

STUDY OF STARTLE/PANIC RESPONSES DUE TO AUDITORY AND HAPTIC
WARNINGS IN ROADWAY LANE DEPARTURE

by

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ABSTRACT

Roadway lane departure accidents caused 25,082 fatalities which accounted for about 58 percent of all roadway fatalities in the United States this year (AASHTO, 2008). In order to reduce these fatalities different types of strategies were implemented such as providing shoulder and/or centerline rumble strips, enhancing delineation of sharp curves, removing or relocating objects, eliminating shoulder drop-offs and providing skid-resistant pavements. Of these strategies, the rumble strips strategy has been found to be more effective to warn drivers. But, the drawbacks of rumble strips have led to the introduction of in-vehicle warning systems. In-vehicle Lane Departure Warning Systems were machine vision-based that use algorithms to interpret video images to check the car's current position and time to lane crossing. However, it is not clear if the warnings themselves may be a potential hazard in terms of distracting or startling drivers. This distraction and startle might impede drivers from quickly and appropriately responding to the original traffic hazard. The present study is intended to better understand how human participants react to such sudden warnings given to them to warn in case of a possible hazard during roadway lane departure.

Twelve participants (six male and six female) were asked to drive a simulated vehicle and they were alerted with auditory, haptic, combination of auditory & haptic and no-warning modalities during their lane departure. The responses of the participants were recorded using electromyography (EMG) from the deltoid, biceps brachii, pronator teres and tibialis anterior muscles. The results of the study determined that there is no significant difference in EMG activity between the warning modalities except for the deltoid muscle. The difference in EMG activity for the deltoid muscle for auditory condition is likely due to the greater maximum steering response. Moreover, there is no significant difference among warning modalities during the participant's first warning event. Also, there is no difference in EMG activity between genders due to warning modalities. Overall, findings suggest that there is no potential startle/panic response perceived by the participants due to warning systems in roadway lane departure.

CHAPTER 1

INTRODUCTION

Roadway lane departure accidents include collision with a fixed object, collision with a non-fixed object, run-off road, head-on collisions and sideswipe collisions. There were 25,082 fatalities due to roadway lane departures which account for about 58 percent of the roadway fatalities in the United States in 2006 (AASHTO, 2008). In order to reduce these fatalities different types of strategies were implemented such as providing shoulder and/or centerline rumble strips, enhancing delineation of sharp curves, removing or relocating objects, eliminating shoulder drop-offs and providing skid-resistant pavements. Of the above strategies, the rumble strips strategy is found to be more effective to warn drivers (Hickey, 2007). Rumble strips consist of either raised or grooved patterns that are installed perpendicular to the direction of travel located in the shoulder and/or centre of roads which adds sound and vibration when traversed by the vehicle tires.

According to the study conducted in New York state from 1991-1997, the number of crashes, injuries and fatalities reduced by nearly 70 percent due to installation of continuous shoulder rumble strips (Perrillo, 1998). But these rumble strips have potential disadvantages, like noise which may be disruptive to the nearby residents, bicycle operations hampered due to the limitation in the shoulder room due to the installation of rumble strips in non-interstate highways, no lane width to accommodate, cost associated with rumble strips and also crash migration further down the roadway without rumble strips.

The drawbacks like safety issues, limited room and crash migration have led to the introduction of in-vehicle warning systems. Recently, as part of the Intelligent Transportation Institute, the U.S. Department of Transportation's Intelligent Vehicle Initiative has introduced new in-vehicle Lane Departure Warning Systems (LDWS). These systems are machine vision-based that use algorithms to interpret video images to check the car's current position and time to lane crossing (TLC). The current position of the car is calculated by determining the position of the front wheel with respect to car width and lane width. TLC is a measure of the time remaining before a vehicle on a given trajectory will depart the road. The TLC is calculated by assuming that a car keeps in its current direction, current steer angle and current velocity from which the presumed time and distance of the lane crossing is detected (Risack, Mohler & Enkelmann, 2000).

Lane Departure Warning systems first appeared in production in Europe on commercial trucks in 2000 and are now available on most trucks sold in Europe. Trucks in North America began installing LDWS in 2002, and today, many upscale passenger cars have a LDWS available. LDWS warn the driver of a lane departure when the vehicle is traveling above a certain speed threshold (typically above 20 miles/hour) and the vehicle's turn signal is not in use (Federal Motor Carrier Safety Administration, 2005).

The different warning systems consist of heads-up display, auditory sound, steering wheel torque and haptic signal (seat vibration, steering wheel vibration). In an experiment, it was found that auditory sound can prevent almost 85% of the lane departure events caused by sleepiness (Rimini-Doering, Altmueller, Ladstaetter & Rossmeier, 2005). In another experiment, rumble strip sound tended to decrease the reaction time following a warning and was also well liked by drowsy drivers. Also, the

steering wheel vibration accompanied with steering wheel torque have a faster reaction time and decrease the magnitude of lane excursion following a warning (Kozak et al., 2006). In another study, haptic modality has faster reaction time and auditory modality has greater steering response due to incorrect maneuver and the combination of Auditory and Haptic was most preferred in overall performance by the participants (Stanley, Marley & Kelly, 2007). In most of the experiments conducted earlier to avoid roadway lane departure, researchers used auditory signal and haptic signal as warning systems.

However, it is not clear if the warnings themselves may be a potential hazard in terms of distracting or startling drivers. This distraction and startle might impede drivers from quickly and appropriately responding to the original traffic hazard. These startle/panic responses may result in adverse effects like overreacting, delayed response, steering in the opposite direction of the lane rather than the required direction and sudden application of brake. The present study is intended to better understand how human participants react to such sudden warnings given to them to warn of a possible hazard during roadway lane departure.

Objective Statement

The major objectives of the study are:

1. To conduct a pilot study in the muscles of upper and lower extremities of the human participants to determine which muscles respond when a human subject is driving a stimulated vehicle and doing simple actions such as steering the wheel and applying brake to the vehicle. This preliminary study is intended to determine

which skeletal muscles are significantly active while driving the simulated vehicle.

2. To determine if there is any startle/panic response perceived by the human participants while receiving three different warnings such as auditory signal (“rumble strip” sound), haptic signal (seat vibration) and the combined modalities of both Haptic and auditory during roadway lane departure. This study is intended to determine the response of the distracted driver on a sudden issuance of warnings (auditory, haptic and combination of both auditory and Haptic) in a roadway lane departure.

Hypotheses

The following null hypotheses will be tested:

- 1) There is no significant increase in electromyographic (EMG) activity (root-mean-square amplitude) on the muscle fibers (Abductor pollicis brevis, Trapezoid, Deltoid, Biceps Brachii, Pronator Teres, Tibialis anterior and soleus muscle) of the human participants due to steering the wheel and applying brake in the stimulated vehicle compared to driving in a straight road without steering the wheel and applying the brake in the stimulated vehicle.

$$H_0: \mu_1 = \mu_2$$

$$H_a: \mu_1 > \mu_2$$

Where μ_i , i = Driving Condition (1 = Rural road with left turns, right turns and stop signs, 2 = Straight rural road with no turns and stop signs)

- 2) There is no significant difference in the percentage of maximum voluntary contraction on the muscle fibers due to the modality of warning such as auditory, haptic, combination of auditory, haptic and no-warning condition.

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

$$H_a: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$$

Where μ_i , i = Warning Condition (1= haptic warning, 2 = auditory, 3 = combination of auditory and haptic warning, 4 = no-warning)

Delimitations and Limitations

There are three primary delimitations to this study. First, the study was delimited to drivers around the Bozeman community with the age limit of 20 to 30 years of age. Secondly, all testing was conducted under simulated conditions. Thirdly, only the limited numbers of muscle group were selected to measure panic responses in the phase I and Phase II. Road conditions were designed to simulate real road driving, but exact conditions were nearly impossible to mimic. The major limitation of this study includes the small sample size used for both the Phase I and Phase II study. In addition, the sampling plan did not account for clothing, obesity, driver experience, or any dominate hand variations.

CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this study was to find if there is any startle/panic responses due to haptic, auditory and combination of auditory and haptic warnings in roadway lane departures. The study was also conducted to find the appropriate muscle group which respond in the upper and lower extremities of the human body while driving a simulated vehicle. The previous studies have revealed the importance of determining the best modality of warnings during the roadway lane departure. This study gives more importance to response of human beings to that modality of warnings.

Studies on Types of Strategies and Warnings
Implemented to Control Lane Departure Accidents

The major accidents occurring in roadways are mainly due to roadway lane departure. These accidents include collision with a

- fixed object
- collision with a non-fixed object
- run-off road, head-on collisions
- sideswipe collisions

There were 25,082 fatalities due to roadway lane departures which account to about 58 percent of the roadway fatalities in the United States in 2006 (AASHTO, 2006). The majority of the above crashes were on the low traffic volume two lane rural roads than the urban roads. Several factors contribute to the roadway lane departure, which include

excessive speed, driver drowsiness or intoxication, lost direction control, evasive maneuvers and driver inattention and vehicle failure.

In order to reduce the lane departure and roadway departure accidents the following strategies were implemented (AASHTO, 2008)

- providing shoulder and/or centerline rumble strips
- enhancing delineation of sharp curves
- removing or relocate objects
- eliminating shoulder drop-offs
- providing skid-resistant pavements

The primary aim of the above said strategies is to keep vehicles in their lane and on the road, minimize the likelihood of crashing into an object or overturning if the vehicle travels off the shoulder and reduce the severity of the crash. These techniques were mostly implemented in the roadway and surroundings of the roadways.

In-Vehicle Warning Systems

Of the quick strategies implemented, rumble strip was found to be more effective. Rumble strips consists of either raised or grooved patterns that are installed perpendicular to the direction of travel located in shoulder and/or centre of roads which adds sound and vibration when traversed by the vehicle tires. However, the physical rumble strip has disadvantages such as noise complaints, bicycle and motorist complaints over the limited shoulder room, crash migration and lack of adequate shoulder width. These disadvantages lead to the introduction of new in-vehicle warning systems proposed by intelligent transport system. In this system, the warnings are present inside the car and it

works in such a way that cameras monitor the white and yellow lines on the road and, if the vehicle crosses the line without the turn signal being activated, the system alerts the driver. Many studies have proven that in-vehicle alert systems are beneficial. The drivers were able to maintain longer and safer headways for at least six months (Ben-Yaacov, Maltz & Shinar, 2002). Warning systems may also reduce the forgetting and increase the memorability (Speed, 2000). But, there is a chance of false alarms because of inefficient system interfaces, which induced the drivers to slow down unnecessarily. Overall false alarms did not have greater impact on the driver performance and led to safer headway maintenance (Maltz & Shinar 2004).

Additionally, the presence of warning systems inside the car instead of physical rumble strips on the road, gave the researchers the lenience of choosing different types of warnings. The different types of warning system include heads-up display, rumble strip sound, steering wheel torque and haptic signal (seat vibration, steering wheel vibration). Out of these warnings system it was found that haptic and auditory are found to be more effective (Stanley, 2006; Kozak et al., 2006).

However there is a potential of negative effects of warnings that may occur such as startling the driver and adding to cognitive load and stress. Horowitz and Dings (1992) study considered four design concepts to reduce the effectiveness of startling the drivers (1) graded sequence of warnings, from mild to severe, (2) a parallel change in modality, from visual to auditory, (3) individualization of warnings, and (4) a headway - distance to lead car – display.

However, there is no actual study conducted to measure the magnitude of startle responses due to the issuance of warnings. This drawback leads to the interest of studying the responses of distracted driver on the issuance warnings.

Definition of Startle/Panic Effect

The startle effect is the response of mind and body to a sudden unexpected stimulus, such as a flash of light, a loud noise, or a quick movement near the face. In human beings, the reaction includes physical movement away from the stimulus, a contraction of muscles of the arms and legs, and often blinking. Also, the startle responses are considered as a brainstem reflex in response to an unexpected stimulus (Kofler, Muller, Reggiani & Valls-sole 2001).

Studies on Startle/Panic Responses

The startle responses are the measures of emotion in humans to the given situation (Vrana, Spence & Lang, 1988). In this study, measuring the startle response after the issuance of warning to a distracted driver will help in measuring the emotion of the distracted driver. There are no particular studies related to measurement of startle/panic responses due to warning systems in the car. However, there were studies that measured startle responses caused by alcohol, sudden sound burst in human beings and some studies even measured startle responses in rats. One such study was conducted with the participants who received alcoholic beverages and they were provided with an acoustic sound burst of 100dB while they were watching pleasant slides. The findings suggest that alcohol attenuated overall startle reactivity. (Curtin, Lang, Patrick & Stritzke, 1998).

A study conducted an experiment with sound intensity varying from 90dB to 110dB and found that women tend to get more auditory startle responses than men (Kofler et al., 2001). In addition with sound burst, darkness also facilitates the startle reflexes (Grillon, Pellowski, Merikangas & Davis, 1997). Another interesting study found that there is no need of any shock or sound burst to provoke startle reflex. It found that, even if the participants were given an anticipation of electric shock the startle reflex can be observed (Grillon & Davis, 1997).

In all the above studies surface EMG was placed on the associated muscles to measure the startle responses. The contraction of muscle fibers is captured by surface EMG and measured in volts. EMG is a technique for evaluating and recording the activation signal of muscles. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells are both mechanically active and at rest (Raez, Hussain & Mohd – Yasin, 2006). Also, above studies reveal that sudden auditory warning has more potential of generating startle reflexes. However, the sound level used is of higher dB level (i.e. > 90dB).

Muscles to Measure Startle Responses

The most common method to measure startle response was capturing the blink response of eyes (Valls-Sole, Valldeoriola, Molinuevo, Cossu & Nobbe, 1999). The muscle associated with the blink responses was orbicularis oculi, which closes the eyelids. The muscle response evolved by a startling stimulus was described as the startle reflex which is superimposed with respect to the voluntary reaction time movement

(Siegmund, Inglis & Sanderson, 2001). Also, the startle reflex is measured in various muscles group depending on the startling stimulus. In a study to measure acoustic startle responses; eight groups of muscles were used such as masseter, orbicularis oculi, sternocleidomastoid, biceps brachii, abductor pollicis brevis rectus femoris, tibialis anterior, and soleus muscles. The experiment was conducted with the participant lying down in a dark room with sudden issuance of sound burst (Kofler et al., 2001). Furthermore, a study conducted to measure startle responses due to ballistic head movements used orbicularis oculi, masseter, sternocleidomastoid and cervical paraspinal muscles. This suggests that the startle response is also associated with the muscles which can react or move due to the startling stimulus. The above suggestions also provide pathways to this study in determining the muscles associated with the driving.

The study on assessment of muscle fatigue while driving a car driving used left, right trapezius and deltoid muscles for measuring muscle fatigue (Hostens & Ramon 2005) and neck muscles were also used in determining fatigue levels in simulated car driving (Dureman & Boden 1972). Tibialis anterior muscle was used to quantitate central and peripheral contributions to the development of muscle fatigue (Kent-Braun, 1999). Most of the studies also used lower back muscle in determining the muscle fatigue (Durkin, Harvey, Hughson & Callaghan, 2006). This reveals that trapezius, deltoid and tibialis anterior are considered as active muscles while driving and were used in measuring muscle fatigue.

In conclusion, the trapezius, deltoid and tibialis anterior muscles were considered for this study which may be produce startle reflexes during to their activeness while driving the car. Since this study is also using auditory warnings, the muscles associated

with measuring acoustic startle reflexes were considered such as biceps brachii, pronator teres, abductor pollicis brevis and soleus muscles. The muscles selected in considering acoustic startle responses were also selected with respect to their activeness in driving. However, phase I experiment for this study is done to select the appropriate muscle from the above considered muscle groups. This study also considered only the right hand side of the body in measuring startle responses.

