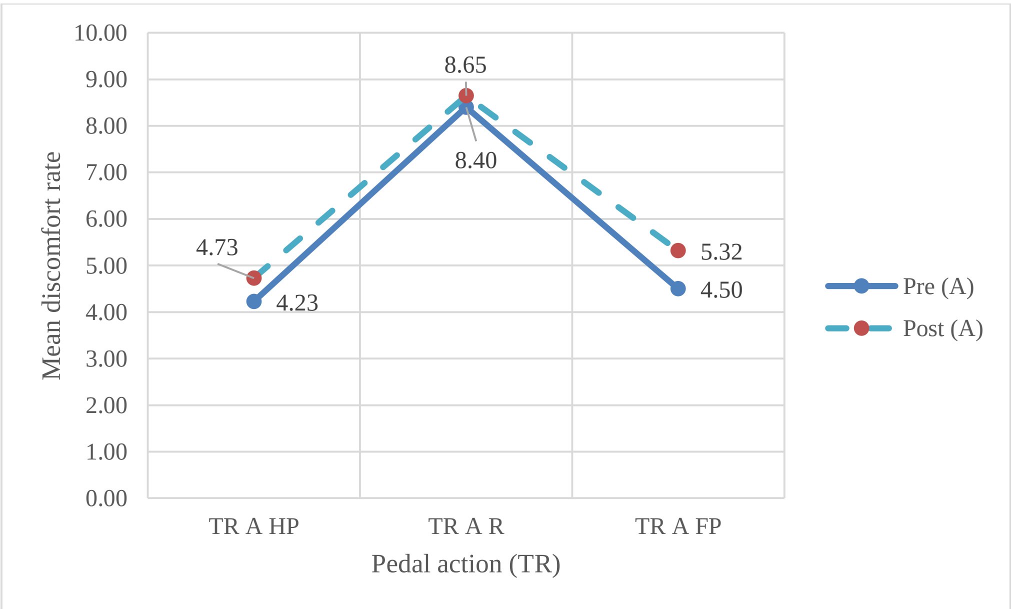


Figure 4.12 Discomfort level based on accelerator pedal task for position A at TR

Figure 4.13 depicts similar trend for pedal task based on discomfort level at position B. R action shows the highest discomfort level from pre to post task: from 5.40 (pre activity) to 6.36 (post activity). The lowest discomfort level is shown at HP action for both periods, 4.77 (pre activity) and 5.55 (post activity).

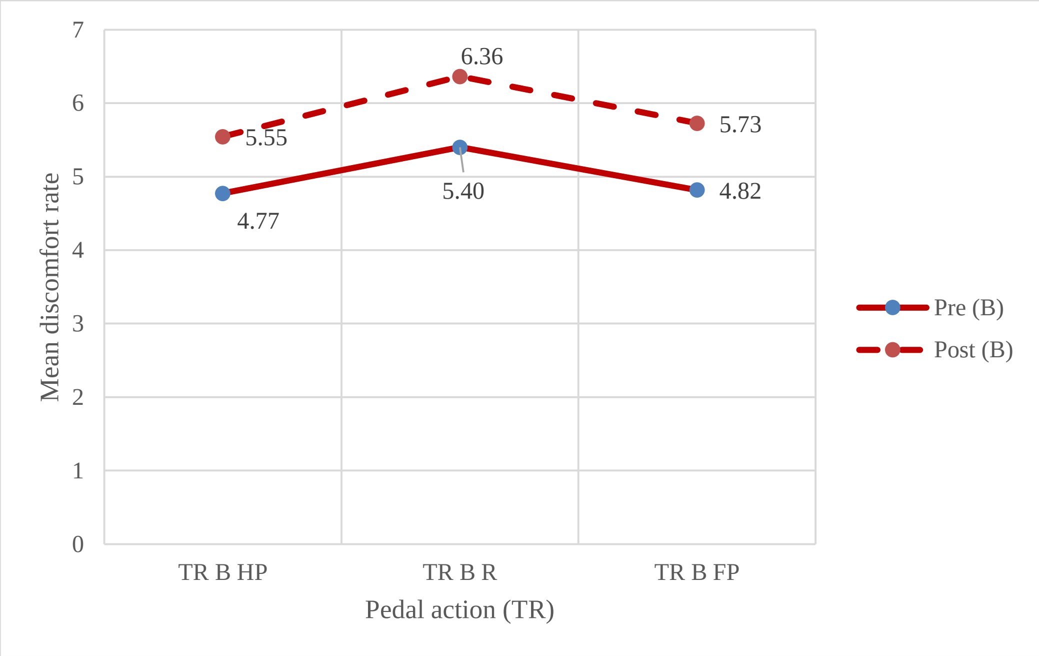


Figure 4.13 Discomfort level based on accelerator pedal task for position B at TR

4.2.3 Seat and Back Rest Pressure according to Driving Position

The previous chapter presented the perception on discomfort from the subjective assessment based on driving task and position. In this section, the perception on pressure felt is gathered and explained. As stated in Section C in the subjective assessment (refer to Appendix E), the main aim of this section is to identify the perception on pressure distribution level when sitting on the car seat based on driving position. As mentioned in Chapter III, there are two parts of the car seats that were evaluated by the subjective assessment: seat pan and back rest part. In addition, each car seat parts has two segments which are referred to as body parts. In this case, body parts for the seat are buttock (B) and thigh (T). Meanwhile, body parts for the back rest are upper back (UB) and lower back (LB). Furthermore, in this section, there are two questions that were asked to the subjects. The first question is regarding the pressure felt level based on driving position, while the second question is more specific and focused on the seat and back rest part. The measurement used in this study is in ratio form.

Figure 4.14 illustrates the general pressure felt based on driving position. It demonstrated that position A shows the highest pressure felt by the subject compared to position B, 6.52 and 5 respectively. This means, the closer the driver is to the steering wheel and other controls (eg: gear and pedal), the more pressure is felt by the driver. It possibly due to the pressure felt is greater at the buttock when sitting in the closer position to the car controls. This is in agreement with the findings from other reseachers, which mentioned that pressure distribution can be clearly seen at the buttock area, and significantly affects discomfort (de Looze et al., 2003; Yun, Donges & Freivalds 1992).

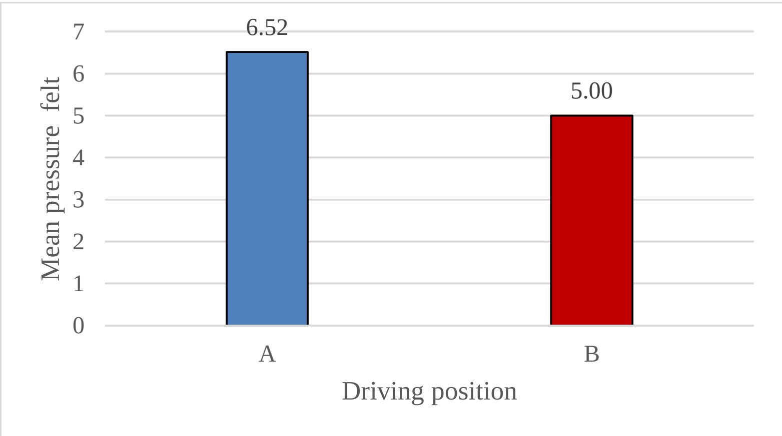


Figure 4.14 Pressure felt based on position

Figure 4.15 and Figure 4.16 depict the results for the second question in Subsection C1.2 for the seat part. According to Figure 4.15, position A shows the highest pressure felt rate compared to position B at the buttock for pre and post activity with 6.52 and 5.00 (pre activity) as well as 7.37 and 5.41 (post activity), respectively.

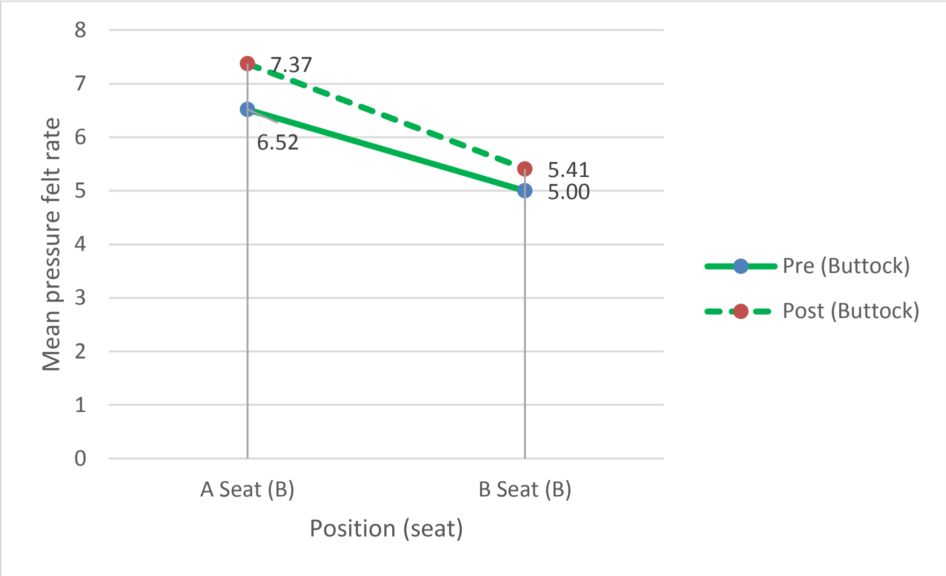


Figure 4.15 Seat pressure felt level based on position at the buttock

Whereas in Figure 4.16, position B shows the highest pressure felt rate at the thigh compared to position A with 5.45 (position B) and 2.00 (position A) for pre activity as well as 5.82 (position B) and 2.36 (position A) for post activity. This situation is possibly due to the buttock's width and knee as well as the knee angle. In general, the closer the driver is to the car control, the driver's buttock is more compressed to the car seat, compared to the thigh. Furthermore, with regards to the knee angle, the smaller the knee angle when sitting on the car seat, the less pressure will be felt at the thigh. In this case, the thigh of the driver does not really touched on the car seat. The next section explains this possibility based on the objective assessment by using the pressure distribution map.

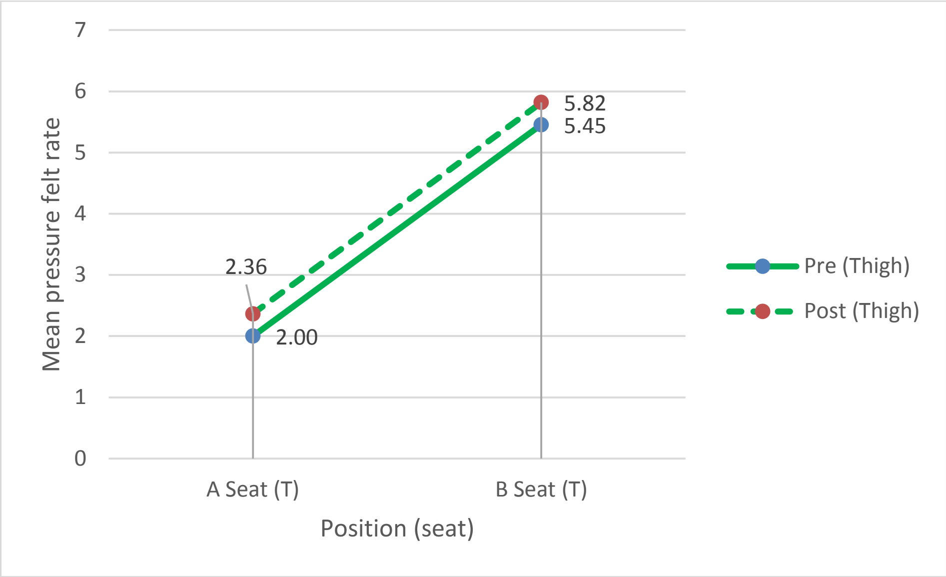


Figure 4.16 Seat pressure felt level based on position at the thigh

Figure 4.17 to Figure 4.19 illustrate the findings for the second question in Subsection C1.2 for the back rest part. Referring to Figure 4.17, position A and B for pre activity, it shows a decrement pattern at the upper back, 2.36 (position A) to 2.00 (position B), respectively. However, there was an increment for post activity from position A to B, 2.45 (position A) to 3.00 (position B), respectively. A large gap between pre and post activities at position A and position B possibly occurred due to the test subjects tend to lean against to the backrest. As a result, it will adds the weight of the upper back to the force exerted by the back muscles and supported by the lower back. Hence, the body pressure will be more concentrate on the upper back to support the posture while handling the car controls.

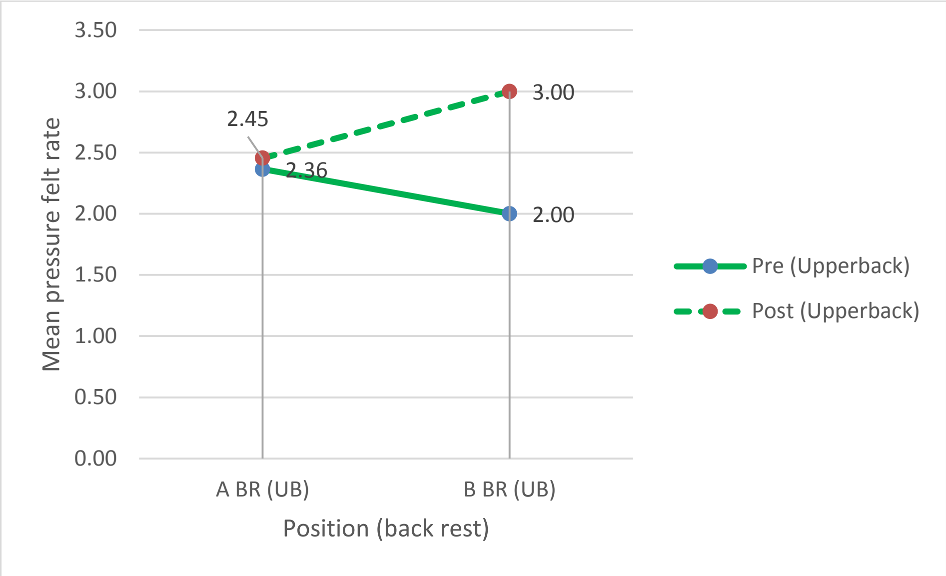


Figure 4.17 Back rest pressure felt level based on position at the upper back

Meanwhile in Figure 4.18, both positions did not show any increment pattern, either from position to position or from pre to post activity with pressure felt level at 2.00 (pre activity) and 3.00 (post activity). The next section explains this possibility based on the objective assessment by using pressure distribution map.

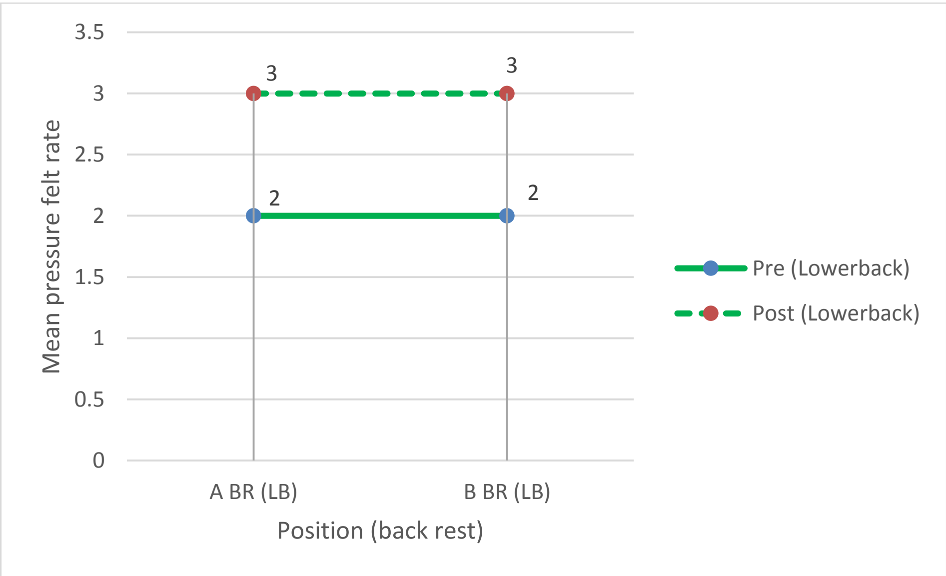


Figure 4.18 Back rest pressure felt level based on position at the lower back

4.2.4 Thorough Analysis for Subjective Assessment using Statistical Analysis

This section explains a thorough analysis carried out to compare two or more variables, based on the subjective assessment parameters, as depicted in Table 4.3. Appendix I depicts detailed analysis for this section by using a suitable statistical analysis.

Table 4.3 Thorough analysis for subjective assessment

Car component & Section in subjective assessment	**Analysis**	**IV**	**DV**	**Significant condition**
Steering wheel (Section B1)	a) Actions	Three different actions (L10, L45 and R45)	Discomfort level for three actions (L10, L45 and R45)	Yes. Refer to Appendix I (Table 1).
	b) Positions	Two different positions	Discomfort level for these two positions	Yes. Refer to Appendix I (Table 2).
	c) Pre and post activities	Two different time periods (pre and post)	Discomfort level for these two periods	Yes. Refer to Appendix I (Table 3).
Gear (Section B2)	d) Actions	Two different actions (G1 and GN)	Discomfort level for these two actions	Yes. Refer to Appendix I (Table 4).
	e) Positions	Two different positions	Discomfort level for these two positions	Yes. Refer to Appendix I (Table 5).
	f) Pre and post activities	Two different time periods	Discomfort level for these two periods	Yes. Refer to Appendix I (Table 6).
Pedal (Section B3)	g) Actions	Three different actions (HP, R and FP)	Discomfort level for these three actions	TR: Yes, except for FP-HP at position A and B for pre activity and FP-HP at position B for post activity GR: Yes. Refer to Appendix I (Table 7).

To be continued…

…continuation

	h) Positions	Two different positions	Discomfort level for these two positions	TR: Yes. GR: Yes. Refer to Appendix I (Table 8).
	i) Pre and post activities	Two different time periods (pre and post)	Discomfort level for these two periods.	Yes. Refer to Appendix I (Table 9).
Car seat (Section C)	j) Positions	Two different positions	Pressure felt level for these two positions	Seat pan: Yes Back rest: No. Refer to Appendix I (Table 10).
	k) Pre and post activities	Two different time periods (pre and post)	Pressure felt level for these two periods.	Seat pan: Yes Back rest: No. Refer to Appendix I (Table 11).

4.2.5 Driver's Condition according to Driving Position

As mentioned in Chapter III, the subjective assessment also evaluated the alertness of the subject by using KSS scale. It shows the subject's performance based on different driving position. The Scale 1 to 4 indicate the subject is under alert condition, scale 5 is in between sleepy or alert while scale 6 to 9 show the subject is under sleepy condition. Figure 4.19 and Figure 4.20 show the alertness pattern for three time periods: before, during and after driving task for position A and B based on eleven subjects. Based on both figures, the majority of the test subjects feel alert at scale 4 for both positions at the beginning of the driving activity. Then, during driving, most of the test subjects evaluated their alertness at scale 6, which means the alertness level was reduced. After driving, majority of them rated their alertness at level 6 and 7, which indicated they feel sleepier at the end of the driving activity for both positions. In terms of difference in driving position, it was found that there is no obvious difference between each position. Hence, based on this study, it can stated that different positions did not show different alertness level. This is believed to occur due to both driving positions parameters in this study were determined at the extreme closer and extreme far away from the car controls. As mentioned in Chapter III (Section 3.2.3), only these two positions were chosen in this study because the highest discomfort rate was obtained in the preliminary study. Therefore, it can be concluded that these positions had a significant effect on discomfort level (as described in the ealier sections), but there is no significant effect on alertness level and driving performance. However, as obtained from the study, there is a significant difference on alertness level between before and after driving for 15 minutes. It shows that driving duration had a significant effect on alertness level. The results obtained agreed with previous work carried out by past researchers (Baldauf, Burgard & Wittmann 2009; Belz 2000; El Falou et al. 2003; Otmani et al., 2005; Trutschel et al. 2011; Wylie, Shultz & Miller 1996).

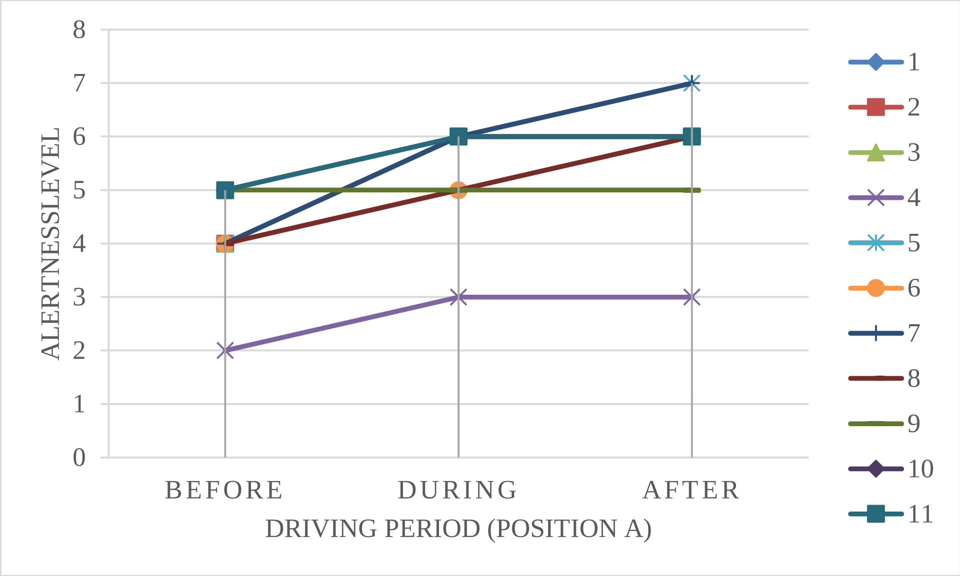


Figure 4.19 Alertness level based on driving period for position A

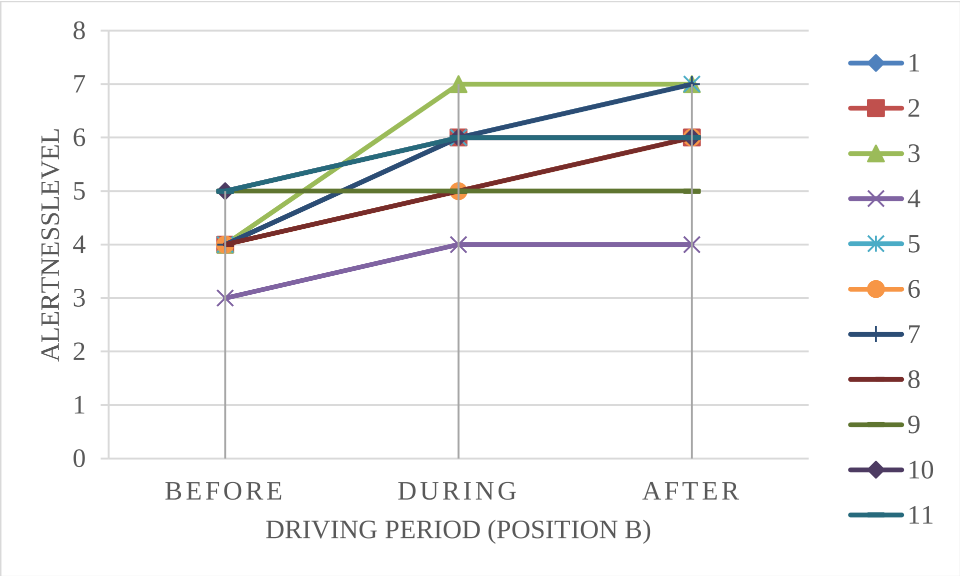


Figure 4.20 Alertness level based on driving period for position B

4.2.6 Cardiovascular Pattern before and after Driving

As stated in Chapter III, the HR and BP of the test subjects were taken to determine the condition of the driver before and after driving. Table 4.3 tabulates the HR and BP for these subjects. Referring to Table 4.4, only two subjects, who are subjects 1 and 6, show an increment of HR before and after driving, with 70 to 78 and 90 to 103, respectively. Meanwhile, for BP, roughly, there is an increment of BP for subjects 1, 2, and 6 before and after driving, with 111/72 to 118/76, 113/69 to 119/70 and 109/83 to 129/87, respectively. The variation in cardiovascular pattern might be possibly due to the variation of stress felt by the test subjects. Besides that, variations in the surrounding environment in the simulated condition such as the the room temperature, road marks input and the road surrounding also influence human response while driving. It is also proved by previous studies carried out by many reseachers (Hallvig et al. 2013; Heinze etal. 2013; Jagannath & Balasubramanian 2004; Reimer et al. 2011; Zhao et al. 2012).

Table 4.4 HR and BP of subjects for two periods of driving

Subject	**HR**		**BP**	
	Before	**After**	**Before**	**After**
1	70	78	111/72	118/76
2	77	73	113/69	119/70
3	64	60	107/71	107/66
4	78	73	127/82	119/70
5	84	75	109/63	97/56
6	90	103	109/83	129/87
7	88	76	117/75	109/68
8	77	76	113/69	92/63
9	70	61	113/69	103/67
10	76	76	113/69	100/70
11	75	70	118/76	111/70

4.2.7 Summary of the Subjective Assessment

This section presents the findings for the subjective assessment. As mentioned earlier, this section responds to the first objective as well as the first and second research questions in this study, which identified driver's discomfort and performance while engaging with the car seat and car controls based on subjective and performance assessment. There are three main sections in the subjective assessment form which evaluated discomfort, pressure felt and alertness level by the test subjects. With respect to the discomfort level, based on the findings as shown in Figure 4.1 to Figure 4.13, the discomfort level perception relies on the steering wheel (from Figure 4.1 to Figure 4.5), manual gear transmission (from Figure 4.6 to Figure 4.8) and accelerator pedal position and action (from Figure 4.9 to Figure 4.13).

With regards to the steering wheel control, position B shows the highest mean score of discomfort level. Whereas in terms of action, R45 turning depicted the highest discomfort level for DL muscle, while L10 turning showed the lowest discomfort level. In contrast, the highest discomfort level for DR muscle was recorded at L45 turning, while the lowest discomfort level was at R10 turning. Similar to the steering wheel control, position B depicted the highest mean score of discomfort level for gear control. G1 action showed the highest discomfort level compared to GN for DL muscle. On the other hand, the accelerator pedal control showed the highest mean score of discomfort level in position A. With respect to action, TR muscle depicted the highest discomfort level in releasing action, while GR muscle showed the highest level in FP action. In contrast, the lowest level for TR muscle was recorded at HP action, while for GR muscle in R action.

Referring to pressure felt outputs on the seat pan as depicted in Figure 4.14 to Figure 4.18, position A depicted the highest pressure felt compared to position B, particularly on the buttock. For the back rest, the lower back shows constant value for both positions, while for the upper back, there was an increment and decrement feature for both positions. Furthermore, based on the alertness level, on average, there was an increment of sleepiness from before driving to after driving. According to cardiovascular readings, on average there were increments in the HR and BP readings.

With respect to driver's condition, there was a decrement of alertness based on KSS from before driving to after driving, as shown in Figure 4.19 to Figure 4.20. It was found that the test subjects feel sleepier towards the end of the driving activity. In addition, there was no significant difference seen on positions A and B. Furthermore, according to the cardiovascular pattern of HR and BP, each test subject showed different pattern of increment and decrement. It is possibly due to the variation of mood sense and restricted movement of the test subjects in the simulator. Another possible explanation is feeling of anxiety, even though the tasks were performed in the laboratory. All these conditions might possibly influenced HR and BP values before and after the experiment. In fact, as mentioned by Jagannath and Balasubramaian (2014), and Li et al. (2004), stress (anxiety) is the main factor that influences the HR and BP data.

4.3 PRESSURE DISTRIBUTION ANALYSIS

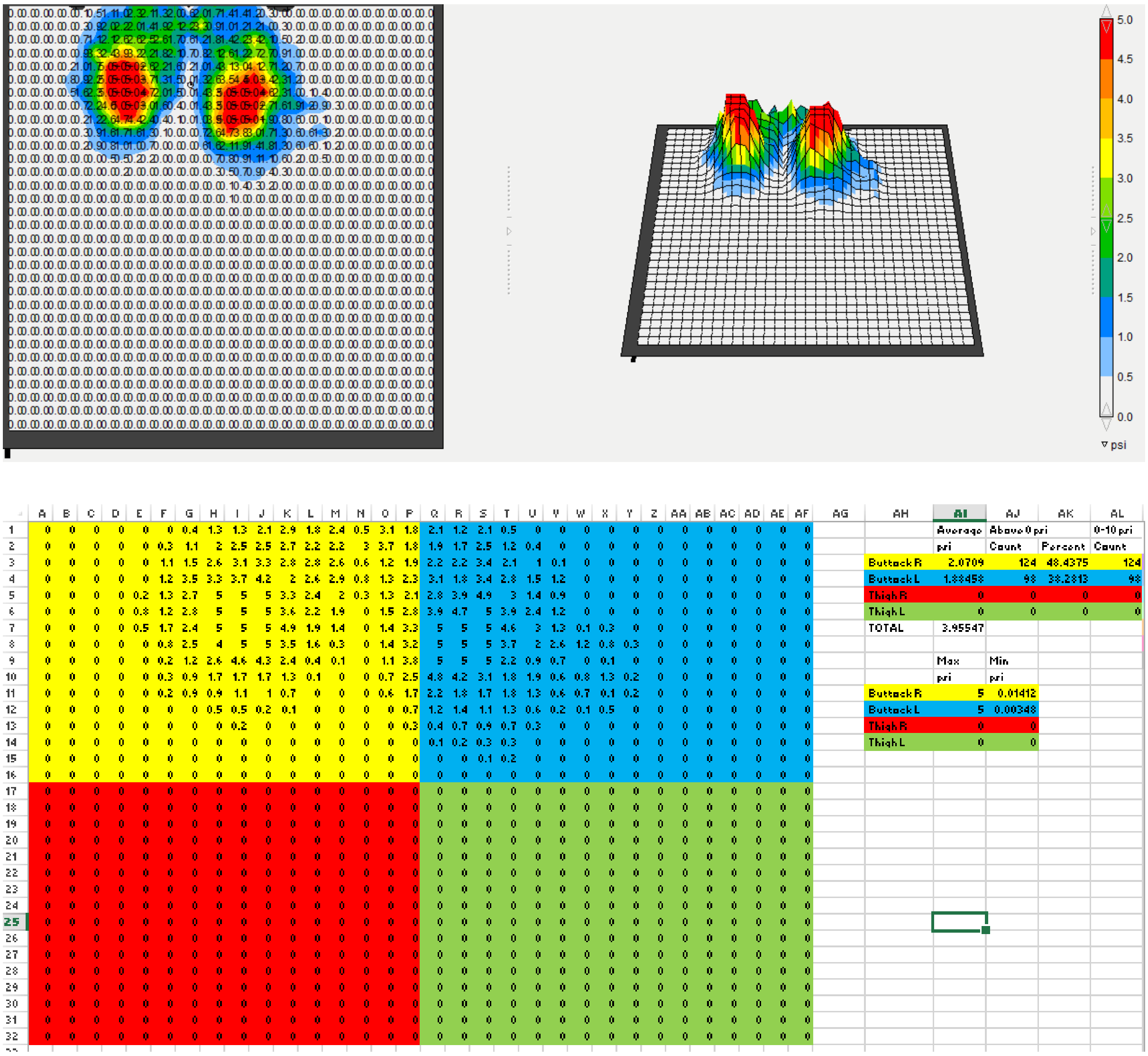
The main aim of this section is to identify the pressure interface on the car seat according to driving position. This section provides answers to the second objective in this study. As stated in Chapter II and Chapter III, there were two assessments of interface pressure (seat pan and back rest) recorded on pressure distribution. Section 4.3.1 and Section 4.3.2 demonstrate the outputs from the seat pan and the back rest for two periods: the pre driving and post driving. Interface pressure was collected to determine if there are any changes in the pressure distribution based on these two periods. Section 4.3.3 presents a thorough analysis based on findings explained in the previous section. Section 4.3.4 encapsulates the main results from the objective measures analysis.

4.3.1 Interface Pressure of the Seat Pan for Pre and Post Task

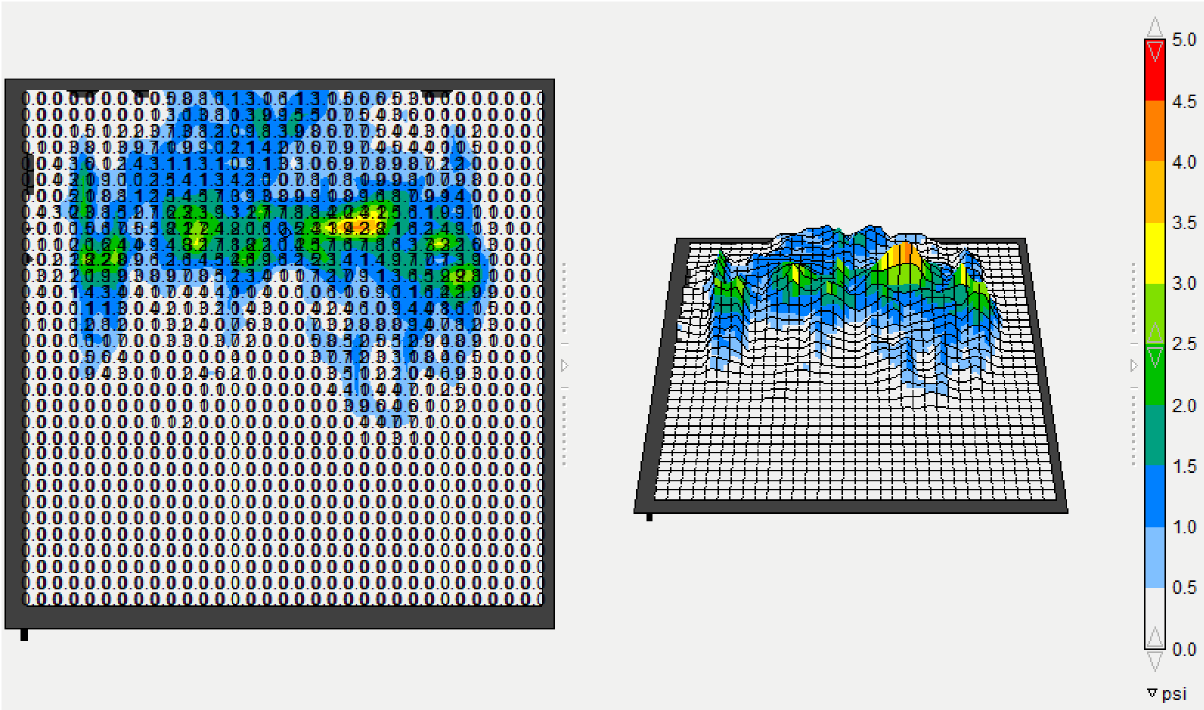
This section describes the findings of the pre driving task and post driving task for the seat pan. This section explains the seat pan pressure distribution's findings by focusing on the Body Mass Index (BMI) and percentile group of all subjects.

a. Seat pan interface pressure between subjects according to the BMI and percentile

Figure 4.21 (a), (b) and (c) illustrate three examples of the pressure distribution for the seat pan from three representatives of underweight subject (BMI=17.1), normal weight subject (BMI=20.8) and overweight subject (BMI=27.3) calculated with the Tactilus software and conversion by Excel 32 x 32. With regards to Figure 4.21 (a) to (c), the pressure of the heavier subjects is more scattered at the buttock area, while the lighter subject has mild stress concentrated under ischium tuberosity. Appendix J shows the results of the pre and post driving task from the interface pressure for the test subjects.



4.21 (a) Underweight subject (UW)



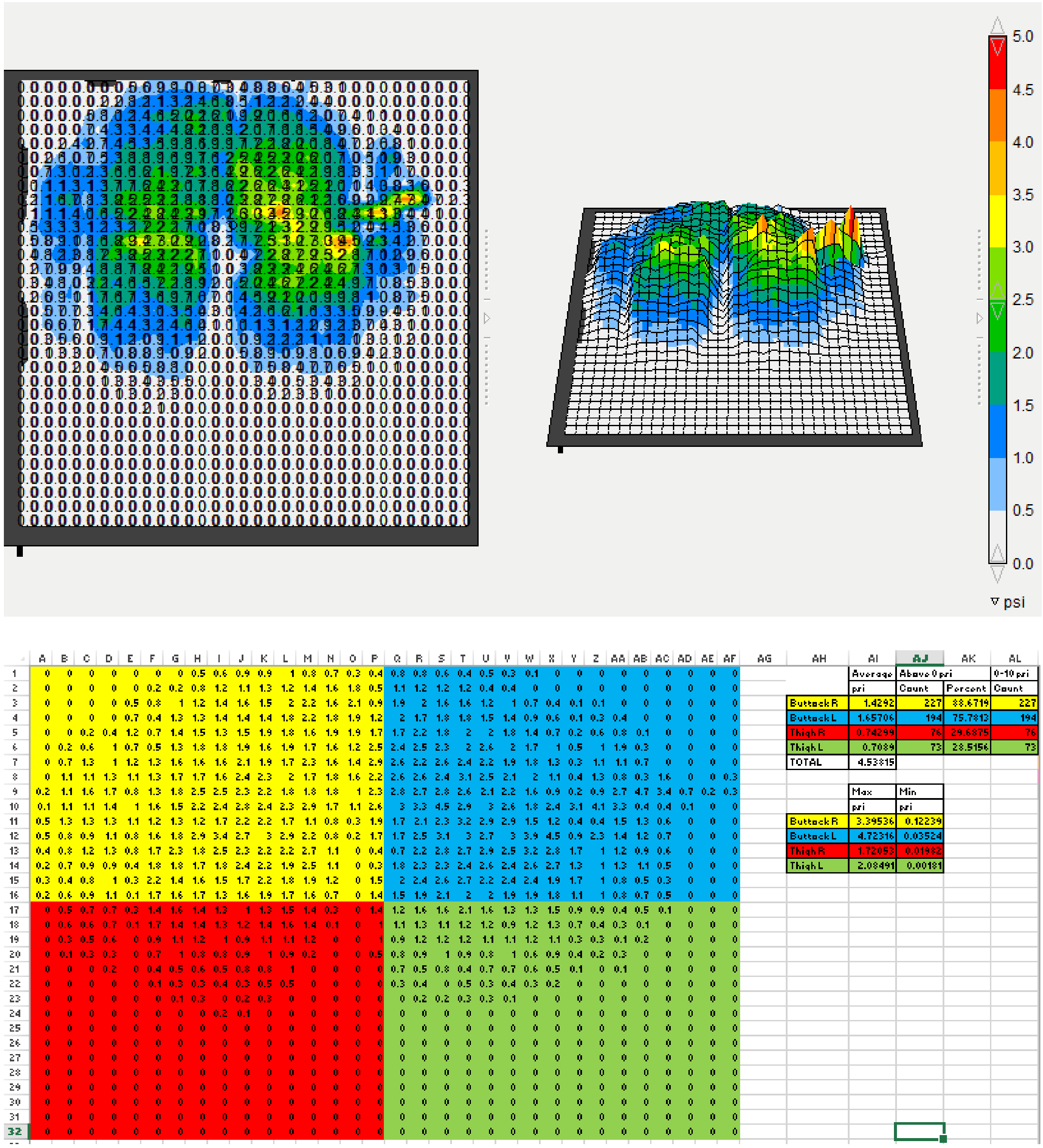
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	0	0	0	0	0	0	0	0	0.5	0.8	0.8	1	1.1	1.3	1.1	0.6
2	0	0	0	0	0	0	0	0.1	0.3	1	1.3	0.8	1	1.3	1.9	0.9
3	0	0	0.1	0.5	0.1	0.2	0.2	0.3	0.7	1.3	0.8	1.2	1	0.9	1.8	1.3
4	0.1	0	0.3	0.8	0.1	0.3	0.9	0.7	1.1	0.9	0.9	1	1.2	1.1	1.4	1.2
5	0	0.4	0.3	1.6	0.1	0.2	1.4	1.3	1.1	1.1	1.3	1.1	1	0.9	1.1	1.3
6	0	0.4	0.3	2.1	0.9	1	1	1.2	1.5	1.4	1.1	1.3	1.4	1.2	1	1
7	0	0	0.5	2.1	0.8	0.8	1.1	1.2	1.5	1.4	1.5	1.7	1.3	0.9	1.3	0.8
8	0.4	0.3	1	2.3	0.8	1.5	1.2	0.7	1.6	2.3	2.3	1.9	1.3	1.1	2.7	1.7
9	0	0.1	0	1.5	0.6	1.7	0.5	0.5	1.8	2.1	2.7	2.4	1.8	2	1.6	1
10	0.1	0.1	0	2	1.6	2.4	1.4	0.9	1.4	1.8	3.2	1.7	1.8	1.8	2.2	1
11	0	0.2	0.1	2.8	2.2	2.8	0.9	0.6	1.2	1.6	1.4	1.5	1.4	2.6	1.9	1.6
12	0.3	0.2	0.1	2	1.9	1.9	0.3	0.8	0.9	0.7	0.8	0.5	1.2	1.3	1.4	0.1
13	0.4	0	0.1	1.4	1.3	1.4	0.4	0.1	0.7	0.4	0.4	0.4	1	1.1	0.4	0
14	0	0	0	1.1	1.1	1.3	0	0.4	0.2	0.1	0.3	0.2	1.1	0.4	0.3	0
15	0.1	0	0	1.2	0.8	1.2	0	0.1	0.3	0.2	0.4	0	0.7	0.6	0.3	0
16	0	0	0	1	1.1	0.7	0	0	0.3	0.3	0	0.3	0.7	0.2	0	0
17	0	0	0	0.5	0.6	0.4	0	0	0	0	0	0	0.4	0	0	0
18	0	0	0	0.9	0.4	0.3	0	0.1	0	0.2	0.4	0.6	0.2	0.1	0	0
19	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
21	0	0	0	0	0	0	0	0.1	0.1	0.2	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	1.1	1.3	1.1	0.5	0.6	0.6	0.5	0.3	0	0	0	0	0	0	0	0
2	1.5	1.5	1	0.7	0.5	0.4	0.3	0.6	0	0.1	0	0	0	0	0	0
3	1.9	0.8	0.6	0.7	0.7	0.5	0.4	0.4	0.3	0	1	0.2	0	0	0	0
4	0.7	0.6	0.7	0.9	0.7	0.4	0.5	0.4	0.4	0	1.1	0.5	0	0	0	0
5	0.3	1	0.6	0.9	0.7	0.8	0.9	0.8	0.7	0.2	1.2	1	0	0	0	0
6	0.7	0.8	1.1	0.8	1.1	0.9	0.9	0.8	1.1	0.7	0.9	0.8	0	0	0	0
7	0.9	0.9	1.1	0.8	0.9	1.6	1.8	1.7	0.9	0.9	1.4	1	0	0	0	0
8	1.8	1.8	1.4	2	2.4	3.1	2.5	1.6	1.1	1.9	0.9	1.1	0.1	0	0	0
9	1.5	2.4	3.1	3.9	4.2	3.8	2.1	1.6	1.2	1.4	1.9	1.1	0.3	0.1	0	0
10	1.4	2.5	1.7	1.6	1.7	1.8	1.6	1.3	1.7	3.3	2.2	1.6	0.3	0	0	0
11	1.2	1.5	2.3	1.4	1.1	1.4	1.9	1.7	1.7	0.7	1.3	1.9	1.1	0	0	0
12	0.1	0.7	1.2	1.7	0.9	1.1	1.3	1.6	1.5	1.9	2.9	2.8	1.1	0	0	0
13	0	1	0.6	1.1	0.6	0.9	1	1.1	1.6	1.4	2.2	1.9	0.9	0	0	0
14	0	0.4	0.2	0.4	0.6	1	0.9	1.4	1.4	0.8	1.6	1.1	0.5	0	0	0
15	0	0.7	0.3	0.2	0.8	0.8	0.8	0.9	1.4	0.7	0.8	1.2	0.3	0	0	0
16	0	0.5	0.8	0.5	1.2	0.5	0.5	1.2	0.9	0.4	0.8	0.9	0.1	0	0	0
17	0	0.3	0.7	0.7	1.2	0.3	0.3	1.1	0.8	0.4	0.6	0.5	0	0	0	0
18	0	0	0.3	0.5	1.1	0.2	0.2	1	0.4	0.6	0.9	0.3	0	0	0	0
19	0	0	0.4	0.4	1.1	0.4	0.4	0.7	0.1	0.2	0.5	0	0	0	0	0
20	0	0	0	0.3	0.9	0.6	0.4	0.6	0.1	0	0.2	0	0	0	0	0
21	0	0	0	0	0.4	0.4	0.7	0.7	0.1	0	0	0	0	0	0	0
22	0	0	0	0	0.1	0	0.3	0.1	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Average	Above 0 psi		0-10 psi
	psi	Count	Percent	Count
Buttock R	0.98777	219	85.5469	219
Buttock L	1.11862	191	74.6094	191
Thigh R	0.21201	27	10.5469	27
Thigh L	0.47857	47	18.3594	47
TOTAL	2.79697			

	Max	Min
	psi	psi
Buttock R	3.19566	0.00109
Buttock L	4.22147	0.01668
Thigh R	0.86722	0.01656
Thigh L	1.21363	0.00254

4.21 (b) Normal weight subject (NW)



4.21 (c) Overweight subject (OW)

Figure 4.21 Pressure distribution pattern based on the BMI for the seat pan

From previous studies, there are many values of the recommended comfortable peak pressure of the ischium tuberosity recorded, which is from 0.84 psi to 4.35 psi (Kamijo et al., 1982; Kolich, Seal & Taboun, 2004). However, Dunk and Callaghan (2005) found the comfortable peak pressure is at 2.61 psi for female and 2.94 psi for male. In addition, Harrison et al. (2000) and Reed et al. (1994) suggested that Figure

4.21 (a) has good pressure distribution due to the less sensitive tissue at the ischium tuberosity compared to the thigh. A good pressure distribution means peak pressure more concentrated under a sitting bone in the lumbar and there is a balance between a right and left side. The sitting bone is refer to a skin fat tissue under ischium tuberosity. As mentioned by Reed et al. (1994), when the body part is less sensitive, there is less discomfort feel by the subject.

Table 4.5 shows the mean pressure of each driving position for all subjects according to the percentile group. The percentile value used in this study is primarily referred to previous study conducted by Daruis (2010) based on Malaysian population. The mean percentile or denoted as 50^{th} percentile in this case is 1.567 cm (height) and 54 kg (weight). Based on Table 4.5 without considering the percentile group, the buttock part is significantly higher than the thigh part, with the different mean pressure between 1 to 2 psi. Based on percentile for position A and B, the highest mean pressure was recorded at group percentile more than 50^{th}. For thigh part, it also shows similar pattern.