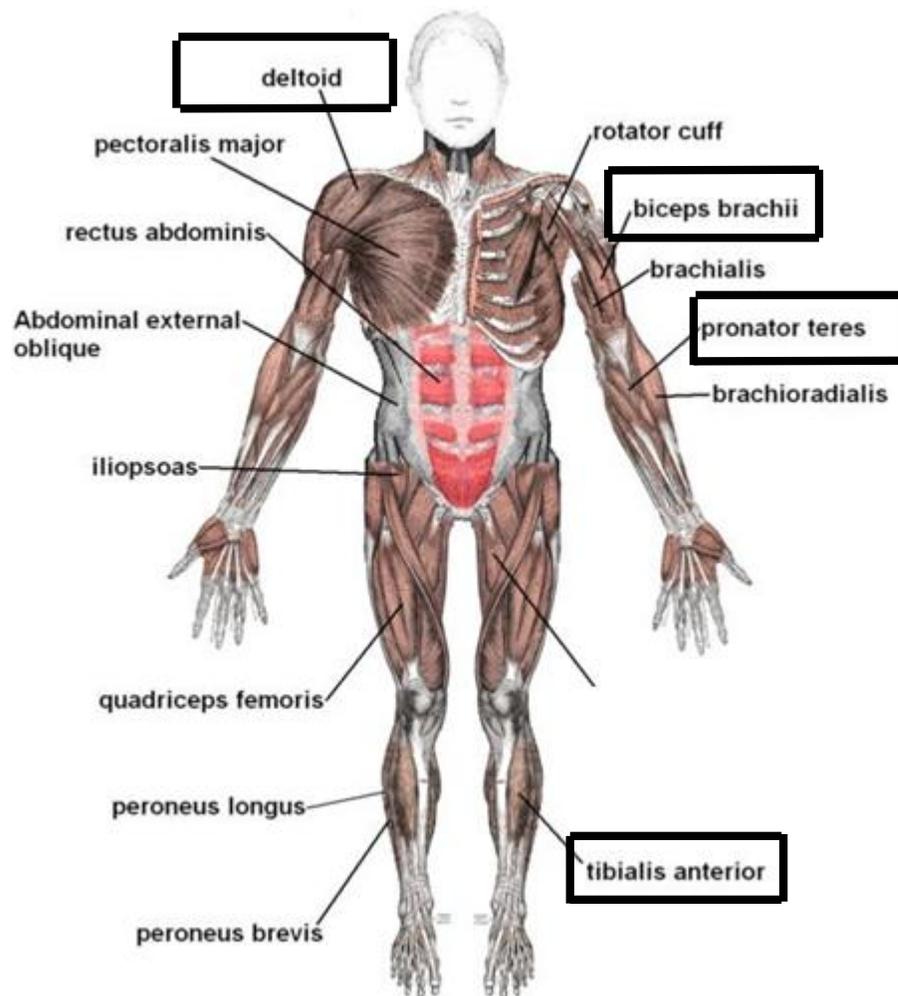


Figure 1. Deltoid, Biceps Brachii, Pronator Teres and Tibialis Anterior

(www.healthyflesh.com/tag/muscle/)

Figure 1. Shows the front view of human body with deltoid, biceps brachii, pronator teres and tibialis anterior highlighted in rectangle boxes,



Figure 2. Abductor Pollicis brevis (www.rad.washington.edu/)

Figure2. shows the Abductor Pelivis muscle and figure 3. shows the trapezius and soleus muscles.

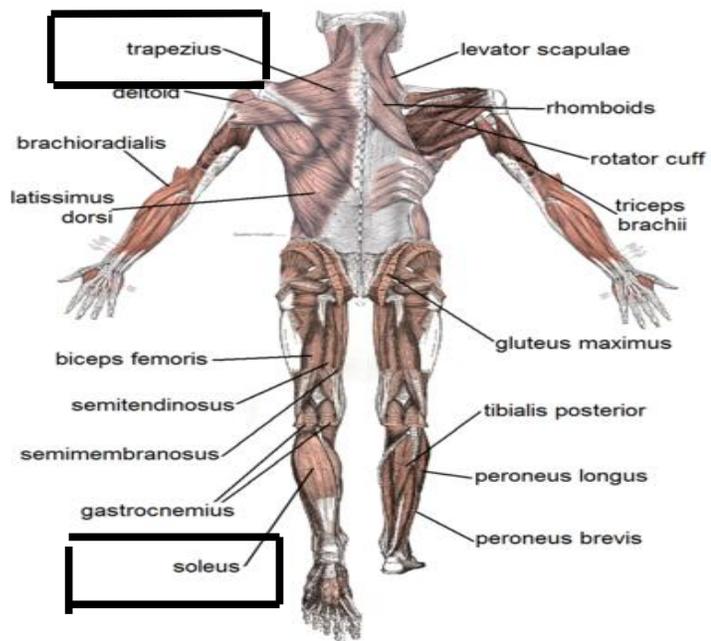


Figure 3. Trapezius and Soleus Muscle

(www.healthyflesh.com/tag/muscle/)

Dependent Variables to Measure Startle Responses

It is known that surface EMG was one of the techniques which were used to measure the startle responses. The most common dependent variable associated with the EMG activity to analyze the startle responses was the EMG amplitude (Kofler et al., 2001). To measure the maximum voluntary contraction (MVC) of muscles, RMS EMG amplitude was measured for 1-second epoch (Hodges, 2003). Furthermore, to study the effects of muscle pain, the MVC for each induced pain was analyzed again using RMS EMG amplitude. In another study to examine the startle response as a emotion or attention used RMS EMG amplitude to analyze its data (Bradley, Cuthbert & Lang, 1990). The studies related to measurement of muscle fatigue used RMS EMG amplitude to analyze it results. However, some studies also used mean amplitude. Once such study used mean amplitude of 50mV as a threshold and traces having background activity more than 50mV are considered as startle reflexes (Kofler et al., 2001). The dilemma arises between the selection of mean amplitude and RMS amplitude. Mean is an exact average of set of values. RMS is a statistical measure of the magnitude of a varying quantity and it is especially useful when variants are both positive and negative such as sinusoidal signals. The EMG signals which are going to be acquired in this study are also in positive and negative volts and these evidence lead to the usage of RMS EMG amplitude as a dependent variable in this study. Additionally, the muscle activity of any muscle was measured as a percentage of MVC due to the variation of muscle activity between participants.

CHAPTER 3

METHODOLOGY

Phase I

Procedures

Prior to testing the principal hypotheses of this experiment (phase II) it is necessary to find which muscle groups are active while driving (steering and applying the brake) in a stimulated vehicle. In this study, a muscle is considered active when there is a significant increase in the EMG activity during the muscle performing some action compared to the baseline EMG activity (i.e. muscle performing no action).

For this study, three male and female college students were selected from Montana State University with a minimum of three years driving experience in the United States. All participants signed a consent form approved by Montana State University Institutional Review Board (IRB) (see Appendix A and Appendix D). Prior to testing in the high fidelity driving simulator in the Western Transportation Institute, the participants went through a training session. In the training session, the participants were asked a series of questions on information regarding driving experience, eye sight, occupation, history of licensure status, previous experience in the driving simulator and history of migraine headaches, claustrophobia, motion sickness and vertigo (pre-screening questionnaires) (see Appendix B). If a participant answered yes to two or more questions in Appendix B, they were disqualified to participate for further study. The qualified participants were then acclimated to the high fidelity driving simulator. They were asked to drive through a series of three scenarios, each lasting for approximately

four to five minutes. At the completion of training, participants were asked the series of questions regarding symptoms like eye strain, temperature increase, dizziness, headache and nausea (post- screening questionnaires) (see Appendix C). The participants having high discomfort were again excluded from the further study. Kennedy & Frank, (1985) study was adopted for the post and pre-screening questionnaires.

Six participants (three male and female) who were qualified from pre and post screening questionnaires, as explained above, were then recruited for Phase I. This study involves the measurement of muscle activity using electromyography (EMG). EMG is a technique for evaluating and recording the activation signal of muscles. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. The EMG technique adapted in phase I began with the experimenter placing electrodes on the seven muscle fibers in the upper and lower extremities of participants. The upper extremity muscle fibers include the abductor pollicis brevis, trapezoid, deltoid, biceps brachii and pronator teres; the lower extremity muscle fibers include the tibialis anterior and soleus.

Placement of Electrodes

Standard electrode placement needs to follow certain criteria such as placing electrode 1) with reference to anthropometrical (see table 1) landmarks 2) with relation to the individual body dimensions and 3) on the muscle bulk parallel to the muscle fibers. With one exception the placements are defined by 1) the lead line connecting two anatomical landmarks and 2) the central lead point about which the bipolar lead electrodes are placed symmetrically on the lead line (Zipp, 1982).

Table 1. Anthropometrical Measures for the Placement of Electrode

No	Muscle	Posture	Lead line	Central lead point (CLP)
1	Abductor pollicis brevis	Sitting; forearm on a table; thumb and index finger extended forming a V	a. Vertex of the b. Basal joint of the index finger	A= distance between 'a' and 'b' CLP = A/2
2	Trapezoid	Sitting or standing: Head straight	c. Acromion d. Spine of the 7 th cervical vertebra	B = distance between 'c' and 'd'; CLP = B/2
3	Deltoid	Sitting or standing; arm limp	e. Acromion f. Suprasternal notch lead line : g. Subsidiary point h. Lateral epicondyle of the humerus	C = distance between 'e' and 'f' D = C/6 from 'e' towards 'f' E = distance between 'g' and 'h' CLP = E/6 from 'D' towards 'h'
4	Biceps brachii	Sitting or standing; Upper arm is vertical; Forearm is horizontal; palm upward	i. Acromion j. Tendon of the biceps muscle in the fossa	F = distance between 'i' and 'j' CLP = F/3 from 'j' towards 'i'
5	Pronator teres	Sitting; forearm on a table; elbow slightly turned inward; palm upward	k. Medial epicondyle of humerus l. Skin fold of the wrist	G = distance between 'k' and 'l' CLP = G/6 from 'k' towards 'l'
6	Tibialis anterior	Standing	m. Lower margin of the patella n. Lateral ankle	H= distance between 'm' and 'n' CLP = H/3 from 'm' towards 'n'
7	Soleus	Standing	o. Head of the fibula p. heel	I = distance between 'o' and 'p' CLP = I/3 from 'o' towards 'p'

Table 1. above explains the anthropometrical landmarks of the seven muscle groups. The distance between each point was measured using flexible tape and the course of tape measure represents the lead line.

Then the central lead point (CLP) for each muscle was calculated as per the formula in column (5) of Table 1. The electrode position (equidistant from the central lead point) was marked on the lead line. Figure 4. shows a schematic illustration of the placement of the electrode with respect to the anthropometrical measures for the muscle fiber tibialis anterior.

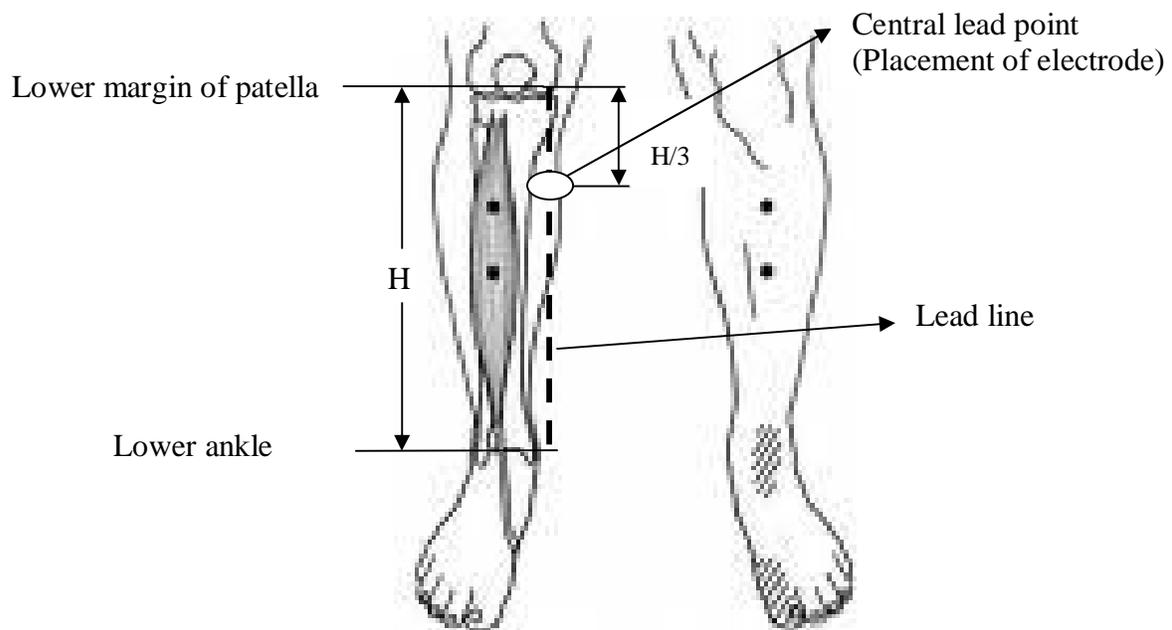


Figure 4. View of Electrode Placement on Tibialis Anterior Muscle Fiber

Skin Preparation, SX230 Surface Electrode and Ground Reference

Skin preparation is also very important before placing electrode since improper electrode placement leads to 1) small electrode contact area 2) low amplifier input impedance, 3) motion artifacts and 4) electrical interference. Skin preparation was done by scrubbing the central lead point with alcohol pads. Once the skin was prepared, bipolar stainless steel SX230 surface electrodes (Biometrics Ltd, VA, USA) were placed using a double sided tape with one end on the electrode and other end on the skin. Figure 5. shows the picture of a SX230 surface electrode with the supply + 4.50 to +5.0 Vdc single sided. It has a cable length of 1.25m with Lemo type (no. FGGOB304CLAD35) plug.



Figure 5. SX230
Surface Electrode



Figure 6. R206
Ground
Reference

There are high chances of electrical interference along with the signals collected from surface electrodes. In order to reduce this electrical interference, a R206 Ground reference plate (Biometrics Ltd, VA, USA) is placed over an inactive site of the human participant. Since this study has considered only the right section of the human

participant to measure muscle activity, the R206 Ground electrode was placed over the left hand elbow and tied with an adjustable elastic strap. Figure 6. above shows the picture of R206 Ground reference plate with cable length of 1.25m and Lemo type (no.FGGOB304CLAD35) plug.

Data Acquisition System

Once the skin preparations, placement of the surface electrode on CLP and ground reference plate are done, electromyographic (muscle) activity needs to be collected for data analysis. The data acquisition system which was used for data collection consists of 32 bit SCXI-1000 Data Acquisition Card (DAQ) (National Instruments, USA) and a portable laptop (Dell Latitude, USA) with Lab view 8.6 (National Instruments, Austin TX) software installed in it. The DAQ card is involved in the conversion of analog signals into digital signals and Labview is a visual programming language used to acquire digital signals from the DAQ card for signal processing.

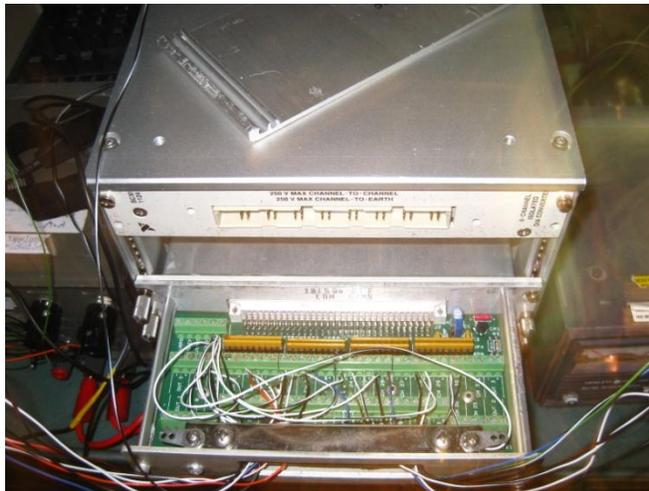


Figure 7. Picture of SCXI-1000 Data Acquisition Card

Figure 7. above shows the picture of DAQ card and Figure 8. below shows the schematic circuit diagram of the data acquisition system. The SX230 surface electrode has three output terminals such as positive (+), common ground (-) and output (0). The positive terminal (+) and common ground (-) were connected to the 5V battery which powers up the SX230 surface electrode. The output terminal (0) and common ground (-) were connected to the DAQ Card, which acquires the muscle activity in 'volts' from the

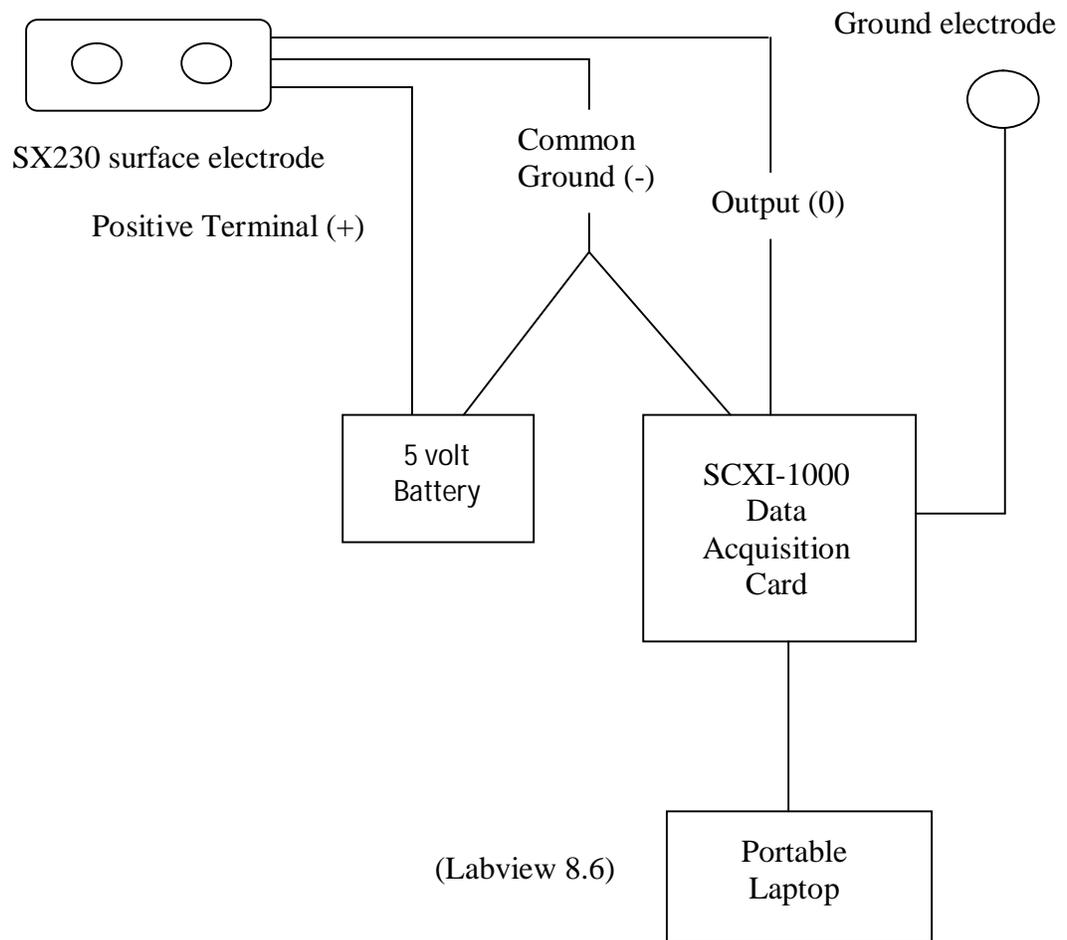


Figure 8. Schematic Circuit Diagram of Data Acquisition System

SX230 surface electrode and converts analog values into digital numeric values that can be manipulated by the computer. Then the portable laptop, installed with Labview, is connected to the DAQ Card to obtain digital numeric values for signal processing. The sampling rate of the DAQ card was set to 1000hertz (Hz).