Table 4.5 Seat pan pressure distribution according to body size for position A and B

Percentile	< 50th	> 50th
	Mean	Mean
A pre buttock	2.71	2.98
B pre buttock	2.22	2.35
A post buttock	3.59	3.14
B post buttock	3.20	2.69
A pre thigh	0.55	0.98
B pre thigh	0.94	0.95
A post thigh	0.74	0.91
B post thigh	1.44	1.13

b. Difference in the seat pan interface pressure according to driving position

Figure 4.22 and Figure 4.23 show the comparison between each position according to the body size for pre and post activity. Roughly, there is an increment in the mean pressure from the pre to post task, with regards to the buttock and thigh body parts of the seat pan. In terms of driving position, there is a slight difference between each position. Based on Figure 4.22 and 4.23, a lighter subject (refer to group less than 50th percentile) produces the highest mean pressure when sitting far away from the car controls (position B). This condition possibly occurred due to thigh part does not touch much the seat pan due to the subject's charateristics that is more smaller compared to group more than 50th percentile.

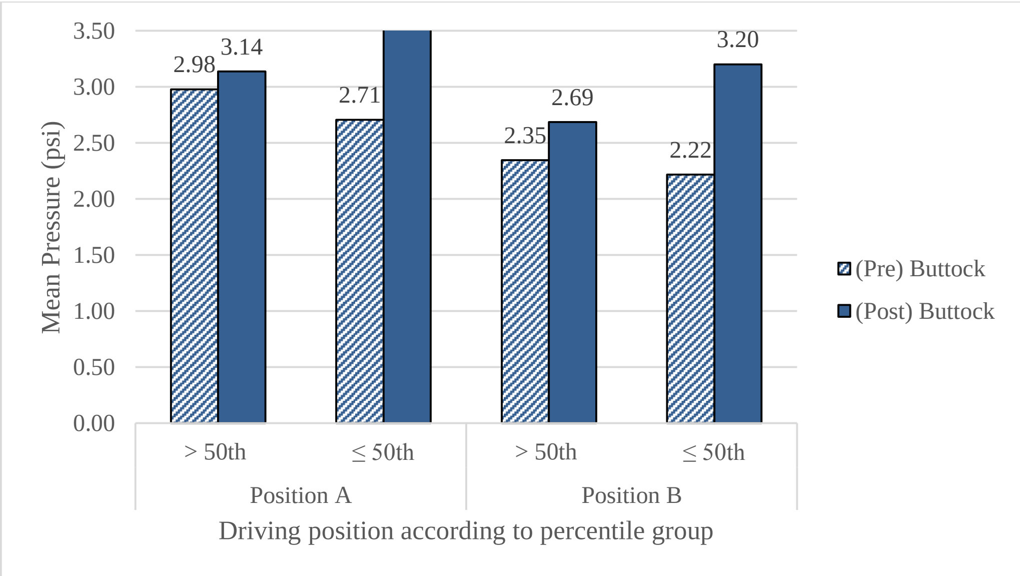


Figure 4.22 Comparison between each position based on the buttock at the seat pan

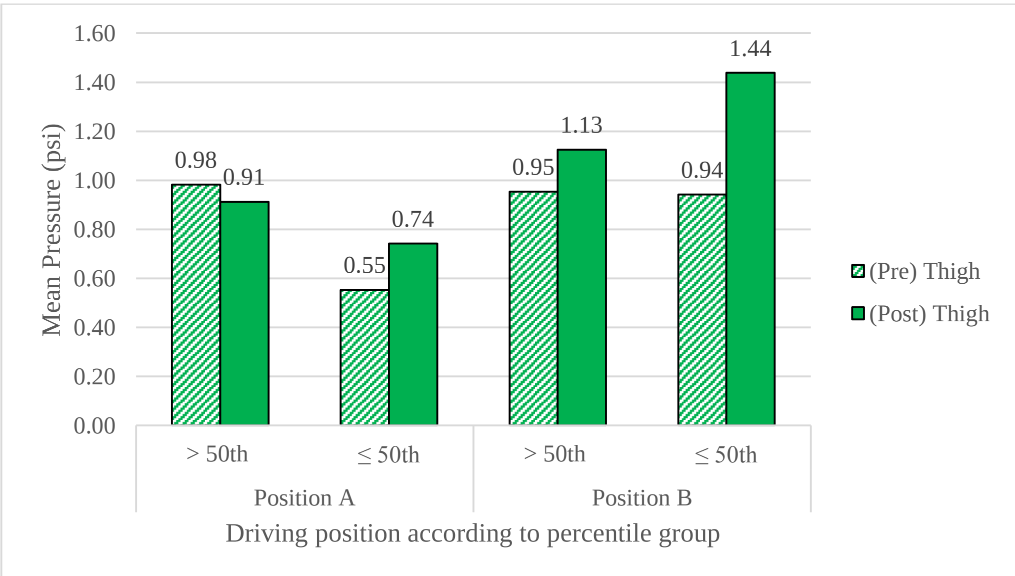


Figure 4.23 Comparison between each position based on the thigh at the seat pan

c. Thorough analysis of seat pan's pressure distribution measurement

In addition, a detailed analysis was carried out to determine the association between each variables by using statistical analysis. Appendix G (Table 5) depicts the normality test results for the seat pan. Details on the statistical analysis results for pressure distribution measurement can be found in Appendix K. Table 4.6 shows the results for thorough analysis of seat pan's pressure distribution measurement.

Table 4.6 Thorough analysis for seat pan's pressure distribution measurement

Analysis	**IV**	**DV**	**Significant**
Positions	Two different positions	Pressure distribution for these two positions	Buttock: Yes Thigh: No Refer to Appendix K (Table 1 and Table 2)
Pre and post activities	Two different time periods (pre and post)	Pressure distribution for these two periods	Buttock: Yes Thigh: Yes, only at position A (pre activity) Refer to Appendix K (Table 3 and 4)

Figure 4.24 and Figure 4.25 depict the mean pressure at the buttock and thigh for position A and B for pre-post activity. In addition, this section also identifies the correlation between the pressure distributions measurements with the anthropometry measurement used in this study. There is a strong correlation between pressure distribution at the buttock and the buttock-popliteal length ($r=-0.804$, $p<0.05$). Refer to Appendix K (Table 5).

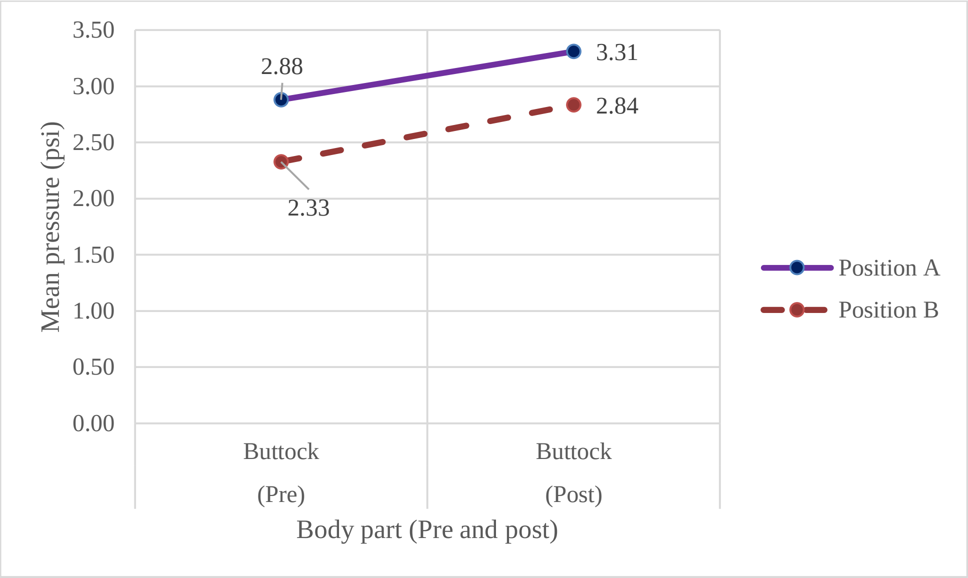


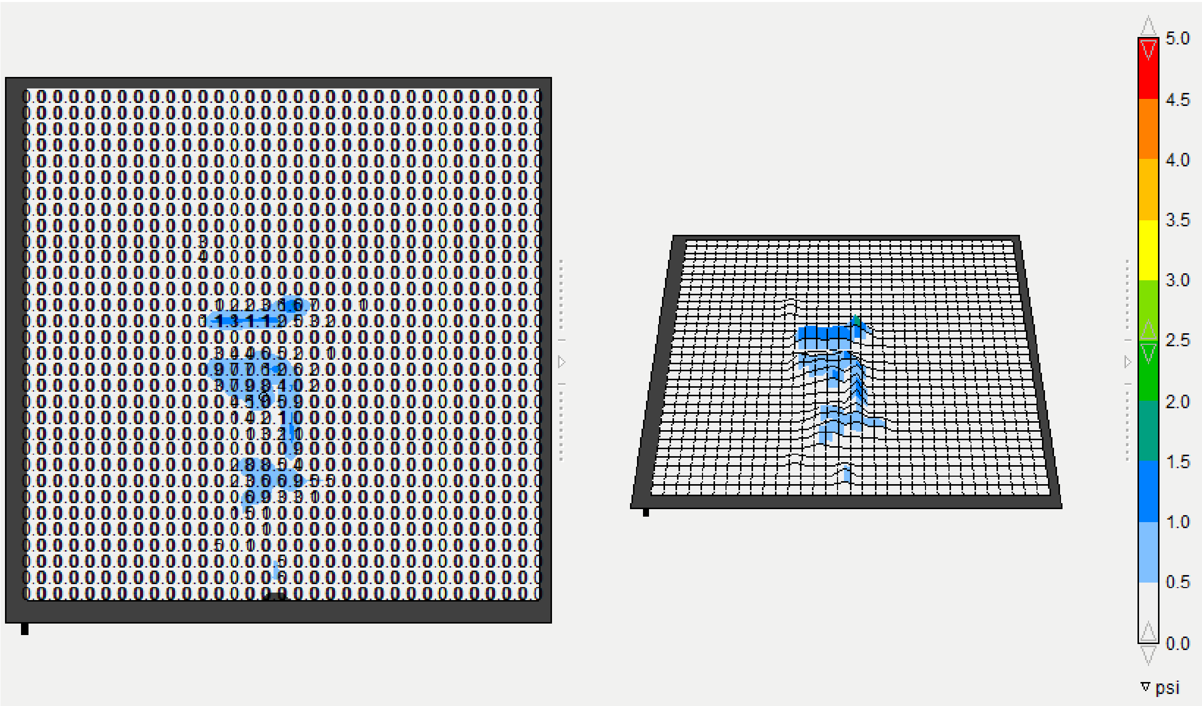
Figure 4.24 Mean plot at the buttock for position A and B for pre-post activity

Figure 4.25 Mean plot at the thigh for position A and B for pre-post activity

4.3.2 Interface Pressure of the Back rest for Pre and Post Task

a. Back rest interface pressure between subjects with regards to the percentile

Figure 4.26 (a) to (f) illustrate three examples of the pressure distribution for the back rest with underweight subject (BMI=17.1), normal weight subject (BMI=20.8) and overweight subject (BMI=27.3) calculated using the Tactilus software and conversion by Excel 32x32. With regards to these three examples, in general, the pressure of the heavier subject is more scattered, and concentrated particularly at the lower back, while the lighter subject has mild stress concentrated at the middle back. Specifically, comfortable seats are indicated by the average pressure levels of 0.2 psi to 0.33 psi in the lumbar region of the back rest (de Looze et al., 2003; Kamijo et al., 1982). Appendix L shows the results from the back rest interface pressure for the subjects. A good pressure distribution at the back rest means peak pressure more concentrated at the lower back, which can provides more support (Kamijo et al. 1982).



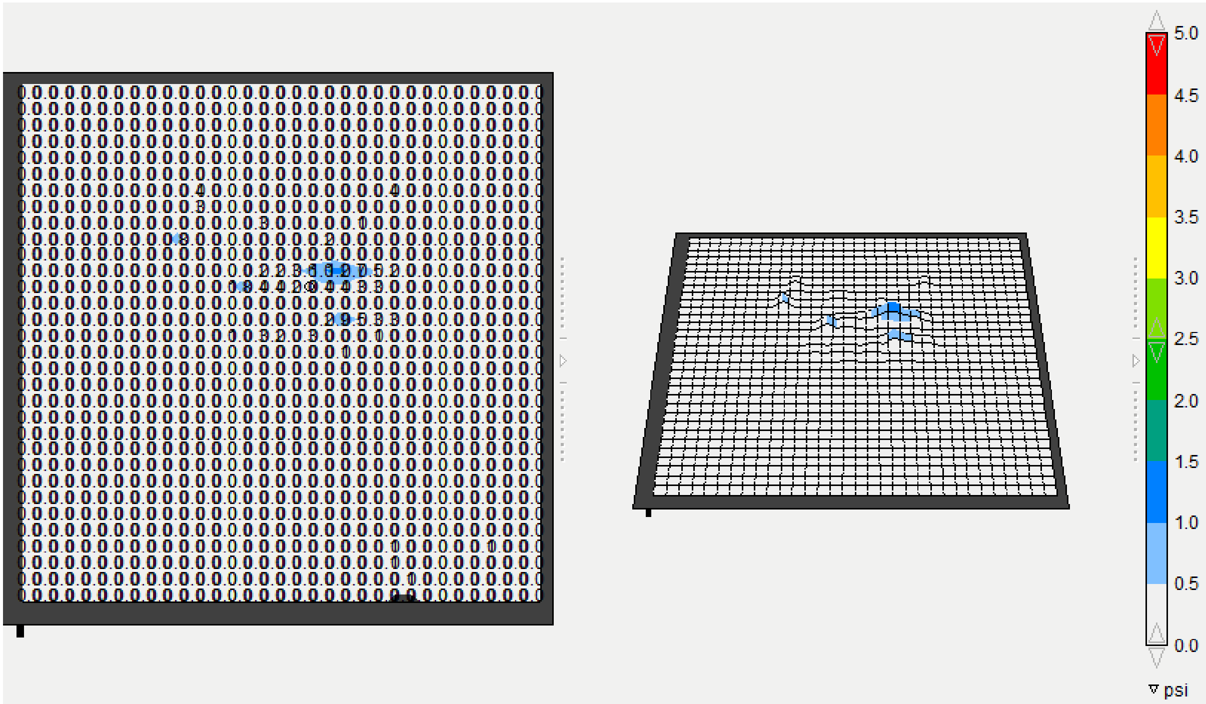
4.26 (a) UW

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
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
2	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
3	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
4	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
5	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
6	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
7	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
8	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
9	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
10	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	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
13	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
14	0	0	0	0	0	0	0	0	0	0	0	0.1	0.2	0.2	0.3	0.6	1.6	0.7	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	1.1	1.3	1.1	1.1	1.2	0.5	0.3	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
16	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
17	0	0	0	0	0	0	0	0	0	0	0	0.3	0.4	0.4	0.6	0.5	0.2	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0.9	0.7	0.7	0.6	1.2	0.6	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0.3	0.7	0.9	0.8	0.4	1	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0.5	1	0.5	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.4	0.2	0.1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.3	0.2	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.8	0.8	0.5	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.3	0.6	0.6	0.9	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0.9	0.3	0.3	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.5	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	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

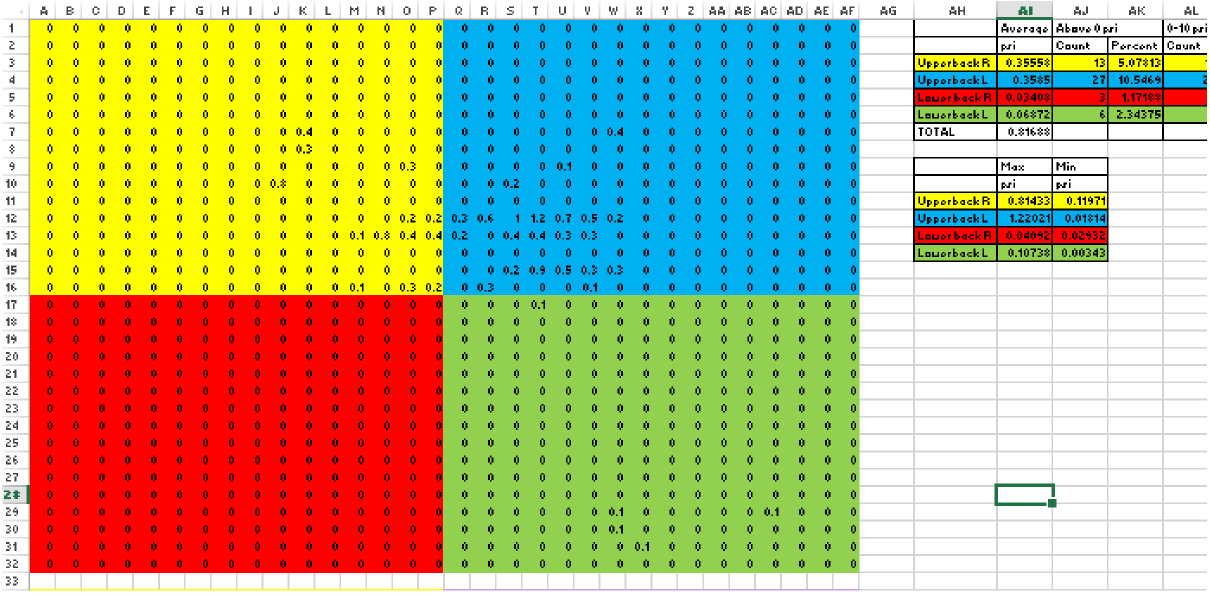
AH	AI	AJ	AK	AL
	Average	Above 0 psi		0-10 psi
	psi	Count	Percent	Count
Upperback R	0.64878	12	4.6875	1
Upperback L	0.47759	7	2.73438	
Lowerback R	0.44748	48	18.75	4
Lowerback L	0.50978	18	7.03125	1
TOTAL	2.08363			

AH	AI	AJ
	Max	Min
	psi	psi
Upperback R	1.32261	0.05466
Upperback L	1.55336	0.01834
Lowerback R	1.22475	0.02529
Lowerback L	1.13814	0.00302

4.26 (b) UW



4.26 (c) NW



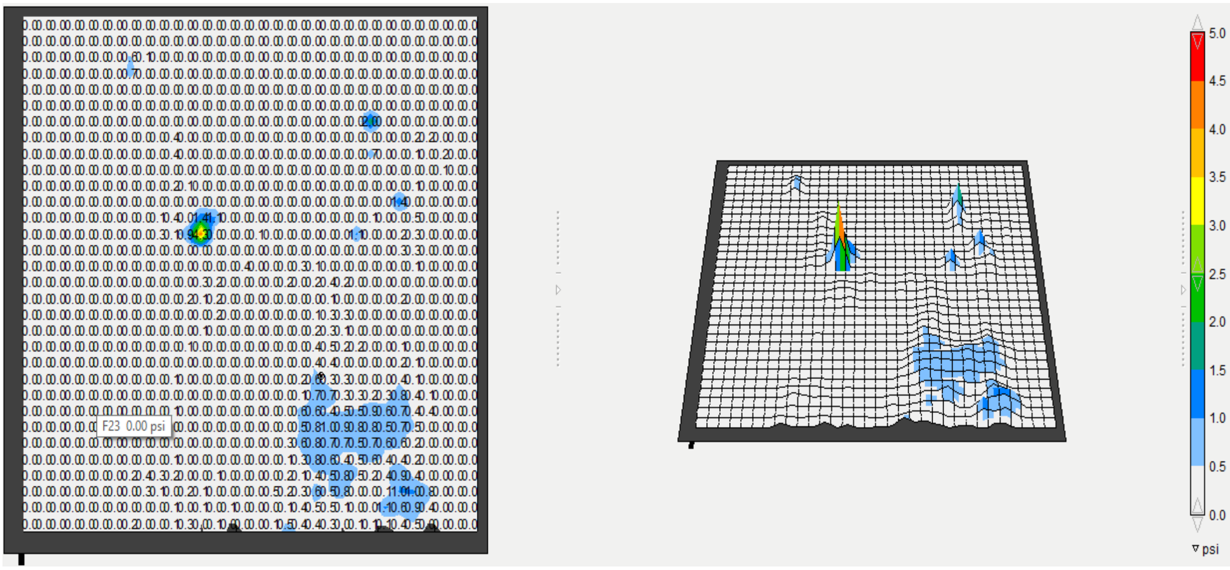
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0
10	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.2
13	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.8	0.4	0.4
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0.3	0.2
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.3	0.6	1	1.2	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0
13	0.2	0	0.4	0.4	0.3	0.3	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0.2	0.9	0.5	0.3	0.3	0	0	0	0	0	0	0	0	0
16	0	0.3	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0.1	0	0	0	0	0	0.1	0	0	0
30	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Average	Above 0 psi		0-10 psi
	psi	Count	Percent	Count
Upperback R	0.35558	13	5.07813	
Upperback L	0.3585	27	10.5469	
Lowerback R	0.03408	3	1.17188	
Lowerback L	0.06872	6	2.34375	
TOTAL	0.81688			

	Max	Min
	psi	psi
Upperback R	0.81433	0.11971
Upperback L	1.22021	0.01814
Lowerback R	0.04092	0.02932
Lowerback L	0.10738	0.00343

4.26 (d) NW



4.26 (e) OW

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0.6	0.1	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0.2	0.1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0.1	0.4	0	1.6	1.1	0	0
14	0	0	0	0	0	0	0	0	0	0.3	0.1	0.9	4.7	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4
17	0	0	0	0	0	0	0	0	0	0	0	0.2	0.3	0.3	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0.3	0.1	0.3	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
29	0	0	0	0	0	0	0	0.2	0.4	0.3	0.2	0	0	0.1	0	0
30	0	0	0	0	0	0	0	0	0.3	0.1	0	0.2	0.1	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0.1	0	0.1	0	0.1	0
32	5	0	0	0	0	0	0	0.2	0	0	0.1	0.3	0	0.1	0	0

	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	2.2	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0.1	0.2	0	0	0
9	0	0	0	0	0	0	0	0	0.8	0	0	0.1	0	0.1	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1.3	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0.1	0	0	0.5	0	0	0	0
14	0.1	0	0	0	0	0	0	1.1	0	0	0.2	0.2	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0.3	0.3	0	0	0	0
16	0	0	0	0.3	0.1	0	0	0	0	0	0	0.1	0	0	0	0
17	0	0	0.2	0	0.2	0.3	0.1	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0.1	0	0	0	0	0.2	0	0	0	0	0
19	0	0	0	0	0.2	0.3	0.3	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0.3	0.3	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0.3	0.5	0.2	0.1	0	0	0	0	0	0	0	0
22	0	0	0	0	0.7	0.6	0.1	0	0	0	0.3	0.1	0	0	0	0
23	0	0	0	0.2	0.6	0.3	0.3	0	0	0	0.5	0.1	0	0	0	0
24	0	0	0	0.1	0.7	0.7	0.3	0.3	0.2	0.3	0.8	0.5	0.2	0	0	0
25	0	0	0	0.7	0.7	0.5	0.5	0.6	0.9	0.8	0.8	0.5	0.5	0	0	0
26	0	0	0	0.7	1	1	1	0.8	0.8	0.6	0.7	0.6	0	0	0	0
27	0	0	0.3	0.6	0.8	0.7	0.7	0.8	0.8	0.6	0.6	0.3	0	0	0	0
28	0	0	0.1	0.3	0.8	0.7	0.5	0.5	0.6	0.5	0.4	0.2	0	0	0	0
29	0	0	0.2	0.1	0.4	0.6	0.9	0.5	0.3	0.5	0.9	0.4	0	0	0	0
30	0	0.5	0.2	0.3	0.6	0.6	0.9	0	0	0	1	1	0.8	0	0	0
31	0	0	0.1	0.5	0.5	0.5	0.1	0	0	1.1	0.6	0.9	0.4	0	0	0
32	0	0.1	0.6	0.4	0.5	0.3	0	0.1	0.1	0.1	0.4	0.5	0	0	0	0

	AH	AI	AJ	AK	AL
1		Average	Above 0 psi		0-10 psi
2		psi	Count	Percent	Count
3	Upperback R	0.71441	17	6.64063	1
4	Upperback L	0.40927	20	7.8125	2
5	Lowerback R	0.26689	38	14.8438	3
6	Lowerback L	0.45324	120	46.875	12
7	TOTAL	1.84381			
8					
9		Max	Min		
10		psi	psi		
11	Upperback R	4.69458	0.00623		
12	Upperback L	2.23691	0.05204		
13	Lowerback R	5	0.00174		
14	Lowerback L	1.10437	0.00094		

4.26 (f) OW

Figure 4.26 Pressure distribution data based on BMI for the back rest

Table 4.7 highlights the mean pressure value of each driving position for all subjects according to the percentile group. In contrast to the group in the above 50th percentile, the group in the below 50^{th} percentile has the highest average P at the lower back, followed by the upper back. According to past studies, discomfort may result from either extreme or lack of pressure on the support, which in this case is the back rest. If the peak pressure is at the upper back, it means the seat design has small support on the lower back part (Daruis, 2010; Harrison et al., 2000). Furthermore, looking at the pre and post driving task for each position, there is not much increment on the average P from pre to post task. In terms of driving position, there is a small difference between each position. According to Daruis (2010), the human spine naturally is in the S form. Without sufficient support for the lumbar area (lower back) at the back rest, the body position of the sitter tends to be curved and bent. As a result, the sitter may experience discomfort at the upper back due to the lack of support. The next subsection clarifies the actual pattern based on this findings with the aid of the graph illustration.

Table 4.7 Back rest pressure distribution according to the body size for position A and B

Percentile	< 50th	> 50th
	Mean (psi)	Mean (psi)
A pre upper back	0.52	0.79
A pre lower back	1.04	0.62
A post upper back	0.56	0.79
A post lower back	0.82	0.67
B pre upper back	0.58	1.0
B pre lower back	1.01	0.73
B post upper back	0.59	0.98
B post lower back	0.58	0.78

b. Difference in back rest interface pressure between subjects with regards to driving position

Figure 4.27 and Figure 4.28 show the comparison between each position according to percentile for pre and post activity. Roughly, there is not much increment on the mean pressure value from pre to post task for the upper and lower body part of the back rest. According to Figure 4.27 and Figure 4.28, heavier subject put much pressure when leaning against to the backrest to support his/her body when controlling the car controls at position B.

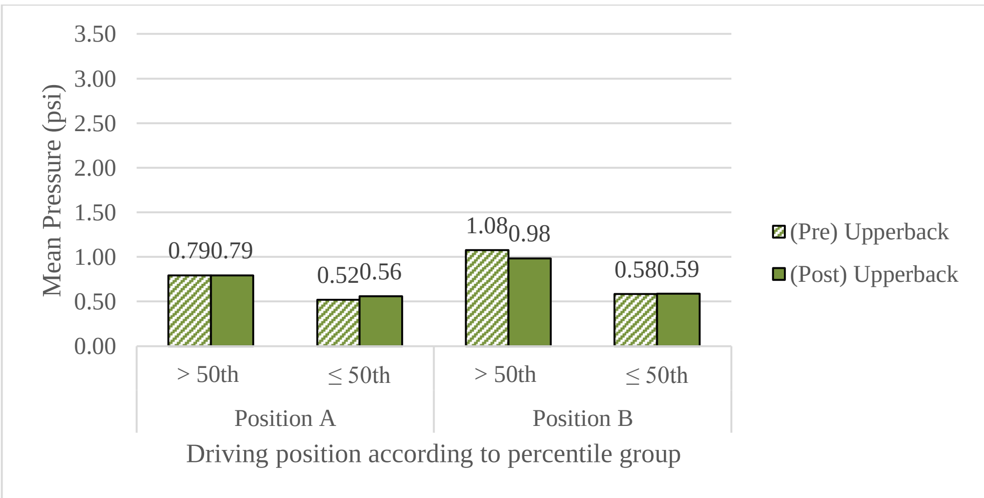


Figure 4.27 Comparison between each position based on the upper back at the back rest

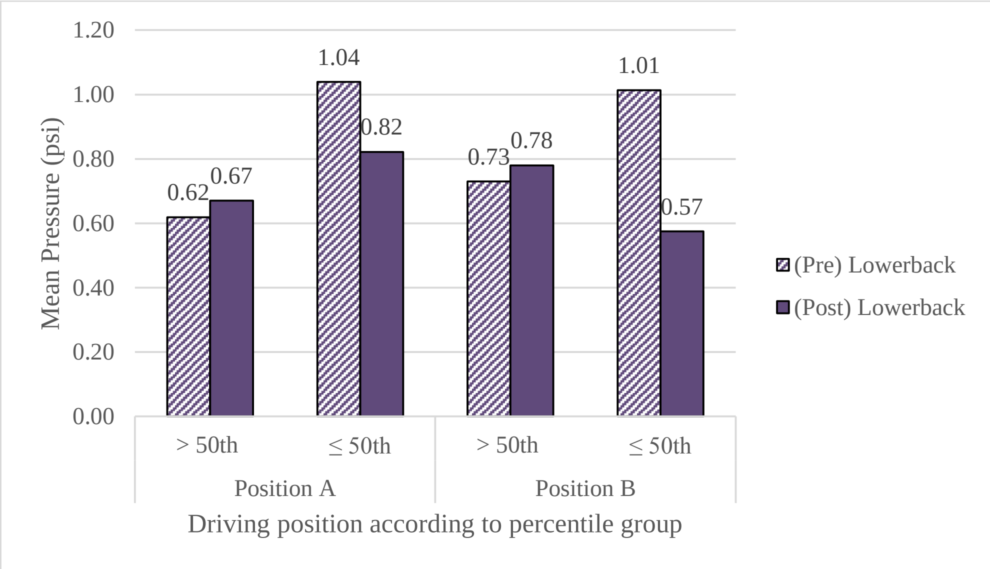


Figure 4.28 Comparison between each position based on the lower back at the back rest

c. Thorough analysis of back rest's pressure distribution measurement

In addition, a detailed analysis was carried out to determine the association between each variables by using statistical analysis. Appendix G (Table 6) depicts the normality test results for the back rest. Details on the statistical analysis results for pressure distribution measurement can be found in Appendix L. Table 4.8 shows thotough analysis for back rest's pressure distribution measurement.

Table 4.8 Thorough analysis for back rest's pressure distribution measurement

Analysis	IV	DV	Significant
Positions	Two different positions	Pressure distribution for these two positions	Upper and lower back: No Refer to Appendix K (Table 3 and Table 4)
Pre and post activities	Two different time periods (pre and post)	Pressure distribution for these two periods	Upper and lower back: No Refer to Appendix L (Table 1 and Table 2)

Figure 4.29 and Figure 4.30 depict the mean pressure at the upper and lower back for position A and B for pre-post activity.

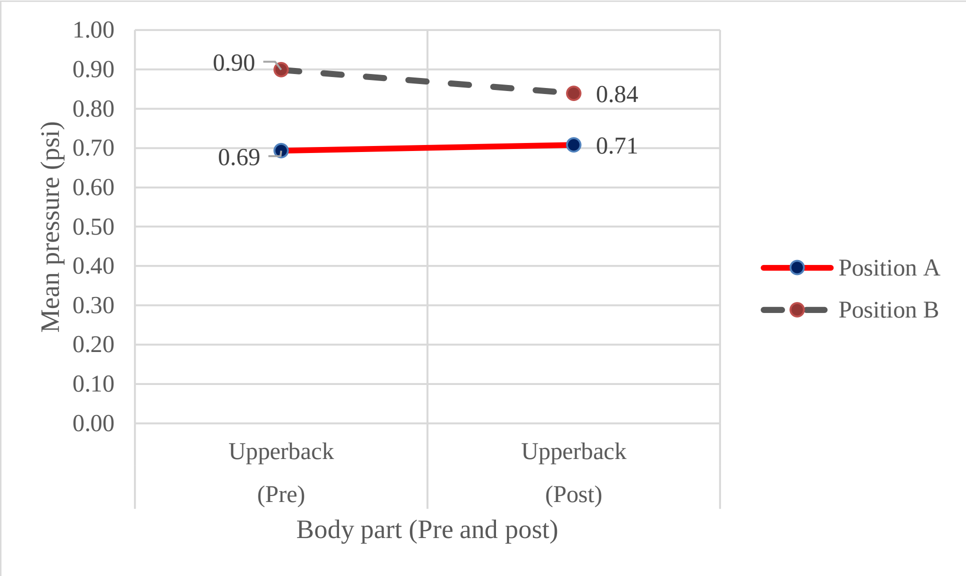


Figure 4.29 Mean plot at the upper back for position A and B for pre-post activity

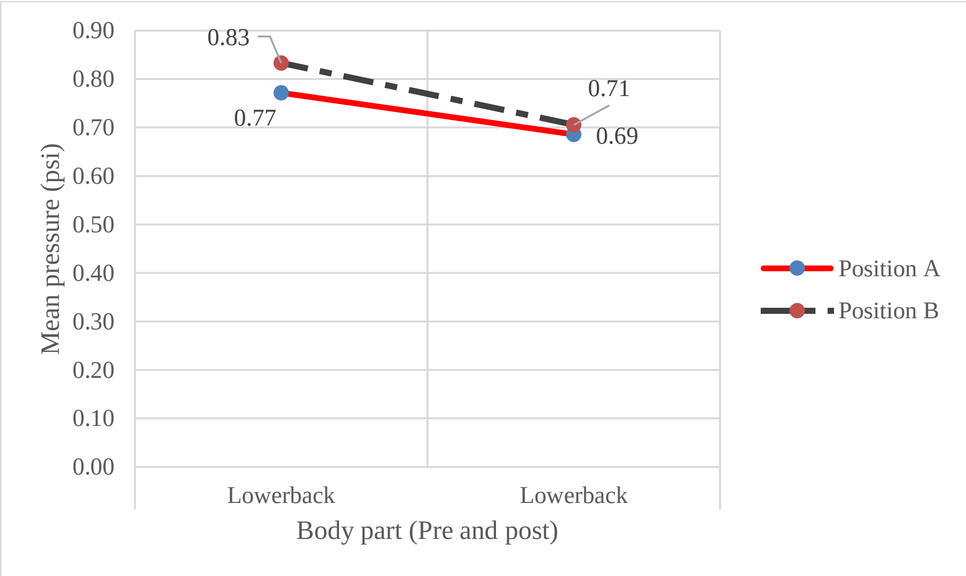


Figure 4.30 Mean plot at the lower back for position A and B for pre-post activity

4.3.3 Summary on Pressure Distribution Measurement

As mentioned earlier, the main aim of this section is to identify the pressure interface on the car seat according to driving position. This section provides answers to the second objective as well as the second and third research questions in this study, which evaluated the pressure interface on the car seat based on different driving positions. All in all, this study shows that the distribution of pressure over seat pan and back rest is slightly influenced by the characteristics of the sitter's body part, in terms of the weight and also buttock-popliteal length as mentioned in the thorough analysis of the seat pan. Based on the findings from the seat pan, the pressure of the heavier subject is more scattered at the buttock area, while the lighter subject has mild stress concentrated under ischium tuberosity. For the back rest, the OW group has a scattered pressure pattern at the lower back, while the NW and the UW have a small amount of focusing point at the middle back.

According to past study, the pressure distribution data is created based on the transmission of the human body's weight by sitting over sitting bones (tuber ossis ischia) and surrounding soft tissue on the seat (Ergic, Ivandic, & Kozak, 2002). This transmission develops a change on the soft tissue and skeleton due to the seat's pressure, which can be seen on the bulk muscular and bulk bones. Normally, this distribution can be seen clearly in the lower back and buttock area (de Looze et al., 2003; Yun, Donges & Freivalds 1992). Seat comfort is best achieved with the correct distribution of weight and support for the body, and the ability to make adjustments if the sitter feels the need to change position. Overall, the seat pan in this study can be categorized as comfortable because the mean pressure at the seat pan is below 4.35 psi as suggested by de Looze et al. (2003) and Kamijo et al. (1982). In terms of back rest, at position B, there is small support at the lower back because the peak pressure is at the upper back.

Based on the detailed analysis on pressure distribution findings, there is statistically significant difference between pre and post task at the buttock. However, there is no significant difference between all other bodies' parts, thigh, upper and lower back. In terms of driving position, there is difference in all positions at the buttock. Buttock part at position A depicts the highest mean pressure compared to the thigh at the similar position. However, there is no significant difference at the other body parts (such as thigh, upper back and lower back). This is because other body parts is less sensitive to the pressure distribution as clarified previously by Harrison et al. (2000). Based on this summary, hence, pressure findings from the buttock at position A will be used to develop the model in Chapter V as it depicts the highest discomfort rate based on the mean score. In addition, there is strong correlation between buttock popliteal length and pressure distribution at the buttock.

4.4 MUSCLE ACTIVITY ANALYSIS

Similar to pressure distribution measurement, two periods (pre and post driving) were recorded by the SEMG to identify the muscle activity and contraction of the test subjects. This section provides answers to the third objective in this study. Section 4.4.1 to Section 4.4.3 demonstrate the SEMG findings for the two periods: pre and post driving. It was collected to determine if there is any changes of the muscle activity for these two periods. Section 4.4.4 summarizes the main results from this objective measures analysis.

4.4.1 Muscle Activation Measurement for Steering Wheel

As mentioned in Chapter III, there are five main actions (L10, M, R10, L45 and R 45) with two active shoulder muscles (DL and DR) documented for pre and post driving activity. Figure 4.31 depicts the flow of the steering wheel action in this study. As mentioned in Chapter III, these actions were performed at pre and post driving activity. The aim of this part is to estimate and investigate the muscle activation of the DL and DR when operating the steering wheel with respect to the direction of turning (to the right or left) and degree of turning (10 and 45 degree).

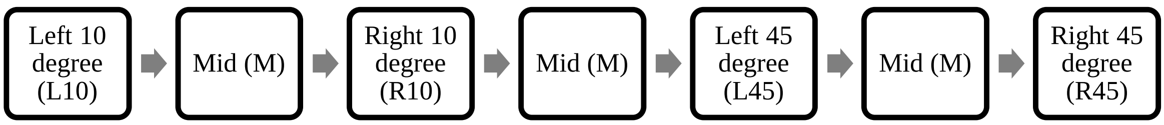


Figure 4.31 Main actions in steering wheel

a. Temporal analysis for steering wheel task

As stated in Chapter II and Chapter III, the Temporal Analysis is conducted to understand the pattern of the muscle when interacting with certain driving tasks. Figure 4.32 and Figure 4.33 show the Temporal Analysis for DL and DR response in steering wheel action after filtering process. Each action was recorded for approximately five seconds. Based on both figures, it is obvious that the DL and the DR muscle operated oppositely when performing the left and right turn. In general, when turning to the left, the DR muscle shows the highest activation, while the DL muscle demonstrates the highest activation when turning to the right. This pattern is obvious and can be seen in Figure 4.32 and Figure 4.33. For instance, when turning the steering wheel to the left, L10 or L45 for the DR muscle is higher than the DL muscle. In contrast, when turning to the right, R10 or R45 for the DR muscle is smaller than the DL muscle.

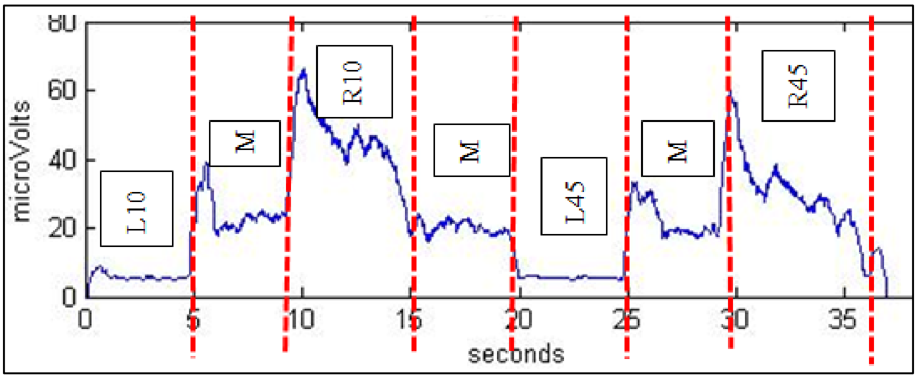


Figure 4.32 Temporal analysis of DL muscle according to steering wheel task

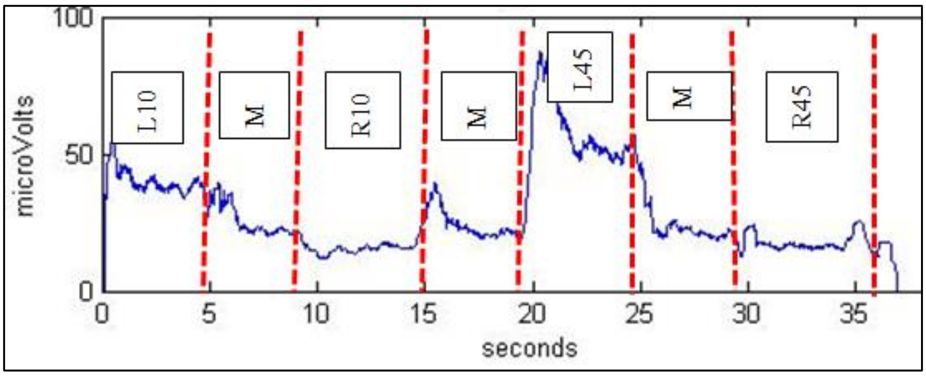


Figure 4.33 Temporal analysis of DR muscle according to steering wheel task

With respect to the degree of turning, when turning to the left, L10 shows a smaller activation than L45. Similarly, when turning to the right, L10 shows a small activation than L45. In the next subsection, only L10, L45 and R45 are evaluated in detail. The aim of this comparison is to investigate the pattern of the muscle according to degree of turning and direction of turning. In this case, L10 and L45 (either 10 degree or 45 degree) are compared in terms of its turning degree, meanwhile L45 and R45 are compared to identify the working muscle (DL and DR) based on the direction of turning (either to the left or right).

b. Amplitude analysis on steering wheel task

As mentioned in Chapter III, the Amplitude Analysis is carried out to determine the muscle contraction when interacting with certain driving tasks. Figure 4.34 to Figure 4.37 show the Amplitude Analysis in the form of mean RMS value for each of steering wheel action for each position. As stated in Chapter III (Section 3.3.2 (b)), each condition has a specific value of %MVIC taken for this study. This %MVIC value is presented in bracket for each action. Based on Figure 4.34, for L10 turning of the DL pre and post driving activity at position A, the mean RMS value are: 6.21 (3%) to 8.62 µV (4%). For L45 turning, the RMS values for pre and post activity are 7.31 (4%) and 6.56 µV (4%). For R45 turning, the RMS values for pre and post activity are 27.55 (17%) and 34.85 µV (20%).

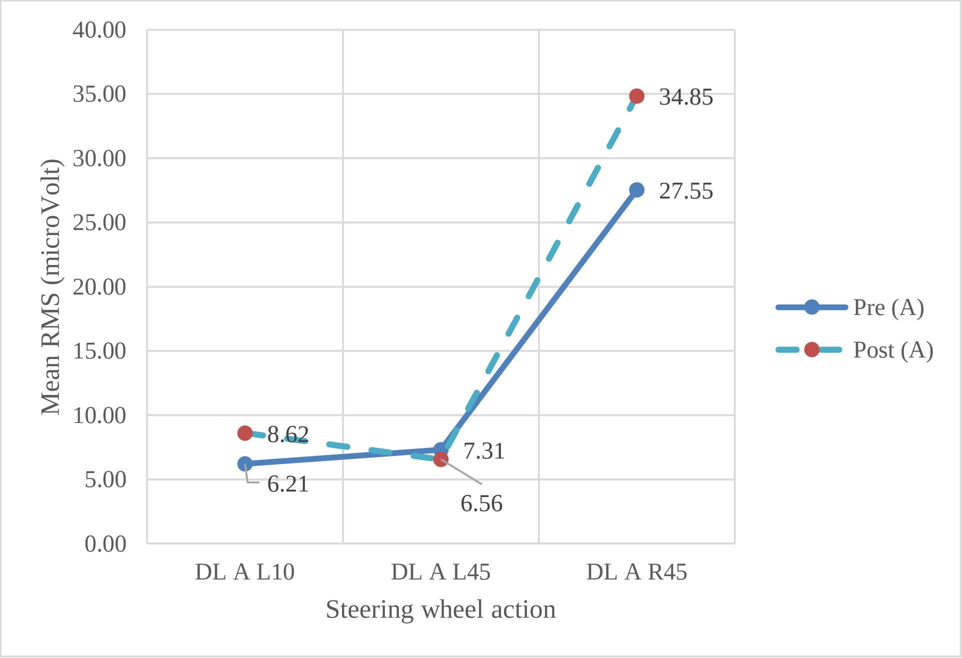


Figure 4.34 Amplitude analysis of DL for L10, L45 and R45 actions according to steering wheel (position A)

Meanwhile, as shown in Figure 4.35, for L10 turning of the DL post driving activity at B, the mean RMS values also demonstrated a similar trend, where the RMS for pre and post activity are 10.56 (6%) and 13.65 µV (7%). For L45 turning, the RMS values for pre and post activity are 13.18 (8%) and 14.09 µV (8%). For R45 turning, the RMS values for pre and post activity are 33.21 (22%) and 37.81 µV (25%). Overall, R45 turning at position B depicts the highest mean RMS compared to position A and in all actions, while L10 shows the lowest mean RMS value at position A compared to position B and in all actions.

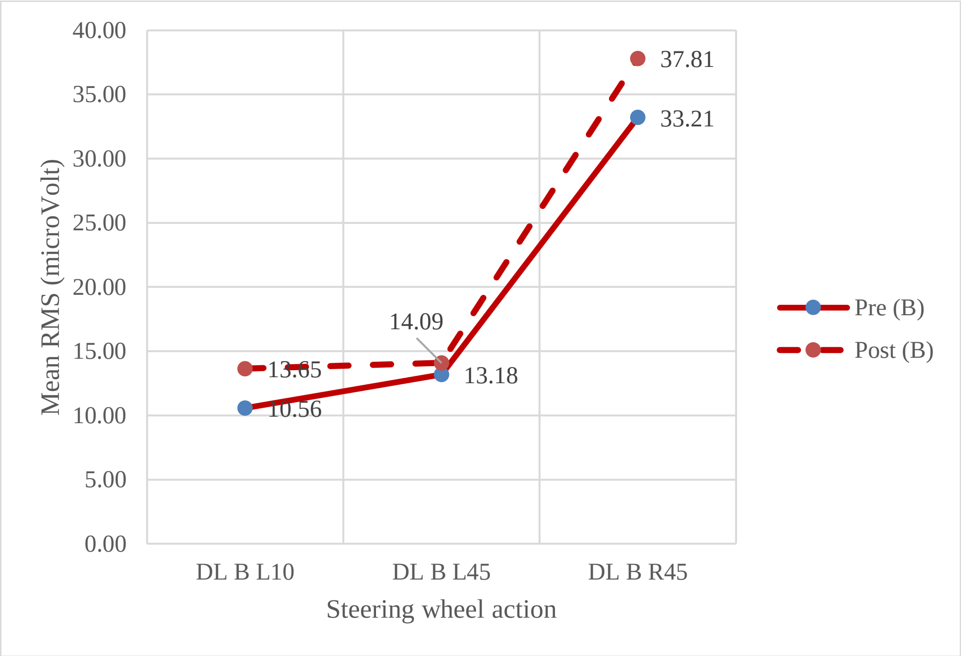


Figure 4.35 Amplitude analysis of DL for L10, L45 and R45 actions according to steering wheel (position B)

According to Figure 4.36 and Figure 4.37, a similar pattern of increment can also be seen for the DR muscle, but based on different turning. In terms of turning direction, L45 depicts the highest mean RMS value at position B compared to position A for both pre-post activity, 34.01 (23%) and 29.45 µV (20%) (pre activity) as well as 33.72 (23%) and 24.51 µV (16%) (post activity). Whereas, R45 showed the lowest mean RMS value at position A compared to position B for both pre-post activity, 13.41 (9%) and 20.22 µV (13%) (pre activity) as well as 11.65 (8%) and 17.57 µV (13%) (post activity).

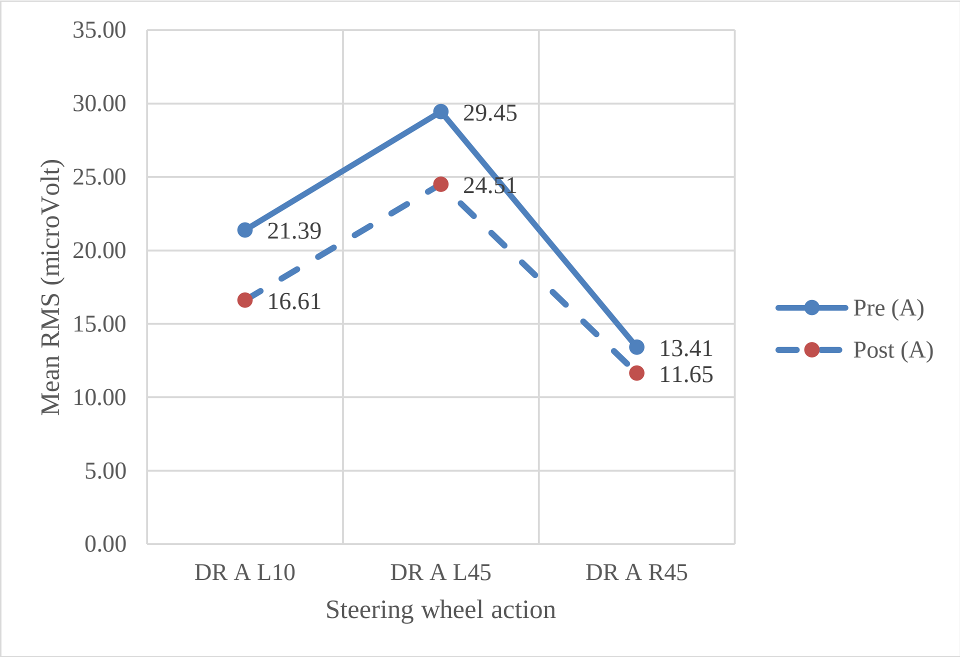


Figure 4.36 Amplitude analysis of DR for L10, L45 and R45 actions in the steering wheel (position A)

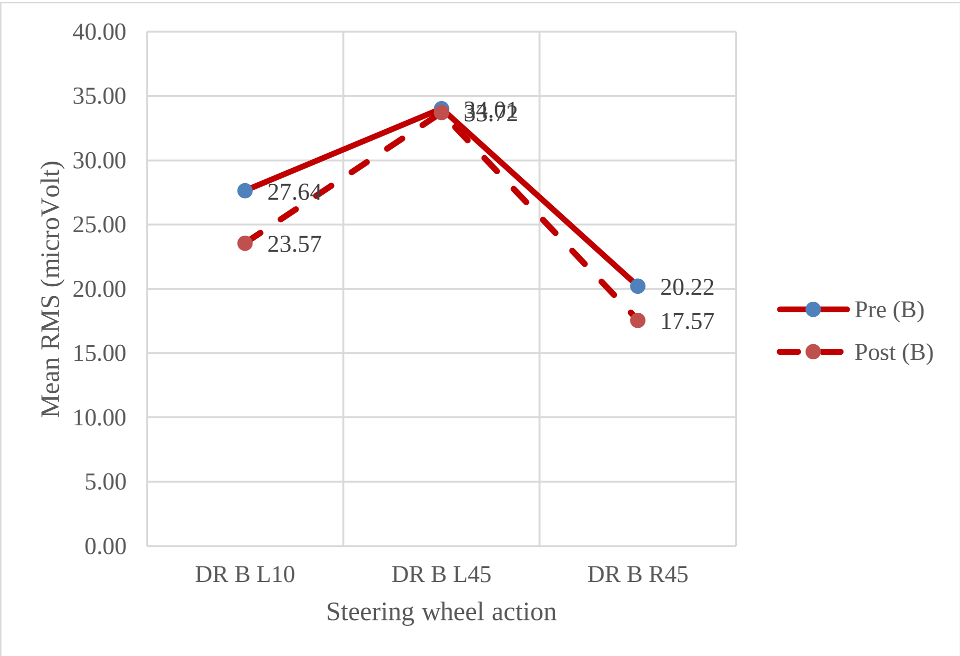


Figure 4.37 Amplitude analysis of DR for L10, L45 and R45 actions in the steering wheel (position B)

As stated in Chapter III, the elbow angle of each position was measured. Based on the elbow angle, the hand when engaged with the steering wheel is in the elbow flexion at mean 114.44^0 (SD=12.00) for position A, while at mean 148.89^0 (SD=6.00) for position B. All in all, with respect to these findings for the DL and DR at position A and B, it shows that there is an increasing pattern with the distance from the steering wheel. It can be concluded that position B showed the highest mean RMS value for all action. On the other hand, in terms of pre and post activity, there was only a slight increment for some actions. However, in order to evaluate whether the pattern is significant or not, a thorough analysis using statistical method was carried out in the next section.

c. Thorough analysis on steering wheel task

A detailed analysis was performed to determine the association between each variables using statistical analysis. As mentioned in Section 4.1, before performing a detailed statistical analysis, normal distribution test should be performed to determine whether the data is under parametric or non-parametric test. In this section, the difference between degree of turning (10 degree and 45 degree), comparison between pre and post activity and also comparison between positions; were investigated using suitable statistical method, as tabulated in Table 4.9. Appendix M depicts the results from statistical analysis for the steering wheel actions.

Table 4.9 Thorough analysis for steering wheel task

Analysis	**IV**	**DV**	**Significant**
Actions	Three different actions (L10, L45 and R45)	Muscle activity for three actions (L10, L45 and R45)	Yes, except L10-L45. Refer to Appendix M (Table 1).
Positions	Two different positions	Muscle activity for these two positions	Yes. Refer to Appendix M (Table 3).
Pre and post	Two different time periods	Muscle activity for these two periods	Yes, only for R45 action. Refer to Appendix M (Table 2).

In the steering wheel task as tabulated in Table 4.9, three major parts of analysis are explained in this section. The first major part is regarding the differences between actions in controlling the steering wheel. In this case, L10, L45 and R45 are evaluated further. The second part is to differentiate the position A and position B. The final part is to find significant differences between pre and post conditions. This section also investigates whether there is correlation between variables for development a linear model in Chapter V. Only the highest action value was selected for this analysis, which is at R45 and L45 actions at position B. Based on the analysis, there is strong correlation between fore arm length with R45 (r=0.680) and L45 (0.659). There is weak correlation between shoulder length and R45 action (r=0.309).

d. Summary from the muscle activity analysis for steering wheel task

The hand placement while coordinating the steering wheel is expected to affect shoulder muscle activity (Bongers et al., 1990; Keir et al., 2011). The findings from this study proved the principle of muscle loading to support shoulder joint movement while coordinating steering wheel in driving. In this study, DL and DR worked oppositely depending on turning. For instance, DL was highly activated when rotating the steering wheel to the right in short duration of driving. The action requires the shoulder joint to work with the increase range of the left shoulder flexion. The DL was working concentrically to provide more range of the shoulder into flexion.

Comparatively, this study found that the DR and the DL have significant differences in signal pattern of muscle activation when turning the steering wheel to the left, to the middle and to the right. The deltoid are the prime movers for shoulder flexors and shoulder abduction which worked concentrically. The findings of this study correlated with the function of the muscle to move and control the shoulder while driving. When the hand grip is used to rotate the steering wheel to the left, the right shoulder experienced high activation to increase range in shoulder flexion and abduction. The prime mover muscles that work for right shoulder flexion and abduction will experience high activation which to produce the motions in order to complete the rotating steering wheel into left. The pattern of movement justified findings of this study which was found that the DR experienced higher activation as the muscles contract concentrically to complete the range during rotating steering wheel. Whereas, when the steering wheel is turned to right, the right deltoid inhibits the right shoulder from going to adduction. Therefore, it confirmed the findings from other studies, such as from Balasubramanian & Adalarasu (2007) and Pandis, Prinold, & Bull (2015) indicated that the placement of hand while coordinating the steering wheel affects the activation of shoulder muscle especially in the deltoid.

In general, deltoid is the most active muscle in maintaining the arm in a raised position (Pandis, Prinold, & Bull, 2015). Activation of deltoid allows scapular to be stabilized prior the movement that occur in glenohumeral joint while raising arm. Therefore, it justify right deltoid showed to be activated when rotating the steering wheel to left. When rotating steering wheel to left, the right shoulder moves in midrange of flexion and abduction. During setting phase (0-30 abduction, 0-60 flexion), occur at glenohumeral joint, scapula at stable position which movements occur solely at glenohumeral joint. As the motion continue towards midrange of flexion and abduction (30-90 abduction, 60-100 flexion), the actions only require movement of scapula and glenohumeral joint is non-dominant. Therefore, elevation of arm at midrange requires the scapula to have greater motion approaching 1:1 ratio with the glenohumeral joint. Without positional control of scapula, efficiency of humeral muscle is decrease. These dynamic control of deltoids will enable the functional elevation of arm for turning the steering wheel to the left.

Moreover, Pandis, Prinold, and Bull (2015) mentioned that the deltoid presents two times higher activation compared to the rest of the muscle for the upper limb. Repeated high muscle activation in a long duration of driving task could result in muscle fatigue since the deltoid is potentially loaded eccentrically (Lieber & Friden, 1993; Proske & Morgan, 2001). This is because when humerus is elevating & scapula is rotating upward while rotating steering wheel, Deltoid work isometrically as dynamic stabilizer for shoulder stability against forward, upward and inferior translation of humeral head.

In addition, with regards to the degree of turning, the greater degree of turning, more muscle activation will be produced, which is explained from the Temporal Analysis in Figure 4.32 and Figure 4.33. With respect to the different driving positions, there are statistically significant and large differences with each position because it involved different shoulder position extension while driving. Different distant may produce different muscle activation. In this study, the more distant the position, the higher muscle activation is produced. It is in line with COG theory which indicated that the COG will change according to the shoulder and hand position (Hamill & Knutzen 2006; Kumar 1999; Nordin & Frankel 2001; Schafer 1987). Hence, muscle activation for position A is smaller than position B for the 10-2 hand position. In fact, a good position while in seated interface is when the elbow is bent to 90 degrees with regards to the vertical upper arm l and horizontal lower arm (Sanders & McCormick, 1993; Walton & Thomas, 2005). In addition, there is strong correlation between the highest contractions of muscle activity at R45 action with fore arm hand length.

4.4.2 Muscle Activity Measurement for Gear Control

For gear and clutch pedal actions, there are two main actions (gear 1 and gear N) for DL muscle recorded for pre and post driving activity as illustrated in Figure 4.38. Roughly, the time taken for each action is three to five seconds. In this section, investigation on the push and pull concept as well as the shoulder abduction and adduction of the gear shift are conducted. In order to change the gear from N to 1, the driver is required to push the gear shift to the front right. Then, to change the gear 1 back to N, the driver is required to pull the gear shift back to the left.

Figure 4.38 Main actions in gear

a. Temporal analysis on gear task

Figure 4.39 shows the example of the DL response with regards to gear action. Roughly, based on Figure 4.39, it is obvious that when controlling the shift gear, DL produces the lowest muscle activation at GN compared to G1 action. The difference between pushing and pulling activity is found from this Temporal Analysis of gear task.

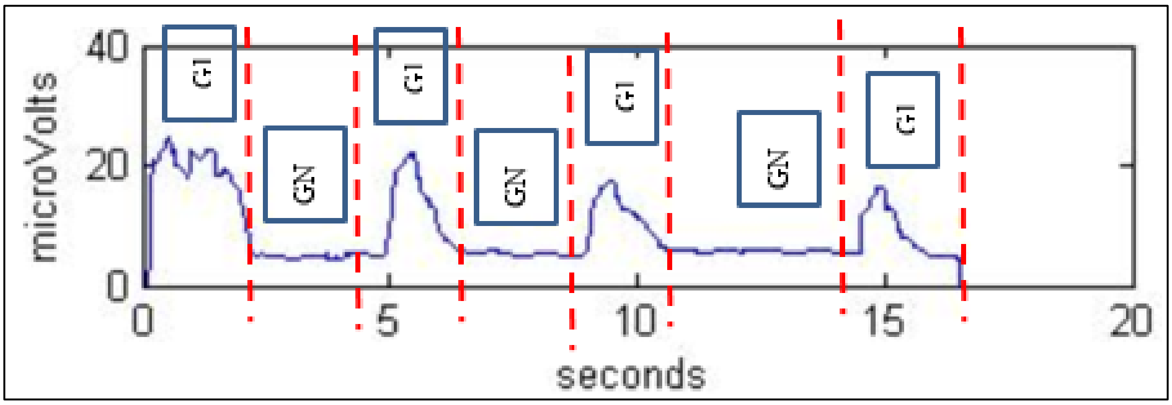


Figure 4.39 Temporal analysis of DL muscle according to gear task

b. Amplitude analysis on gear task

Figure 4.40 and Figure 4.41 show the Amplitude Analysis for gear action for each position. Based on these figures, as mentioned in the previous paragraph, a different activation pattern for G1 and GN is noticed. According to Figure 4.40 and Figure 4.41, in general, there is a significant difference in the pattern between gear 1 and gear N action. The mean RMS value for the pushing activity (from gear N to gear 1) is higher than the pulling activity (from gear 1 to gear N). In addition, with respect to the difference between positions, the mean RMS value increases with the distance from the car control. For G1 action, the mean RMS value for pre-post activity for position A are 21.36 (12%) and 21.33 µV (12%), respectively. Meanwhile, for GN action, the value are 9.36 (5%) and 9.18 µV (5%), respectively.

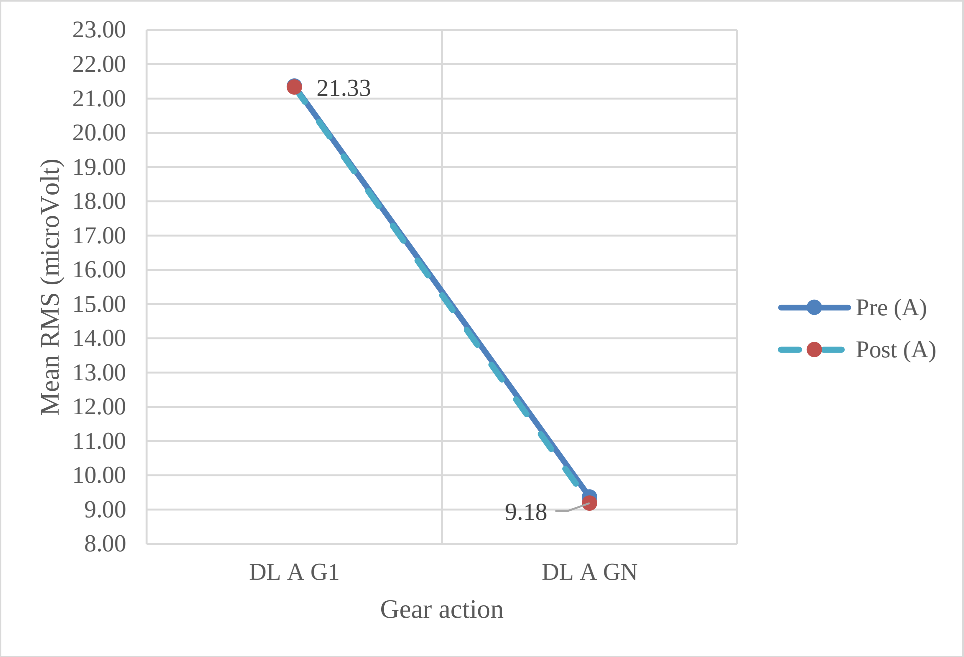


Figure 4.40 Amplitude analysis of DL for G1 and GN actions according to gear task (position A)

With regards to position B as shown in Figure 4.41, similar to the above mentioned figure, the mean RMS value of G1 action for pre-post activity are 35.70 (20%) and 33.82 µV (19%), respectively. Whereas, for GN action, the value are 15.88 (8%) and 13.07 µV (6%), respectively.

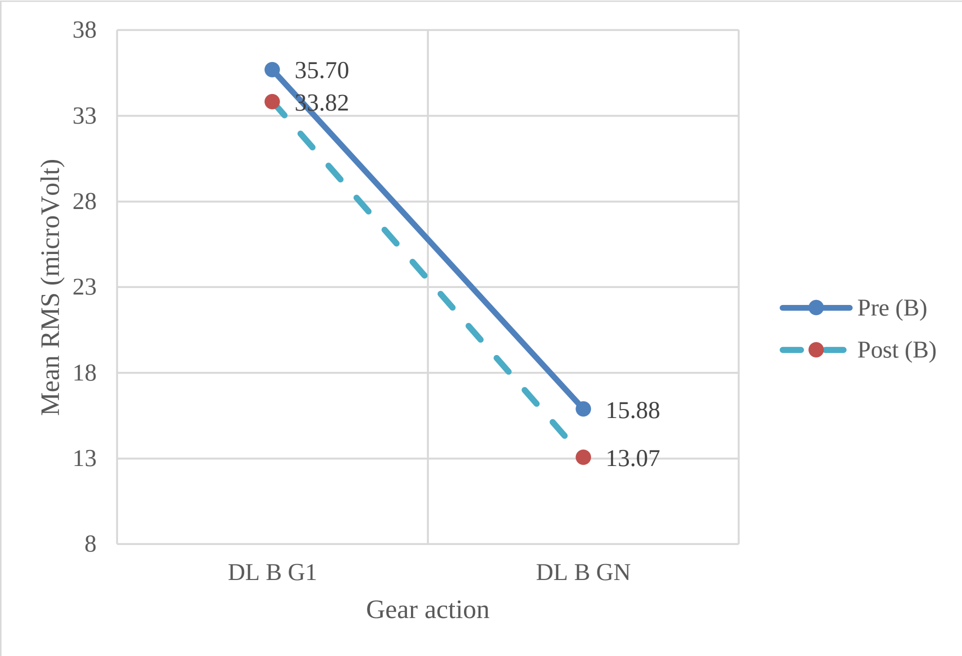


Figure 4.41 Amplitude analysis of DL for G1 and GN actions according to gear task (position B)

c. Thorough analysis on gear control

A detailed analysis was carried out to identify the association between each variable using statistical analysis. In this section, the difference between actions (push and pull concept, referring to G1 and GN), comparison between pre and post activity and also the comparison between positions are analysed using suitable statistical method, as depicted in Table 4.10. Appendix N provides the details on the statistical analysis for this task. The normality test was also carried out on gear task data, as shown in Appendix G.

Table 4.10 Thorough analysis for gear task

Analysis	**IV**	**DV**	**Significant**
Actions	Two different actions (GN, G1)	Muscle activity for two actions (GN, G1)	Yes. Refer to Appendix N (Table 1).
Positions	Two different positions	Muscle activity for these two positions	Yes. Refer to Appendix N (Table 3).
Pre and post	Two different time periods	Muscle activity for these two periods	No. Refer to Appendix N (Table 2).

This section also investigatse whether there is correlation between variables for development a linear model in Chapter V. Only the highest action value was selected for this analysis, which is at G1 action at position B. Based on the analysis, there is strong correlation between shoulder grip length and fore arm length with r above 0.80 ($p<0.05$). Refer to Appendix N (Table 4).

d. Summary on muscle activity for gear task

As clarified in the steering wheel action, the deltoid plays an important role to move and control the shoulder while driving. When the left hand is changing the gear from mid (refer to gear N) to upper-left (refer to gear 1) or otherwise from mid to down-left (refer to gear 2), the shoulder experienced high activation so as to increase the range in shoulder flexion and abduction. In this study, it was found that the pushing activity (gear N to gear 1) requires higher muscle activation compared to the pulling activity (gear 1 to gear N). In fact, DL is the dominant muscle in gearing action, particularly during the pushing task.

According to the different driving positions, findings show similar pattern with steering wheel task. The Temporal Analysis in Figure 4.39 and Figure 4.40 show that, there are significant and large differences with each position because it involved different shoulder position extension while driving. Different distant may produce different muscle activation. The COG theory is applied for this condition due to changes of shoulder range when engaged with the gear. Hence, muscle activation for position A in gearing task is smaller than position B for the 10-2 hand position. In addition, there is strong correlation between muscle activity for G1 action and fore arm length and shoulder grip length.

4.4.3 Muscle Activity Measurement for Accelerator Pedal Action

Accelerator pedal requires action and response from the leg muscle namely, the TA and the GR. In this study, three main actions of the accelerator pedal (HP, R and FP) were recorded as shown in Figure 4.42. Roughly, five seconds is taken for each pedal action.

This study is conducted to investigate the reaction of the leg muscle while performing the HP, R and FP.

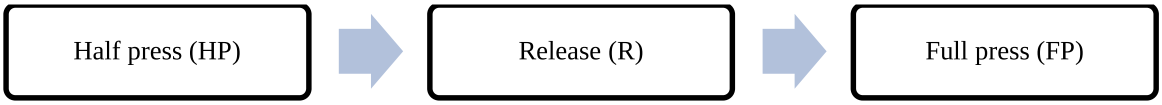


Figure 4.42 Main actions in accelerator pedal

a. Temporal analysis on accelerator pedal task

Figure 4.41 shows the example of Temporal Analysis for the TR, while Figure 4.42 illustrates the example of Temporal Analysis for GR. Based on Figure 4.41 and Figure 4.42, it is obvious that the TR is highly activated in releasing pedal position. In contrast, the GR is highly activated in pressing condition. This is in line with past studies which found that the TR and the GR work in opposite direction during pressing task (Yusoff et al. 2016). Detailed analysis on this finding is performed using statistical analysis to determine the association between each parameter.

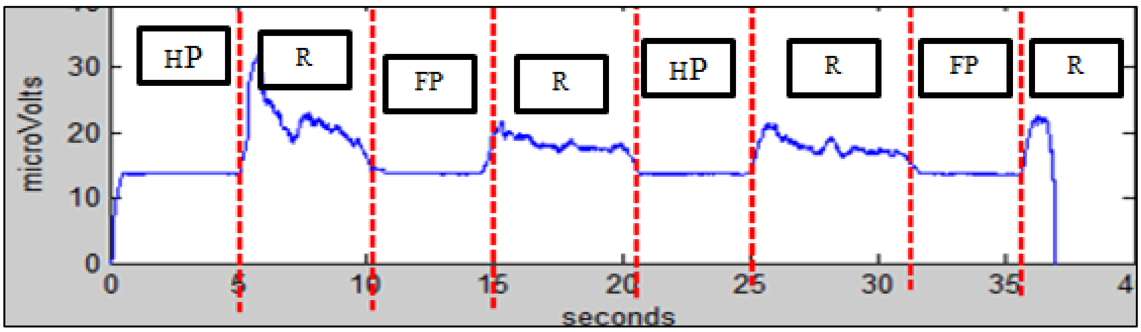


Figure 4.43 Temporal analysis of TR muscle according to pedal task

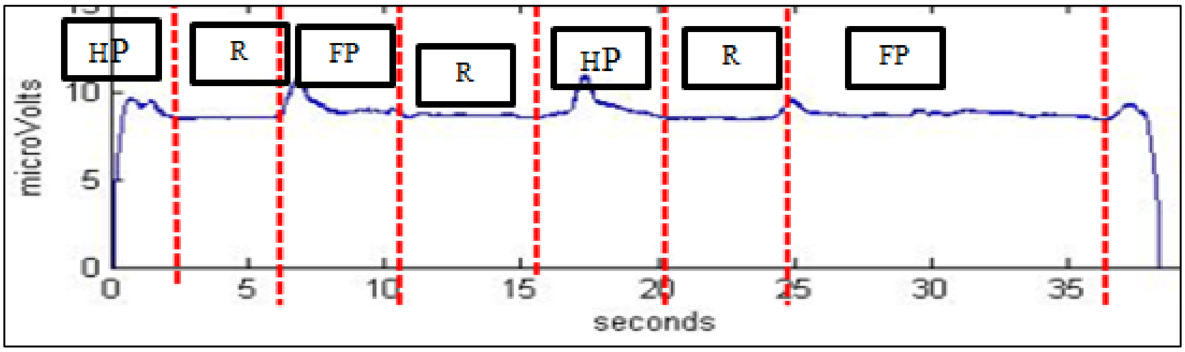


Figure 4.44 Temporal analysis of GR muscle according to pedal task

b. Amplitude analysis on accelerator pedal task

Figure 4.45 and Figure 4.46 show the Amplitude Analysis for both muscles, TR and GR based on RMS value for position A and B. As stated in the previous paragraph, the TR shows a different pattern when pressing and releasing the pedal. In addition, there are some significant differences between each position. Further analysis using statistical analysis method is described after this section. According to Figure 4.45 and Figure 4.46 for TR muscle, in general, there is a significant difference in the pattern for all three actions, HP, R and FP of the car accelerator pedal. The mean RMS value for R action is higher than the HP and FP actions. In addition, with respect to the difference between positions, there is a significant pattern for releasing action based on the knee angle. For HP action, the mean RMS values for pre-post activity for position A are 4.58 (15%) and 5.18 µV (15%) respectively. For R action, the mean RMS values for pre-post activity are 10.09 (30%) and 11.05 µV (30%). Meanwhile, for FP action, the values are 6.37 (20%) and 5.61 µV (20%), respectively.

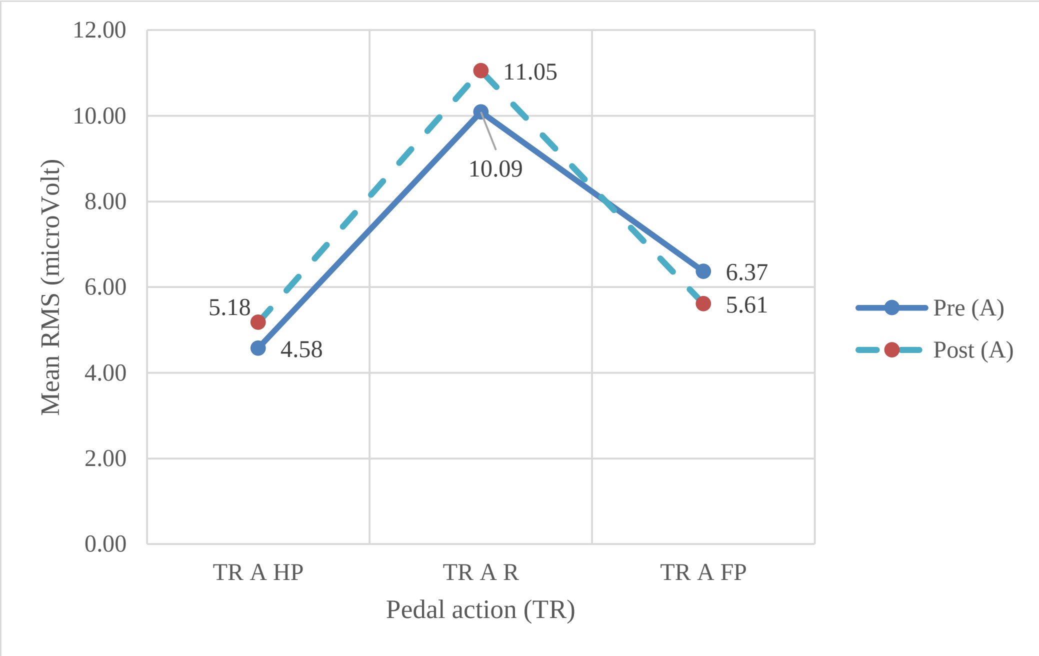


Figure 4.45 Amplitude analysis of TR for HP, R and FP actions according to pedal task (position A)

With regards to position B as shown in Figure 4.46, the mean RMS values of HP action are 5.12 (15%) and 4.69 (15%) µV. For R action, 8.10 (25%) and 9.24 (25%) µV, while for FP action, 5.82 (20%) and 5.53 (20%) µV respectively.

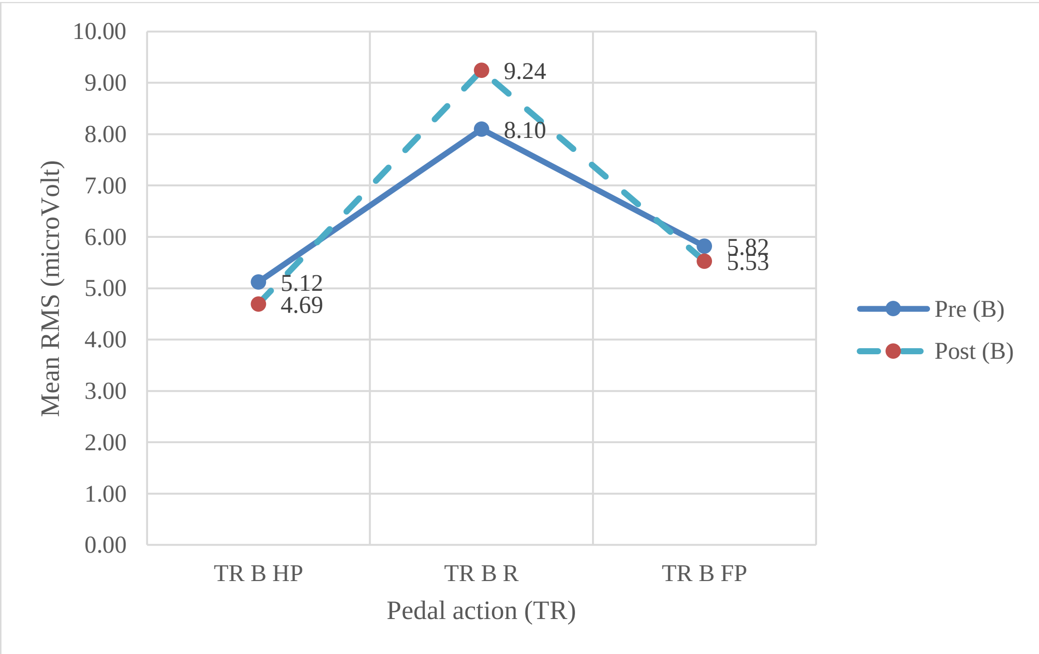


Figure 4.46 Amplitude analysis of TR for HP, R and FP actions according to pedal task (position B)

Figure 4.47 and Figure 4.48 illustrate the amplitude analysis findings for the GR muscle. With respect to the difference between positions, there is significant pattern for pressing action based on the knee angle. The mean RMS values of the FP action increases with the distance of the knee angle. For HP action, the mean RMS values for pre-post activity for position A are 5.54 (23%) and 6.04 µV (23%) respectively. For R action, the mean RMS values are 4.61 (20%) and 5.35 µV (20%). Meanwhile, for FP action, the values are 6.77 (25%) and 6.67 µV (25%), respectively.

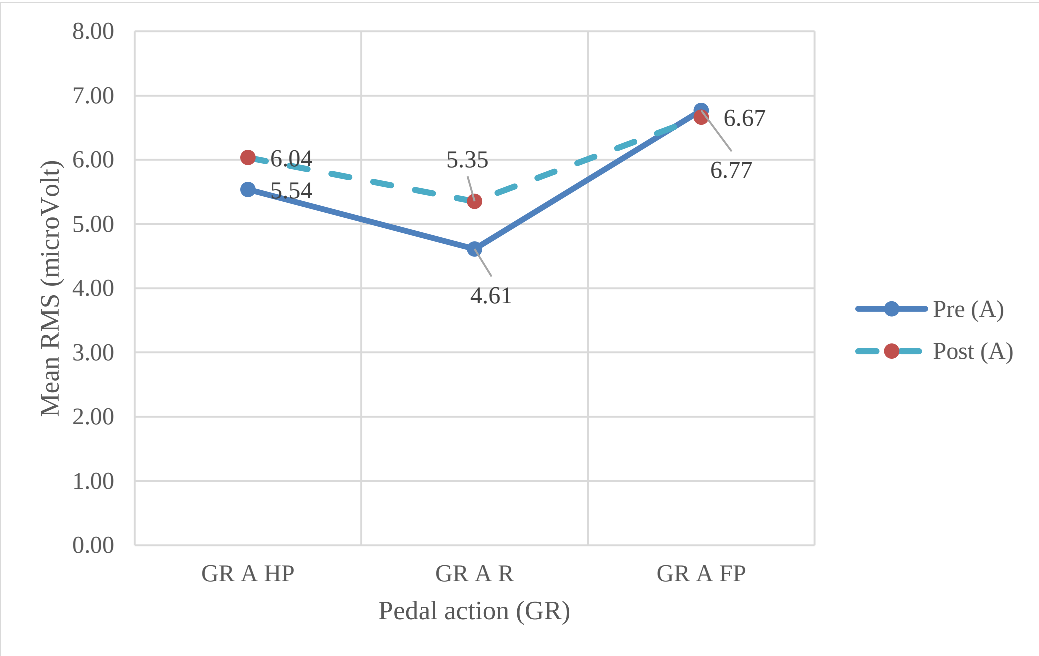


Figure 4.47 Amplitude analysis of GR for HP, R and FP actions according to pedal task (position A)

According to Figure 4.48, the mean RMS values of HP action for pre-post activity are 6.22 (25%) and 6.27 µV (25%), respectively. Meanwhile, for R action, the values are 4.30 (15%) and 4.14 µV (15%), respectively. Meanwhile, for FP action, the values were 7.77 (30%) and 7.63 µV (30%).

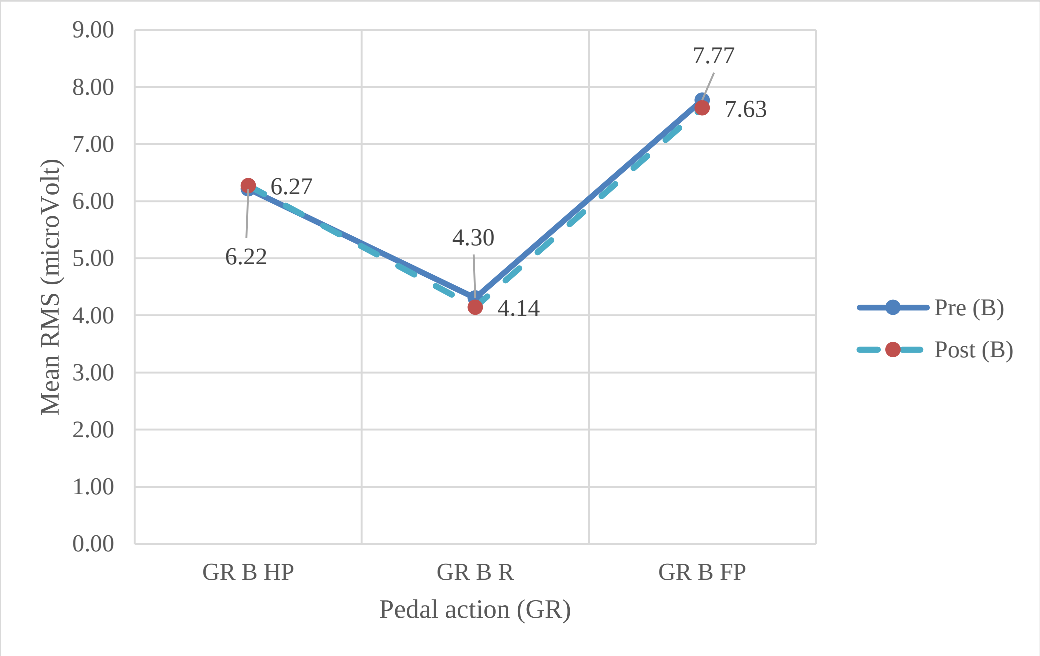


Figure 4.48 Amplitude analysis of GR for HP, R and FP actions according to pedal task (position B)

As stated in Chapter III, the ankle and knee angle of each position was measured. Based on the ankle angle, it showed that the toe when full pressing the accelerator pedal was in the flexion at mean 104^0 (SD=4.00) for position A, while at mean 114^0 (SD=9.00) for position B. For releasing action, the ankle angle at position was at mean 90^0 (SD=2.00), while position B at mean 104^0 (SD=4.00). Whereas, for the knee angle, it showed that the leg when engaging with the pedal was at mean 101.77^0 (SD=4.01) for position A, while at mean 135.09^0 (SD=4.01) for position B. All in all, with respect to the findings for the TR and GR at position A and B, it shows that there is an increasing pattern with the distance from the car control for GR, while the opposite pattern was found at TR. Therefore, it can be concluded that position B gave the highest mean RMS for pressing action at GR muscle, while position A gave the highest mean RMS for releasing action at TR muscle. On the other hand, in terms of pre and post activity, in general, there is only a slight increment for some actions. However, in order to evaluate whether the pattern is significant or not, a thorough analysis using statistical method is performed in the next section.

c. Thorough analysis on accelerator pedal action

A detailed analysis was carried out to identify the association between each variables using statistical analysis. In this section, the difference between action (HP, R and FP), comparison between pre and post activity and also comparison between positions are analysed using suitable statistical method, as demonstrated in Table 4.11. Appendix N provides details on the statistical analysis for this task. Furthermore, the normality test was carried out on the accelerator pedal task data, as shown in Appendix G.

Table 4.11 Thorough analysis for pedal task

Analysis	IV	DV	Significant
Actions	Three different actions (HP, R and FP)	Muscle activity for three actions (HP, R and FP)	TR: Yes, except FP-HP. Refer to Appendix O (Table 1). GR: Yes. Refer to Appendix O (Table 2).
Positions	Two different positions	Muscle activity for these two positions	TR: Yes, except FP-HP. Refer to Appendix O (Table 5). GR: Yes. Refer to Appendix O (Table 6).
Pre and post	Two different time periods	Muscle activity for these two periods	TR: No. Refer to Appendix O (Table 3). GR: No. Refer to Appendix O (Table 4).

This section also investigates whether there is correlation between variables for the development of a linear model in Chapter V. Only the highest action value was selected for this analysis, which is at R action at position A for TR and FP action at position B for GR. Based on the analysis, there is strong correlation between knee angle with R action at position A for TR muscle ($r=0.946$, $p<0.05$) and knee angle with FP action at position B for GR muscle ($r=0.918$, $p<0.05$). Refer to Appendix O (Table 7).

d. Summary on muscle activity for accelerator pedal action

As a conclusion for the accelerator pedal activity, the lower leg is the prime mover for controlling the pedal in the driving task. As stated in Chapter 2, Section 2.7.2, there are two leg positions referring to ankle joint movement; plantar flexion and dorsiflexion (Keene, 2010). In this study, the plantar flexion is referred to the pressing of the pedal, while dorsiflexion is referred to the releasing of the pedal. Dorsiflexion happens when the driver releases the pedal with the ankle joint angle is less than 90° and at the maximum of 70°. Meanwhile, the plantar flexion occurs when the driver presses the pedal with the ankle joint angle greater than 90° and at the maximum of 140°.

With regards to the muscle activation, based on the findings of the TR and GR muscle as shown in Figure 4.43 and Figure 4.44, the TR is the prime mover in the dorsiflexion condition, while the GR plays its role in plantar flexion condition. When releasing the car pedal, TR showed the greatest muscle activation based on the RMS value, which is more than 5 µV. Meanwhile, the GR activated below than 5 µV when releasing the car pedal, particularly for pre activity. In contrast, when pressing the pedal, either a HP or FP, the GR showed the highest activation which is more than 5 µV, while the TR showed a value below 5 µV. According to these findings, it shows that the TR muscle is in the rest condition when pressing the pedal, while the GR muscle is in the rest condition when releasing the pedal, particularly for pre activity. According to Florimond (2009), the muscle is in the rest condition when its amplitude is between +/- 5 µV. If more than +/- 5 µV, it is then activated. With respect to the position, the knee angle and the ankle joint angle determine the activation value of the muscle. In addition, there is a strong correlation between muscle activity and knee angle.

4.4.4 Summary on Muscle Activity Measurement

In this study, musculoskeletal analysis of steering wheel manoeuvre, gear transmission and accelerator pedal function are carried out. This section respond to the fourth research question and third objective in this study, which evaluated the SEMG signal for the muscle activity based on different positions and actions. For the steering wheel and gear action, upper limb muscles, particularly at the shoulders are studied and discussed. Apart from the shoulder, the leg plays an active role in driving task. In this case, the leg is a prime mover for controlling the pedal. Following conclusions are reached based on these assessments from this study:

- Muscle for steering wheel task: The primary muscle for steering wheel are numerous, however each muscle work differently based on the tasks. In this study, deltoid is the prime mover when handling the steering wheel. DL and DR work in opposite way when turning to the left and to the right.

- Steering wheel action: Maximum muscle activity changes considerably due to different steering wheel turning degree and direction of turning. When the steering wheel is near its center, the muscle activity is relatively small but it increases rapidly as the steering wheel begins to turn. There are some fluctuations which amplified gradually until it reached the peak value. According to this study, there is not much difference between different degree of turning with similar direction of turning (10 and 45 degree). For example, muscle activity at R45 action, do not shows much significant difference with R10 action. Nevertheless, there is significant difference with the same degree of turning (L10 and R10 or L45 and R45).
- Muscle for gear task: In this study, deltoid is the most prominent muscle for gearing task. When the left hand is changing the gear, the shoulder experienced high activation due to increment of the range in shoulder flexion and abduction.
- Gear action: Each gear action produces significant difference value. In this study, it was found that the pushing activity (gear N to gear 1) requires higher muscle contraction compared to the pulling activity (gear 1 to gear N). This result is in agreement with the results reported by Vilimek et al. (2011), which mentioned that deltoid shows greater activation in pushing task. Basically, muscle contraction is the activation of tension-generating sites within muscle fibers (Basmajian & De Luca 1985; Neumann 2002; Smith 1995). Pushing activity involves isometric contractions of muscles (tension in the muscle remains constant) in the arms and abdomen. Due to this constant condition, the tension in the muscle resulted in higher muscle contraction to support the activity (Amarantini & Bru 2015; Freund, Budingen & Dietz 1975; Yassierli 2015).
- Muscle for accelerator pedal task: The primary muscle for pedal are numerous, however each muscle work differently based on the tasks. It consists of biomechanical movement in operating the pedal by applying different muscles and joint angle to control the pedal. In this study, the TR is the prime mover when releasing the pedal (works in a dorsiflexion with ankle joint movement is less than 90 degrees), while the GR is the prominent muscle when pressing the

pedal (works in a plantarflexion with ankle joint movement is greater than 90 degrees). Both muscles work in opposite way when operating the car pedal.

- Accelerator pedal action: There is significant differences between R action for TR muscle with HP and FP. However, there is not much different between HP and FP for TR muscle. Meanwhile, for GR muscle, all actions show significant difference.

In terms of pre and post task, generally, there is not much significant difference between both conditions for all car controls tasks. This finding shows that 15 minutes of driving activity does not really contribute to high muscle activation at the end of the journey. It is possibly due to the driving task in this study which do not require much turning, changing the gear, accelerating and deaccelerating the pedal.

With regards to driving position, there is a significant difference between positions and different seat positions (A and B). The results were based on the significant level at α=0.05 (5%) or with confidence level 95%. In addition, this study found out that there is relationship between body measurements with the muscle activity output. In fact, these findings were in line with previous studies, as mentioned in Chapter II (Section 2.7.2, point c). For steering wheel task, there is strong correlation between R45 action and fore arm hand length. For gear task, there is strong correlation between G1 action and shoulder grip length. Both activities involving steering wheel and gearing task involve upper body part, particularly shoulder part to control the car. As mentioned by Fazlollahtabar 2010, reach parameter to the car controls may affect driver's perception on discomfort. It refers to how the driver extend and retract their body to reach the controls, such as steering wheel, gear and accelerator pedal when driving the car. It involves the shoulder, hand and foot to reach the controls. Fore arm and shoulder grip length are two common parameters to determine the working distance and reach (Kee & Lee 2012). In Table 2.4 under subsection 2.5.1, it shows that when the driver is reaching something, it will change the posture. Meanwhile, for pedal task, there are strong correlation between R action and knee angle at position A for TR muscle as well as FP action and knee angle at position B for GR muscle. This is in agreement with the result from Kang et al. (2013) that mentioned the change in the joint angle results in the change of muscle length. As a result, variation of muscle contraction can be produced based on different of the joint angle. This fact is also proved by Yusoff et al. (2016).

4.5 ON-ROAD VALIDATION TEST

On-road validation was conducted to determine the pattern of driver's condition when interacting with car seat and car controls based on the actual road condition as shown in Table 4.12. Based on the findings, the task shows similar pattern as shown in simulated road condition. In this case, the important consideration is to investigate which position and action show the highest value according to different driving conditions. In term of alertness level, the test subjects feel sleepier towards the end of the driving activity. The results obtained agreed with previous work conducted by many reseachers (Babkoff, Caspy & Mikulinear 1991; Davenne et al. 2012; Kecklund & Akerstedt 1993; Otmani et al. (2005); Torsvall & Akerstedt 1987).

Table 4.12 On-road validation results

Component	**Highest value**	**Highest position**
Car seat	Buttock	A
Steering wheel	45 turning action	B
Gear	G1 action	B
Pedal	R action (TR)	A
Pedal	FP action (GR)	B

4.6 SIMULATOR OUTPUT

As mentioned in Chapter III, there are three car controls usage recorded in this study. Simulator output interprets driver's performance by considering turning percentage of steering wheel and pressing percentage of pedal control. Table 4.7 and Figure 4.8 show the usage of each car control at the beginning and at the end of driving activity for position A and B. Appendix P depicts part of simulator output for the test subject.

Approximately, the first five minutes of driving activity is categorized as the beginning of the activity, while the last five minutes is categorized as the end of the activity. However, the gear usage is not depicted in Table 4.13 and Table 4.14 because, the usage frequency of the gear only occurred for nearly less than one minute (to gear 5) at the beginning and at the end of driving activity (to gear N) for both positions. Furthermore, as mentioned in Chapter III, the test subjects were required to change the gear level, only at the beginning and at the end of the driving activity. Therefore, only the steering wheel and accelerator pedal are the main active parameters for this simulator output study. As mentioned in Section 3.3.4 in the same chapter, the steering wheel was measured based on the direction and degree of turning. Meanwhile, the accelerator pedal action was measured by the percentage of pedal pressing.