Signal Processing

Signal processing is done in this phase I to remove the noise from the acquired signal. The frequency of surface EMG ranges from 10Hz to 400Hz. The signals obtained from frequencies less than 10Hz and greater than 400Hz are considered as noise. Also, signal obtained at 60Hz is taken as noise (Electronic noise for USA). To get a clear signal from the EMG, all the noise sources mentioned above was filtered. As the name implies, filters are used to filter out the unwanted frequency components from the signal, to enhance the wanted signal.

This study used a designed a Digital Butterworth filter for subtracting noise from surface electromyogram. The digital filter consists of a second order, high-pass filter with cutoff frequency 10 Hz (passes higher frequencies well but attenuates frequencies lower than the cutoff frequency), an eighth order low-pass filter with cutoff at 400 Hz (passes lower frequencies well but attenuates frequencies higher than the cutoff frequency), and second order six stop-band filters (attenuates the signals between two specific limits) centered at 60 Hz main noise and its harmonics until 360 Hz (Mello, Oliveira & Nadal., 2007). The whole filtering process is done in Labview 8.6 (see Appendix F for Labview code) and the data were set to store in the portable laptop.

Driving Scenario

The qualified participants are then equipped up with EMG setup (surface electrode, ground reference plate) on their right muscle fibers along with the DAQ system and were asked to drive in a DriveSafety™ 500C simulator running HyperDrive™ Simulation Authoring Suite software and Vection™ simulation software version 1.9.8. The simulator is comprised of a cut-down 1996 Saturn SL sedan cab with fully functional controls, five rear projection plasma displays arranged in a semicircle around the front of the cab providing a 150-degree field of view and rear-view mirror, five audio speakers, a simulator operator station, and associated computers. The experiment consists of two sessions of driving scenario with the following elements:

➤ Session 1 Scenario

- ~5- minute scenario
- Straight rural road
- ~ 3 miles
- Speed limit 55mph
- 0 slope
- No ambient traffic
- Daytime and clear weather conditions

➤ Session 2 Scenario

- ~5- minute scenario
- Curvy rural road with 3 left turns and 3 right turns
- 6 stop signs

- ~ 3 miles
- Speed limit 55mph
- 0 slope
- No ambient traffic
- Daytime and clear weather conditions

In both of the sessions, participants were asked to drive without removing their hands from the steering wheel and also they were asked to avoid unnecessary leg movement unless they use the brake to avoid capturing muscle activities other than steering and applying the brake. Session 1 provided the baseline EMG activity of the human participant while driving on a straight road without steering the wheel and applying the brake to the vehicle. Session 2 provided the EMG activity while steering the wheel (3 left turns and 3 right turns) and applying brake (6 stop signs).

Driving Response Dependent Variables

The dependent variables relating to driver performance were sampled at 60Hz which include steering angle and braking response. The steering angle was the rotation of steering wheel in degrees (-360 to + 360). Braking response was the normalized braking input value (0 -1.0).

EMG Dependent Variables

The dependent variables relating to EMG activity were sampled at 1000Hz. Three dependent variables are defined for further analysis

- Baseline upper extremity EMG activity (Ba_u -RMS) was defined as the RMS EMG amplitude on the muscle fibers of the upper extremity of the human participant while driving on a straight road without steering and applying the brake (measured in volts).
- Baseline lower extremity EMG activity (Ba_l -RMS) was defined as the RMS EMG amplitude on the muscle fibers of the lower extremity of the human participant while driving on a straight road without steering and applying the brake (measured in volts).
- Steering EMG activity (S_r -RMS) during was defined as the RMS EMG amplitude on the muscle fibers of the upper extremity of human participant while steering the driving wheel subtracted from Ba_u -RMS (measured in volts).
- Braking EMG activity (B_k -RMS) was defined as the RMS EMG amplitude on the muscle fibers of the lower extremity of the human participant while applying pressure to the brake pedal of the vehicle subtracted from Ba_l -RMS (measured in volts).

Time Synch between Physiology and Driving Simulator Recording

The EMG and driving simulator uses two different computers to collect their respective dependent variables. There is a high chance for the two computers to have variable computer times, which causes time disparity in data collection. In order to time synch the data collection, a Transmission Control Protocol (TCP) port was generated, using the driving simulator data collection computer as the host and the EMG data

collection computer as the server. TCP provides reliable, ordered delivery of a stream of bytes from a program on one computer to another program on another computer. The dependent variables from the driving simulator computer (host) were sent using Tcl code and received by the EMG data collection computer (server) using Labview code (see Appendix G) in real running time. The above data transfer provides the collection of data in one computer with time synchronized in real running time.

Statistical Analysis

The EMG activity variables were managed and analyzed using Minitab 15.1. The statistical analysis of the EMG activity was performed using paired t – test (one – sided) at an alpha level of 0.05. The (S_t -RMS) is compared with (Ba_u -RMS) and (B_k -RMS) is compared with the (Ba_l -RMS) of the human participant.

The RMS is calculated using the Equation 1:

$$x_{\text{rms}} = \sqrt{\frac{1}{n} \sum_{i=1}^n x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \dots + x_n^2}{n}}$$

Equation 1: Root-mean-square (RMS)

Where x = variable of interest, and n = number of observations

Phase II

Description of the Participants

For this study, twelve (six male and six female) college students were selected from Montana State University with a minimum of three years driving experience in the United States. All participants signed a consent form approved by Montana State University Institutional Review Board (IRB) (see Appendix E). Prior to testing in the high fidelity driving simulator in the Western Transportation Institute, the participants went through a training session which includes pre-screening questionnaires (see Appendix B), followed by familiarization with the driving simulator and then post-screening questionnaires (see Appendix C) as explained in the phase I. Twelve qualified participants who successfully completed the training session were recruited for further study.

Study Procedure

The primary aim of this study is to measure the startle/panic responses due to the issuance of warnings (auditory, haptic) and combined during the Roadway Lane Departure (RLDS). In this study, the participants are considered startled/panicked, when the percentage of MVC of the participants during their reaction towards issuance of the warnings such as auditory and haptic in the RLDS is significantly higher than the percentage of MVC of the participants during their natural attention in the RLDS.

Experimental design consists of a randomized block design, where the participant is the block, with four modality treatments per participant (auditory, haptic, auditory & haptic combination and no-warning). The experimental design is shown in Table 2:

Table 2. Experimental Design

Participant Number	Treatment order	
	Distraction 1	Distraction 2
1	Auditory, Haptic, Combo and No-warning	
2	Auditory, Combo, Haptic and No-warning	
3	Auditory, No-warning, Haptic and Combo	
4	Haptic, Auditory, Combo and No-warning	
5	Haptic, Combo, Auditory and No-warning	
6	Haptic, No-warning, Auditory and Combo	
7	Combo, Auditory, Haptic and No-warning	
8	Combo, Auditory, No-warning and haptic	
9	Combo, Haptic, No-warning and Auditory	
10	No-warning, Auditory, Haptic and Combo	
11	No-warning, Haptic, Auditory and Combo	
12	No-warning, Combo, Auditory and Haptic	

Testing was conducted on four separate days where participants drove a six minute scenario on each day. In each testing scenario, the participants experienced one modality of presentation in a randomly assigned order as shown in Table 2. In order to reduce the

biorhythms, all the participants were asked to follow the same time (± 1 hour), they came on the first day, for the next three different days of experimentation. Participants were given instructions to obey all traffic rules and drive as they normally would. The muscle fibers selected from phase I study are placed with EMG electrodes. The placement of electrodes and skin preparation procedures were followed as explained in phase I.

A distracter task was given to all participants at the same section of the roadway approximately three minutes into the scenario. The distracter task consists of seven letter index cards randomly chosen for each modality and placed behind the shoulder of the participants. A beep sound was provided after approximately three minutes driving in the road scenario. This beep sound will provide as an indication for the participant to turn to his right and memorize the letters on the index card. During this time a wind gust was generated from east to west or west to east by the experimenter to provide a forced lane departure in the centre or shoulder of the road. During the course of lane departure, the auditory or haptic or combination of auditory and haptic warning was provided to bring back the driver's attention. After receiving the warning and returning to steady state the participants were asked to report the letters aloud they remember while continuing to drive. The same distracter task was repeated after driving another three minutes (approximately) in the scenario and the same warnings was provided. During the complete experimental session, the participants were asked to avoid removing hands from the steering and applying braking. This is recommended to avoid the intrusion of muscle activities other than the muscle activities during the issuance of warnings. The whole experiment was video -taped using cannon SD1100 camera to see behavior of subjects.

Warning Algorithm

The 0th order Algorithm was used in this study, which is based on the lateral position of the vehicle. The algorithm makes no assumptions about the upcoming roadway geometry or vehicles dynamics (besides position). The 0th order algorithm equation for shoulder line crossing is given below:

If $d \geq 6$ inches, then warn driver

Where d = distance between the outside edge of the tire to the shoulder line marking.

The vehicle will give warning when the tire leaves six inches away from the shoulder line marking. The 6 inch is the mostly common used in transportation highway departments.

In case of centre-line warning the 0th order algorithm equation is given below:

If $d > 0$ inches, then warn driver

Where d = distance between the outer edge of the tire to the centre-line marking

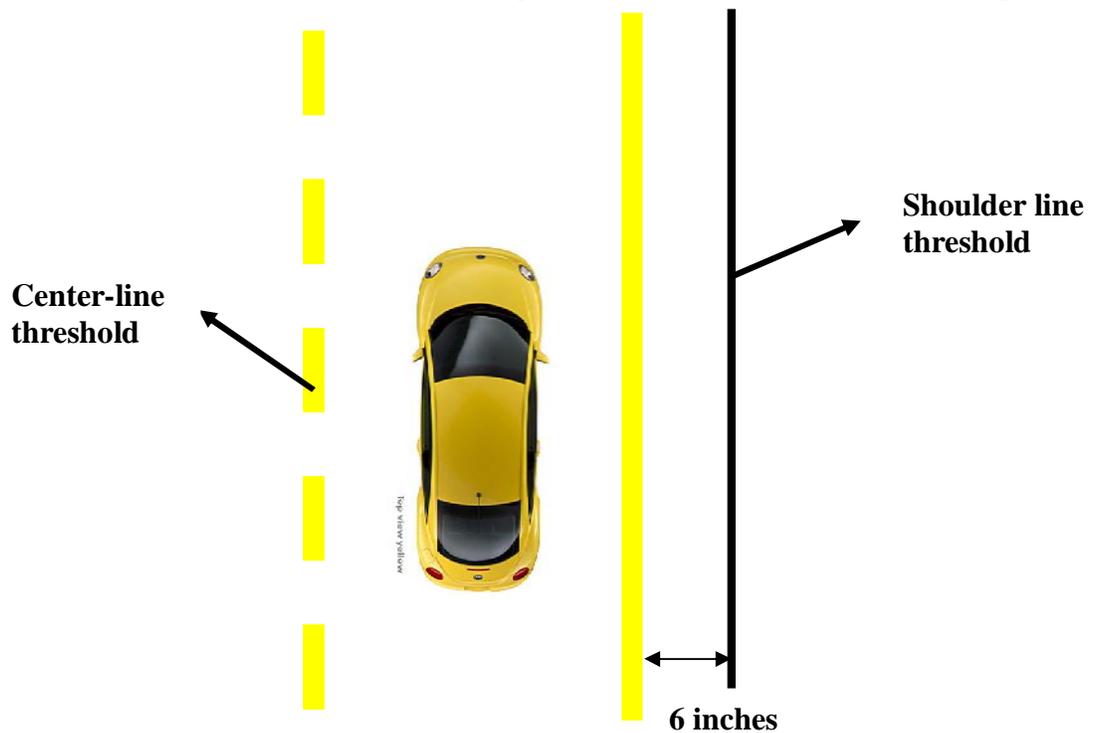


Figure 9. Warning Threshold Locations

The vehicle will give warning when the tire leaves zero inches away from the center-line marking. Figure 9 above shows the diagram of threshold locations (Stanley, 2006).

No-Warning Modality

In No-warning modality, the same distracter task as explained in study procedure was given and the participants were forced to go out of lane. In all other modalities, the participant's attention was brought back by various warnings. But in the case of no-warning modality, the participants were asked to turn back towards the road and drive, once they feel that, they memorized the letters on the index card. No-warning modality was presented to generate a natural attention of the participant after a distraction.

Haptic Seat and Auditory Sound

In order to generate seat vibration, the simulator was equipped and programmed with the IVIBE® Tactile Feedback Seating unit. The IVIBE® Tactile Feedback Seating Unit included a customized interface and was controlled by IVIBE's® IntelliVIBE® software. This software helps in setting the location of seat vibration and rumble seat power (0- 100%) for various speed levels. Figure 10 shows the picture of haptic seat attached in the driver's seat. The auditory signal was provided by the internal speakers using the prerecorded "rumble strip" sound for the line crossings.



Figure 10. Haptic Seat

Sound Level and Haptic-Intensity

Stanley, et al., (2007) study found that $\pm 1g$ of the haptic seat vibration energy is equivalent to approximately 45 decibels of sound from the auditory signal. Another study found that 68.6 decibel is the appropriate level of rumble strip sound warning for lane departure (Rossmeier, Grabsch & Doring, 2005). In the high fidelity driving simulator, the prerecorded rumble strip sound was set to 68.6 decibel and its corresponding haptic seat vibration was calculated as $\pm 1.52g$'s (44.43% of rumble seat power).

Table 3. Sound level and Haptic Intensity

Warnings	Sound Level	Haptic Intensity
Auditory	68.6 decibel	-
Haptic	-	1.33g's
Auditory & Haptic	68.6 decibel	1.52 g's

Also when the participant was driving at 55mph speed, the sound level was measured as 60 decibel and its corresponding haptic seat vibration was calculated as 1.33g's (38.96% of rumble seat power). The Table 3 shows the sound and haptic for various warnings.

Driving Scenario

The Phase II study experiment consisting of four sessions has the same driving scenario with the following elements:

- Session 1 Scenario
 - ~5- minute scenario
 - Straight rural road
 - ~ 3 miles
 - Speed limit 55mph
 - 2 distracter task
 - 0 slope
 - No ambient traffic
 - Daytime and clear weather conditions

EMG Equipment and Signal Processing

The Phase II EMG setup was also done using SX230 surface electrodes, SCXI 1000 DAQ card and portable as explained in phase I. The signal processing was again done using Labview 8.6 with the Digital Butterworth filters used in phase I experiments. Figure 11 shows the experimental setup with EMG equipments and driving simulator.



Figure 11. The Experimental Setup

Again, time synchronisation between physiology and driving simulator recording was used as explained in phase I.

Maximum Voluntary Contraction (MVC)

Muscle strength of each participant might vary from person to person and between male and female. The main dependent variable, RMS EMG amplitude measured from the human participants may produce variable data between each subject because of varying muscle strength. In order to reduce this error, the MVC of each subject was calculated and RMS EMG amplitude was converted into percentage of the MVC (% of MVC).

Driver Response Dependent Variables

The dependent variables relating to driver performance were sampled at 60Hz. These include; reaction time and return to steady state. Reaction time was defined at the point where the change in steering response was 0.3 degrees or more continuously for three samples after the issuance warnings. Time to return to lane was defined at the point where the steering response was decreased to less than five degrees after driver reaction to warning in the positive or negative direction (Lee, McGehee, Brown & Reyes, 2002). The steering response was the rotation of steering wheel in degrees (-360 to + 360). The number of incorrect steering reversals included when participant responded to the warning by turning in the incorrect direction.

EMG Dependent Variables

The dependent variables relating to EMG activity were sampled at 1000Hz. Two dependent variables are defined for further analyses were (1) EMG (mV) at MVC was defined as the RMS EMG amplitude at 1-sec epoch from the peak amplitude during MVC. (2) The % of MVC was defined as the RMS EMG amplitude generated between reaction time and time to return to lane converted as a percentage of MVC.

First Warning Event

The First Warning event was defined as the MVC observed during the first warning event i.e., the warning received by the 12 participants in their first driving scenario. This was measured to find the response of participant when they are exposed for the first time warning since there is a relative chance of participant expectancy for

some kind of warning in their next driving scenarios. The expectancy could well affect the chances of startle responses.

Experimental Design and Statistical Analysis

The EMG activity variables were managed and analyzed using Minitab 15.1. The statistical analysis of the driver performance variables that followed parametric data assumptions (i.e. normally distributed, equal variances, interval level of measurement) was performed using GeneralLinear Model (GLM) analysis of variance. The outliers are kept for analysis and only removed if it does not follow the parametric assumptions. In EMG (mV) at MVC analysis, participants were considered as a random factor and muscle fibers, genders were considered as fixed factors. In the % of MVC analysis, participants were nested with gender and considered as random factor. Modality of warning and gender were considered as fixed factors. The post-hoc test was conducted using Tukey's HSD test to find the difference among the factors which showed significant difference.

The parametric model for % of MVC is

$$Y_{ijk} = \mu + \tau_i + \beta_{j(i)} + \lambda_k + (\tau\lambda)_{ik} + E_{ijkl}$$

Where:

μ = mean

τ_i = i^{th} effect of Gender $i = 1, 2$

$\beta_{j(i)}$ = j^{th} effect of participant nested with gender $j = 1, 2, 3, 4, 5, 6$

λ_k = k^{th} effect of modality of warning; $j = 1, 2, 3, 4$

$(\tau\lambda)_{ik}$ = interaction between gender and modality of warning.

E_{ijk} = Residual error.

CHAPTER 4

RESULTS

Phase I ResultsParticipant Results

The mean age of the six participants (three males and three females) were 27.5 ± 2.51 years (maximum = 32 years of age and minimum = 25 years of age). Two participants were excluded from the study due to high discomfort during familiarization with the driving simulator.

Abductor Pollicis brevis Muscle Fiber Results

Table 4 shows the mean RMS EMG amplitude in millivolts (mV) for the muscle fiber Abductor pollicis brevis. Due to the experiment interface issues, EMG could not be recorded for 2 of the subjects in this portion of experiment. These subjects were excluded from analysis for the abductor pollicis brevis muscle only. Table 4 reveals that the Ba_q -RMS was higher than the S_t -RMS for all participants. There is no significant increase in the S_t -RMS compared to the Ba_q -RMS, $p = 0.999$, T – value = -9.25. Figure 12 shows the box plot for the RMS differences in the driving activity of Abductor pollicis brevis muscle fiber, which also reveals that RMS differences are always less than zero (H_0).

Table 4. RMS EMG amplitude of Abductor Pollicis brevis (in millivolts)

Driving Activity	Participant 1	Participant 3	Participant 5	Participant 6
S_t – RMS	3.308	10.506	0.237	14.446
Ba_u – RMS	41.897	45.463	47.122	42.084

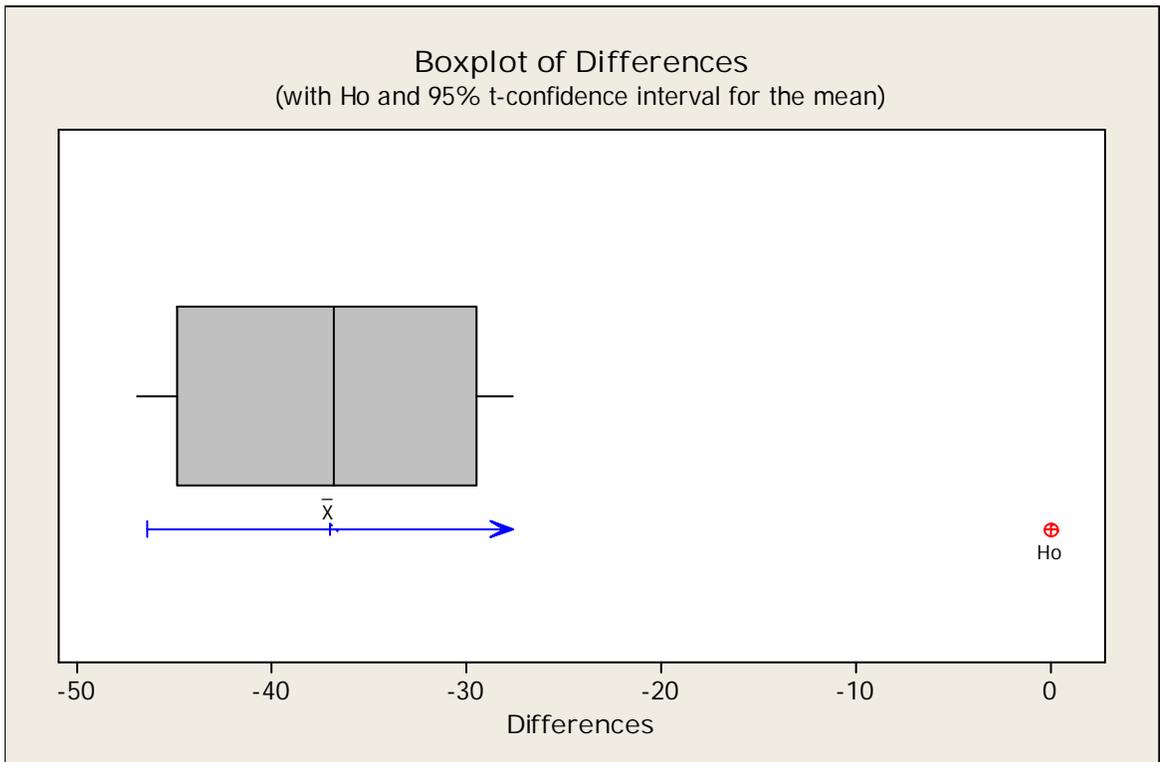


Figure 12. Box plot of RMS differences of Abductor Pollicis brevis

Trapezoid Muscle Fiber Results

Table 5 shows the mean RMS EMG amplitude in mV for the muscle fiber trapezoid.

Table 5. RMS EMG amplitude of Trapezoid (in millivolts)

Driving activity	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
S_t – RMS	12.443	8.745	4.371	5.284	6.023	2.125
Ba_u – RMS	1.694	9.364	2.737	3.290	0.267	1.758

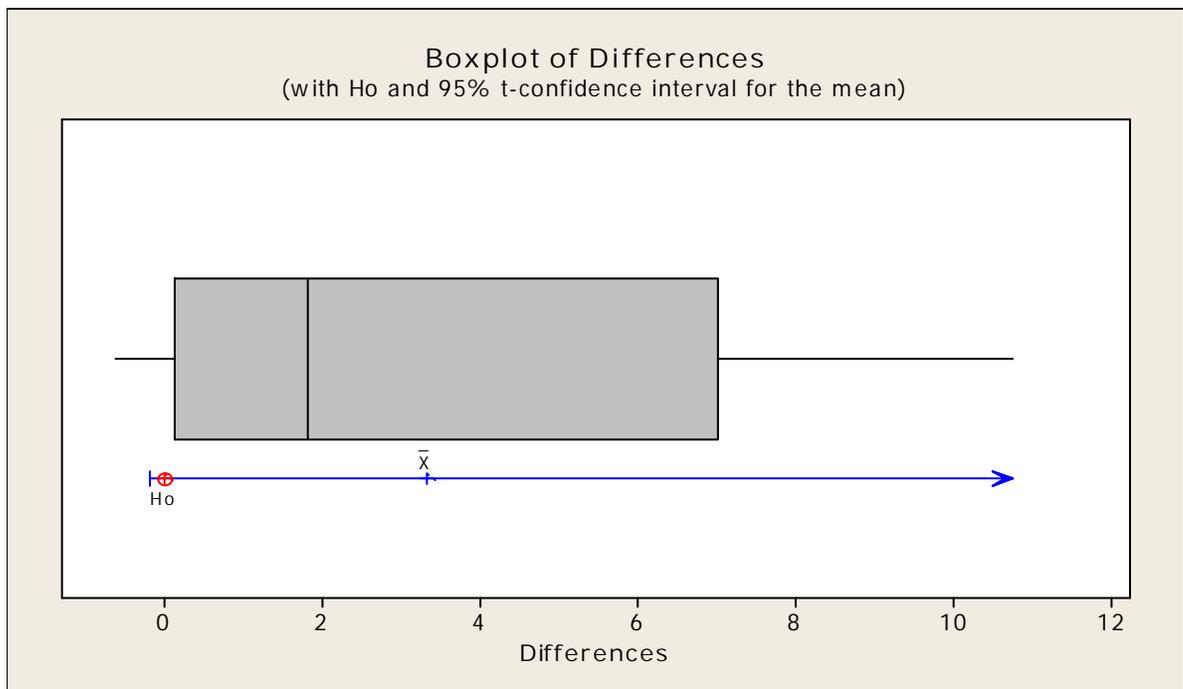


Figure 13. Box plot of RMS differences of Trapezoid Muscle

Table 5 data shows that the mean S_t -RMS is higher than the mean Ba_u -RMS except for the participant 2. Even though, the S_t -RMS is higher, difference between S_t -RMS and Ba_u -RMS is not too large. This is confirmed from paired t – test result, which reveals that there is no significant increase in the S_t -RMS compared to the Ba_u -RMS, $p = 0.057$, T – value = 1.91. Figure 13 shows the box plot for the RMS differences in the driving activity of the trapezoid muscle fiber, which also indicates that RMS differences are close to zero (H_0).

Deltoid Muscle Fiber Results

Table 6 shows the mean RMS EMG amplitude in mV for the muscle fiber deltoid. The data indicates that the mean S_t -RMS is invariably higher than the mean Ba_u -RMS by huge margin. The paired t – test also confirms that there is a significant increase in the S_t -RMS compared to the Ba_u -RMS, $P = 0.010$, T – value = 3.34.

Table 6 RMS EMG amplitude of Deltoid Muscle (in millivolts)

Driving activity	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
S_t – RMS	42.041	67.409	29.304	44.858	61.813	18.810
Ba_u – RMS	2.087	16.123	22.602	32.802	9.288	7.377

Figure 14 also suggests that the RMS differences in driving activity of deltoid muscle fiber is higher zero (H_0) by huge margin.

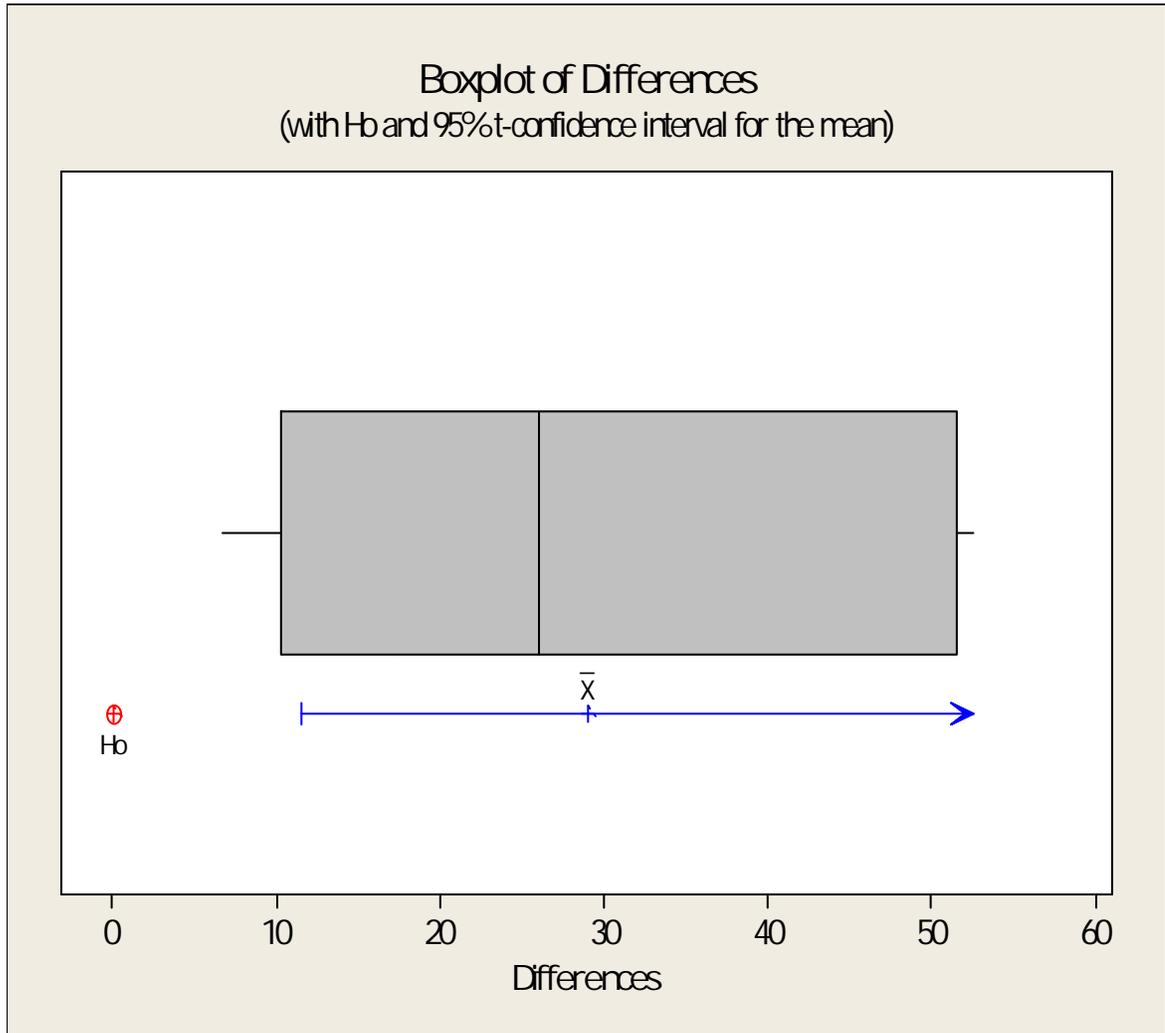


Figure 14. Box plot of RMS differences of Deltoid Muscle

Biceps Brachii Muscle Fiber Results

Table 7 shows the mean RMS EMG amplitude in mV for the muscle fiber Biceps Brachii. The data indicates that the mean S_t -RMS is consistently greater than the mean Ba_u -RMS for all participants.

Table 7. RMS EMG amplitude of Biceps Brachii (milli volts):

Driving Activity	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
S_t – RMS	3.907	12.764	9.945	5.937	5.629	10.315
Ba_u – RMS	1.542	2.962	1.961	2.265	1.220	1.662

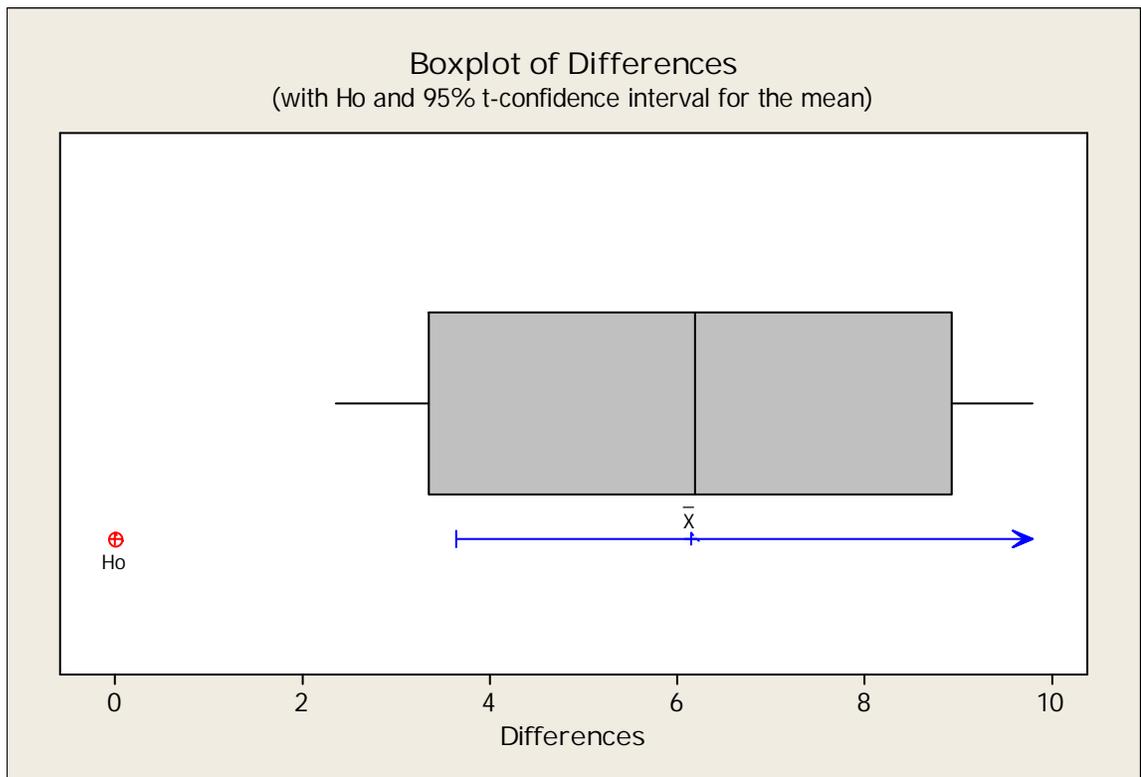


Figure 15. Box plot of RMS differences of Biceps Brachii

The mean difference between the RMS driving activities was 6.15 ± 3.05 mV. Paired t – test also suggest that, there is a significant increase in the S_t -RMS compared to the Ba_u -

RMS, $p = 0.002$, $T - \text{value} = 4.94$. Figure 15 above shows the differences in RMS of biceps brachii muscle which also reveals that RMS differences in the driving activities are always higher than zero (H_0).