Table 4.13 Average usage of car controls at the beginning of driving activity according to simulator output

Position	Subject	Average turning based on steering wheel (degree)	Average pressing based on accelerator pedal (degree)
A	1	0.00072	0.67
	2	0.00015	0.56
	3	-0.00089	0.67
	4	0.00027	0.61
	5	-0.00034	0.62
	6	0.00011	0.6
	7	0.00047	0.57
	8	0.0029	0.51
	9	-0.00016	0.64
	10	0.00030	0.56
	11	0.00020	0.40
B	1	0.0002	0.55
	2	-0.00002	0.55
	3	0.00029	0.61

To be continued…

…continuation

4	0.00711	0.62
5	0.00066	0.62
6	-0.00037	0.57
7	0.00085	0.56
8	-0.00069	0.57
9	0.00047	0.63
10	0.00027	0.50
11	0.00029	0.61

Table 4.14 Average usage of car controls at the end of driving activity according to simulator output

Position	**Subjects**	**Average turning based on steering wheel (degree)**	**Average pressing based on accelerator pedal (degree)**
A	1	-0.00023	0.62
	2	-0.0003	0.54
	3	-0.00026	0.62
	4	-0.00021	0.62
	5	-0.00023	0.62
	6	-0.00013	0.62
	7	-0.00073	0.55
	8	-0.00016	0.59
	9	-0.0001	0.6
	10	-0.0001	0.6
	11	-0.0002	0.6
B	1	-0.0003	0.54
	2	0.00032	0.51
	3	0.0001	0.61

To be continued…

…continuation

4	-0.00039	0.61
5	-0.0009	0.62
6	0.0004	0.62
7	-0.00015	0.54
8	-0.00051	0.56
9	0.00027	0.61
10	0.0001	0.50
11	0.0001	0.50

In Table 4.13, for steering wheel task at position A, it shows that subjects 3, 5 and 9 turned the wheel more to the left side. This is indicated by the negative (-ve) value of the average turning. Meanwhile, for position B in Table 4.13, subjects 2, 6 and 8 show a similar pattern of turning the wheel to the left. According to the average pressing of the accelerator pedal, the test subjects pressed the pedal up to 50 to 60 % for both positions. According to Table 4.14, in terms of steering wheel task, all subjects turned the wheel more to the left at position A. Meanwhile, for position B, only subjects 2, 3, 6 and 9 turned the wheel more to the right, giving a positive (+ve) value of average turning. Differences of average turning and pressing possibly due to driving style of each test subject (Belz 2000; Kircher, Uddman, & Sandin, 2002; Svensson 2004).

4.7 SUMMARY OF CHAPTER IV

Driving in a car requires different tasks compared to just sitting on a car seat. When the driver uses the steering wheel, the hand and arm are higher compared to just sitting on a car seat. In addition, in a manual transmission system, one arm and hand have to shift the gear according to the driving condition. In order to control the pedals, the driver requires extending or retracting the legs to operate the accelerator, brake or clutch pedals. All these arm-hand and leg adjustments are based on the driving position, either near to the steering wheel or far away from the steering wheel. As mentioned in Chapter III, there are two positions evaluated in this study. Position A refers to the test subjects' position being near to the car controls (steering wheel, gear and pedal), while Position B refers to position far away from the car controls as long as the test subject can operate the control.

Based on the findings of the subjective assessment in Section 4.2, the discomfort level perception relies on the driving task, position and action. As mentioned in Chapter III, an evaluation was carried out on the shoulder part and lower leg. The shoulder part is represented by DL and DR muscle for steering wheel, DL muscle for gear control, while the lower leg is represented by TR and GR muscle for accelerator pedal control. With regards to actions in each control, the highest discomfort level was recorded from R45 turning (for DL muscle in steering wheel control), L45 turning (for DR muscle in steering wheel control), G1 action (for DL muscle in gear control), R action (for TR muscle in pedal control) and FP action (for GR muscle in pedal control). Meanwhile, referring to the position for each control, the steering wheel and gear control recorded the highest discomfort level at position B, whereas the pedal control showed the highest discomfort level at position A. With regards to pressure felt level, the buttock showed the highest pressure felt by the test subjects, particularly at position A. To respond to the first and second research question in Chapter I, generally, the driver's perception related to pressure felt and discomfort level is different between car seat and each car control as well as driving positions.

Pressure distribution was recorded while the subject is gripping the steering wheel at certain hand position with different distance positions from the steering wheel. The shape of the car seat may put pressure on selected parts of the legs, back and buttocks, as described in Section 4.3, particularly in Figure 4.22, Figure 4.23, Figure 4.27 and Figure 4.28. This continuous contact in the long run can lead to pain or discomfort at pressure points and may affect blood flow to the legs and feet. Based on Section 4.3, the pressure of heavier subjects is more scattered at the buttock area, while lighter subjects have mild stress concentrated under ischium tuberosity. In terms of back rest, the pressure of heavier subjects is more scattered, and concentrated particularly at the lower back, while lighter subjects have mild stress concentrated at the middle back.

The buttock showed the highest pressure distribution particularly at position A. Overall, this section provides answer for the third research question in Chapter I.

Muscle contraction measurement using SEMG was collected when the subjects are engaged in different driving tasks as mentioned earlier in this chapter. The shoulder part represents the steering wheel and gear task, while the lower leg part represents the accelerator pedal task. Temporal and Amplitude Analysis were performed to identify the pattern of the muscle based on certain driving conditions. The specific aim of both analysis is described in Chapter III.

For the steering wheel task, the shoulder part is represented by DL and DR muscle. Both muscles are the prime mover for turning action and they worked oppositely depending on the direction of turning. When turning to the left, the DR muscle showed the highest activation and when turning to the right, the DL muscle demonstrated the highest activation. Comparison between the position and action was carried out for the steering wheel task. Based on this analysis, for the DL muscle, R45 turning at position B showed the highest mean RMS compared to position A and in all actions. In contrast, for the DR muscle, L45 turning at position B showed the highest mean RMS compared to position A and in all actions. In general, 45 degrees of turning at position B showed the highest mean RMS for both muscles. In terms of muscle selection for the model, the DL muscle is selected based on the consistency of the certain activities derived from thorough statistical analysis. In this case, it refers to the comparison between actions for each data. Overall, there is significant difference of muscle activity for both positions (A and B) and turning action particularly at R45 action. Therefore, at the significant level, $\alpha = .05$ (5%), the first hypothesis for steering wheel control in Chapter I (subsection 1.6.1), H_0 would be rejected.

For gear task, the DL experienced high activation so as to increase the range in shoulder flexion and abduction when pushing and pulling the gear shift to the required gear level. Comparison between action and position was conducted on gear task. Based on this analysis, for DL muscle, G1 action showed the highest mean RMS value compared to GN action. Meanwhile, in terms of position, position B illustrated the highest mean RMS value compared to position A. All in all, G1 action at position B showed the highest mean RMS value for gearing task control. Overall, there is significant difference of muscle activity for both positions (A and B) and gear actions (G1 and GN). Therefore, at the significant level, $\alpha = .05$ (5%), the first hypothesis for gear control in Chapter I (subsection 1.6.1), H_0 would be rejected.

For accelerator pedal task, TR and GR played different roles while engaging with the pedal. TR showed the highest muscle contraction in R action at position A. On the other hand, GR showed the highest muscle contraction in FP action at position B. Overall, based on the findings on the comparison between muscles, each selected muscle in this study demonstrated different activation according to the task. Overall, there is significant difference of muscle activity for both positions (A and B) and pressing action particularly at R and FP action. Therefore, at the significant level, $\alpha = .05$ (5%), the first hypothesis for accelerator pedal control in Chapter I (subsection 1.6.1), H_0 would be rejected.

With respect to the driving position and actions, different positions and different actions can produce different muscle contraction. As mentioned in Chapter II, when the driver is reaching car controls, it will change the posture and also driving position. This section provides answer for the fourth research question in Chapter I. Based on the analysis in Chapter IV, it can be concluded that when the driver sits too close to the car controls (position A), considerable muscular discomfort is caused to the lower leg, particularly in releasing position. This is in agreement with the findings from previous studies, such as Tanaka et al. (2009), Wang et al. (2004), and Yusoff et al. (2016). In addition, the highest pressure can be found at the buttock for the car seat at position A, compared to the thigh at the similar position. However, there is no significant difference at the other body parts (such as upper back and lower back). This is because other body parts is less sensitive to the pressure distribution as clarified previously by Harrison et al. (2000). It is also inline with previous study conducted by Daruis (2010) and Hiemstra-van Mastrigt et al. (2017). As mentioned by both researchers, in terms of different position, buttock part shows significant change of pressure distribution when sitting in different posture.

Meanwhile, when the driver sits too far away from the car controls (position B), muscular discomfort can be seen at the shoulder and lower leg in pressing position. It is inline with previous works carried out by Pandis, Prinold & Bull (2015) for activity involving shoulder part and Tanaka et al. (2009) for activity involving lower leg part in pressing action. Again, these findings answer the first hypothesis, which is there is significant difference between positions for each car controls. Overall, as highlighted in Section 2.8, different positions and actions may influence driver's condition due to difference in seat distance, seat position and hand or leg position or movement. According to the past studies, it has an effect on COG, muscle contraction, muscle force and stability (Hamill & Knutzen 2006; Kumar 1999; Nordin & Frankel 2001; Pandis, Prinold & Bull 2015; Schafer 1987; Tanaka et al. 2009; Yusoff et al. 2016).

With regards to pre and post activity, there were significant differences for subjective assessments. For pressure distribution measurement, there were significant differences for the buttock at both positions. Muscle activity for steering wheel task showed that, there were some significant differences between DL and DR muscle for R45 action at both positions (refer to Section 4.4.1c, point no. 2). In addition, for gear and pedal task, on average, there was no significant difference between certain positions and actions (refer to Section 4.4.2c point no. 2 and Section 4.4.3c, point no. 3 and 4). Hence, it can be concluded that 15 minutes of driving activities did not really contribute to high muscle activity at the end of the driving journey. Overall, there is not much significant difference of muscle activity for pre and post activity for both positions (A and B) for certain car controls task. Therefore, at the significant level, $\alpha = .05$ (5%), the second hypothesis for car controls in Chapter I (subsection 1.6.1), H_0 would be accepted.

Relationship between pressure distribution and muscle activity with the body measurement have been carried out in this study. Based on the findings, there is strong correlation between pressure at the buttock at position A with buttock to popliteal length ($r>0.80$). For the steering wheel task, there is strong correlation between muscle activity at position B for R45 action with fore arm hand length ($r>0.80$). For the gear task, there is strong correlation between muscle activity at position B for G1 action with shoulder grip length ($r>0.80$). For the pedal task, there is strong correlation between TR's muscle activity at position A for R action with knee angle (r>0.80). Moreover, there is also strong correlation between GR's muscle activity at position B for FP action with knee angle (r>0.80).

Driver's condition of the test subjects was also monitored in this study, as shown in Section 4.2.5. There are two approaches used in evaluating driver's condition in this study, alertness scale and cardiovascular pattern. Based on the alertness scale, the majority of test subjects felt sleepier at the end of the driving activity, compared to before and during the activity. Meanwhile, for cardiovascular pattern, the majority of test subjects showed a reduction of HR and BP before and after driving. As stated in Section 4.2.6, the variation in cardiovascular pattern might be possibly due to the variation of stress felt by the test subjects. Besides that, variations in the surrounding environment in the simulated condition such as the the room temperature, road marks input and the road surrounding also influence human response while driving. It is also proved by previous study carried out by Hallvig et al. (2013). In this study, there is slightly different response in terms of physiological factors when comparing results from the simulator and actual experiment. Details on application of simulator in the past studies, can be referred in Section 2.6.1. In addition, simulator output was also gathered in this study. Based on this output, there are variations for the degree of turning value for steering wheel task and percentage of pressing pedal. Overall, assessment on driver's alertness and cardiovascular pattern answers the third hypothesis. There is not much significant difference between alertness level and cardiovascular pattern between two periods of time. Therefore, at the significant level, $\alpha = .05$ (5%), the third hypothesis in Chapter I (subsection 1.6.1), H_0 would be accepted.

The findings in this chapter are elaborated in the Chapter V by determining the association between each parameter with the others variables. Suitable statistical analysis is used to find the relationship between each parameter. Consequently, the driver's condition model can be developed based on the findings for each assessment.

CHAPTER V

MODEL DEVELOPMENT AND VALIDATION

5.1 INTRODUCTION

Chapter V provides explanation on integrated model development for subjective and objective measures in determining drivers' discomfort with regards to driving position and task in a simulated road condition. Data from Chapter IV are used in this chapter to predict and estimate the Dependent Variable (DV) based on the Independence Variables (IVs) by using the Regression Method. The variable to predict is called the DV, while the variable to predict the other variable's value is called the IV or known as the predictor variable. The DV and IV for this study has been determined in Section 3.4.4 (Figure 3.25). In this study, the DV is referred to the subjective assessment, while the IV is referred to the combination of the objective assessment as the first IV (pressure distribution map measurement or muscle activity from the SEMG measurement) with the anthropometric measurement (buttock-popliteal length, shoulder grip length, or fore arm length) or joint angle (knee angle). The variable value (DV and first IV) for each model is based on the highest discomfort rate. Detailed explanation for each model is described in each subsection. This chapter provides the response to the fifth research question and the fourth objective in this study. There are four main sections in this chapter. Section 5.2 describes the integrated model of drivers' discomfort by combining several related IVs in the model. Section 5.3 explains on the validation of sample size, while Section 5.4 provides the Discomfort Index for this study. The final section, Section 5.5 summarizes the findings from Chapter V.

5.2 DRIVER'S DISCOMFORT PREDICTION ACCORDING TO SUBJECTIVE MEASUREMENT, OBJECTIVE MEASUREMENT AND BODY MEASUREMENT

The main focus of this thesis is to develop the model to predict the driver's discomfort when engaging with the car seat and the car controls. This section presents the integrated model of the discomfort level prediction based on the subjective, objective measure and also the body measurement. Multiple regression analysis is performed to develop the integrated model. As mentioned in Chapter III, the anthropometric and joint angle provide significant impact on the human condition based on the activities.

5.2.1 Model for the Pressure Felt Level Prediction

As mentioned in Chapter IV (Section 4.3), buttock-popliteal length showed strong correlation with the pressure distribution with $r=0.914$ ($p<0.05$) (refer to Appendix K). Therefore, this anthropometric measurement is considered in the multiple regression model to predict the pressure felt level on the car seat for the buttock part.

Table 5.1 demonstrates the results from the Regression Method for 5.3.1 model. A value of 0.976 indicates a good level of prediction. The R^2 value is 0.952, while the Adjusted R Square was 0.940, smaller than R Square. Meanwhile, the SEE is 0.260.

Table 5.1 Summary of the pressure felt prediction model

Model	**R**	**R Square**	**Adjusted R Square**	**SEE**
5.2.1	0.976	0.952	0.940	0.260

Table 5.2 depicts the coefficient table for 5.2.1 model. The significant level for IVs were less than 0.05. It indicates the possibility to obtain t value for the constant was 2.761 and the slope for pressure distribution and buttock-popliteal length were 7.175 and -2.334 respectively. Hence, at the significant level, $\alpha = 0.05$ (5%) or at the confidence level 95%, the sixth hypothesis in Chapter I (subsection 1.6), H_0 would be rejected. For full analysis, please refer to Appendix Q.

Table 5.2 Coefficient table for the pressure felt prediction model

Model		**Unstandardized Coefficients**		**Standardized Coefficients**		
		B	**Std. Error**	**Beta**	**t**	**Sig.**
5.2.1	(Constant)	12.936	4.685		2.761	.025
	Pressure unit (x_1)	31.518	4.393	1.365	7.175	.000
	Buttock-popliteal length (x_2)	-.270	.116	-.444	-2.334	.048

a. Dependent Variable: Pressure felt on buttock (Y_1)

Based on the Table 5.2, the equation model to predict the drivers' pressure felt based on pressure distribution and the buttock-popliteal length can be used. It is indicated in Equation (5.1):

$$Y_1 = 31.518x_1 - 0.270x_2 + 12.936 \quad (5.1)$$

As explained in Chapter III (Subsection 3.4.4), in order to validate the multiple linear model, the assumptions related to CLRM should be conducted. The BLUE criteria should be fulfilled with no problem for all five tests; normality, linearity, auto-correlation, heteroscedasticity and multicollinearity. Appendix E shows the full analysis for this model validation. Table 5.3 shows the validation results for the model. According to this findings, the 5.2.1 model fulfilled all these assumptions and in line with the BLUE criteria and OLS method.

Table 5.3 Multiple linear regression validation for the pressure prediction

Assumption	**Pressure felt level**	**Pressure distribution**	**Buttock-popliteal length**
Normality	$df(11)=0.410$, $p > 0.05$	$df(11) = 0.888$, $p > 0.05$	$df(11) = 0.079$, $p > 0.05$
Linearity	-	$r(11) = 0.959$, $p < 0.01$ Positive (linear)	$r(11) = 0.804$, $p < 0.01$ Positive (linear)
Auto-correlation	-	DW test: $0.66 < 0.707 < 1.60$ Run test: Asymp. Sig. (2-tailed) = $0.540 > 0.05$	DW test: $0.66 < 0.707 < 1.60$ Run test: Asymp. Sig. (2-tailed) = $0.540 > 0.05$

To be continued…

…continuation

Heteroscedasticity	-	Beta=1.093, p> 0.05	Beta=1.177, p> 0.05
Multicollinearity	-	Tolerance (0.164 > 0.1) & VIF (6.106 < 10.00)	Tolerance (0.164 > 0.1) & VIF (6.106 < 10.00)

5.2.2 Model for the Discomfort Level Prediction for the Steering Wheel Task

As mentioned in Chapter IV (Subsection 4.4.1), fore arm length showed strong correlation with the muscle activity measurement with r=0.753 (p<0.01) (refer to Appendix M). Therefore, this anthropometric measurement was considered in the multiple regression model to predict the discomfort level for the steering wheel task.

Table 5.4 demonstrates the results from the Regression Method for 5.2.2 model. A value of 0.992 indicates a good level of prediction. The R Square value is 0.983, while the Adjusted R Square was 0.979. Meanwhile, the SEE is 0.139.

Table 5.4 Summary of the discomfort level prediction model for the steering wheel task

Model	R	R Square	Adjusted R Square	SEE
5.2.2	0.992	0.983	0.979	0.139

Table 5.5 demonstrates the coefficient table for 5.2.2 model. The significant level for IVs were less than 0.05. It indicates the possibility to obtain t value for the constant was 0.242 and the slope for R45 action at position B and arm length were 14.181 and -2.489 respectively. Hence, at the significant level, $\alpha = 0.05$ (5%) or at the confidence level 95%, the sixth hypothesis in Chapter I (subsection 1.6), H_0 would be rejected. For full analysis, please refer to Appendix Q.

Table 5.5 Coefficient table for the discomfort prediction model for steering wheel

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
5.2.2	(Constant)	.384	1.585		.242	.815
	R45 action at position B (x_3)	.073	.005	.880	14.181	.000
	Arm length (x_4)	.098	.039	.154	2.489	.038

a. Dependent Variable: Discomfort level (muscle activity R45 action at position B) (Y_2)

Based on the Table 5.5, the p-value for constant or known as intercept is insignificant. Based on theory, the constant is rarely of theoretical interest (Aiken, West & Reno 1991; Frost 2013). In addition, as mentioned by Frost (2013), the constant value should be included in the regression model, even though it is insignificant. If the fitted line does not naturally go through the origin, the regression coefficients and predictions will be biased if do not include the constant. Furthermore, this equation model was validated by using CLRM. The equation model to predict the driver's discomfort level based on muscle activity measurement and arm length can be used. It is indicated in Equation (5.2):

$$Y_2 = 0.073x_3 + 0.098x_4 + 0.384 \quad (5.2)$$

Appendix H shows the full analysis for this model validation. Table 5.6 shows the validation results for the model. According to this findings, the 5.2.2 model fulfilled all these assumptions and in line with the BLUE criteria and OLS method.

Table 5.6 Multiple linear regression validation for the discomfort level prediction for the steering wheel task

Assumption	Discomfort level	Muscle activity	Arm length
Normality	df(11)=0.242, p > 0.05	df(11) = 0.173, p > 0.05	df(11) = 0.607, p > 0.05
Linearity	-	r(11) = 0.985, p < 0.01 Positive (linear)	r(11) = 0.753, p < 0.01 Positive (linear)

To be continued…

…continuation

Auto-correlation	-	DW test: 2.4 < 2.857 <3.34 Run test: Asymp. Sig. (2-tailed) = 0.502 > 0.05	DW test: 2.4 < 2.857 <3.34 Run test: Asymp. Sig. (2-tailed) = 0.502 > 0.05
Heteroscedasticity	-	Beta=0.243, p> 0.05	Beta=0.561, p> 0.05
Multicollinearity	-	Tolerance (0.537 > 0.1) & VIF (1.861 < 10.00)	Tolerance (0.537 > 0.1) & VIF (1.861 < 10.00)

5.2.3 Model for the Discomfort Level Prediction for the Gear Task

As mentioned in Chapter IV (Subsection 4.4.2), fore arm length and shoulder grip length showed strong correlation with the muscle activity measurement with r=0.879 and r=0.815 (p<0.01) (refer to Appendix N). However, only shoulder grip length has an effect on the DV of interest. Therefore, this anthropometric measurement was considered in the multiple regression model to predict the discomfort level for the gear task.

Table 5.7 demonstrates the results from the Regression Method for 5.2.3 model. A value of 0.99 indicates a good level of prediction. The R Square value is 0.98, while the Adjusted R Square was 0.975, smaller than R Square. Meanwhile, the SEE is 0.2.

Table 5.7 Summary of the discomfort level prediction model for the gear task

Model	**R**	**R Square**	**Adjusted R Square**	**SEE**
5.2.3	0.990	0.980	0.975	0.200

Table 5. 8 Coefficient table for the discomfort prediction model for the gear

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
5.2.3	(Constant)	15.756	3.616		4.357	.002
	Gear 1 at position B (x_5)	.090	.006	1.203	13.933	.000
	Shoulder grip length (x_6)	-.191	.059	-.278	-3.214	.012

a. Dependent Variable: Discomfort level (muscle activity G1 action at position B) (Y_3)

Based on the Table 5.8, the equation model to predict the drivers' discomfort level based on the muscle activity measurement and shoulder grip length can be used. It is indicated in Equation (5.3):

$$Y_3 = 0.09x_5 - 0.191x_6 + 15.756 \quad (5.3)$$

Appendix H shows the full analysis for this model validation. Table 5.9 shows the validation results for the model. According to this findings, the 5.2.3 model fulfilled all these assumptions and in line with the BLUE criteria and OLS method.

Table 5.9 Multiple linear regression validation for the discomfort level prediction for the gear task

Assumption	Discomfort level	Muscle activity	Shoulder grip length
Normality	df(11)=0.088, p > 0.05	df(11) = 0.802, p > 0.05	df(11) = 0.679, p > 0.05
Linearity	-	r(11) = 0.977, p < 0.01 Positive (linear)	r(11) = 0.703, p < 0.05 Positive (linear)
Auto-correlation	-	DW test: 2.4 < 2.972 <3.34 Run test: Asymp. Sig. (2-tailed) = 0.19 > 0.05	DW test: 2.4 < 2.972 <3.34 Run test: Asymp. Sig. (2-tailed) = 0.19 > 0.05
Heteroscedasticity	-	Beta=0.564, p> 0.05	Beta=0.242, p> 0.05
Multicollinearity	-	Tolerance (0.336 > 0.1) & VIF (2.975 < 10.00)	Tolerance (0.336 > 0.1) & VIF (2.975 < 10.00)

5.2.4 Model for the Discomfort Level Prediction for the Accelerator Pedal Task (TR)

As mentioned in Chapter IV (Subsection 4.4.3), knee angle for position A showed strong correlation with the muscle activity measurement with r=0.761 ($p<0.01$) (refer to Appendix O). Therefore, this anthropometric measurement was considered in the multiple regression model to predict the TR discomfort level for the accelerator pedal task.

Table 5.10 shows the results from the Regression Method for 5.2.4 model. A value of 0.954 indicates a good level of prediction. The R Square value is 0.911, while the Adjusted R Square was 0.889. Meanwhile, the SEE is 0.244.

Table 5.10 Summary of the discomfort level prediction model for the accelerator pedal task (TR)

Model	R	R Square	Adjusted R Square	SEE
5.2.4	0.954	0.911	0.889	0.244

Table 5.11 illustrates the coefficient table for 5.2.4 model. The significant level for IVs were less than 0.05. It indicates the possibility to obtain t value for the constant was -1.702 and the slope for the R action and knee angle at position A were 5.462 and 2.829 respectively. Hence, at the significant level, $\alpha = 0.05$ (5%) or at the confidence level 95%, the sixth hypothesis in Chapter I (subsection 1.6), H_0 would be rejected. For full analysis, please refer to Appendix Q.

Table 5.11 Coefficient table for the discomfort prediction model for the accelerator pedal task (TR)

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
5.2.4	(Constant)	-10.914	6.413		-1.702	.127
	Release action (x_7)	.229	.042	1.778	5.462	.001
	Knee angle at position A (x_8)	.167	.059	.921	2.829	.022

a. Dependent Variable: Discomfort level (muscle activity R action at position A for TR) (Y_4)

Based on the Table 5.11, the equation model to predict the TR discomfort level based on the muscle activity measurement and knee angle at position A can be used. It is indicated in Equation (5.4):

$$Y_4 = 0.229x_7 + 0.167x_8 -10.914 \quad (5.4)$$

Appendix H shows the full analysis for this model validation. Table 5.12 shows the validation results for the model. According to this findings, the 5.2.4 model fulfilled all these assumptions and in line with the BLUE criteria and OLS method.

Table 5.12 Multiple linear regression validation for the discomfort level prediction for the accelerator pedal task (TR)

Assumption	Discomfort level	Muscle activity	Knee angle at position A
Normality	df(11)=0.461, $p > 0.05$	df(11) = 0.182, $p > 0.05$	df(11) = 0.091, $p > 0.05$
Linearity	-	r(11) = 0.907, $p < 0.01$ Positive (linear)	r(11) = -0.761, $p < 0.01$ Negative (linear)
Auto-correlation	-	DW test: $1.6 < 2.226 < 2.4$	DW test: $1.6 < 2.226 < 2.4$
Heteroscedasticity	-	Beta=1.114, p> 0.05	Beta=1/036, p> 0.05
Multicollinearity	-	Tolerance ($0.336 > 0.1$) & VIF ($2.975 < 10.00$)	Tolerance ($0.336 > 0.1$) & VIF ($2.975 < 10.00$)

5.2.5 Model for the Discomfort Level Prediction for the Accelerator Pedal Task (GR)

As mentioned in Chapter IV (Subsection 4.4.4), knee angle at position B showed strong correlation with the muscle activity measurement with $r=0.918$ ($p<0.01$) (refer to Appendix O). Therefore, this anthropometric measurement was considered in the multiple regression model to predict the GR discomfort level for the accelerator pedal task.

Table 5.13 demonstrates the results from the Regression Method for 5.2.5 model. A value of 0.976 indicates a good level of prediction. The R Square value is 0.952, while the Adjusted R Square was 0.940. Meanwhile, the SEE is 0.244.

Table 5.13 Summary of the discomfort level prediction model for the accelerator pedal task (GR)

Model	**R**	**R Square**	**Adjusted R Square**	**SEE**
5.2.5	0.976	0.952	0.940	0.244

Table 5.14 illustrates the coefficient table for 5.2.5 model. The significant level for IVs were less than 0.05. It indicates the possibility to obtain t value for the constant was -10.491 and the slope for FP action and knee angle at position B were 0.126 and 0.123 respectively. Hence, at the significant level, $\alpha = 0.05$ (5%) or at the confidence level 95%, the sixth hypothesis in Chapter I (subsection 1.6), H_0 would be rejected. For full analysis, please refer to Appendix Q.

Table 5.14 Coefficient table for the discomfort prediction model for the accelerator pedal task (GR)

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
5.2.5	(Constant)	-10.491	6.224		-1.686	.130
	Full-pressing action (x_9)	.126	.049	.504	2.578	.033
	Knee angle at position B (x_{10})	.123	.049	.493	2.521	.036

a. Dependent Variable: Discomfort level (muscle activity FP action at position B for GR) (Y_5)

Based on the Table 5.14, the equation model to predict the drivers' discomfort level based on FP action and knee angle at position B can be used. It is indicated in Equation (5.5):

$$Y_5 = 0.126x_9 + 0.123x_{10} - 10.491 \quad (5.5)$$

Appendix H shows the full analysis for this model validation. Table 5.15 shows the validation results for the model. According to this findings, the 5.2.5 model fulfilled all these assumptions and in line with the BLUE criteria and OLS method.

Table 5.15 Multiple linear regression validation for the discomfort level prediction for the accelerator pedal task (GR)

Assumption	Discomfort level	Muscle activity	Knee angle at position B
Normality	df(11)=0.461, p > 0.05	df(11) = 0.182, p > 0.05	df(11) = 0.091, p > 0.05
Linearity	-	r(11) = 0.956, p < 0.01 Positive (linear)	r(11) = 0.955, p < 0.01 Positive (linear)
Auto-correlation	-	DW test: 1.6 < 1.709 < 2.4	DW test: 1.6 < 1.709 < 2.4
Heteroscedasticity	-	Beta=-0.820, p> 0.05	Beta=1.093, p> 0.05
Multicollinearity	-	Tolerance (0.157 > 0.1) & VIF (6.388 < 10.00)	Tolerance (0.157 > 0.1) & VIF (6.388 < 10.00)

5.3 VALIDATION OF SAMPLE SIZE

In order to determine the minimum size for this study, G*Power software has been used. For this purpose, the lowest R Square from all models obtained from this study has been used, which is 0.911. Based on the finding, G*Power indicated that the minimum sample size was six (6) sample. Therefore, it can be concluded 11 sample was adequate to develop the model for this study. Figure 5.1 exhibits the full result from the G*Power software.

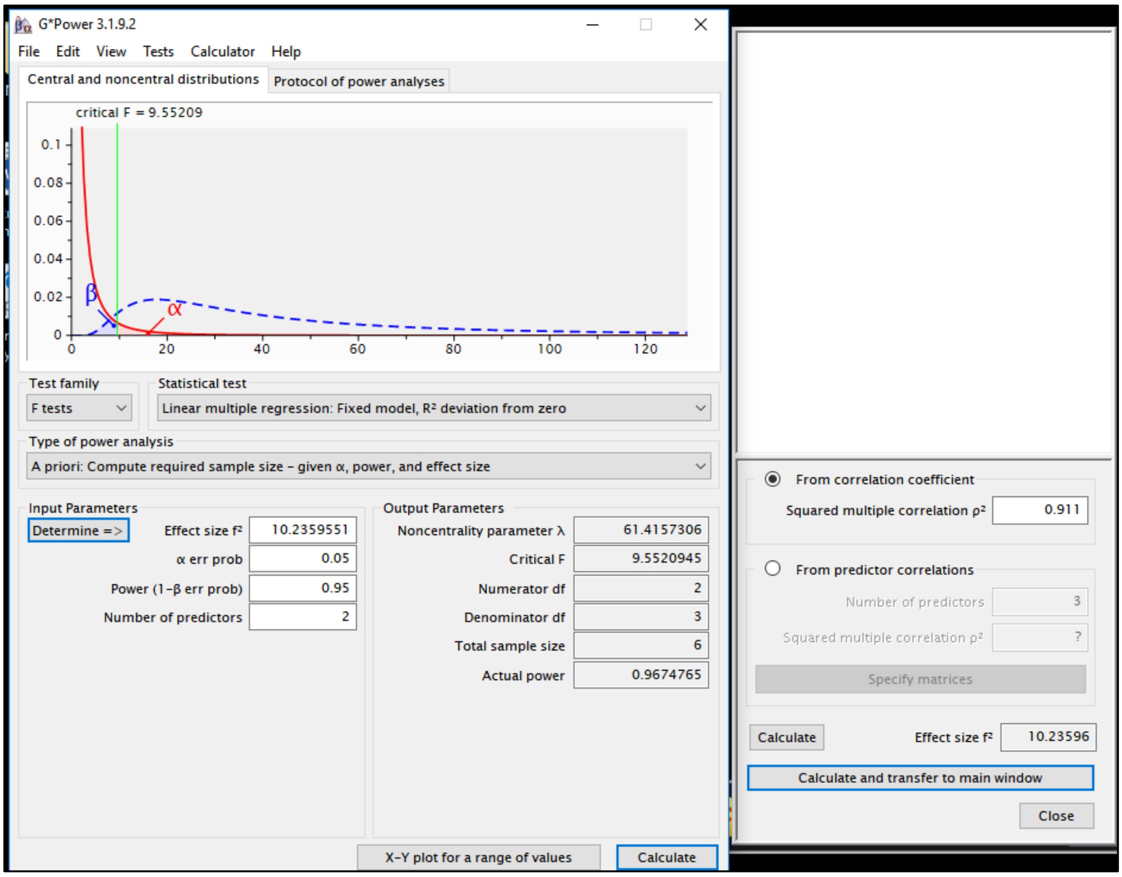


Figure 5.1 Result from G*Power software

5.4 DISCOMFORT INDEX WHEN INTERACTING WITH THE CAR SEAT AND CAR CONTROLS

As stated in the Chapter III (Subsection 3.4.5), the Discomfort Index (DI) interpretation for all models are similar. The DI can be used as reference and guideline to predict discomfort level among the drivers. For instance, in this section, the example of the discomfort level for five main integrated models has been tabulated in the Table 5.16.

Table 5.16 Example of discomfort index

Model	Equation	IV_1	IV_2	DI
5.2.1	$y = 31.518x_1 - 0.270x_2 + 12.936$	0.26	50	7.6
5.2.2	$y = 0.073x_1 + 0.098x_2 + 0.384$	31	44.5	7
5.2.3	$y = 0.09x_1 - 0.191x_2 + 15.756$	37.49	66	6.5
5.2.4	$y = 0.229x_1 + 0.167x_2 -10.914$	18	95	9
5.2.5	$y = 0.126x_1 + 0.123x_2 - 10.491$	9	137	7.5

According to Table 5.16, it can be concluded that the driver feel uncomfortable when engaging with the car seat (7.6), steering wheel (7), gear (6.5) and accelerator pedal in full-pressing action (7.5). In addition, the driver feel very uncomfortable when operating the accelerator pedal in releasing action (9). Hence, the DI can provide useful information regarding the discomfort level for the driver when all independent variables are already measured and known.

5.4 SUMMARY OF CHAPTER V

As mentioned in Chapter I, the main focus of this thesis (referring to the last objective) was to develop the model to predict the drivers' discomfort when operating the car. Hence, this chapter has developed five regression models to estimate and determine drivers' state and discomfort according to driving condition when operating the car by using 11 subjects. These model were established in order to identify the strength of its relationship based on driving task and condition, by referring to R Square value for each condition. The linear regression models has been validated by using classical assumptions. According to the validation study, all requirements as highlighted by BLUE criteria has been fulfilled and therefore, the models are valid for further use. Sample size validation has also been validated by using G*Power software that indicated the amount of sample size in this study is sufficient with eleven subjects. The

DI and its interpretation was presented for the car seat, steering wheel, gear and accelerator pedal task.

There are one model regarding the pressure distribution measurement and four models related to muscle activity measurement. The data distribution were categorized based on the frameworks in Chapter III and findings from Chapter IV. To develop the model by using the Regression Method, the DVs and IVs for each model had been identified. In this case, the DVs for the model were gathered according to the driver's state from subjective measure, while the IVs were referred to the objective measure methods, anthropometric and joint angle measurements. The Regression Method produced the output in the form of R, R Square, Adjusted R Square, SEE, constant, and significance level for each factors that contribute to drivers' state. Each parameter explained the strength and accuracy of the model. The hypothesis for this study has been determined based on the new developed model.

The multiple regression analysis was carried out and thus, five multiple regression models have been developed. As described in Section 5.2, anthropometric and joint angle measurement were taken into consideration due to its strong correlation with other variables (the DV and the first IV). The first model (5.2.1) was regarding the pressure felt level. In this part, the buttock-popliteal length shows strong correlation with both variables, and resulting to greater R^2, 0.952. The 5.2.1 model was indicated in Equation (5.1), $Y_1 = 31.518x_1 – 0.270x_2 + 12.936$. Classical assumptions were carried out for the 5.2.1 model and the findings show that all requirements were fulfilled, as shown in Table 5.3.

Similar to the first model, another model (5.2.2) was performed for the steering wheel task by taking into account, the arm length as the second IV. For this model, which was the second model in this thesis, a multiple regression was run to estimate the discomfort level based on muscle activity for steering wheel task and arm length. This model obtained better R^2 (0.983) in estimating the discomfort level for steering wheel task. The equation to predict the discomfort level based on muscle activity for steering wheel task and arm length was: $Y_2 = 0.073x_3 + 0.098x_4 + 0.384$, as shown in Equation

(5.2). Validation studies were performed on the multiple regression model and the findings were tabulated in Table 5.6.

The third model (5.2.3) depicted the integrated model for the gear task, by taking into account, the shoulder grip length. This anthropometric measurement shows a strong correlation with the DV and the first IV. This 5.2.3 model obtained better R^2 (0.980) in predicting the discomfort level for gear task. The equation to predict the discomfort level based on muscle activity for gear task and shoulder grip length was: $Y_3 = 0.09x_5 - 0.191x_6 + 15.756$, as shown in Equation (5.3). Table 5.9 shows the results from the classical assumptions to validate the model.

Another model was performed for accelerator pedal task for TR muscle by considering, the knee angle at position A as the second IV. For this model (5.2.4), which was the fourth model in this thesis, a multiple regression was carried out to predict the discomfort level based on TR muscle activity when releasing the pedal at position A. This model obtained better R^2 (0.911) in determining the discomfort level for accelerator pedal task. The equation to determine the discomfort level based on TR muscle activity for pedal task and knee angle was: $Y_4 = 0.229x_7 + 0.167x_8 -10.914$, as demonstrated in Equation (5.4). The 5.3.4 model fulfilled the BLUE criteria and the validation results was shown in Table 5.12.

For the GR muscle, the knee angle at position B was highlighted as the second IV for the fifth model (5.3.5). For this model, a multiple regression was carried out to predict the discomfort level based on GR muscle activity for pedal task in pressing position at position B. This model obtained better R^2 (0.952) in determining the discomfort level for accelerator pedal task. The equation to predict the discomfort level based on muscle activity for pedal task and knee angle was: $Y_5 = 0.126x_9 + 0.123x_{10} - 10.491$, as shown in Equation (5.50). Table 5.15 shows the validation results according to the classical assumptions.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

6.1 INTRODUCTION

Chapter I presented the background of this thesis contents, including the main objectives of this research study. Chapter II explained on past methods and findings from the past studies and providing the research gap to establish this research. Then, Chapter III described on research tools and methodology that has been used to support this research. Chapter IV identified and discussed the findings of this study by the aid of illustration and suitable statistical methods. The next chapter, which is the essential chapter for this research, Chapter V explained on the development of driver's discomfort model and index when interacting with car seat and car controls. According to previous chapters, this thesis provides information regarding factors towards driver's condition and discomfort by applying mixed method assessments. In this chapter, the conclusion has been made according to the objectives of the study as stated in Chapter I under subsection 1.5. In addition, contribution of this study and limitation of the study have been described in the Section 6.3 and Section 6.4. Recommendation for future study has also been proposed in the Section 6.5 in Chapter VI.

6.2 SUMMARY ON THE FINDINGS

In this study, mixed method approaches as explained in Chapter III have been applied to evaluate driver's condition according to driving position and tasks. Integration of the subjective and objective measures are necessary to determine driver's condition, particularly driver's discomfort according to driving condition. There are four main subsections for this part to summarise the findings from each assessment. Section 6.2.1 summarises the findings from subjective assessment and performance method, based on the discomfort level, pressure felt level, and cardiovascular pattern as well as alertness level perception. Section 6.2.2 recaps the outputs from pressure distribution measurement, while Section 6.2.3 encapsulates the results from muscle activity measurement by using SEMG method. Section 6.2.4 explains on the development of integrated model to predict driver's discomfort for this study.

6.2.1 Subjective and Performance Assessment to Evaluate and Measure Driver's Discomfort and Performance Level while Engaged with the Car Seat and Car Controls

This section provides an answer for the first research objective (RO) in Chapter I. As described in Chapter III, there are four main sections in the subjective assessment form (refer to subsection 3.3.2 and Appendix E). Section A collected data regarding demographic information (age, gender, weight, height, caffeine intake, food intake, sleep duration and driving experience). Section B collected information regarding discomfort level according to driving position and task based on car controls, while Section C gathered data regarding pressure felt level on the car seat according to driving position. There were two seat parts that have been investigated in the Section C; the seat pan and the back rest. Each part categorised into two segments; buttock and thigh for the seat pan as well as upper back and lower back for the back rest. Both sections in the subjective assessment form used VAS tool as the scale to evaluate the driver's condition level. Therefore, the data derived from these sections were known as continuous variable. Section D collected data on the alertness evaluation based on the KSS scale for three duration; before, during and after driving. As described in Chapter III, this section was used to evaluate performance of the driver by assessing the alertness while driving. In addition, cardiovascular assessment by using HR and BP were carried out in this study to determine driver's performance in this study.

Based on the findings for discomfort level of steering wheel control, the highest discomfort rate was indicated at position B. In term of action, L45 and R45 actions demonstrated the highest mean discomfort rate compared to L10, R10 and M actions. For gear control, similar to steering wheel control, position B depicted the highest level of discomfort. In terms of the manual gear action, G1 action showed the highest discomfort level compared to GN action. Meanwhile, for accelerator pedal control, the test subjects selected position A as the most discomfort position. For pedal action, TR depicted the highest rate at position A for R action, while GR showed the highest rate at position B for FP action. According to the findings for pressure felt level of the car seat, buttock segment from the seat pan part demonstrated the highest pressure felt level at position A. It referred to the mean score of all condition. Detailed explanation on this condition can be found in Chapter IV (point d in Section 4.4.1, 4.4.2, 4.4.3 and Section 4.4.4)

According to performance level, the findings from alertness evaluation showed that, there was increment from before to during and to after driving, which was from alert to moderate and sleepy condition. For the cardiovascular pattern, majority of the test subjects showed decrement trend of HR and BP based on the results for before and after driving. For simulator output, as explained in Section 4.6, there is differences of average turning and pressing of each test subject possibly due to driving style. This finding responded to the third hypothesis. The H_0 of the third hypothesis was accepted.

In general, these results responded to the first objective. According to thorough statistical analysis for this assessment, it can be concluded there is significant difference between perceptions of driver's discomfort and pressure felt level when performing driving tasks in different position and action. In addition, comparison between positions have been carried out. It was found that there was significant difference between position A and B. This finding responded to the first hypothesis. The H_0 of the first hypothesis was rejected, the H_1 was accepted.

6.2.2 Pressure Distribution Assessment to Evaluate and Measure Driver's Pressure while Interacting with the Car Seat

This section provides an answer for the second objective in Chapter I. The pressure map was used to evaluate the pressure distribution. The average pressure value for all body parts were gathered in the unit of psi. As mentioned in Section 6.2.1, there were four main body parts that have been investigated in this study. Based on the findings, the buttock part depicted the highest mean pressure value compared to the thigh, lower back and upper back. In addition, the highest pressure at the buttock was found at position A. This finding responded to the fourth hypothesis. The H_0 was rejected, the H_1 was accepted.

According to thorough statistical analysis for pressure distribution assessment at the set pan, there was significant difference between position at buttock and thigh. In term of pre-post activity, there was significant difference between both periods of time at the buttock. Meanwhile, for the back rest, there was no significant difference between position and also pre-post activity for upper back and lower back. In general, all these results responded to the second objective. Based on this research question, it can be summarised there is significant difference between perception of driver's pressure level when interacting with the car seat in different positions and body regions. Detailed explanation on this condition can be found in Chapter IV (Section 4.3.3).

6.2.3 SEMG Assessment to Evaluate and Measure Driver's Muscle Activity while Engaging with Car Controls

This section provides an answer for third objective in Chapter I. To evaluate the muscle activity, SENIAM recommendations have been used as reference, particularly on selected muscle identification and electrode placement as depicted in Chapter III (Table 3.1). The raw data from this measurement undergone several process, from filtering process to epoch process. All these steps have been explained and demonstrated in Chapter III (Figure 3.17 and Figure 3.18).

Based on the Temporal and Amplitude Analysis of the steering wheel control, it was obvious that R45 and L45 action for DL and DR muscle depicted the highest muscle contraction compared to other actions. Comparison between positions have been conducted on this control. The highest mean RMS score was at position B. Then, for gear control, G1 action at position B demonstrated the highest mean RMS score compared to GN action. Meanwhile, for accelerator pedal, the highest mean RMS value was indicated by TR in R action. This finding responded to the fifth hypothesis. The H_0 was rejected, the H_1 was accepted.

According to thorough statistical analysis for SEMG assessment, there was significant difference between several actions of all controls. Similar to subsection 6.2.1 and 6.2.3, comparison between positions have also been carried out. It was found that there was obvious significant difference between position A and B. In general, all these results responded to the third and fourth research question. According to this research question, it can be concluded there is significant difference between perception of driver's discomfort when performing driving tasks in different position and action. However, pre-post activity do not show similar outcome, where there was significant difference between pre and post activity for all controls. It shows that 15 minutes of driving do not truly contribute to fatigue based on muscle activity value and cardiovascular pattern. This finding responded to the second hypothesis. The H_0 was accepted, the H_1 was rejected.

6.2.4 Development of Integrated Model of Subjective Measure, Objective Measure and Body Measurement to Determine Driver's Discomfort

This section provides an answer for the fourth objective in Chapter I. This study has produced five multiple regression models to predict driver's discomfort according to driving condition when engaging with car seat and car controls. These models were established in order to identify the strength of its relationship based on driving task and condition. It was derived based on the highest discomfort rate produced by each condition. The first model related to the pressure when interacting with the car seat, meanwhile the rest of the model referred to the muscle activity and its relation with the discomfort level. To develop the model by using the Regression Method, the DVs and IVs for each model have been identified. In this case, the DVs for the model were gathered according to the driver's condition level (discomfort level or pressure felt level), while the IVs were referred to the objective measure methods and body measurements, consisting of anthropometric and joint angle.

Multiple Regression Method was carried out in this study. It was performed by integrating anthropometric and joint angle measurement into the model, consisting of knee angle, fore arm length, shoulder grip length and buttock-popliteal length, as depicted in the five models. All these integrated models showed good R^2 in estimating the discomfort level for the car seat and car control. The first model was regarding discomfort level based on pressure distribution of the car seat and the buttock-popliteal length. The second model referred to muscle activity for steering wheel task and fore arm length. For the third model, the Multiple Regression was carried out to predict the discomfort level based on muscle activity for gear task and shoulder grip length. Another model was performed for pedal task by considering, the knee angle as the second IV. For this model, which was the fourth model in this thesis, a multiple regression was carried out to predict the discomfort level based on TR muscle activity for pedal task and knee angle at position A. Similar to the fourth model, another model was performed for pedal task by considering, the knee angle as the second IV. For this model, which was the fifth model in this thesis, a multiple regression was carried out to predict the discomfort level based on GR muscle activity when pressing the pedal and knee angle at position B. This finding responded to the sixth hypothesis. The H_0 was rejected, the H_1 was accepted.