Pronator Teres Muscle Fiber Results

Table 8 shows the mean RMS EMG amplitude in mV for the muscle fiber Pronator Teres. This data also indicates that the mean S_t -RMS is constantly greater than the mean Ba_u -RMS for all the participants.

Table 8. RMS EMG amplitude of Pronator Teres_(milli volts)

Driving Activity	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
$S_t - \text{RMS}$	14.555	19.069	18.762	9.635	6.104	18.110
$Ba_u - \text{RMS}$	7.490	14.772	10.118	5.601	5.725	2.412

The mean difference between RMS driving activities was 6.69 ± 5.25 mV. Paired $t - \text{test}$ also suggest that there is a significant increase in the mean S_t -RMS compared to the mean Ba_u -RMS, $p = 0.013$, $T - \text{value} = 3.12$. Figure 16 below shows the differences in the RMS of pronator teres, which also reveals that the RMS differences in driving activities are always higher than zero (H_0).

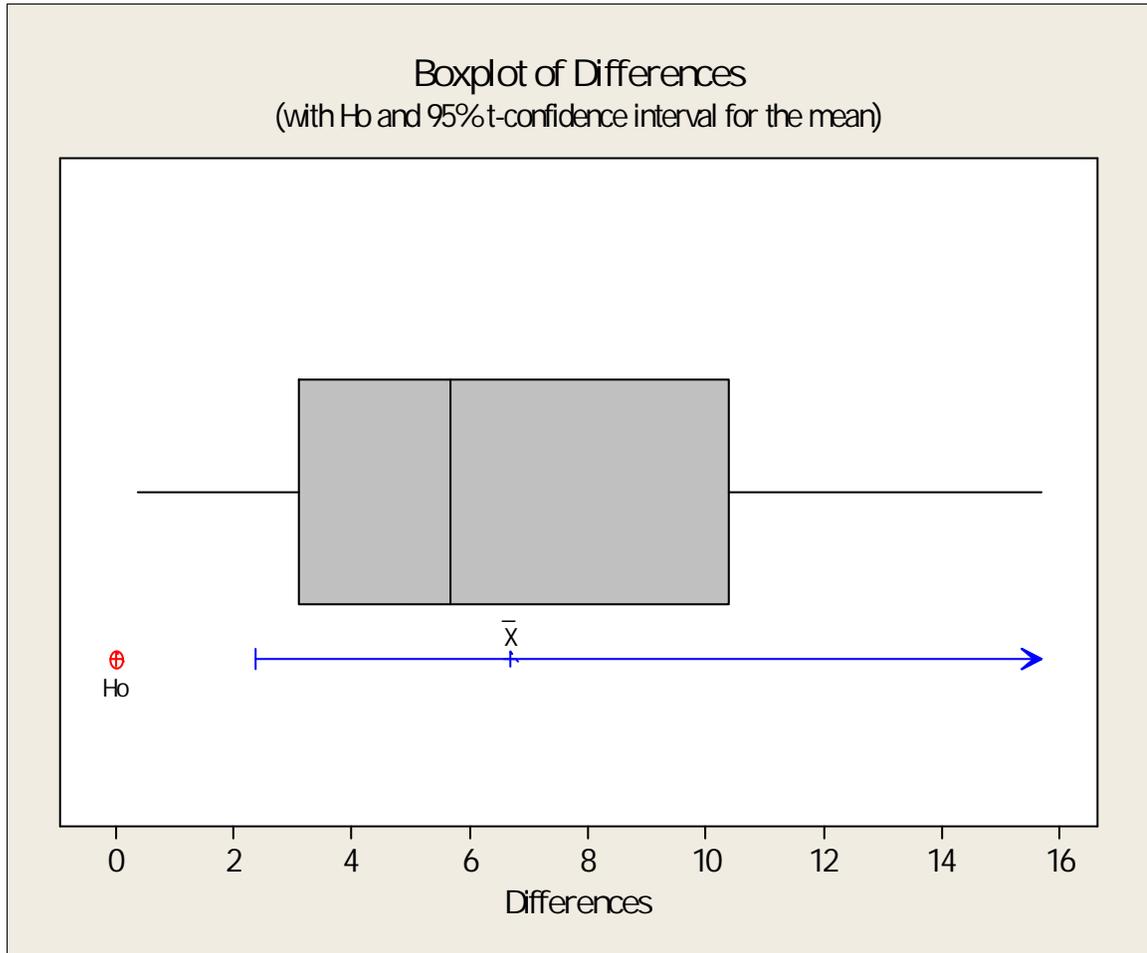


Figure 16. Box plot of RMS differences of Pronator teres

Tibialis Anterior Muscle Fiber Results

Table 9 shows the mean RMS EMG amplitude in mV for the muscle fiber Tibialis anterior. This data also indicates that the mean B_k -RMS is invariably greater than the mean B_{a1} -RMS for all the participants. Paired t – test also suggest that there is a significant increase in the mean B_k -RMS compared to the mean B_{a1} -RMS, $p = 0.014$, T – value = 3.06.

Table 9. RMS EMG amplitude of Tibialis Anterior (milli volts)

Driving Activity	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
$B_k - \text{RMS}$	82.605	56.545	31.813	17.349	94.840	19.311
$B_{a1} - \text{RMS}$	4.459	7.883	2.024	3.163	9.156	18.626



Figure 17. Box plot of RMS differences of Tibialis Anterior

Figure 17 above shows the differences in the RMS of tibialis anterior, which also reveals that the RMS differences in driving activities are always higher than zero (H_0).

Soleus Muscle Fiber Results

Table 10 below shows the mean RMS EMG amplitude in mV for the muscle fiber Soleus. The data indicates that the mean B_k -RMS is not always higher than the mean B_{a1} -RMS for all the participants. The participant 3 and 4 has the mean B_k -RMS less than the mean B_{a1} -RMS. Even though B_k -RMS is higher for all other participants, difference between them is not too large.

Table 10. RMS EMG amplitude of Soleus (milli volts)

Driving activity	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
B_k – RMS	1.552	1.918	1.792	0.441	1.718	0.737
B_{a1} – RMS	1.207	1.159	4.605	1.622	1.226	5.904

The paired t – test also suggest that, there is no significant increase in the mean B_k -RMS compared to the mean B_{a1} -RMS, $p = 0.878$, T – value = -1.32. Figure 18 below shows the differences in the RMS of soleus muscle fiber, which also reveals that the RMS differences in driving activities are less than zero (H_0).

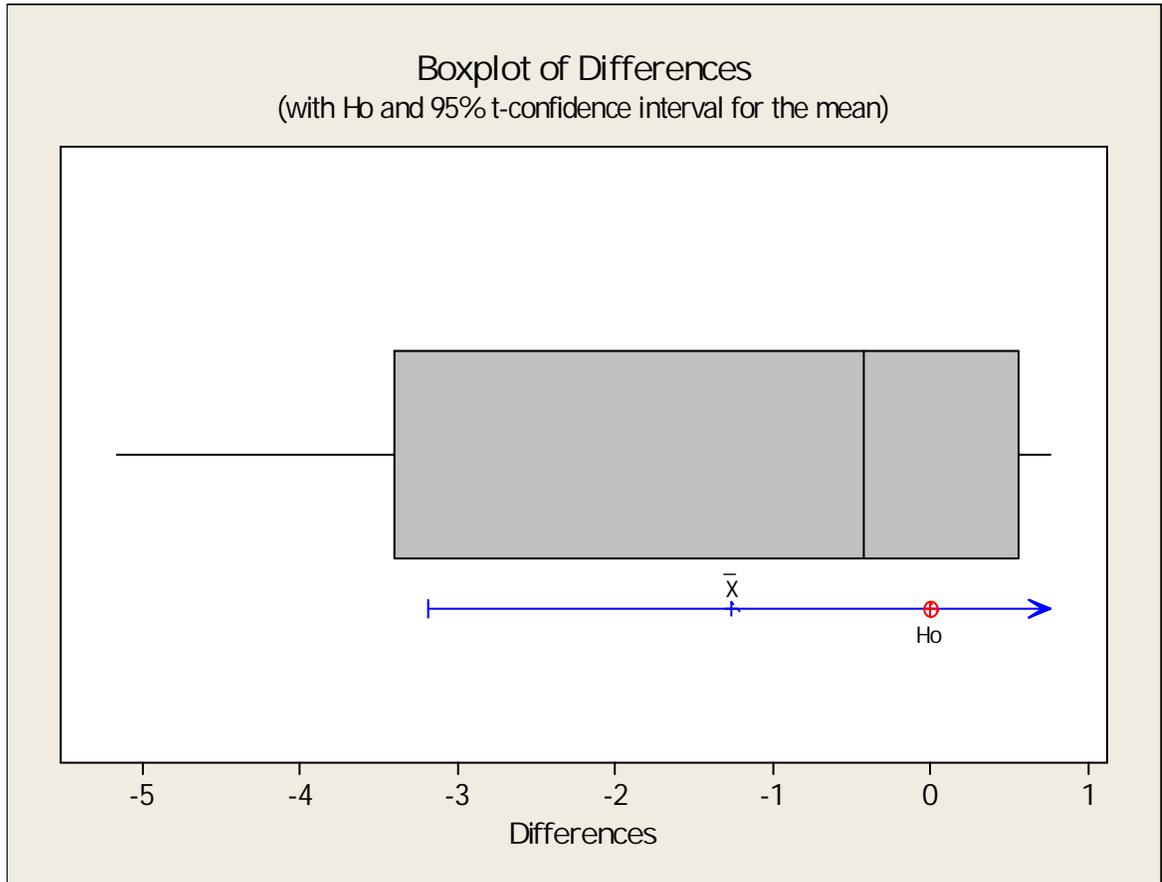


Figure 18. Box plot of RMS differences of Soleus Muscle

Figure 19 shows an example of graphical representation of the muscle activity (in mV) for the participant 4 starting with Abductor pollicis brevis in the top followed by Trapezoid, Deltoid, Biceps Brachii, and Pronator Teres during the steering activity. All upper extremity muscles are time synchronized with respect to the steering activity. The first graph from the bottom of figure 18 shows the steering activities (-360° to 360°) corresponding to the three left and three right turns

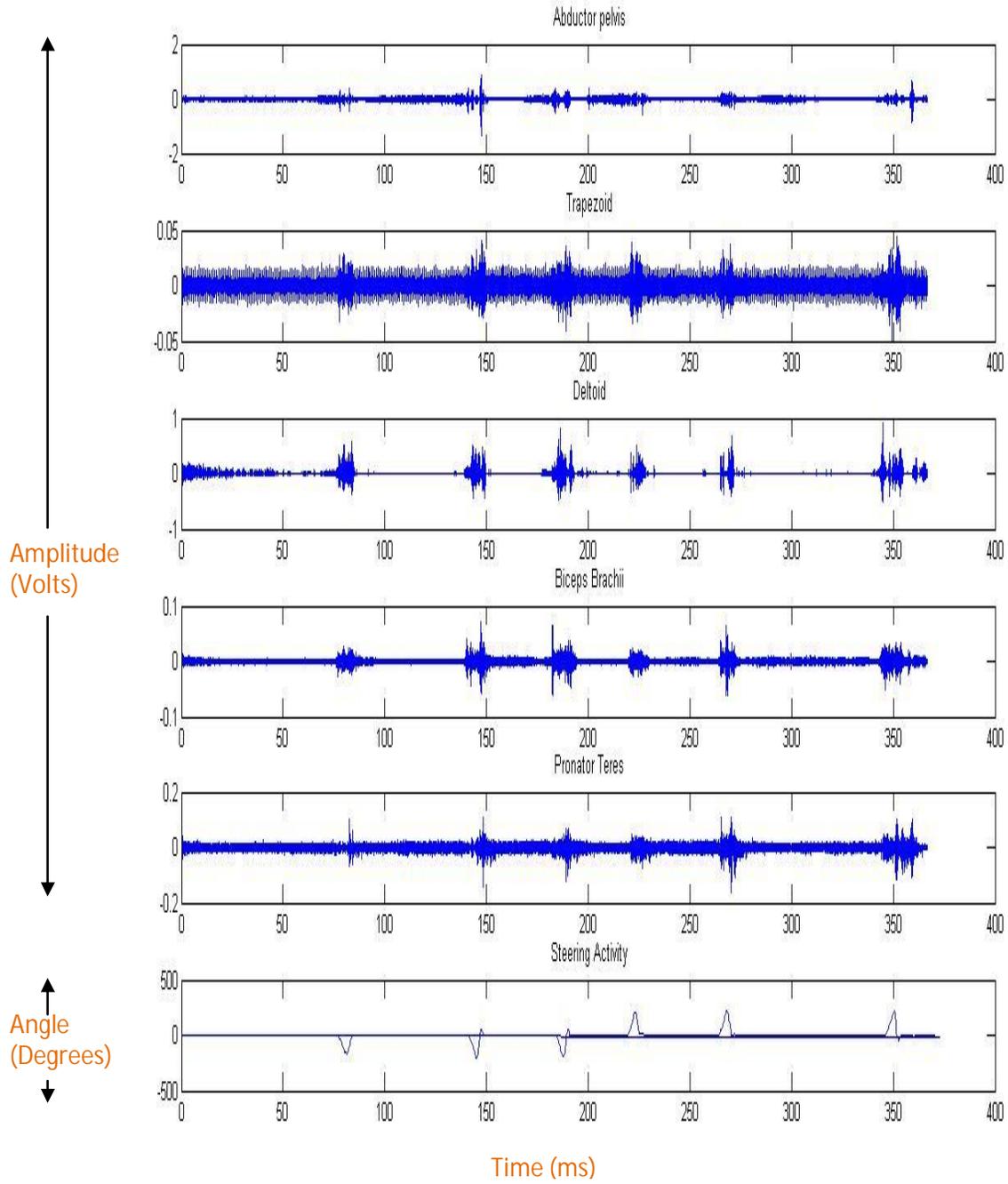


Figure 19. Example Muscle Activity with respect to Steering for a Subject

Figure 20 also shows an example of graphical representation of muscle activity (in mV) for the same participant 4 for the Tibialis anterior and soleus muscles during application of brake. Both the lower extremity muscles are time synchronized with respect to the braking activity. The first graph from the bottom of figure 20 shows the braking activities corresponding to the six stop signs.

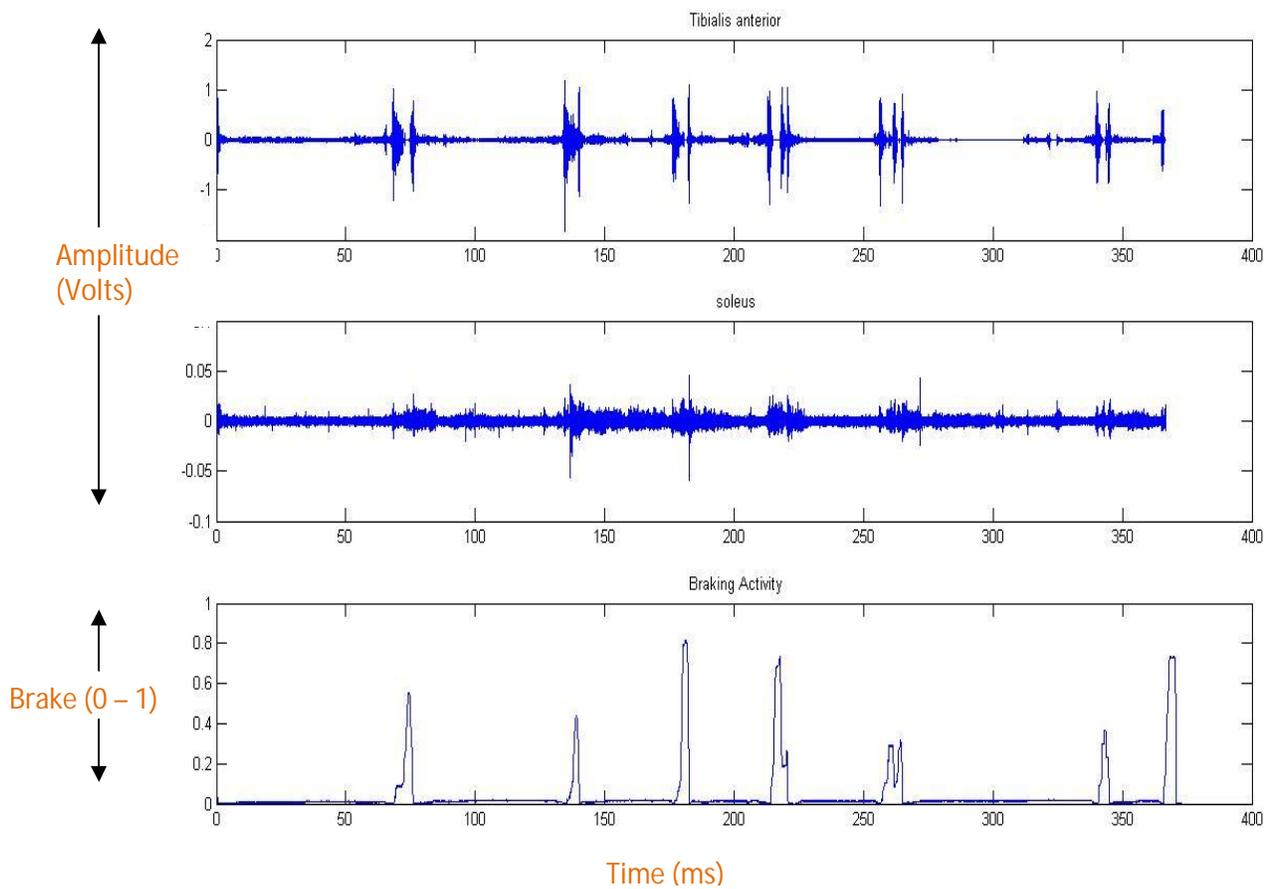


Figure 20. Example Muscle Activity with respect to Braking for a Subject

Figure 21 shows an example of graphical representation the muscle activity (in mV) of all muscles in the normal driving without any driving activities like steering or applying brake to the vehicle. Figure 21 reveals that the Abductor pollicis brevis and Tibialis anterior has little muscle activity since the participant uses Abductor pollicis brevis and Tibialis anterior muscles for holding the steering and accelerating the vehicle respectively.