According to this results, the fourth and fifth research question has been answered. Sample size and model validation by using G*Power and Classical Assumptions have been conducted to produce reliable model. Both validation tests showed that the models are reliable and following all requirements stated in the test. In addition, the Discomfort Index (DI) was produced in this study as described in Chapter V. Therefore, it can be concluded that the integrated model can provide reliable results on the discomfort level while interacting with car seat and car controls. Table 6.1 shows the summary of the findings for this study. It demonstrates the relationship between RO, Research Question (RQ) and Research Hypothesis (RH) as well as provide the answers or findings for each element.

Table 6.1 Summary of the findings for this study

RO	RQ	RH	Respond for RQ	Respond for RH
1	1,2	1,2,3	Highest pressure felt level was found at buttock at position A. Highest discomfort rate was found at 45 deg turn, gear 1, full press actions for Deltoid and GR muscle at position B (steering, gear, pedal). But, for TR muscle, highest value was found at release action at position A. There is increment trend of alertness scale from before driving to the end of driving (from moderate to sleepy). In terms of cardiovascular pattern, majority subjects show decrement trend.	H_0 for RH 1 reject. H_0 for RH 2 and 3 accept for certain actions and positions.
2	2,3	2,4	Highest pressure distribution measurement was found at buttock at position A	H_0 for RH 2 accept for certain condition. H_0 for RH 4 reject.
3	2,4	1,2,5	Highest muscle contraction was found at 45 deg turn, gear 1, full press actions for Deltoid and GR muscle at position B (steering, gear, pedal). But, for TR muscle, highest value was found at release action at position A.	H_0 for RH 1 and RH 5 reject. H_0 for RH 2 accept for certain condition.
4	5	6	Pressure measurement, muscle activity and anthropometric/joint angle measurement contribute to cause & effect of driver's condition when interacting with car seat and car controls.	H_0 for RH 6 reject.

6.3 RESEARCH CONTRIBUTION

This research contributes to the area of manufacturing ergonomics and mechanical engineering area. Specifically, in terms of academics perspective, this research aims to bridge the gap in determining driver's condition when interacting with the car seat and car controls. By incorporating all relevant factors in evaluating driver's condition, it will facilitates the researcher and academicians for future research, particularly on methodology, data collection, measurement, analysis, model development and validation. Appendix R shows a list of publications related to this research produced from 2014 to 2018.

In terms of contribution to the industry, particularly automotive manufacturer, this present work can provide a good references and prediction to detect the onset of driver's discomfort by evaluating the driver's well-being and condition before any significant deterioration in driver's performance occur. The references for improvement on driving characteristics, can be referred in the integrated models that have been developed in this study. Various factors should be taken into account to determine driver's discomfort such as by considering key muscles in driver-car interaction design, seat and pressure distribution charateristics, driver's anthropometric data and driving position as well as driving styles. In fact, nowadays, there is a strong collaboration between the local universities, local automotive manufacturers and government agencies to develop an integrated Malaysian anthropometric system to be used in their future product. In addition, part of this research work was funded by the university grant, as listed in Appendix R.

6.4 RESEARCH LIMITATION

There are a number of limitations that need to be addressed in this study. This was a laboratory-based study by using car simulator. The present state of driving simulator technology makes it possible to incorporate human factors to simulate actual driving conditions. In addition, using a simulator or performing a field work in the laboratory gives the researcher extra advantage because the researcher has the ability to control the environment and it is less hazardous. Detailed information on the reasons using the simulator was described in Chapter II (Section 2.6.1). The driving task in this study was reduced to a lane keeping task to induce task monotony with light curvature and no traffic problem. Future studies should investigate the impact of a congested area towards driver's reaction. Furthermore, longer driving duration should be imposed in the future study.

In addition, this study used the test subjects between the ages of 21 to 35 years old. Future studies could explore the reaction among the older test subjects by using the similar mixed-method assessment. In addition, resources constraints such as financial, and time issues are among the limitations in this study. These constraints influence the progress of the study.

6.5 SUGGESTIONS FOR FUTURE RESEARCH

Nowadays, monitoring of driver's discomfort while engaging with car seat and car controls is ultimate issues to improve driver's safety and comfort. Therefore, integration of subjective and objective measures to evaluate driver's discomfort is one of the approach use by researchers. However, driver's discomfort issues are too broad, therefore, following suggestions for future research work should been conducted:

1. Comparison between different car control systems: Different design of the car control systems may produce different measurement either from subjective or objective measures perspectives. Muscle activity and pressure distribution of drivers with different vehicles and car control systems will be the main focus of future research work.
2. Comparison when adding the armrest: With similar position, the armrest when operating the steering wheel and gear is being added to the current simulator.
3. Comparison between different hand positions: With similar position, the hand is placed on 8-4 o'clock or 9-3 o'clock position.
4. Identification of others objective methods to determine driver's condition: In this study, only SEMG and pressure distribution map have been used as objective measure tools. Another objective methods as described in Chapter II such as vibration measurement, EEG and EOG can be used to determine driver's condition based on driving condition.

REFERENCES

Aaker, D.A., 2012. *Building strong brands*. Simon and Schuster.

Abdul Majid, N.A., Abdullah, M.F.E., Jamaludin, M.S., Notomi, M. & Rasmussen, J. 2013. Musculoskeletal analysis of driving fatigue: The influence of seat adjustments. *Advanced Engineering Forum* 10: 373-378.

Adler, S. 2007. The relation between long-term seating comfort and driver movement. Dipl.-Sportwiss, Friedrich-Schiller-Universitat Jena.

Aiken, L.S., West, S.G. & Reno, R.R., 1991. *Multiple regression: Testing and interpreting interactions*. Sage.

Akin M, Kurt M, Sezgin N. & Bayram M, 2008. Estimating vigilance level by using EEG and EMG signals, Neural Computing. *Applications,* 17 (2008): 227-236.

Aktas, A., & Keskin, B. 2013. Statistical power analysis. *The 7th International Days of Statistics and Economics, Prague, Czech Republic*, hlm. 578-587.

Ali, R.N. 2013. Supraspinatus Tendinities. http:// www.slideshare.net/rahilanajihah/ supraspinatus -tendinitis-30may2013. [13 May 2016].

Amarantini, D. & Bru, B. 2015. Training-related changes in the EMG–moment relationship during isometric contractions: Further evidence of improved control of muscle activation in strength-trained men. *Journal of Electromyography and Kinesiology* 25(4): 697-702.

Anon. 2012. Plantarflexion contractures. walkstaywell.wordpress.com. [1 May 2016].

Anon. 2015. Plantarflexion Contactures. 2 Mei 2015.

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.

Andersson, B. J., Ortengren, R., Nachemson, A. L., Elfström, G., & Broman, H. 1975. The sitting posture: an electromyographic and discometric study. *The Orthopedic Clinics of North America*, 6(1): 105-120.

Andersson, G.B.J. 1980. *The load on the lumbar spine in sitting postures*. D.J. Oborne and J.A. Levis (eds.) Human Factors in Transport Research. New York: Academic Press, 231-239.

Antonson, H., Ahlström, C., Mårdh, S., Blomqvist, G., & Wiklund, M. 2014. Landscape heritage objects' effect on driving: a combined driving simulator and questionnaire study. *Accident Analysis and Prevention*, 62: 168-177.

Antonson, H., Mårdh, S., Wiklund, M., & Blomqvist, G. 2009. Effect of surrounding landscape on driving behaviour: A driving simulator study. *Journal of Environmental Psychology*, 29(4): 493-502.

Anund, A., Fors, C., & Ahlstrom, C. 2017. The severity of driver fatigue in terms of line crossing: a pilot study comparing day-and night time driving in simulator. *European Transport Research Review*, *9*(2), 31.

Arezes, P.M., Neves, M.M., Teixeira, S.F., Leão, C.P., & Cunha, J.L. 2013. Testing thermal comfort of trekking boots: an objective and subjective evaluation. *Applied Ergonomics*, 44(4), 557–565.

Arora, N., & Grenier, S.G. 2013. Acute effects of whole body vibration on directionality and reaction time latency of trunk muscles: the importance of rest and implications for spine stability. *Journal of Electromyography and Kinesiology*, 23(2), 394–401.

Arun, S., Sundaraj, K., & Murugappan, M. 2012. Hypovigilance detection using energy of electrocardiogram signals. *Journal of Scientific & Industrial Research*, 71(December): 794-799.

Astrom, C., Lindkvist, M., Burstrom, L., Sundelin, G., & Stefan, K. J. 2009. Changes in EMG activity in the upper trapezius muscle due to local vibration exposure. *Journal of Electromyography and Kinesiology*, 19: 407–415.

Atieh, M., Youn, R., Khalil, M., & Akdag, H. 2005. Classification of the car seats by detecting the muscular fatigue in the EMG Signal. *International Journal of Computational Cognition*, 3(4): 48-54.

Auberlet, J.-M., Rosey, F., Anceaux, F., Aubin, S., Briand, P., Pacaux, M.-P., & Plainchault, P. 2012. The impact of perceptual treatments on driver's behavior: from driving simulator studies to field tests-first results. *Accident Analysis and Prevention*, 45: 91-98.

Ba, Y., Zhang, W., Salvendy, G., Cheng, A.S.K., & Ventsislavova, P. 2016. Assessments of risky driving: A Go/No-Go simulator driving task to evaluate risky decision-making and associated behavioral patterns. *Applied Ergonomics*, 52: 265-274.

Babkoff, H., Caspy, T., & Mikulinear, M. 1991. Subjective sleepiness ratings: the effects of sleep deprivation, circadian rhythmicity and cognitive performance. *Sleep*, 14(6): 534-9.

Back, T.L., Padberg, F.T., Araki, C.T., Thompson, P.N. & Hobson, R.W., 1995. Limited range of motion is a significant factor in venous ulceration.*Journal of Vascular Surgery*, *22*(5): 519-523.

Balasubramanian, V., & Adalarasu, K. 2007. EMG-based analysis of change in muscle activity during simulated driving. *Journal of Bodywork and Movement Therapies*, 11(2): 151-158.

Baldauf, D., Burgard, E., & Wittmann, M. 2009. Time perception as a workload measure in simulated car driving. *Applied Ergonomics*, 40: 929-935.

Barry, D. T., Hill, T., & Im, D. 1992. Muscle fatigue measured with evoked muscle vibrations. *Muscle & Nerve*, 15(3): 303-309.

Basmajian, J. & De Luca, C.J. 1985. Muscle alive. *Muscles alive: their function revealed by electromyography*, 278: 126.

BC Driving Blog. 2016. How to hold and not hold the steering wheel. http://drivinginstructorblog.com/q-what-is-hooking-the-steering-wheel-other-ways-of-holding-the-wheel/ [10 May 2016].

Beard, G.F., & Griffin, M.J. 2013. Discomfort during lateral acceleration: influence of seat cushion and backrest. *Applied Ergonomics*, 44(4): 588-594.

Bella, F. 2008a. Driving simulator for speed research on two-lane rural roads. *Accident Analysis and Prevention* , 40 (3): 1078-1087.

Bella, F. 2008b. Validation of a driving simulator for work zone design. Transportation Research Record: *Journal of the Transportation Research Board*, 1937: 136-144

Belz, S.M. 2000. An onroad investigation of commercial motor vehcile operators and self rating of alertness and temporal separation as indicator of driver fatigue. PhD Dissertation. Virginia Polytechnic Institute.

Biggs, S.N., Smith, A., Dorrian, J., Reid, K., Dawson, D., van den Heuvel, C., & Baulk, S. 2007. Perception of simulated driving performance after sleep restriction and caffeine. *Journal of Psychosomatic Research*, 63(6): 573-577.

Bittner, A. C., Simsek, O., Levison, W.H., & Campbell, J. L. 2002. On-road versus simulator data in driver model development. Driver performance model experience. *Transportation Research Record: Journal of the Transportation Research Board*, 1803: 38-44.

Blana, E. 1996. A survey of driving research simulators around the world, Institute of Transport Studies, University of Leeds.

Bongers, P. M., Hulshof, C. T., Dljkstra J. L., Boshuizen, H. C., Groenhout, H. J. M. & Valken, E.. 1990. Back pain and exposure to whole body vibration in helicopter pilots. *Ergonomics,* 33 (8): 1007-1026.

Bonnet, M.H., 1985. Effect of sleep disruption on sleep, performance, and mood. *Sleep,* 8 (1): 11-19.

Bougard, C., Moussay, S., & Davenne, D. 2008. An assessment of the relevance of laboratory and motorcycling tests for investigating time of day and sleep deprivation influences on motorcycling performance. *Accident Analysis and Prevention*, 40(2): 635–43.

Bovenzi, M., & Betta, A. 1994. Low-back disorders in agricultural tractor drivers exposed to whole- body vibration and postural stress. *Applied Ergonomics*, 25(4), 231–241.

Bridger, R.S., 1998. Postural adaptions to a sloping chair and work surface. *Human Factors,* 30(2): 237-247.

Brook, S., Freeman, R., Rosala, G., Campean, F., & Dixon, N. 2009. Ergonomic data measuring system for driver-pedals interaction. *SAE International Journal of Passenger Cars - Mechanical Systems*, 2(1): 1071-1078.

Brookhuis, K. 1995. Driver impairment monitoring by physiological measures. *Fatigue and Driving: Driver Impairment, Driver Fatigue, and Driving Simulation*, 181.

Brookhuis, K.., & de Waard, D. 2010. Monitoring drivers' mental workload in driving simulators using physiological measures. *Accident Analysis and Prevention,* 42(3): 898-903.

Brown, I. D. 1994. Driver fatigue. *Human Factors : The Journal of the Human Factors and Ergonomics Society*, 36(2): 298–314.

Brown, I.D. 1997. Prospects for technological countermeasures against driver fatigue. *Accident Analysis & Prevention*, *29*(4), 525-531.

Bush, T.R., & Hubbard, R.P. 2008. A comparison of four office chairs using biomechanical measures. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 50(4): 629-642.

Campagne A, Pebayle T, & Muzet A. 2004. Correlation between driving errors and vigilance level: influence of the driver's age. *Physiol Behav*, 80(4): 515-524.

Cavalcanti Garcia, M.A., & Vieira, T.M.M. 2011. Surface electromyography: Why, when and how to use it. *Revista Andaluza de Medicina Del Deporte*, 4(1): 98–101.

Cawthorn, M., Cummings, C., Walker, J.R., & Donatelli, R. 1991. Isokinetic measurement of foot invertor and evertor force in three positions of plantarflexion and dorsiflexion. *Journal of Orthopaedic & Sports Physical Therapy*, 14(2): 75-81.

Cengiz, T.G., & Babalik, F.C. 2007. An on-the-road experiment into the thermal comfort of car seats. *Applied Ergonomics*, 38(3): 337-347.

Cengiz, T.G., & Babalık, F.C. 2009. The effects of ramie blended car seat covers on thermal comfort during road trials. *International Journal of Industrial Ergonomics*, 39(2): 287-294.

Chaffin, D. B., Faraway, J. J., Zhang, X., & Woolley, C. (2000). Stature, age, and gender effects on reach motion postures. *Human factors*, *42*(3), 408-420.

Chakrabarty N., 1992. Development of action based computerized driver evaluation system, *RRI*, India.

Chai, R., Ling, S. H., San, P. P., Naik, G. R., Nguyen, T. N., Tran, Y. & Nguyen, H. T. 2017. Improving EEG-based driver fatigue classification using sparse-deep belief networks. *Frontiers in Neuroscience*, 11.

Charlton S G, 2009. Driving while conversing: Cell phones that distract and passengers who react, *Accident Analysis & Prevention*, 41: 160-173.

Charlton, S., Baas, P., Alley, B., & Luther, R.. 2003. *Analysis of fatigue levels in New Zealand taxi and local-route truck drivers*. Transport Engineering New Zealand/Road Safety Trust.

Chieh, C., Mustafa, M.M., Hussainl, A., & Zahedi, E. 2003. Detection using steering grip force, SCORED 2003 *Proceedings. Student Conference*, 45-48.

Coelho, D.A., & Dahlman, S. 1999. A pilot evaluation of car seat side support : Leading to a redefinition of the problem. *International Journal of Industrial Ergonomics*, 24: 201-210.

Coelho, D.A., & Dahlman, S. 2012. Articulation at shoulder level--a pilot experimental study on car seat comfort. *Applied Ergonomics*, 43(1): 27-37.

Cohen, L. 1992. Power Primer. *Psychological Bulletin*, 112(1): 155-159.

Cohen, J. 1990. *Things I Have Learned (so far).* American Psychologist, 45, 1304-1312

Connor J, Norton R, Ameratunga S, Robinson E, Civil I, & Dunn R, 2002. Driver sleepiness and risk of serious injury to car occupants: population based case control study. *Br Med J*, 324: 1125-1128.

Constantin, D., Nagi, M. and Mazilescu, C.A., 2014. Elements of discomfort in vehicles. *Procedia-Social and Behavioral Sciences*, 143: 1120-1125.

Corlett, E.N. 1989. Aspect of the evaluation of industrial seating: the ergonomics society lecture. *Ergonomics*, 32: 257-269.

Costanzo, A., Graziani, G. & Orsi, G. 1999. Driving ergonomy: New methodology for the assessment of stresses on upper limbs. *Safety Science Monitor.*

Daruis, D.D.I. 2010. Model bersepadu untuk pengukuran dan penilaian tahap ketidakselesaan tempat duduk kereta. Tesis Doktor Falsafah, Universiti Kebangsaan Malaysia.

Daruis, D.D.I., Md Deros, B., Mohd Nor, M.J., & Hosseine, M. 2011. An integrated model of static and dynamic measurement for seat discomfort. *IEMS*, 10(3): 185-190.

Daruis, Dian Darina Indah Mohd Nor, M. J., & Deros, B. M. 2010. Vibration transmissibility and subjective evaluation on whole body vibration in a field investigation. *The 17th International Congress on Sound and Vibration, Cairo, 18-22 July 2010*, 18-22..

Davenne, D., Lericollais, R., Sagaspe, P., Taillard, J., Gauthier, A., Espié, S., & Philip, P. 2012. Reliability of simulator driving tool for evaluation of sleepiness, fatigue and driving performance. *Accident Analysis and Prevention,* 45: 677-682.

Davies, C., 2006. *Frozen Shoulder Workbook: Trigger Point Therapy for Overcoming Pain & Regaining Range of Motion*. New Harbinger Publications.

Delsys Inc. 2016. Delsys family of product. http://www.delsys.com/products/ [19 May 2016].

De Looze, M.P., Kuijt-Evers, L.F.M., & van Dieën, J. 2003. Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*, 46(10): 985-997.

De Luca, C. J. 1997. The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2): 135-163.

De Waard, D., 1996. *The measurement of drivers' mental workload*. Netherlands: Groningen University, Traffic Research Center.

De Waard, D., Van den Bold, T.G. & Lewis-Evans, B. 2010. Driver hand position on the steering wheel while merging into motorway traffic. *Transportation Research Part F: Traffic Psychology and Behaviour*, 13(2): 129-140.

Deros, B.M., Daruis, D.D.I, & Mohd Nor, M.J. 2009. Evaluation of car seat using reliable and valid vehicle seat discomfort survey. *Industrial Engineering and Management*

Systems (IEMS), 8(2): 121-130.

Deros, B.M., Hassan, N.H.H., Daruis, D.D.I., & Tamrin, S.B.M. 2015. Incorporating Malaysian's population anthropometry data in the design of an ergonomic driver's seat. *Procedia - Social and Behavioral Sciences*, 195: 2753-2760.

Dhingra, H., 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*, V(July 2003): 1-16.

Dixit, V., Harrison, G.W., & Rutström, E.E. 2013. Estimating the subjective risks of driving simulator accidents. *Accident Analysis & Prevention*, 62C: 63-78.

Dohi, T. Sakuma, I. & Liao, H. 2008. *Medical imaging and augmented reality*. 5128: 403-412.

Dong, H., Ugalde, I., Figueroa, N., & El Saddik, A. 2014. Towards whole body fatigue assessment of human movement: a fatigue-tracking system based on combined sEMG and accelerometer signals. *Sensors*, 14(2): 2052-2070.

Döring, T., Kern, D., Marshall, P., Pfeiffer, M., Schöning, J., Gruhn, V., & Schmidt, A. 2011. Gestural interaction on the steering wheel. *Proceedings of the 2011 Annual Conference on Human Factors in Computing Systems*, 483.

Dunk, N. M., & Callaghan, J. P. 2005. Gender-based differences in postural responses to seated exposures. *Clinical Biomechanics*, 20(10), 1101-1110.

Durkin, J.L., Harvey, A., Hughson, R.L., & Callaghan, J.P. 2006. The effects of lumbar massage on muscle fatigue, muscle oxygenation, low back discomfort, and driver performance during prolonged driving. *Ergonomics*, 49(1): 28-44.

El Falou, W., Duchêne, 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.

El Falou, W., Duchêne, J., Hewson, D., Khalil, M., Grabisch, M., & Lino, F. 2005. A segmentation approach to long duration surface EMG recordings. *Journal of Electromyography and Kinesiology*, 15(1); 111-119.

Engström, J., Johansson, E., & Östlund, J. 2005. Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, 8(2): 97–120.

Ergic, T., Ivandic, Z., & Kozak, D. 2002. The significance of contact pressure distribution on the soft tissue by men sitting. *International Design Conference-Design 2002*, 743-748.

Fattahi, A., Ameli, M., Sadeghi, H., & Mahmoodi, B. 2012. Relationship between anthropometric parameters with vertical jump in male elite volleyball players due to game's position. *Journal of Human Sport and Exercise*, 7(3).

Fatollahzadeh, K., 2006. A laboratory vehicle mock-up research work on truck driver's selected seat position and posture: A mathematical model approach with respect to anthropometry, body landmark locations and discomfort, Doctoral Thesis, Royal Institute of Technology.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. 2007. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2): 175-191.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.G. 2009. Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods,* 41(4): 1149-1160.

Fazlollahtabar, H., 2010. A subjective framework for seat comfort based on a heuristic multi criteria decision making technique and anthropometry. *Applied Ergonomics*, 42(1): 16-28.

Fernandez, J. E., & Poonawala, M. F. 1998. How long should it take to evaluate seats subjectively? *International Journal of Industrial Ergonomics*, 22(6): 483-487.

Freeman, R, & Haslegrave, C.M. 2004. Determination of optimal pedal positioning for automobiles using jack. *SAE*, 2004-01-2149

Freund H-J, Budingen HJ, Dietz V. 1975. Activity of single motor units from human forearm muscles during voluntary isometric contractions. *Journal of Neurophysiology.* 38: 933–946.

Filtness, A. J., & Naweed, A. (2017). Causes, consequences and countermeasures to driver fatigue in the rail industry: the train driver perspective. *Applied Ergonomics*, 60: 12-21.

Fouladi, M. H., Inayatullah, O., & Ariffin, A. K. 2011. Evaluation of seat vibration sources in driving condition using spectral analysis. *Journal of Engineering Science and Technology*, 6(3): 339-356.

Florimond, V. 2009. *Basics of surface electromyography applied to physical rehabilitation and biomechanics*, Volume 1, Montreal, Canada: Thought Technology Ltd.

Franz, M., Zenk, R., Vink, P., & Hallbeck, S. 2011. The effect of a lightweight massage system in a car seat on comfort and electromyogram. *Journal of Manipulative and Physiological Therapeutics*, 34(2): 107-113.

Frost, J. 2013. *Regression analysis: how to interpret the constant (y intercept)*. The Minitab Dot Com.

Fu, R., Guo, Y., Chen, Y., Yuan, W., Ma, Y., Peng, J., & Wang, C. 2011. Research on heart rate and eye movement as indicators of drivers' mental workload. *3rd International Conference on Road Safety and Simulation, September 14-16, 2011, Indianapolis, USA*, 1-20.

Fumio, K., Takemasa,W., Misuzu,W., Yasuhiro, A., Teruyuki, T., Taisuke, N., Hikari, F., Kiyomi, T., Akiyoshi, O., Rumi, O., Junichiro, H., 2002. Blood pressure and heart rate variability in taxi drivers on long duty schedules. *Journal of Occupational Health*, 44(4), 214-220.

Fuller, R G.C. 1984. Prolonged driving in convoy: The truck driver's experience. *Accident Analysis and Prevention*, 16(516): 371-382.

Gander, P.H., Nguyen, D., Rosekind, M.R., & Connell, L.J., 1993. Age, circadian rhythms, and sleep loss in flight crews. *Aviator, Space Environ. Med*. 64 (3): 189–195.

Gao, Z. H., Fan, D., Wang, D., Zhao, H., Zhao, K., & Chen, C. 2014. Muscle activity and co-contraction of musculoskeletal model during steering maneuver. *Bio-Medical Materials and Engineering*, 24(6): 2697-2706.

Gastaldi, M., Rossi, R., & Gecchele, G. 2014. Effects of driver task-related fatigue on driving performance. *Procedia-Social and Behavioral Sciences*, 955–964.

Gazendam, M.G., & Hof, A.L. 2007. Averaged EMG profiles in jogging and running at different speeds. *Gait & posture* 25(4), 604-614.

Gerdle, B., Karlsson, S., Day, S. and Djupsjöbacka, M., 1999. Acquisition, processing and analysis of the surface electromyogram. *Modern techniques in neuroscience research*, Springer Berlin Heidelberg. 705-755.

Giacomin, J., Shayaa, M.S., Dormegnie, E., & Richard, L. 2004. Frequency weighting for the evaluation of steering wheel rotational vibration. *International Journal of Industrial Ergonomics*, 33(6): 527-541.

Gimmon, Y., Riemer, R., Oddsson, L., & Melzer, I. 2011. The effect of plantar flexor muscle fatigue on postural control. *Journal of Electromyography and Kinesiology* 21(6): 922-928.

Godley, S., Triggs, T., & Fildes, B. 2002. Driving simulator validation for speed research. A*ccident Analysis and Prevention*, 34 (5): 589- 600

González-Izal, M., Malanda, A., Gorostiaga, E., & Izquierdo, M. 2012. Electromyographic models to assess muscle fatigue. *Journal of Electromyography and Kinesiology*, 22(4): 501-512.

Goonetilleke, R.S., & Feizhou, S. 2001. A methodology to determine the optimum seat depth. *International Journal of Industrial Ergonomics*, 27(4): 207–217.

Grabisch, M., Duchene, J., Lino, F., & Perny, P. 2002. Subjective evaluation of discomfort in sitting position. *Fuzzy Optimization and Decision Making*, 1: 287-312.

Graf, M., Guggenbiihl, U., & Krueger, H. 1993. Investigations on the effects of seat shape and slope on posture, comfort and back muscle activity. *International Journal of Industrial Ergonomics*, 12: 91-103.

Graf, M., Guggenbuhl, U., & Krueger, H. An assessment of seated activity and postures at five workplaces. *International Journal of Industrial Ergonomics*, 15(2): 81-90.

Grandjean, E., 1980. Sitting posture of car drivers form the point of view of ergonomics. *Hum. Fact. Trans. Res.*, 2: 205-213.

Grandjean, E., Hünting, W., & Pidermann, M. 1983. VDT workstation design: Preferred settings and their effects. *Human Factors*, *25*(2), 161-175.

Griffin, M.J., 2012. *Handbook of human vibration.* Academic press.

Groenesteijn, L., Vink, P., de Looze, M., & Krause, F. 2009. Effects of differences in office chair controls, seat and backrest angle design in relation to tasks. *Applied Ergonomics*, 40(3): 362-370.

Gross, C.M., Goonetilleke, R.S. and Menon, K.K., 1994. New developments in the biomechanical assessment and prediction of seat comfort. *Hard facts about soft machines: The ergonomics of seating*.

Gruevski, K.M., Holmes, M.W., Gooyers, C.E., Dickerson, C.R. & Callaghan, J.P., 2016. Lumbar postures, seat interface pressures and discomfort responses to a novel thoracic support for police officers during prolonged simulated driving exposures. *Applied Ergonomics*, 52:160-168.

Grujicic, M., Pandurangan, B., Xie, X., Gramopadhye, A.K., Wagner, D., & Ozen, M. 2010. Musculoskeletal computational analysis of the influence of car-seat design/adjustments on long-distance driving fatigue. *International Journal of Industrial Ergonomics*, 40(3): 345-355.

Gujarati, D.N., & Porter, D.C. 2003. *Basic Econometrics*. Edisi ke-5. New York: McGraw-Hill.

Günzkofer, F., Bubb, H., & Bengler, K. (2012). Maximum elbow joint torques for digital human models. *International Journal of Human Factors Modelling and Simulation, 3*(2), 109-132.

Gupta, S., Kar, S., Gupta, S. & Routray, A., 2010. Fatigue in human drivers: A study using ocular, Psychometric, physiological signals. *Students' Technology Symposium (TechSym),* 234-240.

Gyi, D.E., Porter, J.M. & Robertson, N.K., 1998. Seat pressure measurement technologies: considerations for their evaluation. *Applied Ergonomics,* 29(2): 85-91.

Habsburg, S., & Middendorf, L. 1977. What really connecting seating comfort? Studies of correlates of static seat comfort. *Society of Automotive Engineers Paper*, 770247

Hakkanen, H., & Summala, H., 2000. Sleepiness at work among commercial truck drivers. *Sleep*, 23(1): 49-57.

Hallvig, D., Anund, A., Fors, C., Kecklund, G., Karlsson, J. G., Wahde, M., & Akerstedt, T. 2013. Sleepy driving on the real road and in the simulator-A comparison. *Accident Analysis and Prevention*, 50: 44-50.

Hamill, J., & Knutzen, K. M. 2006. *Biomechanical basis of human movement.* Lippincott Williams & Wilkins.

Harrell, F. 2015. *Regression modeling strategies: with applications to linear models, logistic and ordinal regression, and survival analysis*. USA: Springer.

Harrison, D. D., Harrison, S. O., Croft, A. C., Harrison, D. E., & Troyanovich, S. J. (2000). Sitting biomechanics, part II: optimal car driver's seat and optimal driver's spinal model. *Journal of Manipulative and Physiological Therapeutics*, 23(1), 37-47.

Hartley, L.R., Arnold, P.K., Smythe, G., & Hansen, J. 1994. Indicators of fatigue in truck drivers. *Applied Ergonomics*, 25(3): 143-156.

Hatfield, J., & Chamberlain, T. 2008. The impact of in-car displays on drivers in neighbouring cars: Survey and driving simulator experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*, 11(2): 137-146.

Haworth, N. L., Heffeman, C. L. & Home, E. J. 1989. *Fatigue in truck crashes*. Report No. 3. Melbourne, Australia: Monash University Crash Research Centre.

Healey, J. A. & Picard, R. W., 2005. Detecting stress during real-world driving tasks using physiological sensors, *IEEE Transactions on Intelligent Transportation Systems*, 6 (2005): 156-166.

Hefner, R., Edwards, D., Heinze, C., Sommer, D., Golz, M., Sirois, B., & Trutschel, U.

2009. Operator fatigue estimation using heart rate measures. *Proceedings of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 110-117.

Heinze, C., Trutschel, U., Edwards, D., Sirois, B., & Golz, M. 2011. Asymmetric properties of heart rate variability to assess operator fatigue. *Proceedings of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 475-481.

Heinze, C., Schirmer, S., Trutschel, U., Sirois, B., Golz, M., & Edwards, D. 2013. Can frequency domain heart rate measures detect impaired driver performance? *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, 390-396.

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

Hendrickson AR, Massey PD & Cronan TP. 1993. On the Test-Retest Reliability of Perceived Usefulness and Perceived Ease of Use Scales. MIS Quarterly 1993; 227-230.

Hermens, H.J., Freriks, B., Disselhorst-Klug, C. & Rau, G., 2000. Development of recommendations for SEMG sensors and sensor placement procedures. Journal of electromyography and Kinesiology, 10(5): 361-374.

Hermanns, I., Raffler, N., Ellegast, R.P., Fischer, S., & Göres, B. 2008. Simultaneous field measuring method of vibration and body posture for assessment of seated occupational driving tasks. *International Journal of Industrial Ergonomics*, 38(3-4): 255-263.

Hickey, A.J., Weegar, K., Kadulina, Y., Gagnon, S., Marshall, S., Myers, A., Tuokko, H., Bédard, M., Gélinas, I., Man-Son-Hing, M. & Mazer, B., 2013. The impact of subclinical sleep problems on self-reported driving patterns and perceived driving abilities in a cohort of active older drivers. *Accident Analysis & Prevention*, 61: 296-303.

Hiemstra-van Mastrigt, S., Groenesteijn, L., Vink, P. & Kuijt-Evers, L.F., 2017. Predicting passenger seat comfort and discomfort on the basis of human, context and seat characteristics: a literature review. Ergonomics, 60(7): 889-911.

Hirao, K., Kitazaki, S. & Yamazaki, N. 2006. Development of new driving posture focused on biomechanical loads. *SAE International Journal*, 100: 5-10.

Hostens, I., & Ramon, H. 2005. Assessment of muscle fatigue in low level monotonous task performance during car driving. *Journal of Electromyography and Kinesiology*, 15(3): 266-274.

Hubbard, R.P., & Reynolds, H. M. 1984. Anatomical geometry and seating. *SAE Technical Paper* 840506. Warrendale, PA: Society of Automotive Engineers, Inc.

Hurts, K., Angell, L.S., & Perez, M.A. 2011. The distracted driver: mechanisms, models, and measurement. *Reviews of Human Factors and Ergonomics*, 7(1): 3-57.

International Ergonomics Association (IEA). 2017. Definition and domains of ergonomics. www.iea.cc/whats (1 June 2017).

Ismail, A.R., Nuawi., M.Z., Kamaruddin, N.F., & Bakar, R.A. 2010. Comparative assessment of the whole-body vibration exposure under different car speed based on Malaysian road profile. *Journal of Applied Sciences*, 10(14): 1428-1434.

Ismail, R., Hafezi, M.H., Nor, R.M. & Ambak, K., 2012. Passenger's preference and satisfaction of public transport in Malaysia. *Australian Journal of Basic and Applied Sciences*, 6(8): 410-416.

Isman, R.E., Inman, V.T. & Poor, P.M., 1969. Anthropometric studies of the human foot and ankle. *Bull Prosthetics Res*, 11: .97-108.

Jagannath, M. & Balasubramanian, V., 2014. Assessment of early onset of driver fatigue using multimodal fatigue measures in a static simulator. *Applied Ergonomics*, *45(*4): 1140-1147.

Jap, B. T., Lal, S., Fischer, P., & Bekiaris, E. 2009. Using EEG spectral components to assess algorithms for detecting fatigue. *Expert Systems with Applications*, 36(2): 2352-2359.

Jianghong, Z., & Long, T. 1994. An evaluation of comfort of a bus seat. *Applied Ergonomics*, 25(6): 386-392.

Jiao, K., Li, Z., Chen, M., Wang, C., & Qi, S. 2004. Effect of different vibration frequencies on heart rate variability and driving fatigue in healthy drivers. *International Archives of Occupational and Environmental Health*, 77(3): 205-212.

Johns, M. 2014. Appendix I: the subjective measurement of excessive daytime sleepiness. *Sleep Disorders: Diagnosis and Therapeutics*, 643-657.

Johnson, M.J., Chahal, T., Stinchcombe, A., Mullen, N., Weaver, B., & Bédard, M. 2011. Physiological responses to simulated and on-road driving. *International Journal of Psychophysiology*, 81(3): 203-208.

Jonsson, S., & Jonsson, B. (1975). Function of the muscles of the upper limb in car driving. *Ergonomics*, 18(4), 375-388.

Jorna, P.G.A.M., 1993. Heart rate and workload variations in actual and simulated flight. *Ergonomics*, 36(9): 1043-1054.

Kamijo, K., Tsujimura, H., Obara, H., & Katsumata, M. 1982. Evaluation of seating comfort. *SAE Transactions*, 91(3): 2610-2620.

Kamp, I. 2012. The influence of car-seat design on its character experience. *Applied Ergonomics*, 43(2): 329-335.

Kang, T., Seo, Y., Park, J., Dong, E., Seo, B. and Han, D., 2013. The effects of elbow joint angle change on the elbow flexor muscle activation in pulley with weight exercise. *Journal of Physical Therapy Science*, 25(9): 1133-1136.

Kaptein, N., Theeuwes, J., & van der Horst, R. 1996. Driving simulator validity: some considerations. *Transportation Research Record: Journal of the Transportation Research Board*, 1550: 30-36.

Kawakita E., Itoh M. & Oguri K, 2010. Estimation of driver's mental workload using visual information and heart rate variability, *13th International IEEE Conference on Intelligent Transportation Systems*, 19-22 Sept. 2010.

Kawamura, A, Maeda, C., Shirakawa, T., Ishida, T., Nakatsuji, T. and Himeno, K. 2004. Applicability of a driving simulator as a new tool for the pavement surface evaluation. *Proceedings of the SIIV2004 International Congress.*

Kecklund G. & Akerstedt T. 1993. Sleepiness in long distance truck driving: an ambulatory EEG study of night driving. *Ergonomics*, 36: 1007-1017.

Kee, D., & Lee, I. 2012. Relationships between subjective and objective measures in assessing postural stresses. *Applied Ergonomics*, 43(2): 277-282.

Keene, D. 2010. Guide for assessing ankle range of movement for the AIM trial. Oxford, UK: Ankle Injury Management (AIM).

Keir, P. J., Sanei, K., & Holmes, M. W. 2011. Task rotation effects on upper extremity and back muscle activity. *Applied Ergonomics*, 42(6): 814-819.

Kircher, A., Uddman, M. & Sandin, J., 2002. *Vehicle control and drowsiness*. Linköping, Sweden: Swedish National Road and Transport Research Institute.

Klee, H., Bauer, C., Radwan, E., & Al-Deek, H. 1999. Preliminary validation of driving simulator based on forward speed. *Transportation Research Record: Journal of the Transportation Research Board*, 1689: 33-39.

Klein, J., Obrador, M., Gascons, N. & Reinkensmeyer, D.J. 2008. The effect of dynamic arm support on grip forces and steering errors during simulated driving. *International Journal of Heavy Vehicle Systems*, 15(2-4): 449-459.

Klein, J. 2009. *Performance enhancing mechanisms for human manipulation*. University of California, Irvine. http://search.proquest.com/docview/304851419?accountid=37552 [10 May 2016].

Knofczynski, G.T., & Mundfrom, D. 2008. Sample sizes when using multiple linear regression for prediction. *Educational and Psychological Measurement* 68(3): 431-442.

Kokonozi A K, Michail E M, Chouvarda I C & Maglaveras N M, 2008. A study of heart rate and brain system complexity and their interaction in sleep-deprived subjects, *Computers in Cardiology*, 14-17 Sept. 2008.

Kolich, M. 2003. Automobile seat comfort: occupant preferences vs. anthropometric accommodation. *Applied Ergonomics*, 34(2): 177-184.

Kolich, M., Seal, N., & Taboun, S. 2004. Automobile seat comfort prediction: statistical model vs. artificial neural network. *Applied Ergonomics*, 35(3): 275-284.

Kolich, M. 2008. A conceptual framework proposed to formalize the scientific investigation of automobile seat comfort, *Applied Ergonomics*, 39(2008): 15-27.

Kong, T.W. 2006. Comfort analysis in commercial vehicle’s passenger seat. Thesis. Universiti Teknologi Malaysia.

Kowalski, K., Love, J., Tuokko, H., MacDonald, S., Hultsch, D., & Strauss, E., 2012. The influence of cognitive impairment with no dementia on driving restriction and cessation in older adults. *Accidents Analysis and Prevention*, 49: 308-315

Kozawa, Y. Sugimoto,G. & Suzuki, Y. A new ride comfort meter. *SAE,* paper no. 860430.

Kramer, A.F. 1990. *Physiological metrics of mental workload : A Review of Recent Progress*. San Diego.

Kumar, S. 1999. *Biomechanics in Ergonomics*. CRC Press.

Kumbhar, P.B. 2013. Simulation based virtual driver fatigue prediction and determination of optimal vehicle seat dynamic parameters. Master's thesis, Texas Tech University.

Kyung, G., & Nussbaum, M.A. 2008. Driver sitting comfort and discomfort (part II): Relationships with and prediction from interface pressure. *International Journal of Industrial Ergonomics*, 38(5-6): 526–538.

Kyung, G., Nussbaum, M.A., & Babski-Reeves, K. 2008. Driver sitting comfort and discomfort (part I): Use of subjective ratings in discriminating car seats and correspondence among ratings. *International Journal of Industrial Ergonomics*, 38(5-6): 516-525.

Kyung, G. 2008. An integrated human factors approach to design and evaluation of the driver workspace and interface: driver perception, behaviour, and objective measures.PhD Thesis, Virginia Polytechnic Institute and State University.

Lal, S., & Craig, A. 2000. Driver fatigue: psychophysiological effects. *International Conference on Fatigue and Transportation*.

Lal, S.K.L., & Craig, A. 2001. A critical review of the psychophysiology of driver fatigue. *Biological Psychology*, 55(2001): 173-194.

Lanzotti, A., Trotta, M., & Vanacore, A. 2011. Validation of a new index for seat comfort assessment based on objective and subjective measurements. *Proceedings of the IMProVe 2011 International conference on Innovative Methods in Product Design*, 60-68.

Larue, G.S., Rakotonirainy, A., & Pettitt, A.N. 2011. Driving performance impairments due to hypovigilance on monotonous roads. *Accident Analysis and Prevention*, 43(6): 2037-2046.

Lee, J., & Ferraiuolo, P, 1993. Seat comfort. Technical Paper No. 931005.Society of Automotive Engineers, Inc., Warrendale, PA, USA

Lee, H., & Whang, K.-W. 2012. A quantitative measurement of LCD and PDP TVs for human visual preference and fatigue. *Displays*, 33(1): 1-6.

Lee, N.S., Schneider, L.W., & Ricci, L.L. 1990. *Review of selected literature related to seating discomfort*, University of Michigan: Trasportation Research Institute.

Lenneman, J.K., & Backs, R.W. 2009. Cardiac autonomic control during simulated driving with a concurrent verbal working memory task. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 51(3).

Lenneman, J.K., & Backs, R.W. 2010. Enhancing assessment of in-vehicle technology attention demands with cardiac measures. *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '10*, (AutomotiveUI), 20.

Leung, J., Smith, R., Harvey, L.A., Moseley, A.M., & Chapparo, J. 2014. The impact of simulated ankle plantarflexion contracture on the knee joint during stance phase of gait: a within-subject study. *Clinical Biomechanics*, 29(4): 423-428.

Li, Z., Jiao, K., Chen, M., & Wang, C. 2004. Reducing the effects of driving fatigue with magnitopuncture stimulation. *Accident Analysis and Prevention*, 36(4): 501-505.

Li, Z., Li, S. E., Li, R., Cheng, B., & Shi, J. 2017. Online detection of driver fatigue using steering wheel angles for real driving conditions. *Sensors*, 17(3), 495.

Liao, M. H., & Drury, C. G. (2000). Posture, discomfort and performance in a VDT task. *Ergonomics*, *43*(3), 345-359.

Lieber, R. L., & Friden, J. 1993. Muscle damage is not a function of muscle force but active muscle strain. *Journal of Applied Physiology*, 74(2) 520-526.

Lim, H.E., & Salleh, M.F.M. 2007. *Unjuran dengan model regresi: aplikasi sas*. Sintok: UUM Press.

Liu C C, Hosking S G & Lenné M G, 2009. Predicting driver drowsiness using vehicle measures: Recent insights and future challenges, *Journal of Safety Research*, 40(2009): 239-245.

Liu, Y., Ji, X., Hayama, R., Mizuno, T., & Nakano, S. 2014. Method for measuring a driver's steering efficiency using electromyography. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 228: 1170–1184.

Lueder, R. 2004. *Ergonomics of seated movement: A review of the scientific literature*. Humanics Ergosystem Inc.

Maël, A., Etienne, P., & Vincent, R. 2013. Multimodal approach to automobile driving comfort: The influence of visual setting on assessments of vibro-accoustic comfort in simulators. *Applied Acoustics*, 74(12): 1378-1387.

Mackie, R.R., & Miller, J.C., 1978. *Effects of hours of service, regularity of schedules and cargo loading on truck and bus driving fatigue.* Human Factors Research Inc. CA, Technical report 1765-F.

Maia, Q., Grandner, M.A., Findley, J. & Gurubhagavatula, I., 2013. Short and long sleep duration and risk of drowsy driving and the role of subjective sleep insufficiency. *Accident Analysis & Prevention*, *59*: 618-622.

Majid, N. A. Edzuan Abdullah, M. F., Jamaludin, M.S., Notomi, M., Rasmussen, J. 2013. Musculoskeletal analysis of driving fatigue: the influence of seat adjustments. *Advanced Engineering Forum*, 10: 373-378.

Mansfield, N., Sammonds, G., & Nguyen, L. 2015. Driver discomfort in vehicle seats - Effect of changing road conditions and seat foam composition. *Applied Ergonomics*, 50: 153-159.

Mansfield, N. J., Sammonds, G., Darwazeh, N., Massoud, S., Mocio, A., Patel, T., & Sehdev, A. 2017. Movement analysis to indicate discomfort in vehicle seats.*1st International Comfort Congress*, Salerno, 7-8 June 2017.

Marsalek, K. & Thoren, C. 2003. The DLR alertness management program for companies-fit for driving tests.

Mascord, D.J., & Heath, R.A. 1992. Behavioral and physiological indices of fatigue in a visual tracking task. *Journal of Safety Research*, 23(1): 19-25.

Mayhew, D.R., Simpson, H.M., Wood, K M., Lonero, L., Clinton, K.M., & Johnson, A.G. 2011. On-road and simulated driving: concurrent and discriminant validation. *Journal of Safety Research*, 42(4): 267-275.

McFadden M, Powers J, Brown W, & Walker M. 2000. Vehicle and driver attributes affecting distance from the steering wheel in motor vehicles. *Human Factors*, 42(4):676-682

Medlej, J. 2014. Human Anatomy Fundamentals: Flexibility and Joint Limitations. http://design.tutsplus.com/articles/human-anatomy-fundamentals-flexibility-and-joint-limitations--vector-25401, [13 May 2016].

Mehta, R.K. 2016. Integrating Physical and Cognitive Ergonomics, *IIE Transactions on Occupational Ergonomics and Human Factors*, 4(2-3): 83-87.

Mehta, C.R., & Tewari, V.K. 2010. Damping characteristics of seat cushion materials for tractor ride comfort. *Journal of Terramechanics*, 47(6): 401-406.

Merat, N., & Jamson, A.H. 2013. The effect of three low-cost engineering treatments on driver fatigue: A driving simulator study. *Accident Analysis and Prevention*, 50: 8-15.