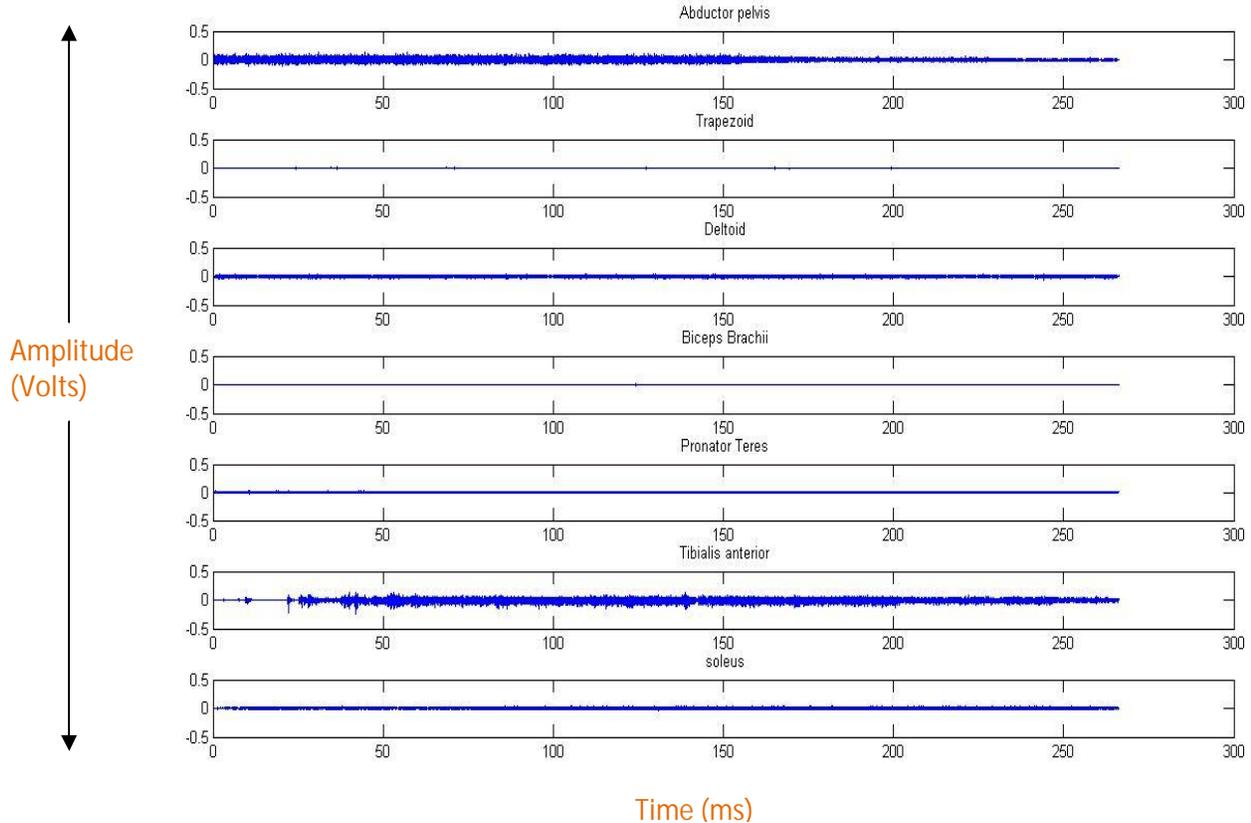


Figure 21. Example Muscle Activity without Driving activity (steering or braking) for a Subject

Phase II Results

Participant Results

Twelve drivers (six male and six female) participated in phase II study. All participants completed the study with no reports of moderate or severe simulator induced discomfort. The mean standard deviation age of the twelve participants was 25.25 ± 4.20 years; the mean driving experience was 8.79 ± 4.19 years; and miles driven per year were 7000 ± 4039.58 miles.

Power Level Analysis

MiniTab's 15.1 power and sample size calculator was utilized to determine the power level of the experiment with respect to the sample size used in the phase II of the study. Variables used in the calculation included the maximum difference between factor level means and standard deviation

Table 11. Power Level Calculation

Alpha = 0.05					
Number of Levels = 4					
Sample			Maximum		
Std Dev	SS Means	Size	Power	Difference	
2.429	8.44	12	0.929	4.109	
1.345	0.217	12	0.140	0.66	
2.145	3.618	12	0.69	2.69	
1.542	0.266	12	0.132	0.73	

The standard deviation for performing subsequent ANOVA analysis was the square root of the mean square error (MS error). Using Minitab’s power and sample size calculator, provided the maximum factor level means differences and sample size the power level was found to be 0.279. Table 11. above shows the power level calculations.

EMG Millivolt (mV) at Maximum Voluntary Contraction (MVC) results

The maximum EMG (mV) at MVC was observed in biceps brachii muscle with the mean of 439 mV and minimum EMG (mV) at MVC was observed in tibialis anterior muscle with the mean of 106.031mV. Figure 22 shows the box plot of EMG (mV) at MVC for all the muscle fibers. The greater variability in EMG (mV) at MVC was observed in biceps brachii muscle ± 212.524 mV.

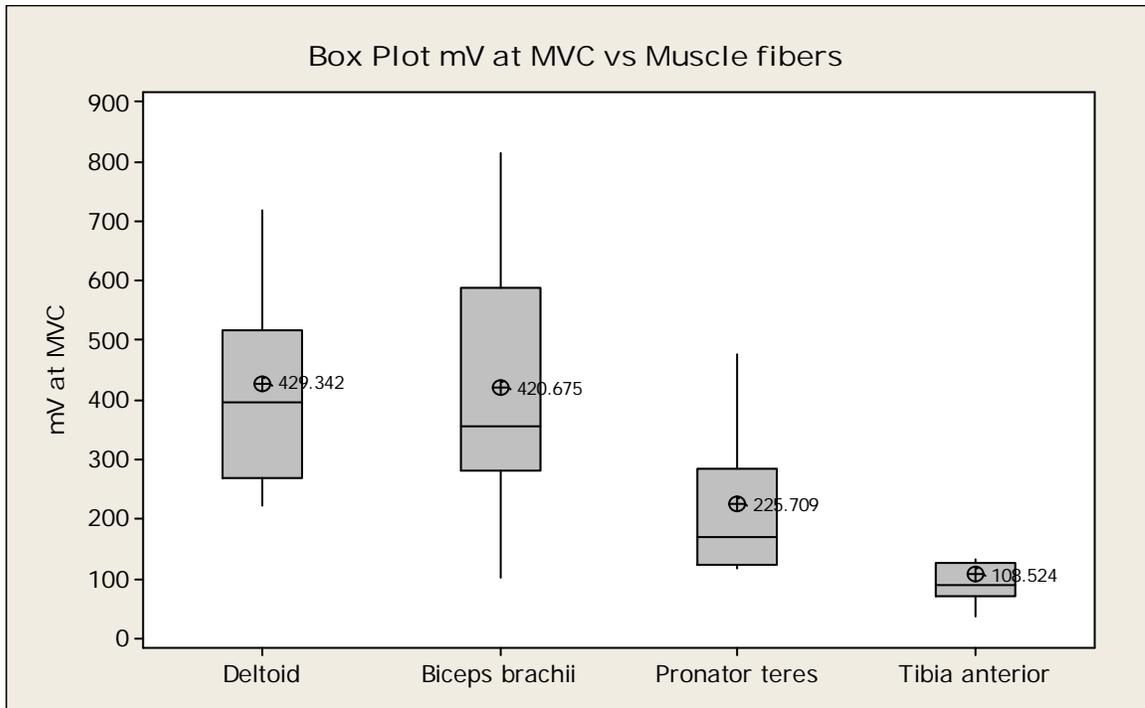


Figure 22. Box plot of EMG (mV) at MVC

Significant differences were found between EMG (mV) at MVC for the muscle fiber factor, $F_{3, 39} = 20.12$, $p < 0.001$ and also significant differences were found between EMG (mV) at MVC for the gender factor $F_{1, 39} = 6.74$, $p = 0.013$. However, there is no interaction between the muscle fibers and gender $F_{3, 39} = 0.95$, $p = 0.424$. Tukey's HSD test among muscle fibers determined that deltoid muscle fiber has greater EMG (mV) at MVC than the pronator teres ($p = 0.0036$) and tibia anterior muscle fiber ($p = 0.000$). Also, Biceps brachii has more EMG (mV) at MVC than the pronator teres ($p = 0.0003$) and tibia anterior muscle fiber ($p = 0.000$). Tukey's HSD test also suggest that EMG (mV) of MVC of males is higher than EMG (mV) at MVC of females ($P = 0.0151$). Table 12 has been provided to summarize the ANOVA procedure.

Table 12. ANOVA for EMG (mV) at MVC.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle fibers	3	1033423	1051562	350521	20.12	0.000
Gender	1	95601	117410	117410	6.74	0.013
Gender*Muscle fibers	3	49874	49874	16625	0.95	0.424
Error	39	679431	679431	17421		
Total	46	1858329				

Figure 23. shows the plot of main effects plot, which demonstrates that the mean EMG (mV) at MVC for deltoid and biceps brachii muscles are greater than that of the pronator teres and tibialis anterior muscles. The plot also shows that the mean EMG (mV) at MVC is greater for males as compared to female participants.

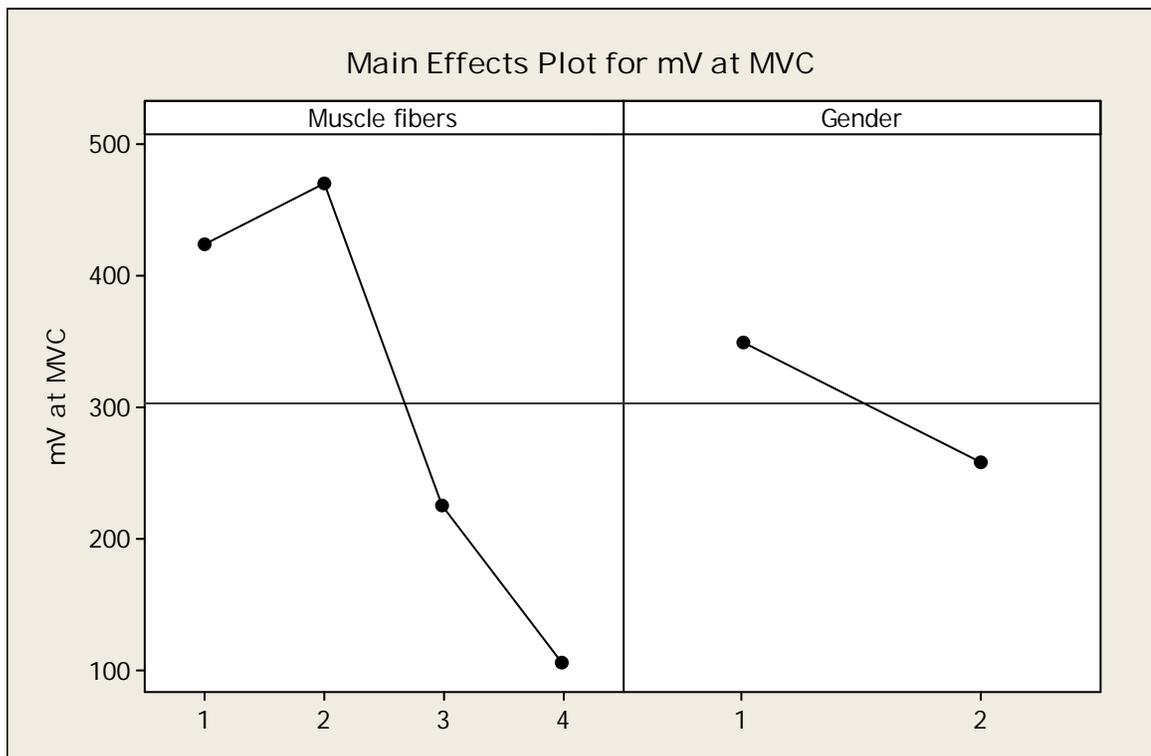


Figure 23. Main Effects Plot for EMG (mV) at MVC

Where Muscle fibers, 1= Deltoid, 2 = Biceps brachii, 3 = Pronator teres and 4 = Tibialis anterior

Gender, 1 = Male, 2 = Female

Reaction Time Results

The mean reaction time for the auditory warning was 736.646ms, mean reaction time for the haptic warning was 953.938ms and mean reaction time for combo warning was 782.9ms. Figure 24 is a box plot of reaction time for each modality of warning. The

slowest reaction time was for the haptic warning at 953.98ms and the fastest reaction time was the auditory warning at 736.646ms.

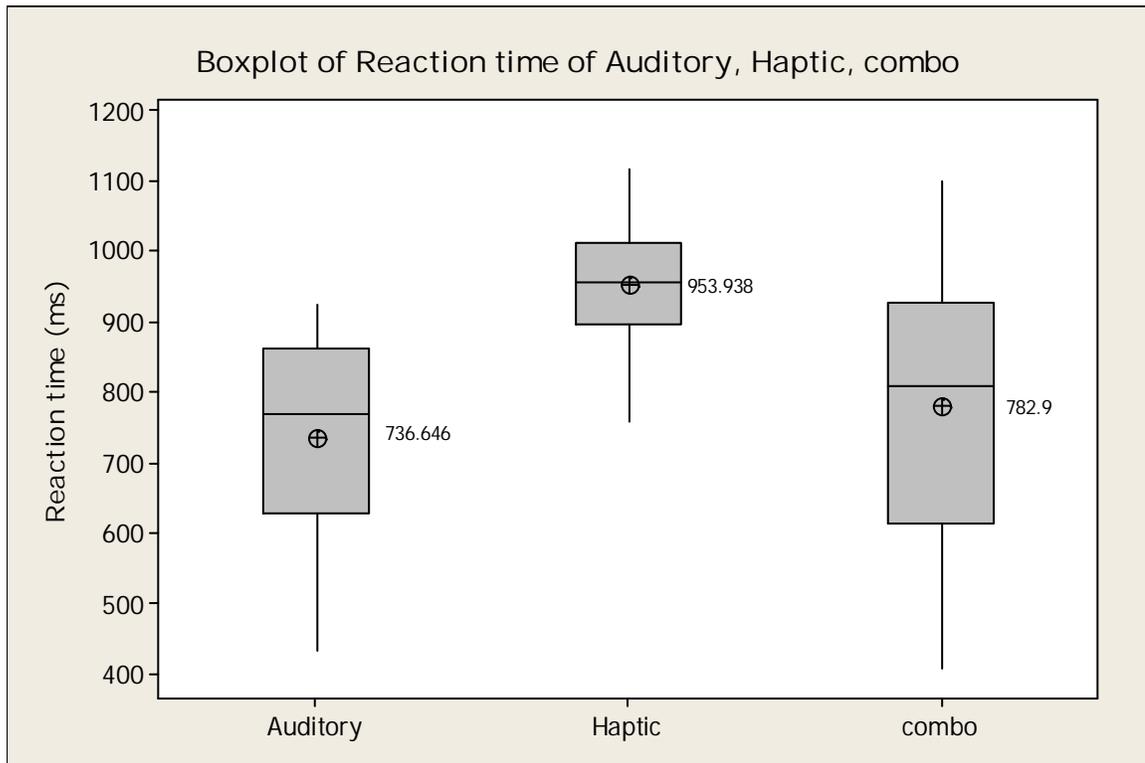


Figure 24. Box plot of % of Reaction Time

Table 13. has been provided to summarize the ANOVA procedure. Significant differences were found in reaction time between modality of warning factor $F_{2, 22} = 6.00$, $p = 0.008$. Tukey's HSD test reveals that auditory warning has faster reaction time than the haptic warning $p = 0.009$ and combo warning has faster reaction time than the haptic warning $p = 0.042$. However, there is no significant difference in reaction time between auditory and combo warning $p = 0.7659$.