Merletti, R., & Parker, P. A. (Eds.). 2004. *Electromyography: physiology, engineering, and non-invasive applications* (Vol. 11). John Wiley & Sons.

Michon, J.A. 1985. *A critical view of driver behaviour models: What do we know, what should we do?* L. Evans and R.C. Schwing (Eds.). Human behaviour and traffic safety. Plenum Press, New York

Millar, M. 2012. Measuring Fatigue. *Asia-Pacific FRMS Seminar*, Bangkok.

MIROS. 2012. MIROS Crash Investigation and Reconstruction. 2012. *Annual Statistical Report 2007-2010.*

MIROS 2016. MIROS. www.miros.com.my [1 May 2015].

Mittal, N., Chakrabarty N., & Sarin S. M., 2004. Safety hazards of distracted driving, *Road Safety Digest*, 14(2).

Miyaji, M, Kawanaka H & Oguri K. 2009. Driver's cognitive distraction detection using physiological features by the adaboost, *12th International IEEE Conference on Intelligent Transportation Systems*, 4-7 Oct. 2009.

Mossey, M. E., Xi, Y., McConomy, S.K., Brooks, J.O., Rosopa, P.J., & Venhovens, P.J. 2014. Evaluation of four steering wheels to determine driver hand placement in a static environment. *Applied Ergonomics*, 45(4): 1187-1195.

Mohamad, D., Deros, B.M., Wahab, D.A., Daruis, D.D.I., & Ismail, A.R. 2010. Integration of comfort into a driver's car seat design using image analysis. *American Journal of Applied Sciences*, 7(7): 937-942.

Mohamad, D., Deros, B.M., Daruis, D.D.I., Ramli, N.F., & Sukadarin, E.H. 2016. Comfortable driver's car seat dimensions based on anthropometrics data. *Iranian Journal of Public Health*, 45(1): 106-113.

Mohan, V., Shamsaimon, N. S., Japri, M. B., Yasin, N. B., Henry, L. J., & Othman, I. R. (2014). Fore arm circumference and hand length predicts maximal hand grip strength among Malaysian population. *Middle-East J. Sci. Res*, *21*(4), 634-639.

Morad, Y., Barkana, Y., Zadok, D., Hartstein, M., Pras, E., & Bar-Dayan, Y. 2009. Ocular parameters as an objective tool for the assessment of truck drivers fatigue. *Accident; Analysis and Prevention*, 41(4): 856-860.

Morioka, M., & Griffin, M.J. 2009. Equivalent comfort contours for vertical vibration of steering wheels: effect of vibration magnitude, grip force, and hand position. *Applied ergonomics* 40(5): 817-825.

Morioka, M. & Griffin, M.J. 2015. Masking of thresholds for the perception of fore-and-aft vibration of seat backrests. *Applied ergonomics* 50: 200-206.

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.

Neumann, D. A. 2002. Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation.

Newell, G.S., & Mansfield, N.J. 2008. Evaluation of reaction time performance and subjective workload during whole-body vibration exposure while seated in upright and twisted postures with and without armrests. *International Journal of Industrial Ergonomics*, 38(5-6), 499-508.

Ng, D., Cassar, T., & Gross, C.M. 1995. Evaluation of an intelligent seat system. *Applied Ergonomics*, 26(2): 109-116.

Nilsson, T., Nelson, T.M., & Carlson, D. 1997. Development of fatigue symptoms during simulated driving. *Accident Analysis & Prevention*, 29(4): 479-488.

Nordin, M., & Frankel, V. H. 2001. *Basic biomechanics of the musculoskeletal system*. Lippincott Williams & Wilkins.

Nurdden, A., Rahmat, R.A.O.K. & Ismail, A., 2007. Effect of transportation policies on modal shift from private car to public transport in Malaysia. *Journal of Applied Sciences*, 7(7): 1013-1018.

Okogbaa, O., Shell, R., & Filipusic, D. 1994. On the investigation of the neurophysiological correlates of knowledge worker mental fatigue using the EEG signal. *Applied Ergonomics*, 25: 355-365.

Okunribido, O.O., Magnusson, M., & Pope, M.H. 2006. Low back pain in drivers: The relative role of whole-body vibration, posture and manual materials handling. *Journal of Sound and Vibration*, 298(3): 540-555.

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

Openshaw, S.D. 2011. Predicting and quantifying seated comfort and discomfort using objective and subjective measures, PhD Dissertation, University of Iowa.

Oron-Gilad, T., & Shinar, D. 2000. Driver fatigue among military truck drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, 3(4): 195-209.

Otmani, S., Pebayle, T., Roge, J., & Muzet, A. 2005. Effect of driving duration and partial sleep deprivation on subsequent alertness and performance of car drivers. *Physiology & Behavior*, 84(5): 715-724.

Pandis, P., Prinold, J. A. I., & Bull, A. M. J. 2015. Shoulder muscle forces during driving: sudden steering can load the rotator cuff beyond its repair limit. *Clinical Biomechanics*, 30(8): 839-846.

Panou, M., Bekiaris, E. and Papakostopoulos. 2001. Modelling Driver Behaviour in European Union and International Projects. In: Cacciabue, C. (Eds.). Modelling driver behaviour in automotive environments. Springer-Verlag London Limited, 3-25.

Parakket, J., Pellettiere, J., Reynolds, D., Sasidharan, M. & El-Zoghbi, M., 2006. *Quantitative methods for determining US Air Force crew cushion comfort* (no. afrl-he-wp-tp-2006-0092). Air force research lab wright-patterson afb oh human effectiveness directorate.

Park, S.J., Kim, C., Kim, C.J., & Lee, J.W. 2000. Comfortable driving postures for Koreans. *International Journal of Industrial Ergonomics*, 26: 489–497.

Piaw, C.Y. 2006. *Asas statistik penyelidikan*. Cetakan Pertama. Shah Alam, Selangor: McGrraw-Hill (Malaysia).

Pilcher, J.J., Pury, C.L.S., & Muth, E.R. 2003. Assessing subjective daytime sleepiness: An internal state versus behaviour approach. *Behavioural Medicine*, 29: 60-67.

Pitrella, F.D. & Käppler, W.D., 1988. Identification and evaluation of scale design principles in the development of the extended range, sequential judgment scale.

Philip, P., Taillard, J., Klein, E., Sagaspe, P., Charles, A., Davies, W. & Bioulac, B. 2003. Effect of fatigue on performance measured by a driving simulator in automobile drivers. *Journal of Psychosomatic Research*, 55(3): 197-200.

Philip, P., Sagaspe, P., Moore, N., Taillard, J., Charles, A., Guilleminault, C., & Bioulac, B. 2005. Fatigue, sleep restriction and driving performance. *Accident Analysis & Prevention*, 37(3): 473-478.

Porter, J.M & Sharp, J.C. 1984. The influence of age, sex, and musculoskeletal health upon the subjective evaluation of vehicle seating. *Contemporary Ergonomics*, 148-154.

Porter, J.M. & Gyi, D.E. 1995. Low back trouble and driving. P*roceedings of the 2nd International Scientific Conference on Prevention of Work-related Musculoskeletal Disorders (PREMUS'95*), Montreal, Canada, September 1995, pp. 117-119.

Porter, J. M., & Gyi, D. E. 1998. Exploring the optimum posture for driver comfort. *International Journal of Vehicle Design*, 19(3): 255-266.

Porter, J.M. & Gyi, D.E. 2002. The prevalence of musculoskeletal troubles among car drivers. *Occupational Medicine*, 52(1): 4-12.

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

Proske, U., & Morgan, D. L. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *The Journal of Physiology*, *537*(2), 333-345.

Qiu, Y., & Griffin, M.J. 2003. Transmission of fore-aft vibration to a car seat using field tests and laboratory simulation. *Journal of Sound and Vibration*, 264: 135-155.

Ranney, T.A., Simmons, L.A. & Masalonis, A.J., 1999. Prolonged exposure to glare and driving time: effects on performance in a driving simulator. *Accident Analysis & Prevention*, 31(6): 601-610.

Reed, M.P., Schneider, L.W., & Ricci, L.L., 1994. Survey of Auto Seat Design Recommendations for Improved Comfort.Report No. UMTRI-94-6.University of Michigan Transportation Research Institute, Ann Arbor, MI, USA

Rencher, A.C. & Schaalje, G.B. 2008. *Linear models in statistics*. Edisi ke-2. Hoboken, New Jersey: John Wiley & Sons.

Reimer, B., Mehler, B., Coughlin, J.F., Roy, N., & Dusek, J.A. 2011. The impact of a naturalistic hands-free cellular phone task on heart rate and simulated driving performance in two age groups. *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(1): 13-25.

Richards, L.G. 1980. On the psychology of passenger comfort. *Human Factors in Transport Research*, 2: 15-23.

Ronen, A., & Yair, N. 2013. The adaptation period to a driving simulator. *Transportation Research Part F: Traffic Psychology and Behaviour*, 18: 94-106.

Roscoe, A.H. 1992. Assessing pilot workload. Why measure heart rate, HRV and respiration? *Biological Psychology*, 34(192): 259-287.

Rossi, R., Gastaldi, M., & Gecchele, G. 2011. Analysis of driver task-related fatigue using driving simulator experiments. *Procedia-Social and Behavioral Sciences*, 20: 666–675.

Rudin-Brown, C. M., Edquist, J., & Lenné, M. G. 2014. Effects of driving experience and sensation-seeking on drivers' adaptation to road environment complexity. *Safety Science*, 62: 121-129.

Rumschlag, G., Palumbo, T., Martin, A., Head, D., George, R., & Commissaris, R.L. 2015. The effects of texting on driving performance in a driving simulator : The influence of driver age. *Accident Analysis and Prevention*, 74(2015): 145-149.

Saginus, K., & Marklin, R. 2013. The Effects of Mobile Computer Location in a Vehicle Cab on Muscle Activity and Body Posture of Large and Small Drivers.

In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 57, No. 1, pp. 902-906). Sage CA: Los Angeles, CA: SAGE Publications.

SAE J4004. 2008. *Positioning the H-Point Design Tool - Seating Reference Point and Seat Track Length*. Warrendale, PA: SAE International.

Saito, K., 1999. Measurement of fatigue in industries. *Industrial health*, *37*(2):.134-142.

Sanders, M.S. & McCormick, E.J. 1993. *Human factors in engineering and design*. Seventh edition. New York: McGraw Hill.

Saxby, D. J., Matthews, G., & Neubauer, C. 2017. The relationship between cell phone use and management of driver fatigue: it's complicated. *Journal of Safety Research*, 61: 129-140.

Schafer, R.C. 1987. Clinical Biomecahnics: Muscoloskeletal Actions and reactions, Chapter 4: body alignment posture and gait. Williams & Wilkins.

Schenkman, M. & Rugo de Cartaya, V., 1987. Kinesiology of the shoulder complex. *Journal of Orthopaedic & Sports Physical Therapy*, 8(9):438-450.

Schliefer, L.M., & Okogbaa, O.G., 1990. System response time and method of pay: cardiovascular stress effects in computer-based tasks. *Ergonomics*, 33(12): 1495-1509.

Schmidt, S., Amereller, M., Franz, M., Kaiser, R. & Schwirtz, A. 2013. A literature review on optimum and preferred joint angles in automotive sitting posture. *Applied Ergonomics*, 45(2): 247-260.

Sekaran, U. 2006. *Research methods for business: A skill building approach*. Edisi ke-4. New Jersey: John Wiley & Sons

SENIAM. 2016. Surface electromyography for non-invasive measurement (SENIAM). www.seniam.org. [19 May 2016].

Shackel, B., Chidsey, K.D., Shipley, P., 1969. The assessment of chair comfort, *Ergonomics*, 12(2): 269-306

Shahid, A., Wilkinson, K., Marcu, S. & Shapiro C.M. 2012. *STOP, THAT and One Hundred Other Sleep Scales, Chapter 91: Stanford Sleepiness Scale*, Springer Science & Business Media LLC, 369-370.

Shen, W., & Galer, I.A.R. 2015. Development of a pressure related assessment model of seating discomfort. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*.

Shen, W., & Parsons, K.C. 1997. Validity and reliability of rating scales for seated pressure discomfort. *International Journal of Industrial Ergonomics*, 20(6): 441-461.

Shiomi, K., Sawa, M., Sato, K., Mizukami, N., & Suzuki, A. 2005. Experimental Results of Measuring Human Fatigue by Utilizing Uttered Voice Processing. *Systems, Man and Cybernetics,* 2008: 5-9.

Short, M.A., Pearce, R., Centofanti, S., Hilditch, C., Banks, S., & Lushigton, K. 2013. Beyond Endurance Sustaining Operations: Do Shorter Shifts Mitigate Fatigue Risk? *Bushfire CRC and AFAC Conference*, 2-5 September 2013, Melbourne.

Slater, K. 1985. Human comfort. Springfield, IL: Thomas.

Smith, L.K. 1995. *Brunnstrom's Clinical Kinesiology*, 5th edition, Book Promotion &Service LTD.

Smith P, Shah M. & Vitoria L.N, 2003. Determining driver visual attention with one camera, *IEEE Transactions on Intelligent Transportation Systems*, 4(2003): 205-218.

Smith, J., Mansfield, N., Gyi, D., Pagett, M., & Bateman, B. 2015. Driving performance and driver discomfort in an elevated and standard driving position during a driving simulation. *Applied Ergonomics*, 49: 25-33.

Soderberg, G.L., & Knutson, L.M. 2000. A guide for use and interpretation of kinesiologic electromyographic data. *Physical Theraphy*, 80: 485-498.

Solaz, J. S., Page, Á., Porcar, R., Mateo, B., Durá, J. V., Gómez, J. A., & Vera, P. 2006. *Functional data analysis as a tool to find discomfort evolution patterns in passenger car seats* (No. 2006-01-1296). SAE Technical Paper.

Son, J., Mehler, B., Lee, T., Park, Y., Coughlin, J., & Reimer, B. 2011. Impact of cognitive workload on physiological arousal and performance in younger and older drivers. *Proceedings of the Sixth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 87-94.

Stephens, A.N., & Groeger, J.A. 2009. Situational specificity of trait influences on drivers' evaluations and driving behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, 12(1): 29-39.

Sung, E.-J., Min, B.-C., Kim, S.-C., & Kim, C.-J. 2005. Effects of oxygen concentrations on driver fatigue during simulated driving. *Applied Ergonomics*, 36(1): 25–31.

Svensson, U. 2004. *Blink behaviour based drowsiness detection – method development and validation*. Linköping University: LiU-IMT-EX-04/369

Tan, C.F., Chen, W., & Rauterberg, M. 2010. Seat discomfort of Dutch truck driver seat : A survey study and analysis. *SAE International*, 1-8.

Tan, C. F., Delbressine, F., Chen, W., & Rauterberg, M. 2008. Subjective and objective measurements for comfortable truck driver's seat. *AVEC*, 851-856.

Tanaka, Y., Kaneyuki, H., Tsuji, T., Miyazaki, T., Nishikawa, K., & Nouzawa, T. 2009. Mechanical and perceptual analyses of human foot movements in pedal operation. *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, (October), 1674-1679.

Thakurta, K., Koester, D., Bush, N., Bachle, S. 1995. Evaluating short and long term seating comfort. *Society of Automotive Engineers*, 950144.

Tewari, V. K., & Prasad, N. 2000. Optimum seat pan and back-rest parameters for a comfortable tractor seat. Ergonomics, 43(2): 167-186.

The Star Online. 2017. Mr. Foreman: manual transmission. https://www.nst.com.my/cbt/2017/05/239315/mr-foreman-manual-transmissions [30 January 2018].

Thiffault, P., & Bergeron, J. 2003. Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis and Prevention*, 35(3): 381–91.

Tijerina, L., Glecker, M., Stoltzfus, D., Johnston, S., Goodman, M.J., & Wierwille, W.W. 1999. *A Preliminary assessment of algorithms for drowsy and inattentive driver detection on the road*, No. HS-808 905.

Ting, P.H., Hwang, J.R., Doong, J.L. & Jeng, M.C., 2008. Driver fatigue and highway driving: A simulator study. *Physiology & Behavior*, *94*(3): 448-453.

Torsvall, L., & Åkerstedt, T. 1987. Sleepiness on the job: continuously measured EEG changes in train drivers. *Electroencephalography and Clinical Neurophysiology*, 66: 502-511.

Trutschel, U., Sirois, B., Sommer, D., Golz, M. & Edwards, D. 2011. Perclos: an alertness measure of the past. *Proceedings of the Sixth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 172-179.

Tsutsumi, H., Hoda, Y., Tanabe, S.I. & Arishiro, A., 2007. Effect of car cabin environment on driver's comfort and fatigue. *2007 World Congress*.

Udo, H., Fujimura, M., & Yoshinaga, F. 1999. The effect of a tilting seat on back, lower back and legs during sitting work. *Industrial Health*, *37*(4): 369-381.

Ünal, A.B., de Waard, D., Epstude, K., & Steg, L. 2013. Driving with music: effects on arousal and performance. *Transportation Research Part F: Traffic Psychology and Behaviour*, 21: 52-65.

Vaghefi, S. H. E., Elyasi, L., Amirian, S. R., & Vaghefi, S. E. 2014. Anthropometric survey of worker population in Bandar-Abbas. *Thrita*, *3*(1).

Veltman, J.A, & Gaillard, A.W. 1998. Physiological workload reactions to increasing levels of task difficulty. *Ergonomics,* 41(5): 656-669.

Vergara, M., & Page, A. 2000. System to measure the use of the backrest in sitting-posture office tasks. *Applied Ergonomics*, 31(3): 247-254.

Vergara, M., & Page, A. 2002. Relationship between comfort and back posture and mobility in sitting-posture. *Applied Ergonomics,* 33: 1-8.

Verver, M. M., de Lange, R., van Hoof, J., & Wismans, J.S.H.M. 2005. Aspects of seat modelling for seating comfort analysis. *Applied Ergonomics,* 36(1): 33-42.

Viano, D.C. &Andrzejak, D.V., 1992. Research issues on the biomechanics of seating discomfort: an overview with focus on issues of the elderly and low-back pain. *SAE Technical Paper*, 920130.

Victor T.W, Harbluk J.L & Engström J.A. 2005. Sensitivity of eye- movement measures to in-vehicle task difficulty, *Transportation Research Part F: Traffic Psychology and Behaviour,* 8(2005): 167-190.

Vilimek, M., Horak, Z., & Petr, K. 2011. Optimization of shift lever position. *Journal of Chemical Information and Modeling*, 53: 1689-1699.

Vink, P., & Hallbeck, S. 2012. Editorial: comfort and discomfort studies demonstrate the need for a new model. *Applied Ergonomics*, 43(2): 271-276.

Walton, D., & Thomas, J.A. 2005. Naturalistic observations of driver hand positions. *Transportation Research Part F: Traffic Psychology and Behaviour,* 8(3): 229–238.

Wang, X., Le Breton-Gadegbeku, B., & Bouzon, L. 2004. Biomechanical evaluation of the comfort of automobile clutch pedal operation. *International Journal of Industrial Ergonomics*, 34(3): 209-221.

Wewers M.E. & Lowe N.K. 1990. A critical review of visual analogue scales in the measurement of clinical phenomena. *Research in Nursing and Health*, 13: 227-236.

Wierwille, W.W., & Eggemeier, F.T. 1993. Recommendations for mental workload measurement in a test and evaluation environment. *Human Factors*, 35(2): 263-281.

Wierwille, W., Ellsworth, L., Wreggit, S., Fairbanks, R., & Kirn, C. 1994. *Research on vehicle based driver status/performance monitoring; development, validation and refinement of algorithms for detection of driver drowsiness.* (No. DOT HS 808 247): National Highway Safety Administration Final Report.

Wilder, D., Magnusson, M. L., Fenwick, J., & Pope, M. 1994. The effect of posture and seat suspension design on discomfort and back muscle fatigue during simulated truck driving. *Applied Ergonomics*, 25(2): 66-76.

Wilke, H.J., Neef, P., Caimi, M., Hoogland, T. & Claes, L.E. 1999. New in vivo measurements of pressures in the intervertebral disc in daily life. *Spine*, 24(8): 755-762.

Williamson, A. 2007. Fatigue and coping with driver distraction. *Distracted Driving*, 611-622.

Williamson, A., Feyer, A., & Friswell, R. 1996. The impact of work practices on fatigue in long distance truck drivers. *Accident Analysis & Prevention*, 28(6): 709-719.

Williamson, A., & Chamberlain, T. 2005. *Review of on road driver fatigue monitoring devices*, NSW Injury Risk Management Research Centre, University of New South Wales, Australia.

Williamson, A., Lombardi, D., Folkard, S., Stutts, J., Courtney, T, & Connor, J. 2011. The link between fatigue and safety. *Accident Analysis and Prevention*, 43(2): 498–515.

Wilson, G.F., Caldwell, J.A. & Russell, C.A., 2007. Performance and psychophysiological measures of fatigue effects on aviation related tasks of varying difficulty. *The International Journal of Aviation Psychology*, 17(2): 219-247.

Wilson, G.F. & Russell, C. 2006. *Performance and Psychophysiological Measures of Fatigue Effects on Aviation Related Tasks of Varying Difficulty*, 1–51.

Wind, A. E., Takken, T., Helders, P. J., & Engelbert, R. H. (2010). Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults?. *European Journal of Paediatrics*, 169(3), 281-287.

Wright, H. & Lack, L. 2014. *Encyclopedia of Quality of Life and Well-Being Research*, Springer Netherlands, 1950-1951.

Wylie, C.D., Shultz, T. & Miller, J.C., 1996. Commercial motor vehicle driver fatigue and study alertness. Technical summary

Wu, X., Rakheja, S., & Boileau, P.-É. 1999. Distribution of human–seat interface pressure on a soft automotive seat under vertical vibration. *International Journal of Industrial Ergonomics*, 24(5): 545-557.

Xiao F, Bao-Cai Y & Yan-Feng S, 2007. Yawning Detection for Monitoring Driver Fatigue, *International Conference on Machine Learning and Cybernetics*, Hong Kong, 19-22 August 2007.

Yadav, O.P. & Goel, P.S. 2008. Customer satisfaction driven quality improvement target planning for product development in automotive industry. *International Journal of Production Economics* 113(2): 997-1011.

Yamazaki, N. 1992. Analysis of sitting comfortability of driver's seat by contact shape. Ergonomics. 35(5-6): 677-692.

Yassierli, 2005. Muscle fatigue during isometric and dynamic efforts in shoulder abduction and torso extension: age effects and alternative electromyographic measures, PhD Thesis, Virginia Polytechnic Institute and State University.

Yun, M.H., Donges, L. & Freivalds, A. 1992, *Using force sensitive resistors to evaluate the driver seating comfort*, in S. Kumar (ed.), Advances in Industrial Ergonomics and Safety IV (London: Taylor and Francis), 403-410

Yusoff, A.R. 2017. Pembangunan model linear untuk meramal ketidakselesaan pemandu ketika mengawal dan mengendali pedal minyak kereta. Tesis Doktor Falsafah, Universiti Kebangsaan Malaysia.

Yusoff, A.R., Deros, B.M, and Daruis, D.D.I. 2012. Vibration transmissibility on foot during controlling and Operating Car Accelerator Pedal. *Proceedings of 4th International Conference on Noise, Vibration and Comfort (NVC 2012), 27-28 November 2012, Kuala Lumpur, Malaysia*, 210-215.

Yusoff, A.R., Deros, B. M., Daruis, D. D. I., & Joseph, H. L. 2016. Tabialis anterior muscle contraction on driver's knee angle posture less than 101 deg for foot pressing and releasing an automotive pedal. *Malaysian Journal of Public Health Medicine*, 1*:* 102-107.

Zeier, H. 1979. Concurrent physiological activity of driver and passenger when driving with and without automatic transmission in heavy city traffic.pdf. *Ergonomics*, 22(7): 799-810.

Zenk, R., Franz, M. & Bubb, H. 2007. Spine load in the context of automotive seating. *Society of Automotive Engineers. Inc*. Technical Paper, no. 2007-01-2485.

Zhang, L., Helander, M.G., & Drury, C.G. 1996. Identifying factors of comfort and discomfort in sitting. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 38(3): 377-389.

Zhao, C., Zhao, M., Liu, J., & Zheng, C. 2012. Electroencephalogram and electrocardiograph assessment of mental fatigue in a driving simulator. *Accident Analysis and Prevention*, 45: 83-90.

APPENDIX A

ETHICS APPROVAL FROM UKM COMMITTEES

UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

Pusat Pengurusan Penyelidikan dan Instrumentasi / ***Centre for Research and Instrumentation Management***

Rujukan : UKM PPI/111/8/JEP-2016-200
Tarikh : 21 April 2016

Profesor Dr. Baba Md. Deros
Jabatan Kejuruteraan Mekanik & Bahan
Fakulti Kejuruteraan & Alam Bina
Universiti Kebangsaan Malaysia

Y.bhg. Profesor/Datuk/Dato'/Datin/Tuan/Puan,

Kelulusan Etika Menjalankan Penyelidikan di UKM

Tajuk : Ergonomik Dan Kejuruteraan Faktor Manusia Di Dalam Bidang Automotif

Perkara yang tersebut di atas adalah dirujuk.

Sukacita dimaklumkan, Jawatankuasa Etika Penyelidikan UKM meluluskan permohonan penyelidikan Y. Bhg. Profesor/Datuk/Dato'/Datin/Tuan/Puan bagi tajuk diatas. Tempoh kelulusan penyelidikan adalah daripada **14 April 2016 - 13 April 2019**. Sila kemukakan sebarang Laporan **Kesan Sampingan, Laporan Kemajuan Setiap 6 Bulan** dan **Laporan Akhir** sebaik sahaja penyelidikan tamat kepada Jawatankuasa Etika Penyelidikan UKM.

Sukacita diingatkan projek penyelidikan ini hanya boleh dijalankan setelah mendapat **surat kelulusan menjalankan penyelidikan** dari Timbalan Dekan Penyelidikan Fakulti.

Sekian, terima kasih.

Yang benar,

PROFESOR MADYA (K) DATO' DR. FUAD ISMAIL
Pengerusi
Jawatankuasa Etika Penyelidikan
Universiti Kebangsaan Malaysia

s.k. - **Pengarah**
Pusat Pengurusan Penyelidikan dan Instrumentasi (CRIM)
Universiti Kebangsaan Malaysia

- **Timbalan Dekan (Penyelidikan & Penjanaan)**
Fakulti Kejuruteraan & Alam Bina
Universiti Kebangsaan Malaysia

- **Ketua Jabatan Kejuruteraan Mekanik & Bahan**
Fakulti Kejuruteraan & Alam Bina
Universiti Kebangsaan Malaysia

Sekretariat Etika Penyelidikan Universiti Kebangsaan Malaysia, Tingkat 1, Blok Klinikal, Hospital Canselor Tuanku Muhriz, Pusat Perubatan UKM Jalan Yaacob Latif, Bandar Tun Razak, 56000 Cheras Kuala Lumpur. MALAYSIA. Telefon: **+603-9145 9046 / 9048**

Mengilham Harapan, Mencipta Masa Depan • *Inspiring Futures, Nurturing Possibilities* www.ukm.my

- **Ahmed Rithauddeen Yusoff (P60216)**
- **Nor Kamaliana Khamis (P68152)**
- **Shukriah Abdullah (P78501)**
- **Darliana Mohamad (P65747)**
- **Rusalbiah Che Mamat (P69997)**
  Jabatan Kejuruteraan Mekanik & Bahan
  Fakulti Kejuruteraan & Alam Bina
  Universiti Kebangsaan Malaysia

- Fail **JEP-2016-200**

- Fail Surat Kelulusan 2016

F/hai/JEP-2016-200

APPENDIX B

CONSENT FORM

Researcher:

Nor Kamaliana binti Khamis
PhD Candidate
Universiti Kebangsaan Malaysia, Malaysia / Universtity of Duisburg-Essen, Germany

I have read and understand all research information and also was briefed by researcher about this study. Therefore, I agreed to get involved with this project and adhere to the given instructions and the necessary requirements.

Name and Identity Card:

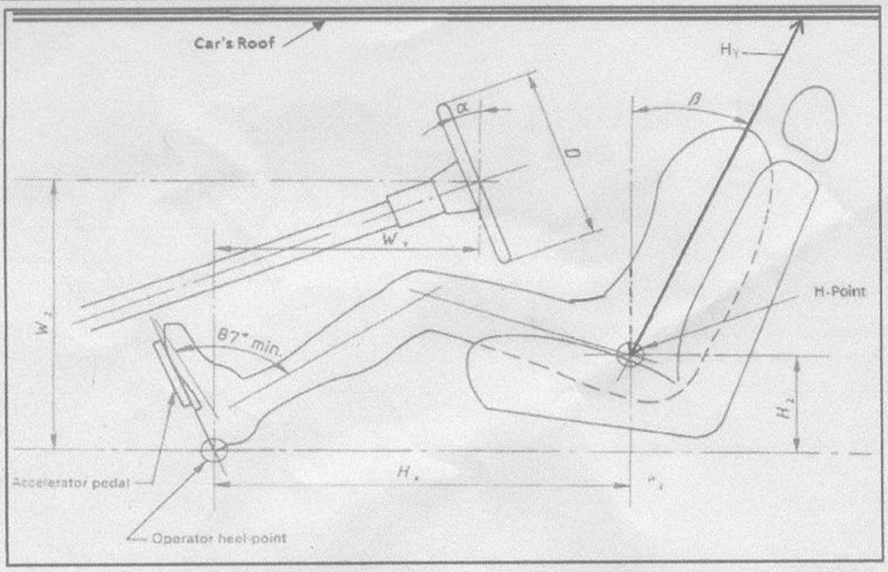
Date:

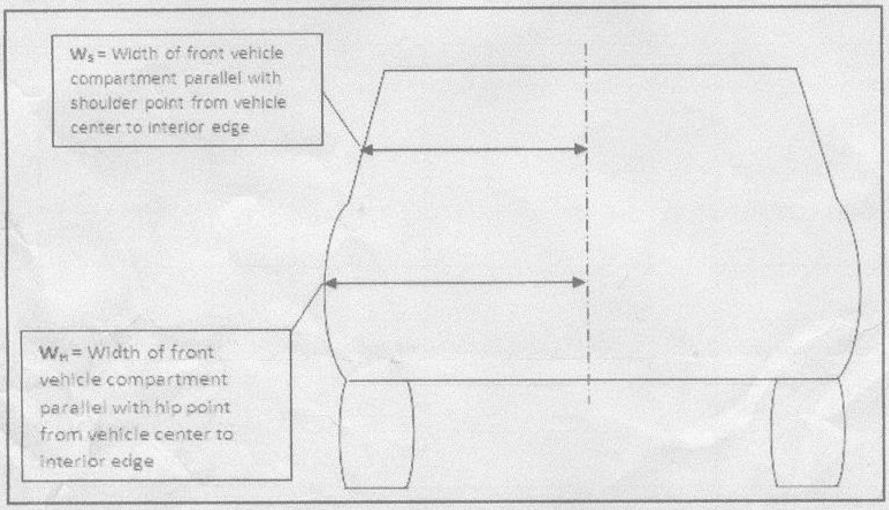
Signature:

APPENDIX C

SIMULATOR DESIGN AND SEAT PARAMETER

MEASUREMENT FOR DRIVING SIMULATOR SEAT POSITION **DATE: 08/12/09**





LOCATION	DIMENSION VALUE		REMARKS
	MIROS MYVI 1.3 STD 5M/T (REFERENCE)	UKM DRIVING SIMULATOR	
H_Z	445 mm	370 mm	ASIS – LM
H_X	745 mm	760 mm	ASIS – LM
W_X	330 mm	310 mm	ASIS – LM
β	22.4°	22.4 mm	ASIS – LM
H_Y	870 mm	870 mm	ASIS – LM
W_S	720 mm	–	–
W_H	640 mm	–	–
α	27 °	20 mm	ASIS – LM
D	355 mm	275 mm	ASIS – LM
W_z	685 mm	700 mm	ASIS – LM
Seat Track travel	222 mm	222 mm	ASIS – LM

Notes:

1) Height of sample person = 181 cm
2) Reference standard: MS ISO 3958: 2005 , MS 1826:2005
3) Measurement is based on the most comfort sitting positon for driver

APPENDIX D

PILOT STUDY RESULT

Position 1 (Discomfort level)

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P1 Neck/Head	56.8125	201.835	.337	.816	.954
P1 Shoulder Posture 1	56.6563	197.781	.502	.870	.952
P1 Upperback Posture 1	56.5000	193.548	.667	.950	.950
P1 Arm/Hand Posture 1	57.1250	187.339	.743	.805	.949
P1 Lowerback Posture 1	56.5625	188.835	.757	.923	.948
P1 Buttock Posture 1	56.3438	198.233	.530	.854	.951
P1 Thigh Posture 1	56.9063	186.926	.777	.889	.948
P1 Knee Posture 1	57.0313	185.322	.805	.941	.947
P1 Calf Posture 1	57.0625	186.770	.772	.914	.948
P1 Ankle/Feet Posture 1	57.1250	188.242	.691	.847	.949
ReP1 Neck/Head Posture 1	56.6250	192.048	.628	.772	.950
ReP1 Shoulder Posture 1	56.5938	196.765	.527	.891	.951
ReP1 Upperback Posture 1	56.4375	200.319	.472	.885	.952
ReP1 Arm/Hand Posture 1	56.9063	185.959	.813	.874	.947
ReP1 Lowerback Posture 1	56.5625	194.770	.602	.902	.951
ReP1 Buttock Posture 1	56.4375	192.383	.676	.862	.950
ReP1 Thigh Posture 1	56.6875	186.157	.791	.917	.948
ReP1 Knee Posture 1	57.1875	184.738	.829	.940	.947
ReP1 Calf Posture 1	57.0938	182.797	.884	.942	.946
ReP1 Ankle/Feet Posture 1	57.1875	184.222	.802	.946	.948

Position 2 (Discomfort level)

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P2 Neck/Head Posture 2	62.0313	194.741	.273	.	.949
P2 Shoulder Posture 2	62.0938	193.378	.346	.	.948
P2 Upperback Posture 2	61.9063	187.830	.574	.	.945
P2 Arm/Hand Posture 2	62.2188	185.596	.604	.	.944
P2 Lowerback Posture 2	61.7188	182.144	.711	.	.943
P2 Buttock Posture 2	61.5313	188.322	.606	.	.944
P2 Thigh Posture 2	61.7813	188.628	.640	.	.944
P2 Knee Posture 2	62.0313	184.547	.709	.	.943
P2 Calf Posture 2	62.1563	183.168	.817	.	.941
P2 Ankle/Feet Posture 2	62.2500	183.355	.701	.	.943
ReP2 Neck/Head Posture 2	61.9375	183.996	.709	.	.943
ReP2 Shoulder Posture 2	61.9688	180.870	.735	.	.942
ReP2 Upperback Posture 2	61.8750	181.790	.734	.	.942
ReP2 Arm/Hand Posture 2	62.1875	180.480	.645	.	.944
ReP2 Lowerback Posture 2	61.6875	180.996	.780	.	.942
ReP2 Buttock Posture 2	61.7188	184.080	.712	.	.943
ReP2 Thigh Posture 2	61.8750	181.855	.784	.	.942
ReP2 Knee Posture 2	61.8750	180.306	.742	.	.942
ReP2 Calf Posture 2	62.0625	178.577	.771	.	.942
ReP2 Ankle/Feet Posture 2	62.2500	176.000	.755	.	.942

Position 3 (Discomfort level)

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P3 Neck/Head Posture 3	27.19	71.190	.665	.705	.923
P3 Shoulder Posture 3	27.28	68.402	.730	.795	.919
P3 Upperback Posture 3	26.91	68.991	.833	.862	.914
P3 Arm/Hand Posture 3	27.53	68.773	.656	.524	.924
P3 Lowerback Posture 3	26.56	70.512	.744	.845	.919
P3 Buttock Posture 3	26.41	72.120	.746	.834	.920
P3 Thigh Posture 3	26.78	69.596	.741	.802	.919
P3 Knee Posture 3	26.88	70.113	.694	.869	.921
P3 Calf Posture 3	27.06	69.738	.696	.855	.921
P3 Ankle/Feet Posture 3	27.13	68.823	.732	.825	.919

Position 1 (Pressure felt level)

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P1 Seat(L) Bolster Posture 1	50.1563	288.394	.546	.	.947
P1 Seat(L) Buttock Posture 1	49.2500	270.129	.754	.	.944
P1 Seat(L) Thigh Posture 1	49.4375	290.448	.390	.	.949
P1 Seat(R) Buttock Posture 1	49.1875	270.867	.741	.	.944
P1 Seat(R) Thigh Posture 1	49.4063	292.636	.341	.	.949
P1 Seat(R) Bolster Posture 1	50.1875	288.286	.595	.	.946
P1 Backrest(L) Bolster Posture 1	50.0938	285.507	.684	.	.945
P1 Backrest(L) Upper Posture 1	49.7188	288.725	.538	.	.947
P1 Backrest(L) Lower Posture 1	49.1563	278.910	.667	.	.945
P1 Backrest(R) Upper Posture 1	49.6875	288.609	.534	.	.947
PI Backrest(R) Lower Posture 1	49.1875	280.673	.634	.	.946
P1 Backrest(R) Bolster Posture 1	50.0938	285.959	.701	.	.945
ReP1 Seat(L) Bolster Posture 1	50.2813	291.628	.491	.	.947
ReP1 Seat(L) Buttock Posture 1	49.5313	270.193	.769	.	.944
ReP1 Seat(L) Thigh Posture 1	49.8125	280.480	.666	.	.945
ReP1 Seat(R) Buttock Posture 1	49.5313	271.225	.759	.	.944
ReP1 Seat(R) Thigh Posture 1	49.7188	283.951	.583	.	.946
ReP1 Seat(R) Bolster Posture 1	50.2500	291.548	.473	.	.947
ReP1 Backrest(L) Bolster Posture 1	50.0313	287.902	.542	.	.947
ReP1 Backrest(L) Upper Posture 1	49.7813	276.241	.825	.	.943
ReP1 Backrest(L) Lower Posture 1	49.4688	271.547	.854	.	.943
ReP1 Backrest(R) Upper Posture 1	49.7500	276.129	.818	.	.943
ReP1 Backrest(R) Lower Posture 1	49.4063	270.507	.858	.	.942
ReP1 Backrest(R) Bolster Posture 1	50.0000	287.806	.532	.	.947

Position 2 (Pressure felt level)

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P2 Seat(L) Bolster Posture 2	49.0000	281.097	.463	.	.959
P2 Seat(L) Buttock Posture 2	48.2500	267.548	.668	.	.957
P2 Seat(L) Thigh Posture 2	48.2813	270.531	.623	.	.957
P2 Seat(R) Buttock Posture 2	48.1563	263.491	.738	.	.956
P2 Seat(R) Thigh Posture 2	48.2500	268.645	.656	.	.957
P2 Seat(R) Bolster Posture 2	48.8125	278.286	.453	.	.959
P2 Backrest(L) Bolster Posture 2	48.9688	272.612	.697	.	.957
P2 Backrest(L) Upper Posture 2	48.3750	277.661	.517	.	.958
P2 Backrest(L) Lower Posture 2	48.2500	267.419	.736	.	.956
P2 Backrest(R) Upper Posture 2	48.2813	274.467	.586	.	.958
P2 Backrest(R) Lower Posture 2	48.2188	267.015	.745	.	.956
P2 Backrest(R) Bolster Posture 2	48.7813	271.660	.654	.	.957
ReP2 Seat(L) Bolster Posture 2	48.9688	278.354	.545	.	.958
ReP2 Seat(L) Buttock Posture 2	48.2500	261.677	.775	.	.956
ReP2 Seat(L) Thigh Posture 2	48.4688	264.386	.854	.	.955
ReP2 Seat(R) Buttock Posture 2	48.1563	260.394	.823	.	.955
ReP2 Seat(R) Thigh Posture 2	48.3125	267.835	.758	.	.956
ReP2 Seat(R) Bolster Posture 2	48.9063	276.604	.562	.	.958
ReP2 Backrest(L) Bolster Posture 2	48.8125	273.383	.670	.	.957
ReP2 Backrest(L) Upper Posture 2	48.4375	270.770	.720	.	.956
ReP2 Backrest(L) Lower Posture 2	48.3438	262.104	.839	.	.955
ReP2 Backrest(R) Upper Posture 2	48.3438	268.297	.778	.	.956
ReP2 Backrest(R) Lower Posture 2	48.2813	263.112	.823	.	.955
ReP2 Backrest(R) Bolster Posture 2	48.7500	271.613	.691	.	.957

Position 3 (Pressure felt level)

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P3 Seat(L) Bolster Posture 3	52.7813	267.725	.521	.	.947
P3 Seat(L) Buttock Posture 3	52.2188	255.660	.771	.	.944
P3 Seat(L) Thigh Posture 3	52.1250	260.113	.607	.	.946
P3 Seat(R) Buttock Posture 3	52.0938	251.378	.803	.	.943
P3 Seat(R) Thigh Posture 3	52.0313	260.999	.548	.	.947
P3 Seat(R) Bolster Posture 3	52.6875	262.802	.598	.	.946
P3 Backrest(L) Bolster Posture 3	52.7188	264.402	.537	.	.947
P3 Backrest(L) Upper Posture 3	52.3125	267.060	.442	.	.948
P3 Backrest(L) Lower Posture 3	52.1563	260.136	.608	.	.946
P3 Backrest(R) Upper Posture 3	52.2813	266.918	.428	.	.948
P3 Backrest(R) Lower Posture 3	52.0938	258.733	.612	.	.946
P3 Backrest(R) Bolster Posture 3	52.6563	264.878	.452	.	.948
ReP3 Seat(L) Bolster Posture 3	52.6875	266.286	.465	.	.947
ReP3 Seat(L) Buttock Posture 3	52.1875	249.254	.806	.	.943
ReP3 Seat(L) Thigh Posture 3	52.0938	254.152	.744	.	.944
ReP3 Seat(R) Buttock Posture 3	52.1875	248.867	.799	.	.943
ReP3 Seat(R) Thigh Posture 3	52.0313	253.580	.742	.	.944
ReP3 Seat(R) Bolster Posture 3	52.6563	260.233	.645	.	.945
ReP3 Backrest(L) Bolster Posture 3	52.7188	257.757	.785	.	.944
ReP3 Backrest(L) Upper Posture 3	51.9688	263.128	.626	.	.946
ReP3 Backrest(L) Lower Posture 3	52.2188	260.047	.735	.	.944
ReP3 Backrest(R) Upper Posture 3	51.9375	265.480	.547	.	.946
ReP3 Backrest(R) Lower Posture 3	52.1563	260.459	.715	.	.945
ReP3 Backrest(R) Bolster Posture 3	52.6563	258.233	.794	.	.944

APPENDIX E
SUBJECTIVE ASSESSMENT FORM

SECTION A: DEMOGRAPHIC INFORMATION

Instruction: *Please fill in the blank and tick (✓) the suitable answers.*

1. Age: __________ years 2. Gender: ☐ Male ☐ Female

3. Weight/Height: _____kg / _____ cm

4. Caffeine intake before driving: ☐ Yes ☐ No

5. Food intake before driving:
   ☐ Heavy meal
   ☐ Light meal
   ☐ Do not take any food

6. Sleep duration last night:
   ☐ Less than 3 hours
   ☐ 3 to 6 hours
   ☐ More than 6 hours

7. Driving experience:
   ☐ Less than 1 year
   ☐ 1 to 3 years
   ☐ 3 to 5 years
   ☐ More than 5 years

<u>SECTION B: DISCOMFORT LEVEL ACCORDING TO DRIVING POSTURE AND DRIVING TASK</u>

Aim: To identify the body part discomfort level of the driver according to different driving position (*) and driving task (**)

***Posture:** A and B

****Driving task:** Steering wheel (B1), Gear (B2) and Accelerator pedal (B3)

Instruction:

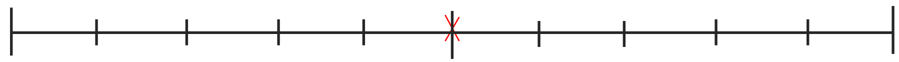
Table 1 shows the body part with specific muscle involved in this study.

Table 1: Body part with specific muscle involved based on the driving task

Body part	Task	Specific muscle
Shoulder	Steering wheel (B1)	Left deltoid
		Right deltoid
	Gear (B2)	Left deltoid
Lower leg	Accelerator pedal (B3)	Right tibialis anterior
		Right medial gastrocnemius

In this section, you are required to evaluate the discomfort level based on driving position and driving task by marking (x) at the horizontal line as follow.