Table 13. ANOVA of Reaction Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Modality of Warning	2	314436	314436	157218	6.00	0.008
PARTICIPANT	11	158277	158277	14389	0.55	0.848
ERROR	22	576178	576178	26190		
Total	35	1048892				

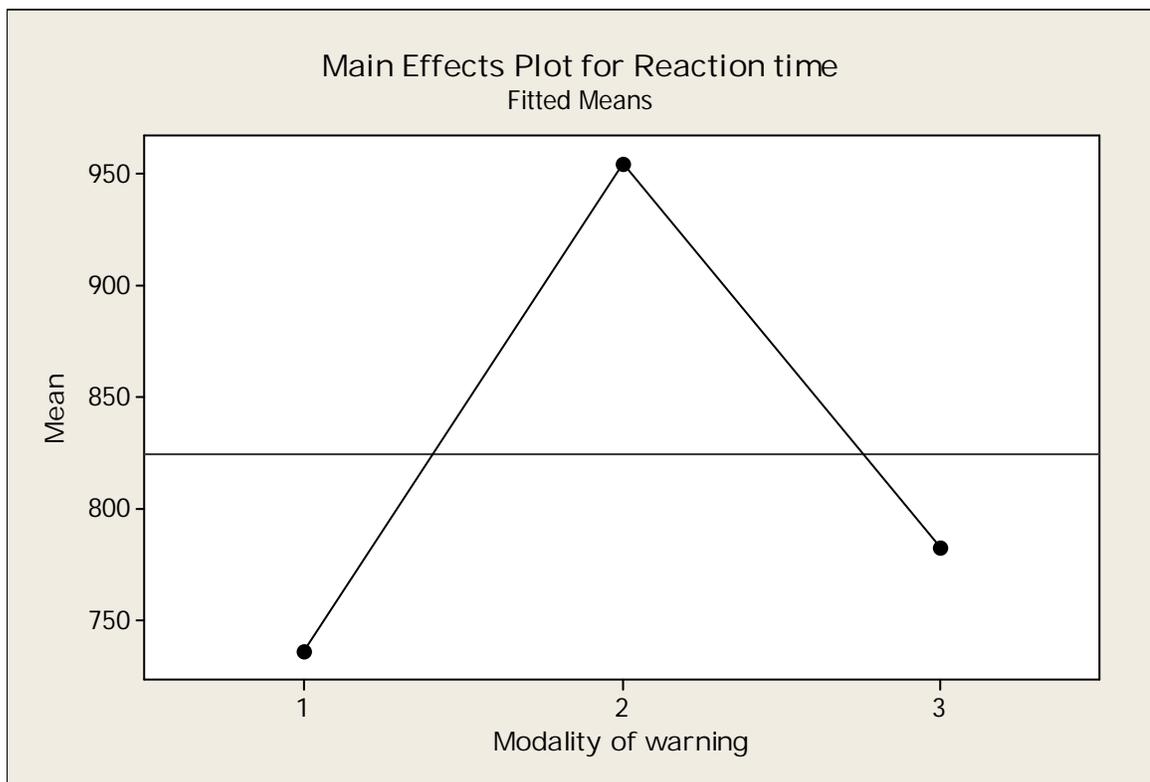


Figure 25. Main effect plot of Reaction Time

Figure 25. shows the main effect plot of the reaction time for all modality of warning which confirms that the auditory warning and combo warning has faster reaction time than the haptic warning.

Time to Return to Lane

The mean time to return to lane for the auditory warning was 4519.7ms; mean time to return to lane for the haptic warning was 4367.85ms; mean time to return to lane for combo warning was 4571.24ms and mean time to return to lane for no-warning was 4299.7ms. Figure 26 is a box plot of time to return to lane for each modality of warning. The fastest time to return to lane was the no-warning at 4299.7ms and the slowest time to return to lane was the combo warning at 4571.24ms.

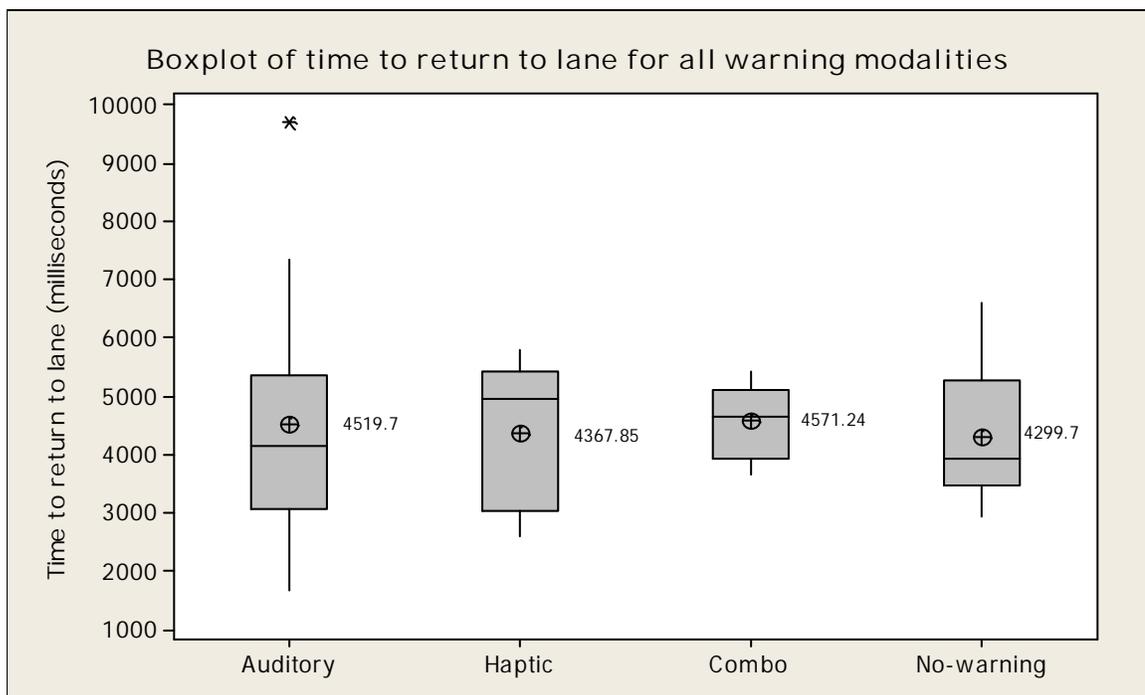


Figure 26. Box plot of Time to Return to Lane

Table 14. has been provided to summarize the ANOVA procedure. No significant differences were found in time to return to lane between modality of warning factor $F_{2, 22} = 0.08$, $p = 0.970$.

Table 14. ANOVA of time to return to lane

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Modality of Warning	3	546310	737141	245714	0.08	0.970
PARTICIPANT	11	33450573	33450573	3040961	1.01	0.465
ERROR	27	81384945	81384945	3014257		
Total	41	115381827				

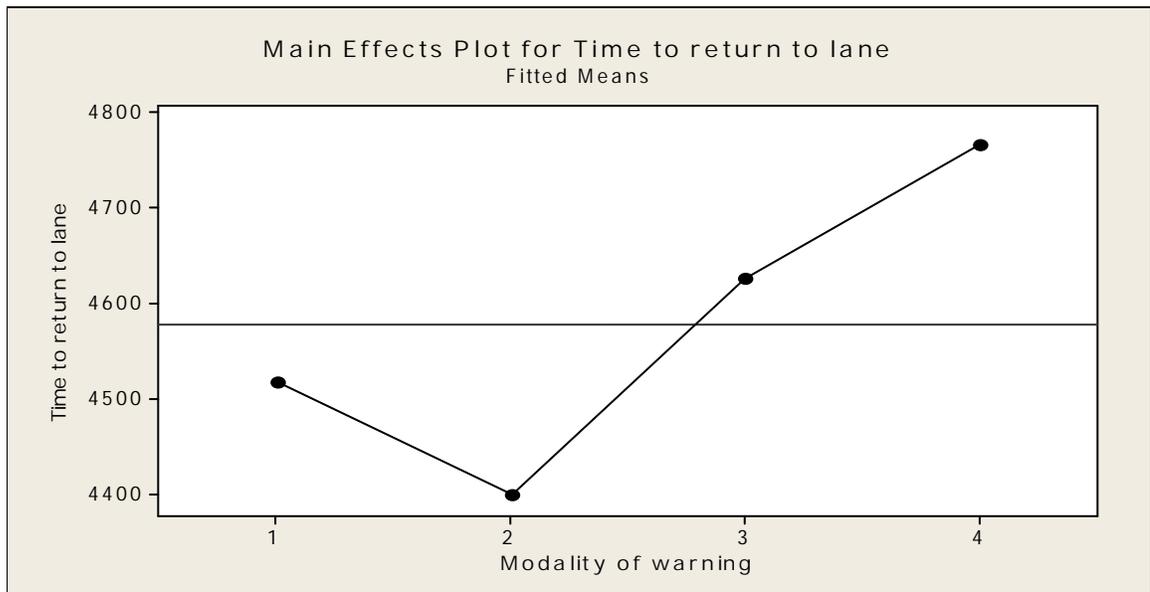


Figure 27. Main effect plot of Time to Return to Lane

Figure 27. shows the main effect plot of the time to return to lane for all modality of warning.

Incorrect Maneuvers

The number of incorrect responses to the warning for each modality at the first and second distraction task is shown in Table 19. The most incorrect number of steering maneuvers occurred consistently at the second distraction task.

Table 15. Descriptive statistics of Incorrect Maneuvers

Incorrect Maneuvers	Auditory	Haptic	Combo	No-warning
1 st Distraction	2	1	2	3
2 nd Distraction	4	3	5	2

This data leads to the percentage of incorrect maneuvers at the first distraction task for the auditory, haptic, combination and no-warning treatment to include 8.3%, 4.1%, 8.3% and 12.5% respectively. For the percentage of incorrect maneuvers at the second distraction task for the auditory, haptic, combination and no-warning condition was 16.6%, 12.5%, 20.83% and 8.3% respectively.

The nonparametric chi-square test found no significant differences among modalities ($p > 0.05$). However, significantly more participants turned into the wrong direction in the second distraction ($p < 0.05$). The bar chart in Figure 28 better

demonstrates the magnitude of the number of incorrect maneuvers at the second distraction task.

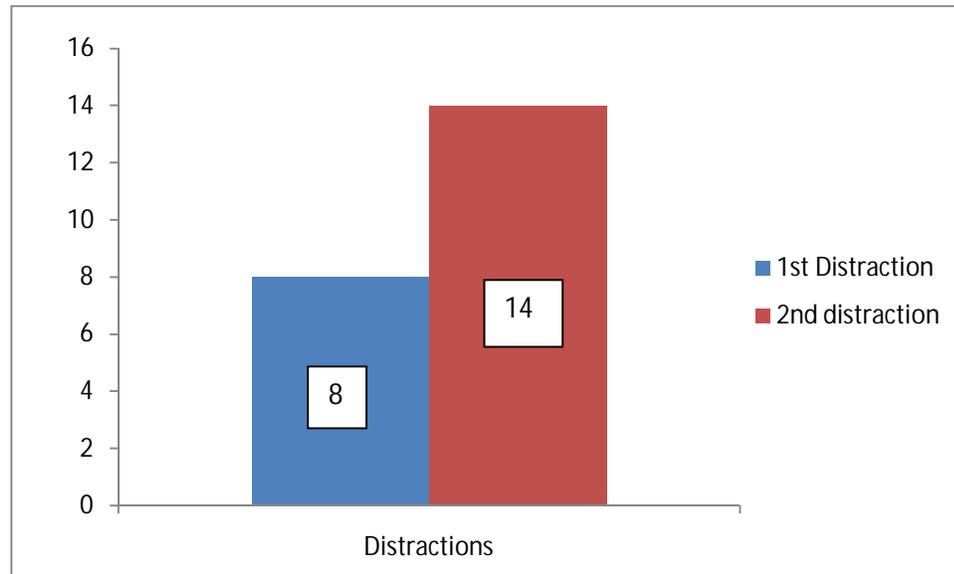


Figure 29. Number of Incorrect Steering Maneuvers

Deltoid Muscle Fiber Results

The higher percentage of MVC was observed during auditory warning with the mean of 13.266% of MVC. The lower percentage of MVC was observed during haptic warning with the mean of 7.535% of MVC. The greater variability in the percentage of MVC was the auditory warning at $\pm 6.440\%$ of MVC and the least amount of variability was the no-warning condition at $\pm 4.334\%$ of MVC. Figure 29 shows the box plot of the percentage of MVC for each warning condition which suggests that the percentage of MVC of auditory warning is higher than the percentage of MVC of the haptic, combo and no-warning condition.

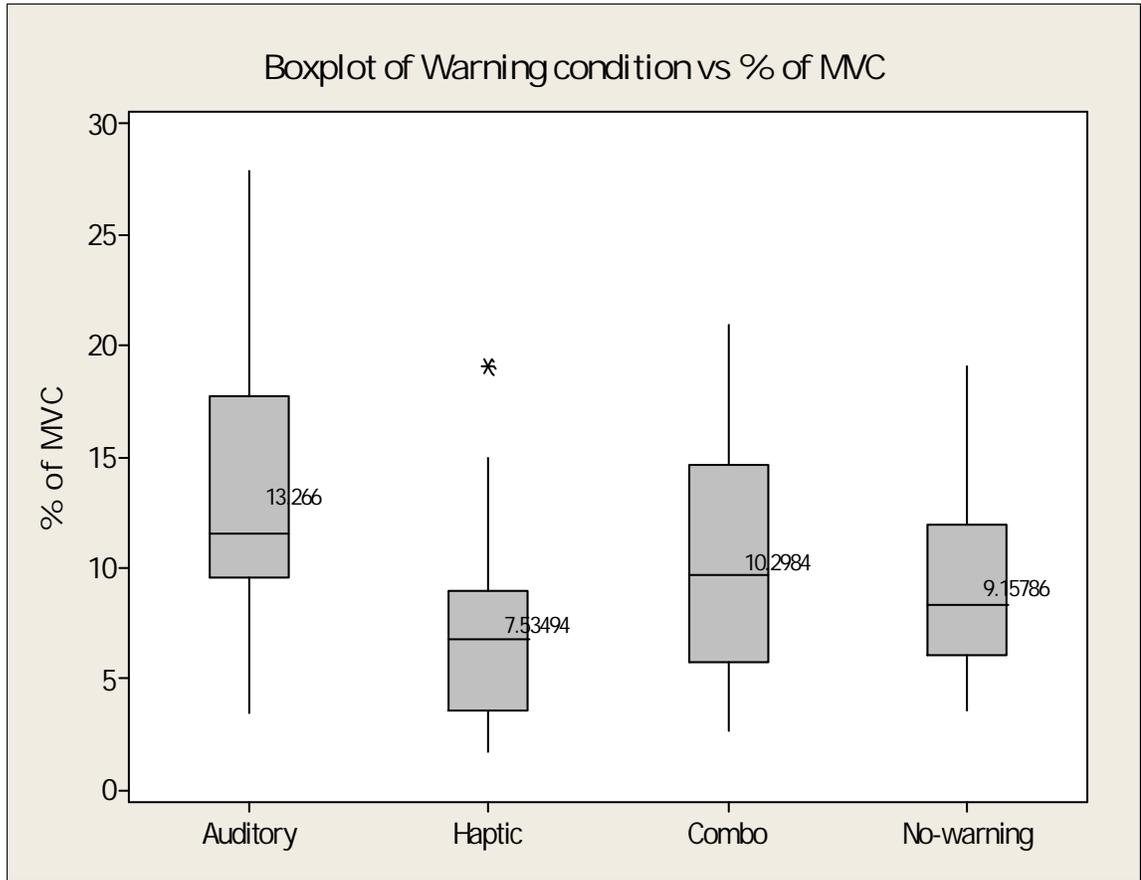


Figure 29. Box plot of % of MVC for Deltoid Muscle

Table 16. has been provided to summarize the ANOVA procedure. No significant differences were found between male and female participants, $F_{1, 30} = 1.59$, $p = 0.236$ and significant differences were found between modality of warning factor $F_{3, 30} = 16.233$, $p < 0.001$. Furthermore, there is no interaction between the modality of warning and gender factor $F_{3, 30} = 16.233$, $p = 0.439$. Tukey's HSD test reveals that percentage of MVC during auditory warning is greater than haptic warning $p < 0.001$, combo warning $p = 0.0267$ and no-warning condition $p = 0.0014$. The increase in mean percentage of MVC during auditory condition over the haptic, auditory and no-warning condition was 5.731%

of MVC, 2.968% of MVC, 4.108% of MVC respectively. Combo warning condition is also greater than the haptic warning, $p = 0.0430$. The combo warning condition has mean of 2.763% of MVC higher than the haptic condition.

Table 16. ANOVA of % of MVC for Deltoid muscle

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Gender	1	152.186	152.186	152.186	1.59	0.236
PARTICIPANT (Gender)	10	957.910	957.910	95.791	16.233	0.000
Modality of Warning	3	210.298	210.298	70.099	11.879	0.000
Gender* Modality of warning	3	16.434	16.434	5.478	0.928	0.439
ERROR	30	177.032	177.032	5.901		
Total	47	1513.860				

There were no significant differences found between the haptic and no-warning condition, $p = 0.3743$. Also, there were no significant differences found between the combo and no-warning condition, $p = 0.6621$.