Example: (Score: 5) **Very comfortable (0)** **Moderate (5)** **Very uncomfortable (10)**

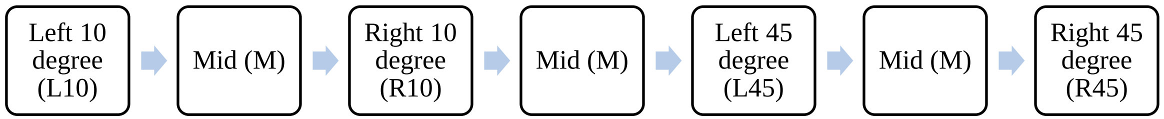


<u>B1: DRIVING TASK- STEERING WHEEL CONTROL</u>

Aim: *To identify the discomfort level at the shoulder muscle, Left Deltoid (DL) and Right Deltoid (DR) at the Posture A and B*

Instruction: *You are required to turn the steering wheel as shown in Figure 1.*

Figure 1: Steering wheel task



B1.1 *Please rate the discomfort level based on the driving posture for the steering wheel control.*

A	
B	

B1.2 *Please rate the discomfort level based on driving task according to driving posture*

Posture A:

TASK / COND		DL	DR
L10	**Pre**		
	Post		
M	**Pre**		
	Post		
R10	**Pre**		
	Post		
L45	**Pre**		
	Post		
R45	**Pre**		
	Post		

Posture B:

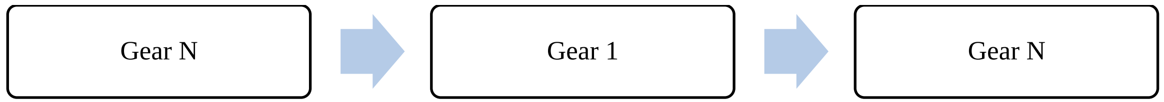
TASK / COND		DL	DR
L10	Pre		
	Post		
M	Pre		
	Post		
R10	Pre		
	Post		
L45	Pre		
	Post		
R45	Pre		
	Post		

<u>B2: DRIVING TASK- GEAR CONTROL</u>

Aim: *To identify the discomfort level at the shoulder muscle, Left Deltoid (DL) at the Posture A and B*

Instruction: *You are required to operate the gear as shown in Figure 2.*

Figure 2: Gear task



B2.1 *Please rate the discomfort level based on the driving posture for the gear control.*

A	
B	

B2.2 *Please rate the discomfort level based on driving task according to driving posture*

Posture A:

TASK	COND	DL
Gear N to gear 1	**Pre**	
	Post	
Gear 1 to N	**Pre**	
	Post	

Posture B:

TASK	COND	DL
Gear N to gear 1	**Pre**	
	Post	
Gear 1 to N	**Pre**	
	Post	

B3: DRIVING TASK- ACCELERATOR PEDAL CONTROL

Aim: *To identify the discomfort level at the lower leg muscle, Right Gastrocnemius Medial (GR) and Right Tibialis Anterior (TR) at the Posture A and B.*

Instruction: *You are required to operate the accelerator pedal as shown in Figure 3.*

Figure 3: Accelerator pedal task

Half press (HP) → Release (R) → Full press (FP)

B3.1 *Please rate the discomfort level based on the driving posture for the accelerator pedal control.*

A	
B	

B3.2 *Please rate the discomfort level based on driving task according to driving posture.*

Posture A:

TASK / COND		GR	TR
HP	**Pre**		
	Post		
R	**Pre**		
	Post		

FP	**Pre**		
	Post		

Posture B:

TASK / COND		**GR**	**TR**
HP	**Pre**		
	Post		
R	**Pre**		
	Post		
FP	**Pre**		
	Post		

SECTION C: SEAT AND BACK REST PRESSURE ACCORDING TO DRIVING POSTURE

Aim: To identify the perception on pressure distribution level based on driving posture

Instruction: *In this section, you are required to evaluate the pressure felt based on driving position and part by marking (x) at the horizontal line as follow.*

Example: (Score: 6) **No pressure felt (0)** **Moderate (5)** **Extreme pressure felt (10)**

C1.1 *Please rate the pressure felt based on the driving posture according to the above-mentioned scale.*

A	
B	

C1.2 *Please rate the pressure felt level according to driving posture.*

Posture A:

SEAT PART	COND	Pressure felt
Buttock	**Pre**	
	Post	
Thigh	**Pre**	
	Post	

BACK REST PART	COND	Pressure felt
Upper back	**Pre**	
	Post	
Lower back	**Pre**	
	Post	

Posture B:

SEAT PART	COND	Pressure felt
Buttock	**Pre**	
	Post	
Thigh	**Pre**	
	Post	

BACK REST PART	COND	Pressure felt
Upper back	**Pre**	
	Post	
Lower back	**Pre**	
	Post	

<u>SECTION D: ALERTNESS EVALUATION</u>

Definition: A self-report scale that measures the subject's drowsiness (from alertness to sleepiness).

Instruction: Here are some descriptors about how alert or sleepy you might be feeling right now. Please read them carefully and tick (✓) the statement that best corresponds to the statement describe how you feel at the moment (before, during and after driving).

Before driving:

Category	Scale	Statement	Tick (✓) one only
Alert	1	Extremely alert	
	2	Very alert	
	3	Alert	
	4	Rather alert	
Middle	5	Neither alert nor sleepy	
Sleepy	6	Some signs of sleepiness	
	7	Sleepy, no effort to stay awake	
	8	Sleepy, some effort to keep alert	
	9	Extremely sleepy, great effort to stay awake, fighting sleep	

During driving:

Category	Scale	Statement	Tick (✓) one only
Alert	1	Extremely alert	
	2	Very alert	
	3	Alert	
	4	Rather alert	
Middle	5	Neither alert nor sleepy	
Sleepy	6	Some signs of sleepiness	
	7	Sleepy, no effort to stay awake	
	8	Sleepy, some effort to keep alert	
	9	Extremely sleepy, great effort to stay awake, fighting sleep	

After driving:

Category	Scale	Statement	Tick (✓) one only
Alert	1	Extremely alert	
	2	Very alert	
	3	Alert	
	4	Rather alert	
Middle	5	Neither alert nor sleepy	
Sleepy	6	Some signs of sleepiness	
	7	Sleepy, no effort to stay awake	
	8	Sleepy, some effort to keep alert	
	9	Extremely sleepy, great effort to stay awake, fighting sleep	

APPENDIX F

PROGRAMMING CODE FOR PROCESSING SEMG RAW DATA

```
%%%%%%%%%%%%%%%%%%%INPUT RAW SIGNAL%%%%%%%%%%%%%%%%%
x=load('Nurin Bprep gr1.txt');
i=length(x);
fs=1000;
T=1/fs;
ts=i/fs;
t=[ts/i:ts/i:ts];

subplot(4,1,1)
plot(t,x)
title('Raw Data EMG');
ylabel ('microVolts');
xlabel ('seconds');

%%%%%%Remove any DC offset of the signal%%%%%%%%%%%%%%%%

x2=detrend(x);

%%%%%%%%%CUTOFF HIGH-PASS FILTER(10Hz), LOW-PASS FILTER(500Hz)
%%%%%%%%%AND NOTCH FILTER (50Hz) WITH BUTTERWORTH ORDER 4%%%%%

%High-pass filter
filt1=fdesign.highpass('n,f3db',4,2*10*(1/1000));  %high-pass filter, cut off
frequency at 10Hz, sampling frequency of 1kHz
H1=design(filt1,'butter');
highpass_EMG=filter(H1,x2);   % sampling frequency of 1kHz

%Notch Filter (50hz)
filt3=fdesign.notch(4,0.1,10);   %notch filter (50Hz)
H3=design(filt3);
notch=filter(H3,highpass_EMG);

%Low-pass filter
filt2=fdesign.lowpass('n,f3db',4,2*500*(1/1000)); %low-pass filter, cut off
frequency at 500Hz
H2=design(filt2,'butter');
cleaned_EMG=filter(H2,notch);

subplot(3,1,1)
plot(t,cleaned_EMG,'red')
title('EMG after filter');
ylabel ('microVolts');
xlabel ('seconds');

%%%%%%%%%%%%%FULLWAVE RECTIFIER SIGNAL%%%%%%%%%%%%%%%%%%%%%%%%%%%%
abs_x=abs(x);

%subplot(3,1,2)
%plot(t,abs_x)
%title('Fullwave rectifier');
%ylabel ('microVolts');
```

```
%xlabel ('seconds');

%%%%%%%%%%%%%%%%%RMS AT 500 ms%%%%%%%%%%%%%%%%%%%%%%%%%%%%
yy=x.^2;
ss=smooth(yy,500,'moving');
rms_ss=ss.^0.5;

subplot(1,1,1)
plot(t,rms_ss)
title('Temporal Analysis');
ylabel ('microVolts');
xlabel ('seconds');

%%%%FREQUENCY DOMAIN%%%%%%%%

%%%%FFT%%%%
%k=[0:i-1];
%f_k=fft(cleaned_EMG);
%f_k=abs(f_k);
%w=k*(1/ts);

subplot(6,1,5)
plot(w(1:i/2),f_k(1:i/2));
title('FFT');
ylabel ('microVolts');
xlabel ('seconds');

%%PSD%%%%
%nfft=1024;
%[Pxx,f]=periodogram(cleaned_EMG,[],nfft, fs);

%subplot(6,1,6); plot(f,Pxx)
%title('PSD');
%ylabel ('(microVolt)^2');
%xlabel ('Hz');

%%%%%%%%%%%%%%%%%MEDIAN AND MEAN POWER FREQUENCY%%%%%%%%%%%%%%%%

% calculate median freq%

%h=spectrum.periodogram;
%Hpsd=psd(h,cleaned_EMG,'fs',1000,'nfft',2^nextpow2(length(cleaned_EMG)));
%Pdist=cumsum(Hpsd.Data);
%Freq=Hpsd.Frequencies;
%OverHalfIdx=find(Pdist>=Pdist(end)/2,1,'first');
%UnderHalfIdx=find(Pdist<=Pdist(end)/2,1,'last');
%MidFreq=(Freq(OverHalfIdx)+Freq(UnderHalfIdx))/2

%%calculate mean%

%meanfreq=sum(Freq.*Pdist)/sum(Pdist)
```

APPENDIX G

NORMALITY TEST

Table 1 Subjective assessment-steering wheel task

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SUBJA1L10	.251	11	.050	.815	11	.015
SUBJA1L45	.367	11	.000	.694	11	.000
SUBJA1R45	.303	11	.006	.731	11	.001
SUBJB1L10	.200	11	.200*	.928	11	.389
SUBJB1L45	.245	11	.063	.811	11	.013
SUBJB1R45	.242	11	.070	.910	11	.242
SUBJA2L10	.267	11	.028	.788	11	.007
SUBJA2L45	.284	11	.014	.808	11	.012
SUBJA2R45	.204	11	.200*	.838	11	.030
SUBJB2L10	.226	11	.121	.863	11	.062
SUBJB2L45	.212	11	.178	.855	11	.050
SUBJB2R45	.145	11	.200*	.943	11	.561

Table 2 Subjective assessment-gear task

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SUBJA1G1	.228	11	.113	.860	11	.057
SUBJA1GN	.198	11	.200*	.908	11	.231
SUBJB1G1	.188	11	.200*	.874	11	.088
SUBJB1GN	.318	11	.003	.843	11	.034
SUBJA2G1	.186	11	.200*	.927	11	.379
SUBJA2GN	.233	11	.098	.874	11	.088
SUBJB2G1	.186	11	.200*	.934	11	.453
SUBJB2GN	.227	11	.117	.833	11	.025

Table 3 Subjective assessment-pedal task

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
subj Apre HP TR	.248	11	.056	.801	11	.010
subj Apre R TR	.158	11	.200*	.935	11	.461
subj Apre FP TR	.233	11	.097	.892	11	.149
subj Apost HP TR	.219	11	.146	.889	11	.134
subj Apost R TR	.213	11	.177	.898	11	.173
subj Apost FP TR	.165	11	.200*	.947	11	.610
subj Bpre HP TR	.218	11	.150	.874	11	.088
subj Bpre R TR	.197	11	.200*	.866	11	.069
subj Bpre FP TR	.199	11	.200*	.868	11	.073
subj Bpost HP TR	.256	11	.043	.893	11	.150
subj Bpost R TR	.160	11	.200*	.962	11	.801
subj Bpost FP TR	.363	11	.000	.810	11	.013
gr SUBJ AHP PRE	.175	11	.200*	.912	11	.257
gr SUBJ ARPRE	.182	11	.200*	.896	11	.166
gr SUBJ AFP PRE	.163	11	.200*	.924	11	.351
gr SUBJ AHP POST	.215	11	.167	.887	11	.127
gr SUBJ AR POST	.213	11	.175	.868	11	.073
gr SUBJ AFP POST	.152	11	.200*	.939	11	.508
gr SUBJ BHP PRE	.157	11	.200*	.904	11	.205
gr SUBJ BR PRE	.219	11	.148	.889	11	.136
gr SUBJ BFP PRE	.227	11	.119	.896	11	.166
gr SUBJ BHP POST	.394	11	.000	.675	11	.000
gr SUBJ BR POST	.294	11	.009	.869	11	.075
gr SUBJ BFP POST	.149	11	.200*	.963	11	.812

Table 4 Subjective assessment-pressure felt level

Tests of Normality[b,c,d,e,f,g]

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SUBJ A ButtPRE	.185	11	.200*	.930	11	.410
SUBJ B ButtPRE	.409	11	.000	.674	11	.000
SUBJ A ButtPOST	.283	11	.014	.783	11	.006
SUBJ B ButtPOST	.343	11	.001	.697	11	.000
subj A ThighPRE	.232	11	.101	.795	11	.008
subj B ThighPRE	.353	11	.000	.649	11	.000
subj A ThighPOST	.282	11	.015	.786	11	.006
subj B ThighPOST	.492	11	.000	.486	11	.000
subj br A ub1	.432	11	.000	.619	11	.000
subj br A ub2	.382	11	.000	.701	11	.000

Table 5 Steering wheel normality test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
A1L10	.338	11	.001	.611	11	.000
A1L45	.297	11	.007	.707	11	.001
A1R45	.145	11	.200*	.948	11	.624
B1L10	.231	11	.105	.849	11	.041
B1L45	.197	11	.200*	.852	11	.045
B1R45	.238	11	.081	.898	11	.173
A2L10	.296	11	.008	.741	11	.002
A2L45	.362	11	.000	.658	11	.000
A2R45	.202	11	.200*	.839	11	.031
B2L10	.186	11	.200*	.840	11	.031
B2L45	.219	11	.145	.800	11	.009
B2R45	.196	11	.200*	.927	11	.382

Table 6 Gear normality test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
A1G1	.216	11	.159	.961	11	.788
A1GN	.255	11	.044	.811	11	.013
B1G1	.152	11	.200*	.962	11	.802
B1GN	.255	11	.045	.778	11	.005
A2G1	.154	11	.200*	.951	11	.651
A2GN	.371	11	.000	.684	11	.000
B2G1	.147	11	.200*	.902	11	.195
B2GN	.292	11	.009	.726	11	.001

Table 7 Accelerator pedal normality test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Apre TR HP	.188	11	.200*	.939	11	.506
Apre TR R	.199	11	.200*	.899	11	.182
Apre TR FP	.327	11	.002	.802	11	.010
Apost TR HP	.231	11	.104	.727	11	.001
Apost TR R	.338	11	.001	.670	11	.000
Apost TR FP	.211	11	.183	.810	11	.013
Bpre TR HP	.210	11	.190	.831	11	.024
Bpre TR R	.266	11	.029	.815	11	.015
Bpre TR FP	.275	11	.020	.780	11	.005
Bpost TR HP	.281	11	.015	.724	11	.001
Bpost TR R	.374	11	.000	.630	11	.000
Bpost TR FP	.186	11	.200*	.877	11	.097
Apre GR HP	.171	11	.200*	.929	11	.405
Apre GR R	.148	11	.200*	.960	11	.774
Apre GR FP	.225	11	.125	.838	11	.029
Apost GR HP	.185	11	.200*	.928	11	.387
Apost GR R	.167	11	.200*	.946	11	.591
Apost GR FP	.165	11	.200*	.915	11	.281
Bpre GR HP	.112	11	.200*	.944	11	.568
Bpre GR R	.123	11	.200*	.963	11	.809
Bpre GR FP	.127	11	.200*	.934	11	.449

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
A1G1	.216	11	.159	.961	11	.788
A1GN	.255	11	.044	.811	11	.013
B1G1	.152	11	.200*	.962	11	.802
B1GN	.255	11	.045	.778	11	.005
A2G1	.154	11	.200*	.951	11	.651
A2GN	.371	11	.000	.684	11	.000
B2G1	.147	11	.200*	.902	11	.195
B2GN	.292	11	.009	.726	11	.001
Bpost GR HP	.203	11	.200*	.922	11	.334
Bpost GR R	.171	11	.200*	.922	11	.335
Bpost GR FP	.227	11	.118	.901	11	.191

Table 8 Pressure distribution of the car seat normality test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
A prebutt	.160	11	.200*	.967	11	.853
B prebutt	.269	11	.026	.719	11	.001
A postbutt	.205	11	.200*	.873	11	.084
B postbutt	.186	11	.200*	.874	11	.088
A prethigh	.168	11	.200*	.929	11	.401
B prethigh	.135	11	.200*	.957	11	.728
A post thigh	.217	11	.157	.937	11	.481
B post thigh	.110	11	.200*	.957	11	.730
A preUB	.161	11	.200*	.958	11	.746
B preUB	.176	11	.200*	.898	11	.174
A preLB	.181	11	.200*	.897	11	.170
B preLB	.165	11	.200*	.939	11	.509
A post UB	.214	11	.168	.914	11	.272
B post UB	.180	11	.200*	.910	11	.244
A post LB	.131	11	.200*	.968	11	.863
B post LB	.124	11	.200*	.971	11	.898

APPENDIX H

LINEAR MODEL VALIDATION

Table 1: Normality test

a. Steering wheel

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
B1R45	.238	11	.081	.898	11	.173
SUBJB1R45	.242	11	.070	.910	11	.242
armlength	.184	11	.200*	.947	11	.607

b. Gear

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
B1G1	.152	11	.200*	.962	11	.802
SUBJB1G1	.188	11	.200*	.874	11	.088
shoulderlength	.130	11	.200*	.953	11	.679

c. Pedal (TR)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SUBJA1TRR	.158	11	.200*	.935	11	.461
KNEEANGLEA	.250	11	.054	.875	11	.091
A1TRR	.199	11	.200*	.899	11	.182

d. Pedal (GR)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
B1GRFP	.127	11	.200*	.934	11	.449
SUBJB1GRFP	.227	11	.119	.896	11	.166
KNEEANGLEB	.234	11	.094	.887	11	.129

e. Pressure

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pressure unit in kg/cm-2	.159	11	.200*	.970	11	.888
Pressure felt on buttock	.185	11	.200*	.930	11	.410
Buttock knee length	.235	11	.092	.870	11	.079

Table 2: Linearity test

a. Steering wheel

Correlations

		B1R45	SUBJB1R45	armlength
B1R45	Pearson Correlation	1	.985**	.680*
	Sig. (2-tailed)		.000	.021
	N	11	11	11
SUBJB1R45	Pearson Correlation	.985**	1	.753**
	Sig. (2-tailed)	.000		.007
	N	11	11	11
armlength	Pearson Correlation	.680*	.753**	1
	Sig. (2-tailed)	.021	.007	
	N	11	11	11

b. Gear

Correlations

		B1G1	SUBJB1G1	shoulderlength
B1G1	Pearson Correlation	1	.977**	.815**
	Sig. (2-tailed)		.000	.002
	N	11	11	11
SUBJB1G1	Pearson Correlation	.977**	1	.703*
	Sig. (2-tailed)	.000		.016
	N	11	11	11
shoulderlength	Pearson Correlation	.815**	.703*	1
	Sig. (2-tailed)	.002	.016	
	N	11	11	11

c. Pedal (TR)

d. Pedal (GR)

Correlations

		A1TRR	SUBJA1TRR	KNEEANGLEA
A1TRR	Pearson Correlation	1	.907**	-.946**
	Sig. (2-tailed)		.000	.000
	N	11	11	11
SUBJA1TRR	Pearson Correlation	.907**	1	-.761**
	Sig. (2-tailed)	.000		.007
	N	11	11	11
KNEEANGLEA	Pearson Correlation	-.946**	-.761**	1
	Sig. (2-tailed)	.000	.007	
	N	11	11	11

Correlations

		B1GRFP	SUBJB1GRFP	KNEEANGLEB
B1GRFP	Pearson Correlation	1	.956**	.918**
	Sig. (2-tailed)		.000	.000
	N	11	11	11
SUBJB1GRFP	Pearson Correlation	.956**	1	.955**
	Sig. (2-tailed)	.000		.000
	N	11	11	11
KNEEANGLEB	Pearson Correlation	.918**	.955**	1
	Sig. (2-tailed)	.000	.000	
	N	11	11	11

Pressure

Correlations

		Pressure felt on buttock	Pressure unit in kg/cm-2	Buttock knee length
Pressure felt on buttock	Pearson Correlation	1	.959**	.804**
	Sig. (2-tailed)		.000	.003
	N	11	11	11
Pressure unit in kg/cm-2	Pearson Correlation	.959**	1	.914**
	Sig. (2-tailed)	.000		.000
	N	11	11	11
Buttock knee length	Pearson Correlation	.804**	.914**	1
	Sig. (2-tailed)	.003	.000	
	N	11	11	11

Table 3: Auto correlation test

a. Steering wheel	**b. Gear**

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.985[a]	.971	.967	.17390	2.231

a. Predictors: (Constant), B1R45

b. Dependent Variable: SUBJB1R45

Model Summary[c]

Model	R	R Square	Adjusted R Square	SEE	Durbin-Watson
1	.985[a]	.971	.967	.17390	
2	.992[b]	.983	.979	.13848	2.857

a. Predictors: (Constant), B1R45

b. Predictors: (Constant), B1R45, VAR00001

c. Dependent Variable: SUBJB1R45

Runs Test

	Unstandardized Residual
Test Value[a]	.00577
Cases < Test Value	5
Cases >= Test Value	6
Total Cases	11
Number of Runs	8
Z	.671
Asymp. Sig. (2-tailed)	.502

a. Median

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.977[a]	.954	.949	.28598	2.213

a. Predictors: (Constant), B1G1

b. Dependent Variable: SUBJB1G1

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.977[a]	.954	.949	.28598	
2	.990[b]	.980	.975	.20038	2.972

Runs Test

	Unstandardized Residual
Test Value[a]	-.02797
Cases < Test Value	5
Cases >= Test Value	6
Total Cases	11
Number of Runs	9
Z	1.312
Asymp. Sig. (2-tailed)	.189

a. Median

c. Pedal (TR)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.907[a]	.822	.802	.32493	2.705

a. Predictors: (Constant), A1TRR

b. Dependent Variable: SUBJA1TRR

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.907[a]	.822	.802	.32493	
2	.954[b]	.911	.889	.24368	2.226

a. Predictors: (Constant), A1TRR

b. Predictors: (Constant), A1TRR, KNEEANGLEA

c. Dependent Variable: SUBJA1TRR

Runs Test

	Unstandardized Residual
Test Value[a]	-.08762
Cases < Test Value	5
Cases >= Test Value	6
Total Cases	11
Number of Runs	7
Z	.029
Asymp. Sig. (2-tailed)	.977

d. Pedal (GR)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.956[a]	.914	.905	.30824	1.059

a. Predictors: (Constant), B1GRFP

b. Dependent Variable: SUBJB1GRFP

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.956[a]	.914	.905	.30824	
2	.976[b]	.952	.940	.24408	1.709

a. Predictors: (Constant), B1GRFP

b. Predictors: (Constant), B1GRFP, KNEEANGLEB

c. Dependent Variable: SUBJB1GRFP

Pressure

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.959[a]	.919	.910	.31928	
2	.975[b]	.951	.939	.26224	.707

a. Predictors: (Constant), pressure a1butt

b. Predictors: (Constant), pressure a1butt, Buttock knee length

c. Dependent Variable: Pressure felt on buttock

Runs Test

	Unstandardized Residual
Test Value[a]	-.04108
Cases < Test Value	5
Cases >= Test Value	6
Total Cases	11
Number of Runs	5
Z	-.612
Asymp. Sig. (2-tailed)	.540

a. Median

Table 4: Heteroscedasticity test

a. Steering wheel

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.081	.110		.738	.480
	B1R45	.001	.003	.114	.344	.739

a. Dependent Variable: absut1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-1.132	.926		-1.222	.256
	B1R45	-.002	.003	-.243	-.560	.591
	armlength	.030	.023	.561	1.290	.233

a. Dependent Variable: absut

b. Gear

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.299	.093		3.213	.011
	B1G1	-.002	.002	-.261	-.810	.439

a. Dependent Variable: absut1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.746	1.524		.489	.638
	B1G1	.003	.003	.564	1.005	.344
	shoulderlength	-.011	.025	-.242	-.432	.677

a. Dependent Variable: Absut

c. Pedal (TR)

d. Pedal (GR)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.391	.092		4.248	.002
	A1TRR	-.014	.008	-.494	-1.706	.122

a. Dependent Variable: absut1

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	3.340	3.082		1.084	.310
	KNEEANGLEA	-.029	.028	-1.036	-1.018	.339
	A1TRR	-.022	.020	-1.114	-1.094	.306

a. Dependent Variable: AbsUt

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.223	.162		1.378	.201
	B1GRFP	-.006	.019	-.106	-.319	.757

a. Dependent Variable: absut1

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-5.317	3.905		-1.362	.210
	B1GRFP	-.032	.031	-.820	-1.040	.329
	KNEEANGLEB	.042	.031	1.093	1.385	.203

a. Dependent Variable: AbsUt

Pressure

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	4.253	2.679		1.588	.151
	pressure a1butt	.252	.177	1.093	1.424	.192
	Buttock knee length	-.101	.066	-1.177	-1.533	.164

a. Dependent Variable: AbsUt

Table 5: Multi collinearity test

a. **Steering wheel**

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.315	.166		25.944	.000		
	B1R45	.082	.005	.985	17.245	.000	1.000	1.000

a. Dependent Variable: SUBJB1R45

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.315	.166		25.944	.000		
	B1R45	.082	.005	.985	17.245	.000	1.000	1.000
2	(Constant)	.384	1.585		.242	.815		
	B1R45	.073	.005	.880	14.181	.000	.537	1.861
	VAR00001	.098	.039	.154	2.489	.038	.537	1.861

a. Dependent Variable: SUBJB1R45

b. Gear

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.143	.210		19.708	.000		
	B1G1	.073	.005	.977	13.673	.000	1.000	1.000

a. Dependent Variable: SUBJB1G1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.143	.210		19.708	.000		
	B1G1	.073	.005	.977	13.673	.000	1.000	1.000
2	(Constant)	15.756	3.616		4.357	.002		
	B1G1	.090	.006	1.203	13.933	.000	.336	2.975
	shoulderlength	-.191	.059	-.278	-3.214	.012	.336	2.975

a. Dependent Variable: SUBJB1G1

c. Pedal (TR)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	7.224	.207		34.884	.000		
	A1TRR	.117	.018	.907	6.448	.000	1.000	1.000

a. Dependent Variable: SUBJA1TRR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	7.224	.207		34.884	.000		
	A1TRR	.117	.018	.907	6.448	.000	1.000	1.000
2	(Constant)	-10.914	6.413		-1.702	.127		
	A1TRR	.229	.042	1.778	5.462	.001	.105	9.531
	KNEEANGLEA	.167	.059	.921	2.829	.022	.105	9.531

a. Dependent Variable: SUBJA1TRR

d. Pedal (GR)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	5.192	.211		24.618	.000		
	B1GRFP	.239	.024	.956	9.793	.000	1.000	1.000

a. Dependent Variable: SUBJB1GRFP

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	5.192	.211		24.618	.000		
	B1GRFP	.239	.024	.956	9.793	.000	1.000	1.000
2	(Constant)	-10.491	6.224		-1.686	.130		
	B1GRFP	.126	.049	.504	2.578	.033	.157	6.388
	KNEEANGLEB	.123	.049	.493	2.521	.036	.157	6.388

a. Dependent Variable: SUBJB1GRFP

a. Pressure

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	2.028	.455		4.461	.002		
	pressure a1butt	1.559	.154	.959	10.110	.000	1.000	1.000
2	(Constant)	12.940	4.736		2.732	.026		
	pressure a1butt	2.221	.313	1.365	7.095	.000	.164	6.106
	Buttock knee length	-.271	.117	-.445	-2.311	.050	.164	6.106

a. Dependent Variable: Pressure felt on buttock

APPENDIX I

STATISTICAL ANALYSIS FOR SUBJECTIVE ASSESSMENT

Table 1 Comparison between actions for steering wheel task

Test Statistics[b]

	SUBJA1L45 - SUBJA1L10	SUBJA1R45 - SUBJA1L10	SUBJA1R45 - SUBJA1L45	SUBJB1L45 - SUBJB1L10	SUBJB1R45 - SUBJB1L10	SUBJB1R45 - SUBJB1L45
Z	-2.739[a]	-2.941[a]	-2.950[a]	-2.956[a]	-2.952[a]	-2.739[a]
Asymp. Sig. (2-tailed)	.006	.003	.003	.003	.003	.006

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Test Statistics[b]

	SUBJA2L45 - SUBJA2L10	SUBJA2R45 - SUBJA2L10	SUBJA2R45 - SUBJA2L45	SUBJB2L45 - SUBJB2L10	SUBJB2R45 - SUBJB2L10	SUBJB2R45 - SUBJB2L45
Z	-2.694[a]	-2.807[a]	-2.809[a]	-2.944[a]	-2.940[a]	-2.620[a]
Asymp. Sig. (2-tailed)	.007	.005	.005	.003	.003	.009

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 2 Comparison between positions for steering wheel task

Test Statistics[b]

	SUBJB1L10 - SUBJA1L10	SUBJB1L45 - SUBJA1L45	SUBJB1R45 - SUBJA1R45	SUBJB2L10 - SUBJA2L10	SUBJB2L45 - SUBJA2L45	SUBJB2R45 - SUBJA2R45
Z	-2.956[a]	-2.956[a]	-2.947[a]	-2.938[a]	-2.943[a]	-2.402[a]
Asymp. Sig. (2-tailed)	.003	.003	.003	.003	.003	.016

Table 3 Comparison between pre-post activities for steering wheel task

Test Statistics[b]

	SUBJA2L10 - SUBJA1L10	SUBJA2L45 - SUBJA1L45	SUBJA2R45 - SUBJA1R45	SUBJB2L10 - SUBJB1L10	SUBJB2L45 - SUBJB1L45	SUBJB2R45 - SUBJB1R45
Z	-1.958[a]	-2.060[a]	-2.823[a]	-1.869[a]	-3.022[a]	-2.988[a]
Asymp. Sig. (2-tailed)	.050	.039	.005	.062	.003	.003

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 4 Comparison between actions for gear task

Test Statistics[b]

	SUBJA1GN - SUBJA1G1	SUBJB1GN - SUBJB1G1	SUBJA2GN - SUBJA2G1	SUBJB2GN - SUBJB2G1
Z	-2.944[a]	-2.938[a]	-2.333[a]	-2.965[a]
Asymp. Sig. (2-tailed)	.003	.003	.020	.003

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

Table 5 Comparison between positions for gear task

Test Statistics[b]

	SUBJB1G1 - SUBJA1G1	SUBJB1GN - SUBJA1GN	SUBJB2G1 - SUBJA2G1	SUBJB2GN - SUBJA2GN
Z	-2.940[a]	-2.988[a]	-2.144[a]	-2.271[a]
Asymp. Sig. (2-tailed)	.003	.003	.032	.023

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 6 Comparison between pre-post activities for gear task

Test Statistics[b]

	SUBJA2G1 - SUBJA1G1	SUBJA2GN - SUBJA1GN	SUBJB2G1 - SUBJB1G1	SUBJB2GN - SUBJB1GN
Z	-2.060[a]	-2.966[a]	-2.947[a]	-2.739[a]
Asymp. Sig. (2-tailed)	.039	.003	.003	.006

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 7 Comparison between actions for pedal task

Test Statistics[c]

	subj Apre R TR - subj Apre HP TR	subj Apre FP TR - subj Apre HP TR	subj Apre FP TR - subj Apre R TR	subj Bpre R TR - subj Bpre HP TR	subj Bpre FP TR - subj Bpre HP TR	subj Bpre FP TR - subj Bpre R TR
Z	-2.936[a]	-1.382[a]	-2.936[b]	-2.692[a]	-1.000[a]	-2.536[b]
Asymp. Sig. (2-tailed)	.003	.167	.003	.007	.317	.011

a. Based on negative ranks.

b. Based on positive ranks.

c. Wilcoxon Signed Ranks Test

Test Statistics[c]

	subj Apost R TR - subj Apost HP TR	subj Apost FP TR - subj Apost HP TR	subj Apost FP TR - subj Apost R TR	subj Bpost R TR - subj Bpost HP TR	subj Bpost FP TR - subj Bpost HP TR	subj Bpost FP TR - subj Bpost R TR
Z	-2.937[a]	-2.264[a]	-2.937[b]	-2.774[a]	-1.414[a]	-2.412[b]
Asymp. Sig. (2-tailed)	.003	.024	.003	.006	.157	.016

a. Based on negative ranks.

b. Based on positive ranks.

c. Wilcoxon Signed Ranks Test

Test Statistics[c]

	gr SUBJ ARPRE - gr SUBJ AHP PRE	gr SUBJ AFP PRE - gr SUBJ AHP PRE	gr SUBJ AFP PRE - gr SUBJ ARPRE	gr SUBJ BR PRE - gr SUBJ BHP PRE	gr SUBJ BFP PRE - gr SUBJ BHP PRE	gr SUBJ BFP PRE - gr SUBJ BR PRE
Z	-2.549[a]	-3.035[b]	-3.002[b]	-2.585[a]	-2.940[b]	-2.936[b]
Asymp. Sig. (2-tailed)	.011	.002	.003	.010	.003	.003

Test Statistics[c]

	subj Apre R TR - subj Apre HP TR	subj Apre FP TR - subj Apre HP TR	subj Apre FP TR - subj Apre R TR	subj Bpre R TR - subj Bpre HP TR	subj Bpre FP TR - subj Bpre HP TR	subj Bpre FP TR - subj Bpre R TR
Z	-2.936[a]	-1.382[a]	-2.936[b]	-2.692[a]	-1.000[a]	-2.536[b]
Asymp. Sig. (2-tailed)	.003	.167	.003	.007	.317	.011

a. Based on positive ranks.

b. Based on negative ranks.

c. Wilcoxon Signed Ranks Test

Test Statistics[c]

	gr SUBJ AR POST - gr SUBJ AHP POST	gr SUBJ AFP POST - gr SUBJ AHP POST	gr SUBJ AFP POST - gr SUBJ AR POST	gr SUBJ BR POST - gr SUBJ BHP POST	gr SUBJ BFP POST - gr SUBJ BHP POST	gr SUBJ BFP POST - gr SUBJ BR POST
Z	-2.549[a]	-2.414[b]	-2.980[b]	-2.460[a]	-2.818[b]	-2.812[b]
Asymp. Sig. (2-tailed)	.011	.016	.003	.014	.005	.005

a. Based on positive ranks.

b. Based on negative ranks.

c. Wilcoxon Signed Ranks Test

Table 8 Comparison between positions for pedal task

Test Statistics[c]

	subj Bpre HP TR - subj Apre HP TR	subj Bpre R TR - subj Apre R TR	subj Bpre FP TR - subj Apre FP TR	subj Bpost HP TR - subj Apost HP TR	subj Bpost R TR - subj Apost R TR	subj Bpost FP TR - subj Apost FP TR
Z	-1.736[a]	-2.941[b]	-1.321[a]	-2.460[a]	-2.941[b]	-1.403[a]
Asymp. Sig. (2-tailed)	.083	.003	.187	.014	.003	.161

a. Based on negative ranks.

b. Based on positive ranks.

c. Wilcoxon Signed Ranks Test

Test Statistics[b]

	subj Apost HP TR - subj Apre HP TR	subj Apost R TR - subj Apre R TR	subj Apost FP TR - subj Apre FP TR	subj Bpost HP TR - subj Bpre HP TR	subj Bpost R TR - subj Bpre R TR	subj Bpost FP TR - subj Bpre FP TR
Z	-2.271[a]	-2.201[a]	-2.410[a]	-2.549[a]	-2.848[a]	-2.379[a]
Asymp. Sig. (2-tailed)	.023	.028	.016	.011	.004	.017

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Test Statistics[c]

	gr SUBJ BHP PRE - gr SUBJ AHP PRE	gr SUBJ BR PRE - gr SUBJ ARPRE	gr SUBJ BFP PRE - gr SUBJ AFP PRE	gr SUBJ BHP POST - gr SUBJ AHP POST	gr SUBJ BR POST - gr SUBJ AR POST	gr SUBJ BFP POST - gr SUBJ AFP POST
Z	-.104[a]	-.726[b]	-2.937[a]	-2.539[a]	-1.581[a]	-2.950[a]
Asymp. Sig. (2-tailed)	.917	.468	.003	.011	.114	.003

Test Statistics[b]

	subj Apost HP TR - subj Apre HP TR	subj Apost R TR - subj Apre R TR	subj Apost FP TR - subj Apre FP TR	subj Bpost HP TR - subj Bpre HP TR	subj Bpost R TR - subj Bpre R TR	subj Bpost FP TR - subj Bpre FP TR
Z	-2.271[a]	-2.201[a]	-2.410[a]	-2.549[a]	-2.848[a]	-2.379[a]
Asymp. Sig. (2-tailed)	.023	.028	.016	.011	.004	.017

a. Based on negative ranks.

b. Based on positive ranks.

c. Wilcoxon Signed Ranks Test

Table 9 Comparison between pre-post activities for pedal task

Test Statistics[b]

	gr SUBJ AHP POST - gr SUBJ AHP PRE	gr SUBJ AR POST - gr SUBJ ARPRE	gr SUBJ AFP POST - gr SUBJ AFP PRE	gr SUBJ BHP POST - gr SUBJ BHP PRE	gr SUBJ BR POST - gr SUBJ BR PRE	gr SUBJ BFP POST - gr SUBJ BFP PRE
Z	-2.953[a]	-2.640[a]	-2.971[a]	-2.844[a]	-2.754[a]	-2.941[a]
Asymp. Sig. (2-tailed)	.003	.008	.003	.004	.006	.003

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 10 Comparison between positions and pre-post activities for Section C (seat)

Test Statistics[c]

	SUBJ B ButtPRE - SUBJ A ButtPRE	SUBJ B ButtPOST - SUBJ A ButtPOST	SUBJ A ButtPOST - SUBJ A ButtPRE	SUBJ B ButtPOST - SUBJ B ButtPRE
Z	-2.825[a]	-2.940[a]	-2.807[b]	-2.121[b]
Asymp. Sig. (2-tailed)	.005	.003	.005	.034

a. Based on positive ranks.

b. Based on negative ranks.

c. Wilcoxon Signed Ranks Test

Test Statistics[b]

	subj B ThighPRE - subj A ThighPRE	subj B ThighPOST - subj A ThighPOST	subj A ThighPOST - subj A ThighPRE	subj B ThighPOST - subj B ThighPRE
Z	-3.017[a]	-2.979[a]	-2.000[a]	-1.633[a]
Asymp. Sig. (2-tailed)	.003	.003	.046	.102

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 11 Comparison between positions and pre-post activities for Section C (back rest)

Test Statistics[c]

	subj br B ub1 - subj br A ub1	subj br B ub2 - subj br A ub2	subj br A ub2 - subj br A ub1	subj br B ub2 - subj br B ub1
Z	-1.633[a]	-2.121[b]	-.577[b]	-3.317[b]
Asymp. Sig. (2-tailed)	.102	.034	.564	.001

a. Based on positive ranks.

b. Based on negative ranks.

c. Wilcoxon Signed Ranks Test

Test Statistics[c]

	subj br B lb1 - subj br A lb1	subj br B lb2 - subj br A lb2	subj br A lb2 - subj br A lb1	subj br B lb2 - subj br B lb1
Z	.000[a]	.000[a]	-3.317[b]	-3.317[b]
Asymp. Sig. (2-tailed)	1.000	1.000	.001	.001

a. The sum of negative ranks equals the sum of positive ranks.

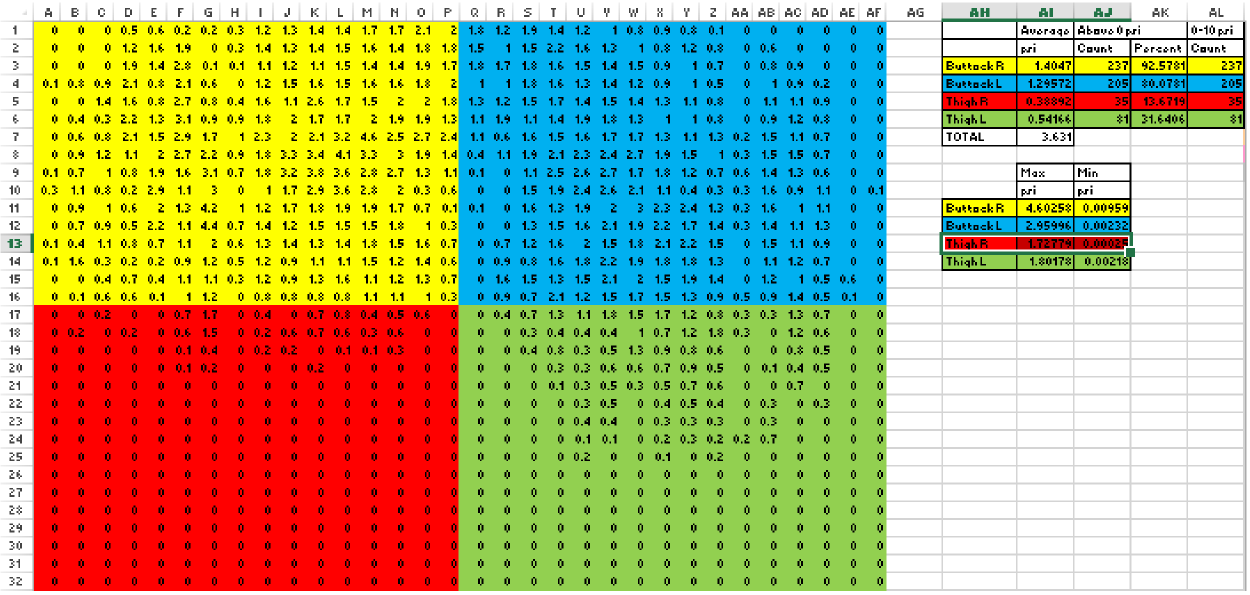
b. Based on negative ranks.

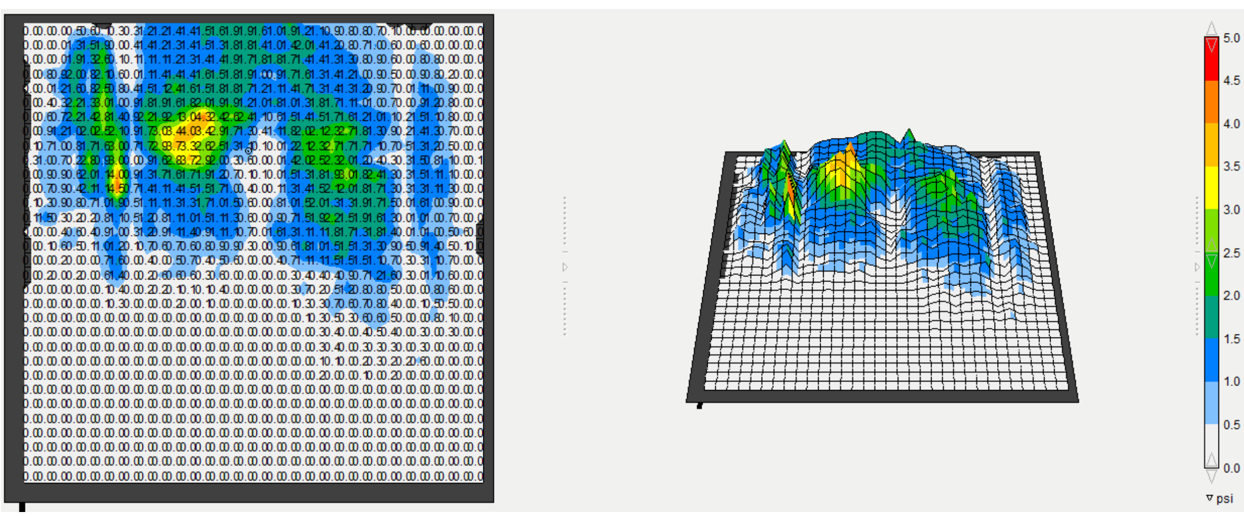
c. Wilcoxon Signed Ranks Test

APPENDIX J

EXAMPLE OF PRESSURE DISTRIBUTION RESULTS OF THE SEAT PAN AND THE BACK REST

- Result from conversion Excel 32 x 32
- Result from Tactilus software before conversion to Excel 32 x 32





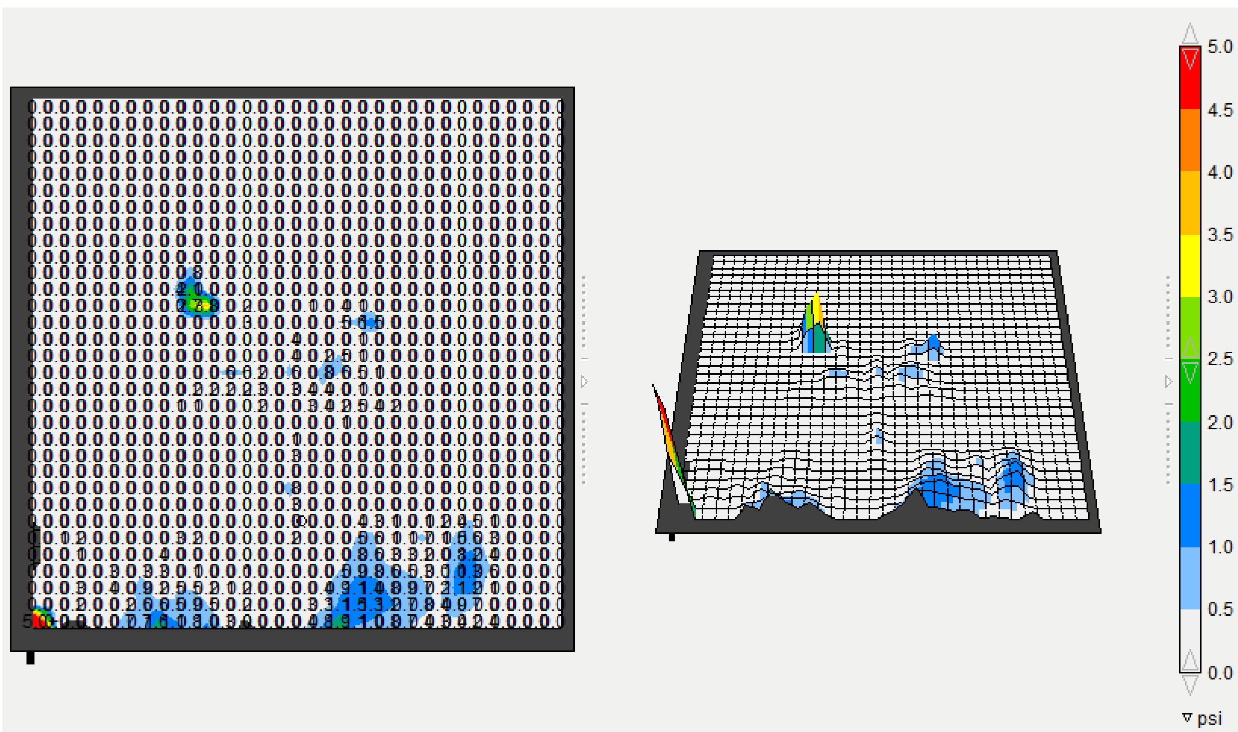
(a) Seat pan

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0.4	2.1	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	2.7	3.8	0	0.2	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4
17	0	0	0	0	0	0	0	0	0	0	0	0.6	0.6	0.2	0	0.6
18	0	0	0	0	0	0	0	0	0	0.2	0.2	0.2	0.2	0.3	0	0.3
19	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0.2	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0.1	0.2	0	0	0	0	0	0.3	0.2	0	0	0	0	0	0.2
28	0	0	0.1	0	0	0	0	0.4	0	0	0	0	0	0	0	0
29	0	0	0	0	0.3	0	0.3	0.3	0	0.1	0	0	0.1	0	0	0
30	0	0	0.3	0	0.4	0	0.9	0.2	0.5	0.5	0.2	0.1	0.2	0	0	0
31	0	0	0.2	0	0	0.2	0.6	0.6	0.5	0.9	0.5	0	0.2	0	0	0
32	5	0	0	0	0	0.7	0.7	1.6	1.1	0.8	1	0.3	0	0	0	0

	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.1	0	0.4	0.1	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0.5	0.6	1.5	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0.2	0.5	0.1	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0.8	0.6	0.5	0.1	0	0	0	0	0	0	0	0	0	0	0
18	0.4	0.4	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
19	0.3	0.4	0.2	0.5	0.4	0.2	0	0	0	0	0	0	0	0	0	0
20	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0.4	0.3	0.1	0	0.1	0.2	0.4	0.5	0.1	0	0	0	0
27	0	0	0	0.5	0.6	0.1	0.1	0.7	0.1	0.5	0.6	0.3	0	0	0	0
28	0	0	0	0.8	0.6	0.3	0.3	0.2	0	0.8	1.2	0.4	0	0	0	0
29	0	0	0.5	0.9	0.8	0.6	0.5	0.3	0	1	1.3	0.6	0	0	0	0
30	0	0.4	0.9	1.1	1.4	0.8	0.9	0.7	0.2	1.1	1.2	0.1	0	0	0	0
31	0.3	0.3	1.1	1.5	1.3	1.2	0.7	0.8	0.4	0.9	0.7	0	0	0	0	0
32	0.4	0.8	1.9	1.1	1	0.8	0.7	0.4	0.3	0.4	0.2	0.4	0	0	0	0

	Average	Above 0 psi		0-10 psi
	psi	Count	Percent	Count
Upper R	0.92684	12	4.6875	12
Upper L	0.40897	10	3.90625	10
Lower R	0.42603	61	23.8281	61
Lower L	0.55251	87	33.9844	87
TOTAL	2.31435			

	Max	Min
	psi	psi
Buttock R	3.80549	0.0066
Buttock L	1.47851	0.05374
Thigh R	5	0.00115
Thigh L	1.86672	0.00453



(b) Back rest

APPENDIX K

STATISTICAL ANALYSIS ON SEAT PAN PRESSURE DISTRIBUTION

Table 1 Comparison between pre and post activity (buttock)

Test Statistics[b]

	A postbutt - A prebutt	B postbutt - B prebutt
Z	-2.134[a]	-2.192[a]
Asymp. Sig. (2-tailed)	.033	.028

Table 2 Comparison between pre and post activity (thigh)

Test Statistics[b]

	A post thigh - A prethigh	B post thigh - B prethigh
Z	-.153[a]	-2.090[a]
Asymp. Sig. (2-tailed)	.878	.037

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 3 Comparison between postures (buttock)

Test Statistics[b]

	B prebutt - A prebutt	B postbutt - A postbutt
Z	-2.224[a]	-2.666[a]
Asymp. Sig. (2-tailed)	.026	.008

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

Table 4 Comparison between postures (thigh)

Test Statistics[b]

	B prethigh - A prethigh	B post thigh - A post thigh
Z	-1.428[a]	-2.491[a]
Asymp. Sig. (2-tailed)	.153	.013

Test Statistics[b]

	B prethigh - A prethigh	B post thigh - A post thigh
Z	-1.428[a]	-2.491[a]
Asymp. Sig. (2-tailed)	.153	.013

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 5: Correlation

		Buttock knee length
Pressure felt on buttock	Pearson Correlation	.804**
	Sig. (2-tailed)	.003
	N	11

APPENDIX L

STATISTICAL ANALYSIS ON BACK REST PRESSURE DISTRIBUTION

Table 1 Comparison between pre and post activity (upper back)

Test Statistics[c]

	A post UB - A preUB	B post UB - B preUB
Z	-.178[a]	-.445[b]
Asymp. Sig. (2-tailed)	.859	.657

Table 2 Comparison between pre and post activity (lower back)

Test Statistics[b]

	A post LB - A preLB	B post LB - B preLB
Z	-.800[a]	-.800[a]
Asymp. Sig. (2-tailed)	.424	.424

Table 3 Comparison between postures (upper back)

Test Statistics[b]

	B preUB - A preUB	B post UB - A post UB
Z	-1.600[a]	-.178[a]
Asymp. Sig. (2-tailed)	.110	.859

Table 4 Comparison between postures (lower back)

Test Statistics[b]

	B preLB - A preLB	B post LB - A post LB
Z	-1.423[a]	-.356[a]
Asymp. Sig. (2-tailed)	.155	.722

APPENDIX M

STATISTICAL ANALYSIS FOR STEERING WHEEL ACTIVITY

Table 1 Comparison between each action (left10-left45 and right45) (pre and post activity)

Test Statistics[b]

	A1L45 - A1L10	A1R45 - A1L10	A1R45 - A1L45	B1L45 - B1L10	B1R45 - B1L10	B1R45 - B1L45
Z	-2.401[a]	-2.934[a]	-2.934[a]	-1.867[a]	-2.934[a]	-2.934[a]
Asymp. Sig. (2-tailed)	.016	.003	.003	.062	.003	.003

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Test Statistics[c]

	A2L45 - A2L10	A2R45 - A2L10	A2R45 - A2L45	B2L45 - B2L10	B2R45 - B2L10	B2R45 - B2L45
Z	-.357[a]	-2.934[b]	-2.934[b]	-.089[b]	-2.934[b]	-2.934[b]
Asymp. Sig. (2-tailed)	.721	.003	.003	.929	.003	.003

a. Based on positive ranks.

b. Based on negative ranks.

c. Wilcoxon Signed Ranks Test

Table 2 Comparison between pre and post activity for all actions

Test Statistics[c]

	A2L10 - A1L10	A2L45 - A1L45	A2R45 - A1R45	B2L10 - B1L10	B2L45 - B1L45	B2R45 - B1R45
Z	-1.423[a]	-1.067[b]	-2.045[a]	-.889[a]	-.711[a]	-2.045[a]

Asymp. Sig. (2-tailed)	.155	.286	.041	.374	.477	.041

a. Based on negative ranks.

b. Based on positive ranks.

c. Wilcoxon Signed Ranks Test

Table 3 Posture comparison for all actions

Test Statistics[b]

	B1L10 - A1L10	B1R45 - A1L45	B1R45 - A1R45	B2L10 - A2L10	B2L45 - A2L45	B2R45 - A2R45
Z	-2.312[a]	-2.934[a]	-1.778[a]	-2.134[a]	-2.934[a]	-.622[a]
Asymp. Sig. (2-tailed)	.021	.003	.075	.033	.003	.534

Table 4 Correlation

		B1R45	B1L45
armlength	Pearson Correlation	.680[*]	.659[*]
	Sig. (2-tailed)	.021	.027
	N	11	11
shoulderlength	Pearson Correlation	.309	.631[*]
	Sig. (2-tailed)	.355	.037
	N	11	11

APPENDIX N

STATISTICAL ANALYSIS FOR GEAR ACTIVITY

Table 1 Comparison between each action (G1 and GN)

Test Statistics[b]

	A1GN - A1G1	B1GN - B1G1	A2GN - A2G1	B2GN - B2G1
Z	-2.934[a]	-2.934[a]	-2.803[a]	-2.934[a]
Asymp. Sig. (2-tailed)	.003	.003	.005	.003

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

Table 2 Comparison between pre and post activity for all actions

Test Statistics[c]

	A2G1 - A1G1	A2GN - A1GN	B2G1 - B1G1	B2GN - B1GN
Z	-.267[a]	-.356[b]	-.267[b]	-1.247[b]
Asymp. Sig. (2-tailed)	.790	.722	.790	.212

a. Based on negative ranks.

b. Based on positive ranks.

c. Wilcoxon Signed Ranks Test

Table 3 Posture comparison for all actions

Test Statistics[b]

	B1G1 - A1G1	B1GN - A1GN	B2G1 - A2G1	B2GN - A2GN
Z	-2.934[a]	-2.402[a]	-2.937[a]	-2.670[a]
Asymp. Sig. (2-tailed)	.003	.016	.003	.008

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 4 Correlation

		shoulderlength	armlength
B1G1	Pearson Correlation	.815**	.879**
	Sig. (2-tailed)	.002	.000
	N	11	11

APPENDIX O

STATISTICAL ANALYSIS FOR ACCELERATOR PEDAL

Table 1 Comparison between each action (HP, R and FP) at TR

Test Statistics[c]

	Apre TR R - Apre TR HP	Apre TR FP - Apre TR HP	Apre TR FP - Apre TR R	Apost TR R - Apost TR HP	Apost TR FP - Apost TR HP	Apost TR FP - Apost TR R
Z	-2.934[a]	-2.223[a]	-2.934[b]	-2.934[a]	-1.071[a]	-2.934[b]
Asymp. Sig. (2-tailed)	.003	.026	.003	.003	.284	.003

Test Statistics[c]

	Bpre TR R - Bpre TR HP	Bpre TR FP - Bpre TR HP	Bpre TR FP - Bpre TR R	Bpost TR R - Bpost TR HP	Bpost TR FP - Bpost TR HP	Bpost TR FP - Bpost TR R
Z	-2.756[a]	-1.778[a]	-2.934[b]	-2.934[a]	-1.868[a]	-2.934[b]
Asymp. Sig. (2-tailed)	.006	.075	.003	.003	.062	.003

Table 2 Comparison between each action (HP, R and FP) at GR

Test Statistics[c]

	Apre GR R - Apre GR HP	Apre GR FP - Apre GR HP	Apre GR FP - Apre GR R	Apost GR R - Apost GR HP	Apost GR FP - Apost GR HP	Apost GR FP - Apost GR R
Z	-2.578[a]	-2.848[b]	-2.845[b]	-2.497[a]	-2.713[b]	-2.845[b]
Asymp. Sig. (2-tailed)	.010	.004	.004	.013	.007	.004

Test Statistics[c]

	Bpre GR R - Bpre GR HP	Bpre GR FP - Bpre GR HP	Bpre GR FP - Bpre GR R	Bpost GR R - Bpost GR HP	Bpost GR FP - Bpost GR HP	Bpost GR FP - Bpost GR R
Z	-2.934[a]	-2.669[b]	-2.934[b]	-2.934[a]	-2.667[b]	-2.934[b]
Asymp. Sig. (2-tailed)	.003	.008	.003	.003	.008	.003

Table 3 Comparison between pre and post activity for all actions (TR)

Test Statistics[c]

	Apost TR HP - Apre TR HP	Apost TR R - Apre TR R	Apost TR FP - Apre TR FP	Bpost TR HP - Bpre TR HP	Bpost TR R - Bpre TR R	Bpost TR FP - Bpre TR FP
Z	-.800[a]	-.978[a]	-1.376[b]	-1.580[b]	-1.067[a]	-.890[b]
Asymp. Sig. (2-tailed)	.424	.328	.169	.114	.286	.373

Table 4 Comparison between pre and post activity for all actions (GR)

Test Statistics[c]

	Apost GR R - Apre GR HP	Apost GR R - Apre GR R	Apost GR FP - Apre GR FP	Bpost GR HP - Bpre GR HP	Bpost GR R - Bpre GR R	Bpost GR FP - Bpre GR FP
Z	-.255[a]	-1.599[b]	-.459[b]	-.357[b]	-1.682[a]	-.459[b]
Asymp. Sig. (2-tailed)	.799	.110	.646	.721	.093	.646

Table 5 Posture comparison for TR for all actions

Test Statistics[c]

	Bpre TR HP - Apre TR HP	Bpre TR R - Apre TR R	Bpre TR FP - Apre TR FP	Bpost TR HP - Apost TR HP	Bpost TR R - Apost TR R	Bpost TR FP - Apost TR FP
Z	-1.334[a]	-2.599[b]	-.445[b]	-1.023[b]	-2.934[b]	-.622[b]
Asymp. Sig. (2-tailed)	.182	.009	.656	.306	.003	.534

Table 6 Posture comparison for GR for all actions

Test Statistics[c]

	Bpre GR HP - Apre GR HP	Bpre GR R - Apre GR R	Bpre GR FP - Apre GR FP	Bpost GR HP - Apost GR HP	Bpost GR R - Apost GR R	Bpost GR FP - Apost GR FP
Z	-1.778[a]	-.934[b]	-1.070[a]	-.255[a]	-2.045[b]	-1.689[a]
Asymp. Sig. (2-tailed)	.075	.350	.285	.799	.041	.091

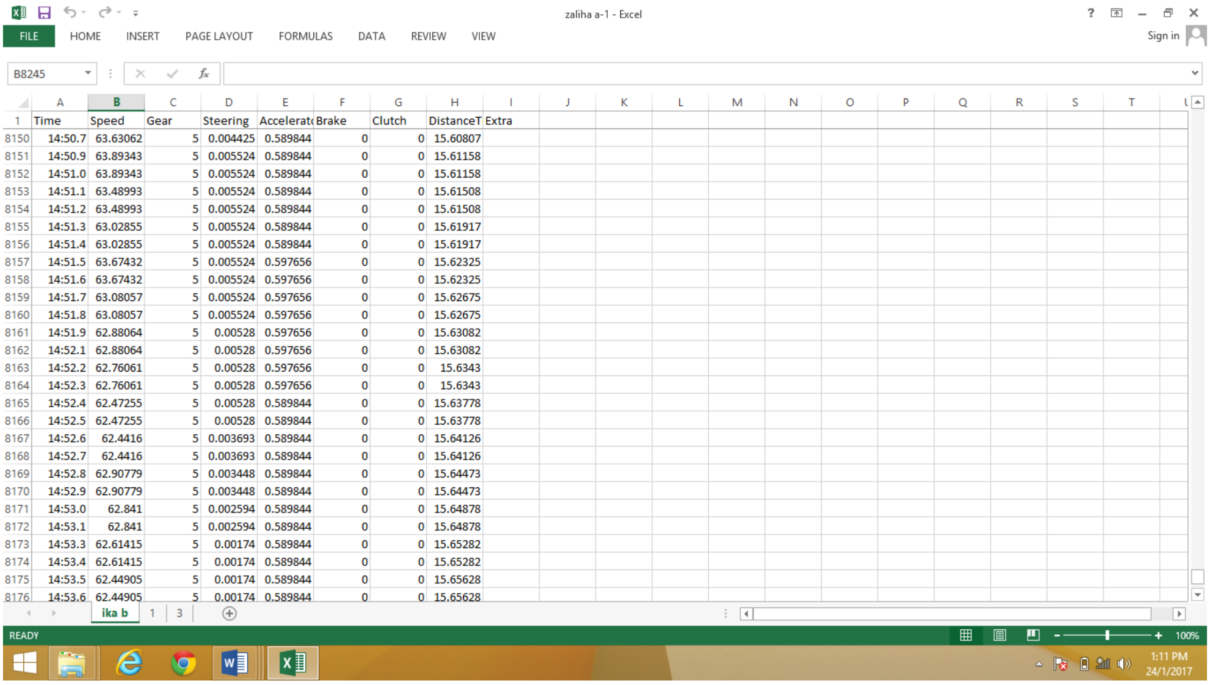
Table 7 Correlation

		KNEEANGLEB	KNEEANGLEA	armlength	shouldergriplength
Apre TR R	Pearson Correlation	-.051	-.946**	.452	.392
	Sig. (2-tailed)	.881	.000	.163	.233
	N	11	11	11	11
Bpre GR FP	Pearson Correlation	.918**	-.062	.477	.253
	Sig. (2-tailed)	.000	.855	.138	.452
	N	11	11	11	11

APPENDIX P

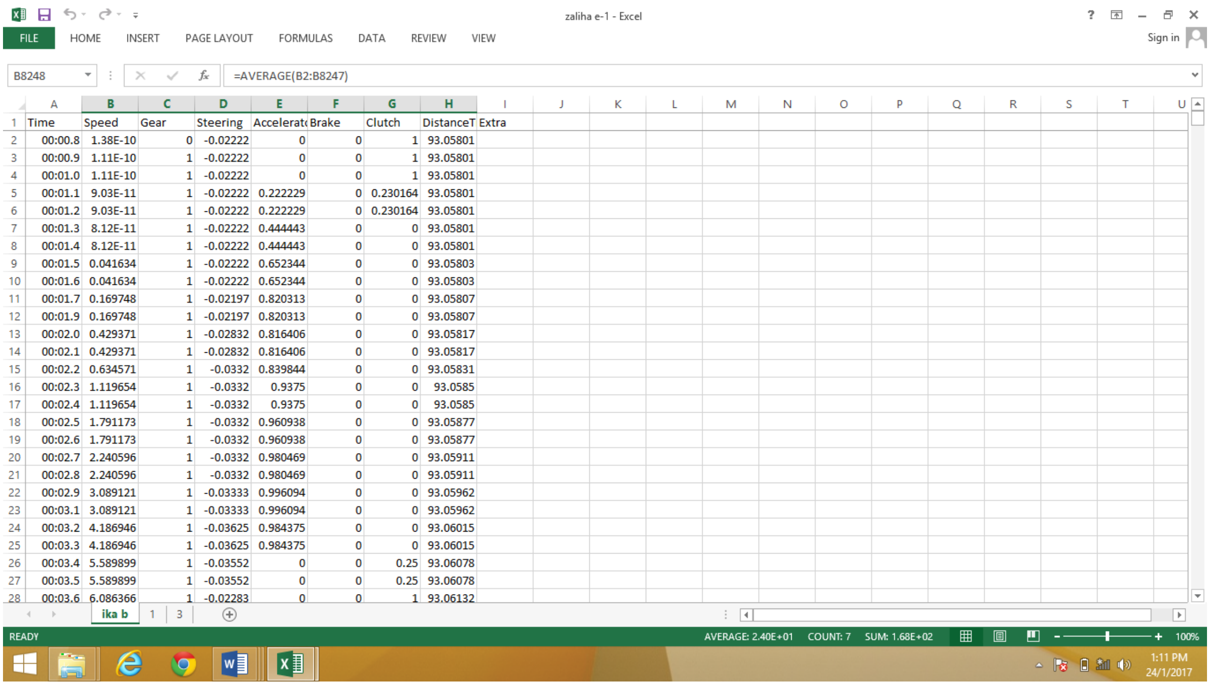
EXAMPLE OF SIMULATOR OUTPUT

Subject 1 (position A)



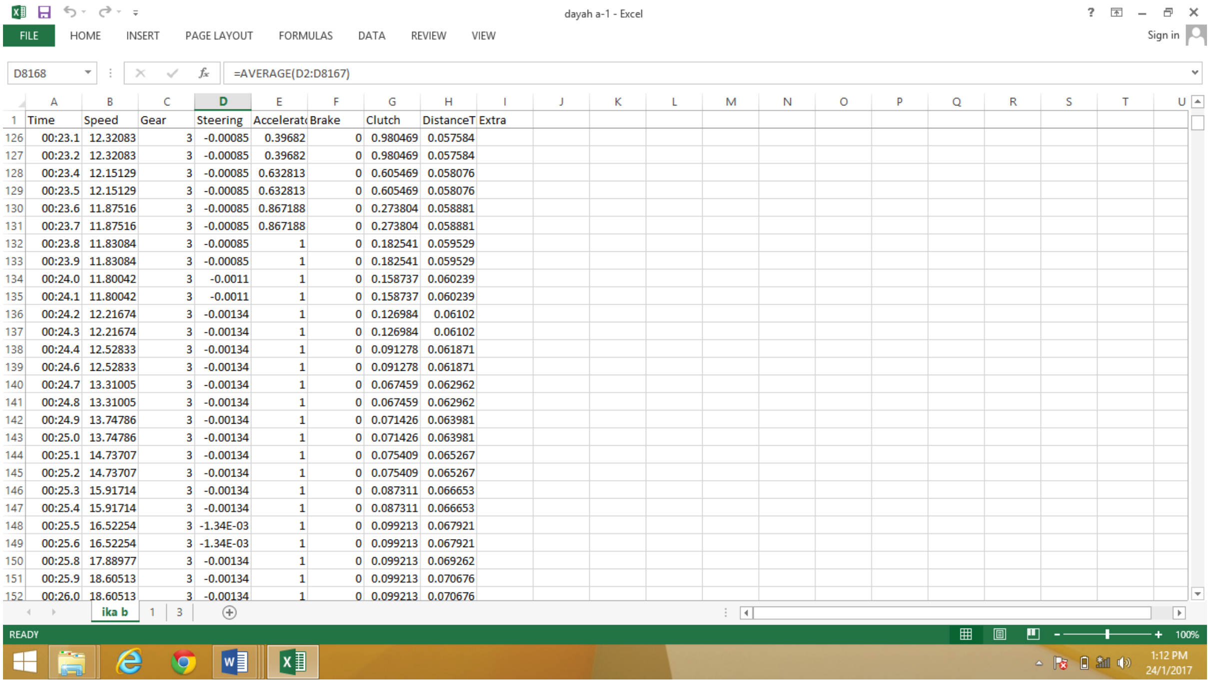
	Time	Speed	Gear	Steering	Accelerat	Brake	Clutch	DistanceT	Extra
8150	14:50.7	63.63062	5	0.004425	0.589844	0	0	15.60807	
8151	14:50.9	63.89343	5	0.005524	0.589844	0	0	15.61158	
8152	14:51.0	63.89343	5	0.005524	0.589844	0	0	15.61158	
8153	14:51.1	63.48993	5	0.005524	0.589844	0	0	15.61508	
8154	14:51.2	63.48993	5	0.005524	0.589844	0	0	15.61508	
8155	14:51.3	63.02855	5	0.005524	0.589844	0	0	15.61917	
8156	14:51.4	63.02855	5	0.005524	0.589844	0	0	15.61917	
8157	14:51.5	63.67432	5	0.005524	0.597656	0	0	15.62325	
8158	14:51.6	63.67432	5	0.005524	0.597656	0	0	15.62325	
8159	14:51.7	63.08057	5	0.005524	0.597656	0	0	15.62675	
8160	14:51.8	63.08057	5	0.005524	0.597656	0	0	15.62675	
8161	14:51.9	62.88064	5	0.00528	0.597656	0	0	15.63082	
8162	14:52.1	62.88064	5	0.00528	0.597656	0	0	15.63082	
8163	14:52.2	62.76061	5	0.00528	0.597656	0	0	15.6343	
8164	14:52.3	62.76061	5	0.00528	0.597656	0	0	15.6343	
8165	14:52.4	62.47255	5	0.00528	0.589844	0	0	15.63778	
8166	14:52.5	62.47255	5	0.00528	0.589844	0	0	15.63778	
8167	14:52.6	62.4416	5	0.003693	0.589844	0	0	15.64126	
8168	14:52.7	62.4416	5	0.003693	0.589844	0	0	15.64126	
8169	14:52.8	62.90779	5	0.003448	0.589844	0	0	15.64473	
8170	14:52.9	62.90779	5	0.003448	0.589844	0	0	15.64473	
8171	14:53.0	62.841	5	0.002594	0.589844	0	0	15.64878	
8172	14:53.1	62.841	5	0.002594	0.589844	0	0	15.64878	
8173	14:53.3	62.61415	5	0.00174	0.589844	0	0	15.65282	
8174	14:53.4	62.61415	5	0.00174	0.589844	0	0	15.65282	
8175	14:53.5	62.44905	5	0.00174	0.589844	0	0	15.65628	
8176	14:53.6	62.44905	5	0.00174	0.589844	0	0	15.65628	

Subject 1 (position B)



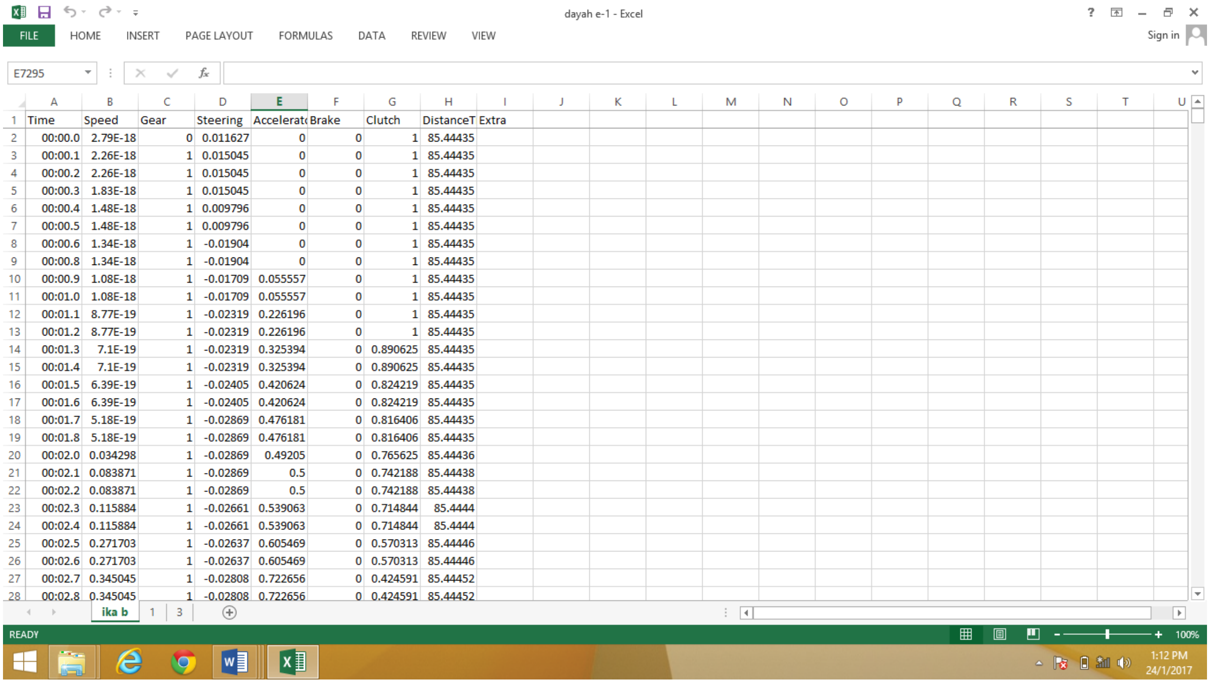
	Time	Speed	Gear	Steering	Accelerat	Brake	Clutch	DistanceT	Extra
2	00:00.8	1.38E-10	0	-0.02222	0	0	1	93.05801	
3	00:00.9	1.11E-10	1	-0.02222	0	0	1	93.05801	
4	00:01.0	1.11E-10	1	-0.02222	0	0	1	93.05801	
5	00:01.1	9.03E-11	1	-0.02222	0.222229	0	0.230164	93.05801	
6	00:01.2	9.03E-11	1	-0.02222	0.222229	0	0.230164	93.05801	
7	00:01.3	8.12E-11	1	-0.02222	0.444443	0	0	93.05801	
8	00:01.4	8.12E-11	1	-0.02222	0.444443	0	0	93.05801	
9	00:01.5	0.041634	1	-0.02222	0.652344	0	0	93.05803	
10	00:01.6	0.041634	1	-0.02222	0.652344	0	0	93.05803	
11	00:01.7	0.169748	1	-0.02197	0.820313	0	0	93.05807	
12	00:01.9	0.169748	1	-0.02197	0.820313	0	0	93.05807	
13	00:02.0	0.429371	1	-0.02832	0.816406	0	0	93.05817	
14	00:02.1	0.429371	1	-0.02832	0.816406	0	0	93.05817	
15	00:02.2	0.634571	1	-0.0332	0.839844	0	0	93.05831	
16	00:02.3	1.119654	1	-0.0332	0.9375	0	0	93.0585	
17	00:02.4	1.119654	1	-0.0332	0.9375	0	0	93.0585	
18	00:02.5	1.791173	1	-0.0332	0.960938	0	0	93.05877	
19	00:02.6	1.791173	1	-0.0332	0.960938	0	0	93.05877	
20	00:02.7	2.240596	1	-0.0332	0.980469	0	0	93.05911	
21	00:02.8	2.240596	1	-0.0332	0.980469	0	0	93.05911	
22	00:02.9	3.089121	1	-0.03333	0.996094	0	0	93.05962	
23	00:03.1	3.089121	1	-0.03333	0.996094	0	0	93.05962	
24	00:03.2	4.186946	1	-0.03625	0.984375	0	0	93.06015	
25	00:03.3	4.186946	1	-0.03625	0.984375	0	0	93.06015	
26	00:03.4	5.589899	1	-0.03552	0	0	0.25	93.06078	
27	00:03.5	5.589899	1	-0.03552	0	0	0.25	93.06078	
28	00:03.6	6.086366	1	-0.02283	0	0	1	93.06132	

Subject 2 (position A)



	Time	Speed	Gear	Steering	Accelerat	Brake	Clutch	DistanceT	Extra
126	00:23.1	12.32083	3	-0.00085	0.39682	0	0.980469	0.057584	
127	00:23.2	12.32083	3	-0.00085	0.39682	0	0.980469	0.057584	
128	00:23.4	12.15129	3	-0.00085	0.632813	0	0.605469	0.058076	
129	00:23.5	12.15129	3	-0.00085	0.632813	0	0.605469	0.058076	
130	00:23.6	11.87516	3	-0.00085	0.867188	0	0.273804	0.058881	
131	00:23.7	11.87516	3	-0.00085	0.867188	0	0.273804	0.058881	
132	00:23.8	11.83084	3	-0.00085	1	0	0.182541	0.059529	
133	00:23.9	11.83084	3	-0.00085	1	0	0.182541	0.059529	
134	00:24.0	11.80042	3	-0.0011	1	0	0.158737	0.060239	
135	00:24.1	11.80042	3	-0.0011	1	0	0.158737	0.060239	
136	00:24.2	12.21674	3	-0.00134	1	0	0.126984	0.06102	
137	00:24.3	12.21674	3	-0.00134	1	0	0.126984	0.06102	
138	00:24.4	12.52833	3	-0.00134	1	0	0.091278	0.061871	
139	00:24.6	12.52833	3	-0.00134	1	0	0.091278	0.061871	
140	00:24.7	13.31005	3	-0.00134	1	0	0.067459	0.062962	
141	00:24.8	13.31005	3	-0.00134	1	0	0.067459	0.062962	
142	00:24.9	13.74786	3	-0.00134	1	0	0.071426	0.063981	
143	00:25.0	13.74786	3	-0.00134	1	0	0.071426	0.063981	
144	00:25.1	14.73707	3	-0.00134	1	0	0.075409	0.065267	
145	00:25.2	14.73707	3	-0.00134	1	0	0.075409	0.065267	
146	00:25.3	15.91714	3	-0.00134	1	0	0.087311	0.066653	
147	00:25.4	15.91714	3	-0.00134	1	0	0.087311	0.066653	
148	00:25.5	16.52254	3	-1.34E-03	1	0	0.099213	0.067921	
149	00:25.6	16.52254	3	-1.34E-03	1	0	0.099213	0.067921	
150	00:25.8	17.88977	3	-0.00134	1	0	0.099213	0.069262	
151	00:25.9	18.60513	3	-0.00134	1	0	0.099213	0.070676	
152	00:26.0	18.60513	3	-0.00134	1	0	0.099213	0.070676	

Subject 2 (position B)



	Time	Speed	Gear	Steering	Accelerat	Brake	Clutch	DistanceT	Extra
2	00:00.0	2.79E-18	0	0.011627	0	0	1	85.44435	
3	00:00.1	2.26E-18	1	0.015045	0	0	1	85.44435	
4	00:00.2	2.26E-18	1	0.015045	0	0	1	85.44435	
5	00:00.3	1.83E-18	1	0.015045	0	0	1	85.44435	
6	00:00.4	1.48E-18	1	0.009796	0	0	1	85.44435	
7	00:00.5	1.48E-18	1	0.009796	0	0	1	85.44435	
8	00:00.6	1.34E-18	1	-0.01904	0	0	1	85.44435	
9	00:00.8	1.34E-18	1	-0.01904	0	0	1	85.44435	
10	00:00.9	1.08E-18	1	-0.01709	0.055557	0	1	85.44435	
11	00:01.0	1.08E-18	1	-0.01709	0.055557	0	1	85.44435	
12	00:01.1	8.77E-19	1	-0.02319	0.226196	0	1	85.44435	
13	00:01.2	8.77E-19	1	-0.02319	0.226196	0	1	85.44435	
14	00:01.3	7.1E-19	1	-0.02319	0.325394	0	0.890625	85.44435	
15	00:01.4	7.1E-19	1	-0.02319	0.325394	0	0.890625	85.44435	
16	00:01.5	6.39E-19	1	-0.02405	0.420624	0	0.824219	85.44435	
17	00:01.6	6.39E-19	1	-0.02405	0.420624	0	0.824219	85.44435	
18	00:01.7	5.18E-19	1	-0.02869	0.476181	0	0.816406	85.44435	
19	00:01.8	5.18E-19	1	-0.02869	0.476181	0	0.816406	85.44435	
20	00:02.0	0.034298	1	-0.02869	0.49205	0	0.765625	85.44436	
21	00:02.1	0.083871	1	-0.02869	0.5	0	0.742188	85.44438	
22	00:02.2	0.083871	1	-0.02869	0.5	0	0.742188	85.44438	
23	00:02.3	0.115884	1	-0.02661	0.539063	0	0.714844	85.4444	
24	00:02.4	0.115884	1	-0.02661	0.539063	0	0.714844	85.4444	
25	00:02.5	0.271703	1	-0.02637	0.605469	0	0.570313	85.44446	
26	00:02.6	0.271703	1	-0.02637	0.605469	0	0.570313	85.44446	
27	00:02.7	0.345045	1	-0.02808	0.722656	0	0.424591	85.44452	
28	00:02.8	0.345045	1	-0.02808	0.722656	0	0.424591	85.44452	

APPENDIX Q

REGRESSION OUTPUT

Table 1: Pressure

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.959[a]	.920	.911	.31749
2	.976[b]	.952	.940	.25972

a. Predictors: (Constant), Pressure unit in kg/cm-2; b. Predictors: (Constant), Pressure unit in kg/cm-2, Buttock popliteal length

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.429	1	10.429	103.462	.000[a]
	Residual	.907	9	.101		
	Total	11.336	10			
2	Regression	10.797	2	5.398	80.031	.000[b]
	Residual	.540	8	.067		
	Total	11.336	10			

a. Predictors: (Constant), Pressure unit in kg/cm-2; b. Predictors: (Constant), Pressure unit in kg/cm-2, Buttock popliteal length; c. Dependent Variable: Pressure felt on buttock

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.959[a]	.920	.911	.31749
2	.976[b]	.952	.940	.25972

a. Dependent Variable: Pressure felt on buttock

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	2.034	.451		4.510	.001
Pressure	22.144	2.177	.959	10.172	.000
(Constant)	12.936	4.685		2.761	.025
Pressure	31.518	4.393	1.365	7.175	.000
Buttock popliteal length	-.270	.116	-.444	-2.334	.048

a. Dependent Variable: SUBJB1R45

Excluded Variables[b]

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
armlength	.154[a]	2.489	.038	.661	.537

a. Predictors in the Model: (Constant), B1R45; b. Dependent Variable: SUBJB1R45

Excluded Variables[b]

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance

1	Buttock popliteal length	-.444[a]	-2.334	.048	-.637	.164

a. Predictors in the Model: (Constant), Pressure unit in kg/cm-2; b. Dependent Variable: Pressure felt on buttock

Table 2: SEMG

a. **Steering wheel**

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.985[a]	.971	.967	.17390
2	.992[b]	.983	.979	.13848

a. Predictors: (Constant), B1R45; b. Predictors: (Constant), B1R45, fore arm length

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.993	1	8.993	297.386	.000[a]
	Residual	.272	9	.030		
	Total	9.265	10			
2	Regression	9.112	2	4.556	237.590	.000[b]
	Residual	.153	8	.019		
	Total	9.265	10			

a. Predictors: (Constant), B1R45, b. Predictors: (Constant), B1R45, fore arm length; c. Dependent Variable: SUBJB1R45

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.315	.166		25.944	.000
	B1R45	.082	.005	.985	17.245	.000

2	(Constant)	.384	1.585		.242	.815
	B1R45	.073	.005	.880	14.181	.000
	armlength	.098	.039	.154	2.489	.038

a. Dependent Variable: SUBJB1R45

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	armlength	.154[a]	2.489	.038	.661	.537

a. Predictors in the Model: (Constant), B1R45; b. Dependent Variable: SUBJB1R45

b. Gear

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.977[a]	.954	.949	.28598
2	.990[b]	.980	.975	.20038

a. Predictors: (Constant), B1G1; b. Predictors: (Constant), B1G1, shoulder length

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15.289	1	15.289	186.944	.000[a]
	Residual	.736	9	.082		
	Total	16.025	10			
2	Regression	15.704	2	7.852	195.564	.000[b]
	Residual	.321	8	.040		
	Total	16.025	10			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.977[a]	.954	.949	.28598
2	.990[b]	.980	.975	.20038

a. Predictors: (Constant), B1G1; b. Predictors: (Constant), B1G1, shoulder length; c. Dependent Variable: SUBJB1G1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.143	.210		19.708	.000
	B1G1	.073	.005	.977	13.673	.000
2	(Constant)	15.756	3.616		4.357	.002
	B1G1	.090	.006	1.203	13.933	.000
	shoulderlength	-.191	.059	-.278	-3.214	.012

a. Dependent Variable: SUBJB1G1

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	shoulderlength	-.278[a]	-3.214	.012	-.751	.336

a. Predictors in the Model: (Constant), B1G1; b. Dependent Variable: SUBJB1G1

c. Pedal (TR)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate

1	.907[a]	.822	.802	.32493
2	.954[b]	.911	.889	.24368

a. Predictors: (Constant), A1TRR; b. Predictors: (Constant), A1TRR, KNEEANGLEA

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.390	1	4.390	41.577	.000[a]
	Residual	.950	9	.106		
	Total	5.340	10			
2	Regression	4.865	2	2.432	40.965	.000[b]
	Residual	.475	8	.059		
	Total	5.340	10			

a. Predictors: (Constant), A1TRR; b. Predictors: (Constant), A1TRR, KNEEANGLEA; c. Dependent Variable: SUBJA1TRR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.224	.207		34.884	.000
	A1TRR	.117	.018	.907	6.448	.000
2	(Constant)	-10.914	6.413		-1.702	.127
	A1TRR	.229	.042	1.778	5.462	.001
	KNEEANGLEA	.167	.059	.921	2.829	.022

a. Dependent Variable: SUBJA1TRR

Excluded Variables[b]

Model	Beta In	t	Sig.	Partial	Collinearity Statistics

				Correlation	Tolerance
1 KNEEANGLEA	.921[a]	2.829	.022	.707	.105

a. Predictors in the Model: (Constant), A1TRR; b. Dependent Variable: SUBJA1TRR

d. Pedal (GR)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.956[a]	.914	.905	.30824
2	.976[b]	.952	.940	.24408

a. Predictors: (Constant), B1GRFP; b. Predictors: (Constant), B1GRFP, KNEEANGLEB

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.112	1	9.112	95.905	.000[a]
	Residual	.855	9	.095		
	Total	9.967	10			
2	Regression	9.491	2	4.745	79.652	.000[b]
	Residual	.477	8	.060		
	Total	9.967	10			

a. Predictors: (Constant), B1GRFP; b. Predictors: (Constant), B1GRFP, KNEEANGLEB; c. Dependent Variable: SUBJB1GRFP

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.192	.211		24.618	.000

	B1GRFP	.239	.024	.956	9.793	.000
2	(Constant)	-10.491	6.224		-1.686	.130
	B1GRFP	.126	.049	.504	2.578	.033
	KNEEANGLEB	.123	.049	.493	2.521	.036

a. Dependent Variable: SUBJB1GRFP

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	KNEEANGLEB	.493[a]	2.521	.036	.665	.157

a. Predictors in the Model: (Constant), B1GRFP; b. Dependent Variable: SUBJB1GRFP

APPENDIX R

LIST OF PUBLICATIONS (2014-2017)

INDEXED JOURNAL

1. **Khamis, N.K**. and Deros, B.M. Development of a statistical model for predicting seat pressure felt level in simulated condition based on direct and anthropometric measurement. Physical Science Therapy Journal (JPTS) (Q2 Journal: accepted, waiting for correction approval from the editor based on the reviewer's comment)

2. **Khamis, N.K.,** Ismail, A.H. and Deros, B.M. 2018. The Effect of Grasping the Steering Wheel while Positioning the Shoulder Closer to the Body, Malaysian Journal of Public Health Medicine (SCOPUS: accepted, waiting to be published)

3. **Khamis, N.K.,** Deros, B.M., Schramm, D., Koppers, M. and Maas, N. 2018. Deltoid Anterior Contraction in Maneuvering the Steering Wheel, Malaysian Journal of Public Health Medicine (SCOPUS: accepted, waiting to be published)

4. **Khamis, N.K.,** Deros B.M., Nuawi, M.Z. & Schramm, D. 2018. Pattern of Lower Leg Muscle Contraction in Car Pedal Operation. Jurnal Kejuruteraan. (In-press)

5. Roslan, N.A.F., **Khamis, N.K**. and Deros, B.M. 2018. Comparative study of pressure interface measurement at the local car seats under static and dynamic circumstances. Malaysian Journal of Public Health Medicine (accepted, waiting to be published)

6. **Khamis, N.K.,** Deros, B.M., and Nuawi, M.Z. 2017. Muscle Activity of the Upper and Lower Body Part in Car Gearing Action: A Preliminary Study. Journal of Mechanical Engineering, SI 3 (2): 157-165.

7. **Khamis, N.K.**, Deros, B., Ismail, F.R. and Tahir, N.H., 2016. Motorcycle deliveryman's perceptions on riding conditions. Malaysian Journal of Public Health Medicine, 1(Specialissue1): 1-5.

8. Kamal, S.A., Baba, M.D., **Khamis, N.K**., Rasdan, I.A. and Abu, A., 2016. A study on user's comfort level and seat mismatch in a lecture theatre. Malaysian Journal of Public Health Medicine, 16: 5-13.

9. **Khamis, N.K.,** Deros, B.M., Schramm, D., Hesse, B., Nuawi, M.Z. and Ismail, F.R., 2016. Subjective and indirect methods to observe driver's drowsiness and alertness: An overview. Journal of Engineering Science and Technology, 11: 28-39.

10. **Khamis, N.K.,** Ismail, F.R., Hesse, B., Schramm, D., Maas, N., Koppers, M., Nuawi, M.Z. and Deros, B.M. 2016. Suitability of Heart Rate Recording as Physiological Measures Tool to Determine Drivers' Performance Impairment: A Preliminary Study. Jurnal Teknologi, 78: 25-30.

11. Ismail, F.R., Nuawi, M.Z., Schramm, D. and **Khamis, N.K**., 2016. Suitability of driving simulators as a tool to study driving fatigue due to vibration and environment: A review. Malaysian Journal of Public Health Medicine, 1(Specialissue1): 95-101.

12. Ismail, F.R., **Khamis, N.K.,** Nuawi, M.Z., Schramm, D. and Hesse, B., 2016. Measurement of heart rate to determine car drivers' performance impairment in simulated driving: An overview. Jurnal Teknologi, 78(6-9): 15-23

13. **Khamis, N.K.,** Basrah, N., Deros, B.M. and Nuawi, M.Z., 2015. Electromyography as an objective measurement for evaluating physical fatigue: An overview. Jurnal Teknologi, 77(27): 51-57.

14. Deros, B.M., Daruis, D.D., **Khamis, N.K.,** Mohamad, D., Daud, S.F.M., Amdan, S.M., Aziz, R.A. & Jamal, N., 2014. Prevalence of work related musculoskeletal disorders symptoms among construction workers: A case study in Malaysia. Iranian Journal of Public Health, 43(3): 53.

15. **Khamis, N.K.,** Deros, B.M.,Abdul Aziz, F. & Md. Saad, M.H., 2014. Optimized Manual Lifting Condition amongst Workers using an Ergonomics Guidelines: A Case Study. Advances in Environmental Biology, 116-120.

16. **Khamis, N.K.,** Nuawi, M.Z., Deros, B.M., Ismail, F.R., Mohamad, D. and Md Tahir, N.H., 2014. Assessment of Whole Body Vibration Exposure among Motorcyclist in Malaysia under Different Speeds and Different Road Profiles: A Preliminary Study, Advances in Environmental Biology, 160-163.

PROCEEDING

1. **Khamis, N.K.,** Deros, B.M., Schramm, D., Maas, N., Nuawi, M.Z. and Koppers, M., 2017. Predicting pressure level felt under the seat pan due to changes in driving position. PressAcademia Procedia, 5(1): 325-334.

2. **Nor Kamaliana Khamis**, Baba Md Deros, Mohd Zaki Nuawi, Dieter Schramm, Martin Koppers, Niko Maas. 2017. Predicting muscle activity of lower leg according to joint angle measurement in a simulated condition. Proceedings of the Tuanku Ja'far Conference (TJC), page 534-541.

3. **Khamis, N.K.,** Deros, B.M. and Ismail, F.R., 2015. Two Way Assessments in Measuring Vibration Exposure among Workers: A Review. Applied Mechanics and Materials. 786: 161-165.

4. **Khamis, N.K.,** Deros, B.M., Nuawi, M.Z. and Ismail, F.R., 2015. Objective Assessment of Vibration Exposure among Workforces: A Review. Applied Mechanics and Materials, 786: 166-173.

5. Mohamad, D., Deros, B.M., Daruis, D.D.I., **Khamis, N.K.** and Tahir, N.H.M., 2014. Assessment of hand-arm vibration exposure among motorcyclist in Malaysia. Applied Mechanics and Materials, 663: 395-399.

6. Deros, B.M., **Khamis, N.K.,** Mohamad, D., Kabilmiharbi, N. and Daruis, D.D.I., 2014, December. Investigation of oil palm harvesters' postures using RULA analysis. Biomedical Engineering and Sciences (IECBES), 2014 IEEE Conference on (pp. 287-290). IEEE.

7. **Khamis, N.K.,** Deros, B.M., Nuawi, M.Z. and Omar, R.B., 2014. Driving fatigue among long distance heavy vehicle drivers in Klang Valley, Malaysia. Applied Mechanics and Materials, 663: 567-573.

8. **Khamis, N.K.,** Deros, B.M. and Nuawi, M.Z., 2014. A preliminary study on motorcyclists' perceptions of fatigue risk factors. Applied Mechanics and Materials, 471: 178-183.

CONFERENCE PAPERS

1. **Khamis, N.K.,** Deros, B.M., Yusoff, A.R., Nawawi, R. and Nuawi, M.Z. 2016. Muscle activation pattern of the shoulder part while handling car steering wheel. International Conference on Environmental & Occupational Health (ICEOH 2016), Putrajaya.

2. **Nor Kamaliana Khamis,** Baba Md Deros, Mohd Zaki Nuawi and Dieter Schramm. 2015. Association between mental workload, workers' performance and heart pulse based on actual and simulator studies: an overview, ERGOSYM 2015, Perlis, Malaysia.

3. **Khamis, N.K.,** Deros, B.M., Schramm, D., Hesse, B. and Nuawi, M.Z. 2015. A literature study on heart rate measures and human performance in daily activities under controlled measurement. NVC 2015, Kuala Lumpur, Malaysia.

BOOK (AS CO-EDITOR)

1. Rozli Zulkifli, Shahrum Abdullah, Sallehuddin Mohamed Haris, Zulkifli Mohd Nopiah, Zambri Harun, Mohd Radzi Abu Mansor and **Nor Kamaliana Khamis**, 2014, *Automotive Engineering and Mobility Research*, Applied Mechanics and Materials, Ed. 663, 714, Trans Tech Publications, Switzerland.

RESEARCH GRANT

1. GUP-2017-094
2. FRGS/2/2014/TK01/UKM/01/1
3. SCIENCE FUND