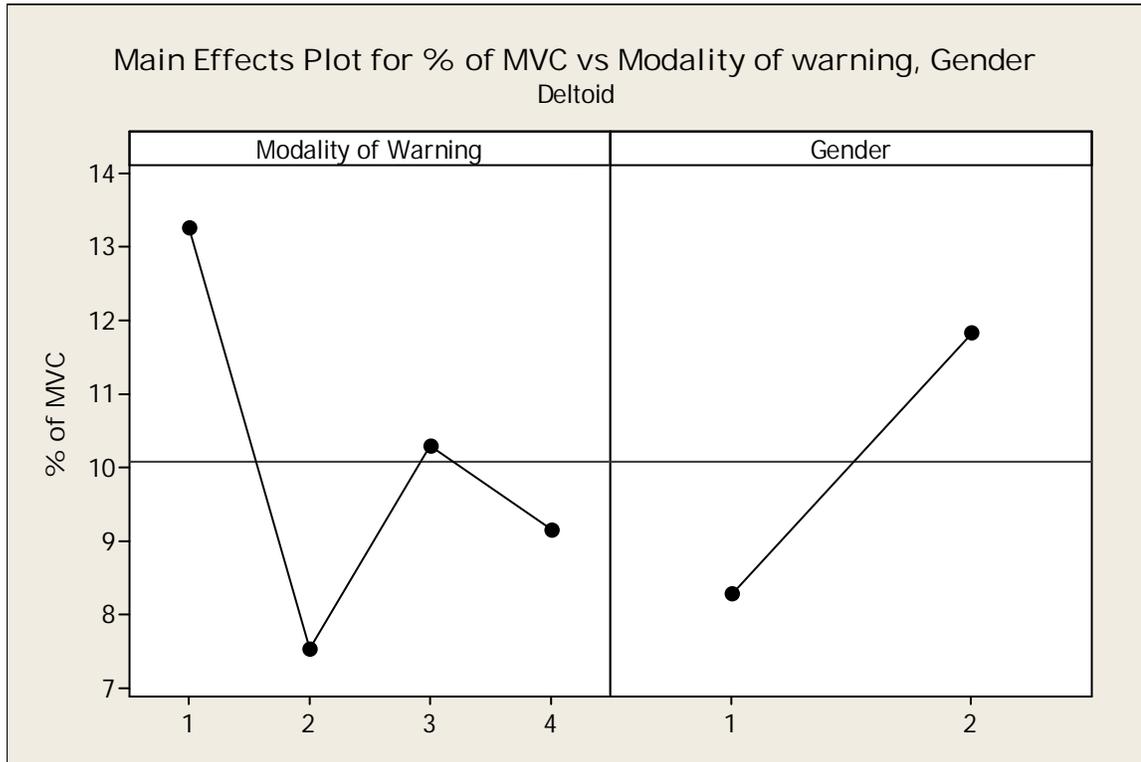


Figure 30. Main Effects Plot for % of MVC for the Deltoid Muscle
Where Modality of warning, 1= Auditory, 2 = Haptic, 3 = Combo and 4 = No-warning
Gender, 1 = Male, 2 = Female

Figure 30. shows the main effect plot of the percentage of MVC for deltoid muscle. Even though the graph shows that female has the more percentage of MVC than the males, they are not statistically different by the above ANOVA test. Figure 30. also confirms that the auditory warning has the high percentage of MVC than the haptic, combo and no-warning modalities and the combo warning has more percentage of MVC than the haptic warning. Moreover, figure 30. also reveals that No-warning has no significant difference between combo and haptic modalities.

Biceps Brachii Muscle Fiber Results

There was no huge difference in percentage of MVC between the warning conditions for biceps brachii. The higher percentage of MVC was observed during combo warning with the mean of 2.482% of MVC. The lower percentage of MVC was observed during haptic warning with the mean of 1.571% of MVC. Figure 31. shows the box plot of % of MVC for four modalities of warning. There were some outliers in the figure 26 shown as asterisks marks may due to the difference in strength level of participants for biceps brachii.

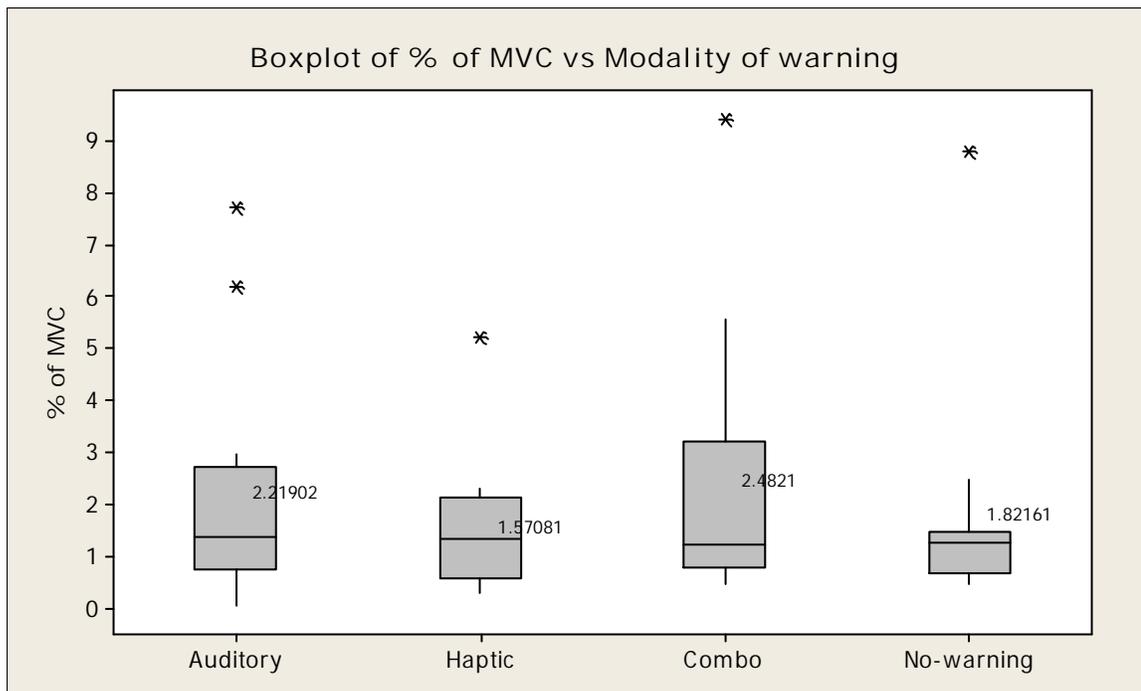


Figure 31. Box plot of % of MVC for Biceps Brachii Muscle

No significant differences were observed between gender for the biceps brachii muscle $F_{1, 33} = 0.10$, $p = 0.930$ and also no significant differences were observed between modality of warning for biceps brachii muscle $F_{3, 33} = 1.54$, $p = 0.224$. Since, there is no

significant impact of gender and modality of warning in the percentage of MVC for biceps brachii, the interaction between gender and modality of warning was not considered for ANOVA analysis. Table 17. shows the summary of the ANOVA procedure for biceps brachii.

Table 17. ANOVA of % of MVC for biceps Brachii Muscle

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Gender	1	0.138	0.138	0.138	0.010	0.930
PARTICIPANT (Gender)	10	169.626	169.232	16.923	13.000	0.000
Modality of Warning	3	5.931	5.931	1.977	1.54	0.224
ERROR	33	42.488	42.488	1.288		
Total	47	218.182				

Figure 32. shows the main effects plot for the biceps brachii muscle which also demonstrates that there is no significant difference in the gender and modality of warnings.

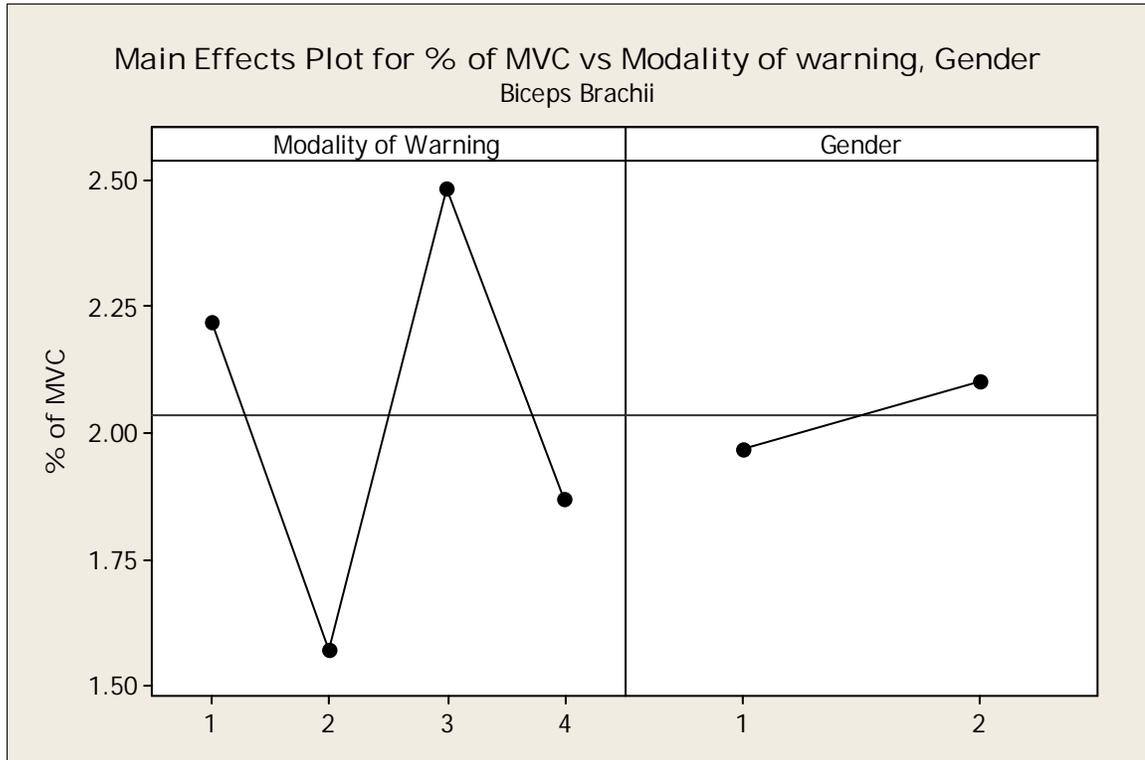


Figure 32. Main Effects Plot for % of MVC for the Biceps Brachii
Where Modality of warning, 1= Auditory, 2 = Haptic, 3 = Combo and 4 = No-warning
Gender, 1 = Male, 2 = Female

Pronator Teres Muscle Fiber Results

The higher percentage of MVC was observed during auditory warning with the mean of 6.141% of MVC. The lower percentage of MVC was observed during no-warning modality with the mean of 4.338% of MVC. Figure 33. shows the box plot of the percentage of MVC for four modalities of warning, which suggest that the greater variability in percentage of MVC was the auditory warning at $\pm 3.750\%$ of MVC and the least amount of variability was the haptic warning condition at $\pm 2.391\%$ of MVC

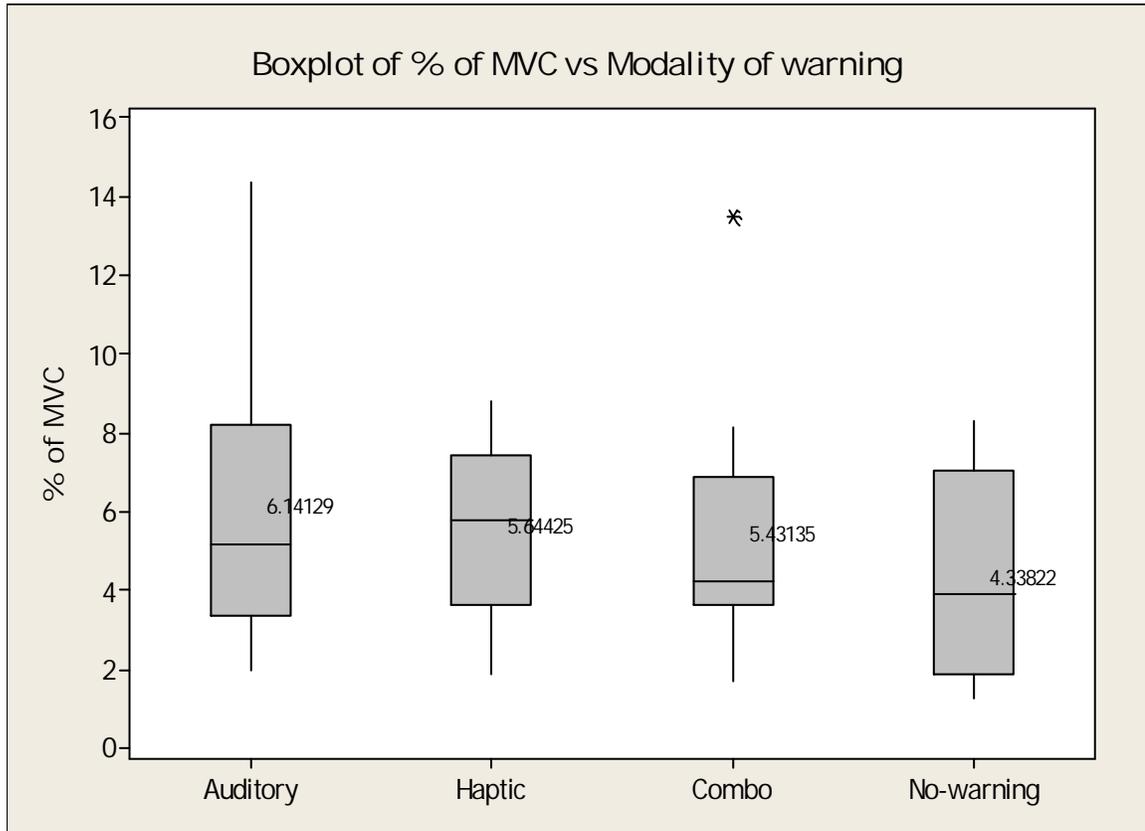


Figure 33. Box plot of % of MVC for Pronator Teres Muscle

No significant differences were observed between gender for the pronator teres muscle $F_{1, 33} = 0.26$, $p = 0.619$ and also no significant differences were observed between modality of warning for pronator teres muscle $F_{3, 33} = 1.51$, $p = 0.230$. Since, there is no significant impact of gender and modality of warning in the percentage of MVC for pronator teres, the interaction between gender and modality of warning was not considered for ANOVA analysis. Table 18. shows the summary of the ANOVA procedure for biceps brachii.

Table 18. ANOVA Model of % of MVC for Pronator Teres.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Gender	1	6.344	6.344	6.344	0.26	0.619
PARTICIPANT (Gender)	10	241.047	241.047	24.105	5.24	0.000
Modality of Warning	3	20.844	20.844	6.948	1.51	0.230
ERROR	33	151.929	151.929	4.604		
Total	47	420.164				

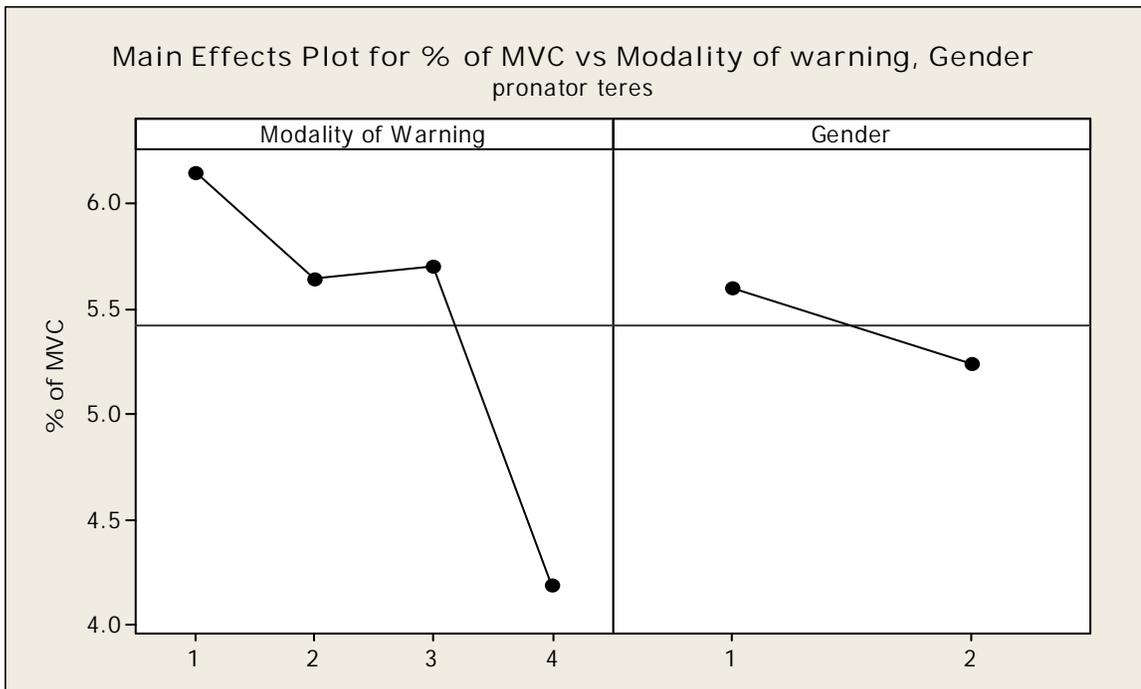


Figure 34. Main Effects Plot for % of MVC for the Pronator Teres
 Where Modality of warning, 1= Auditory, 2 = Haptic, 3 = Combo and 4 = No-warning
 Gender, 1 = Male, 2 = Female

Figure 34. shows the main effect plot for the pronator muscle. The graph shows that the percentage of MVC of the no-warning is less compared to the auditory, haptic and combo warning modalities, but they are not statistically different by the ANOVA analysis. The graph also confirms that the percentage of MVC of gender is not significantly different.

Tibialis Anterior Muscle Fiber Results

The higher percentage of MVC was observed during no-warning condition with the mean of 2.456% of MVC. The lower percentage of MVC was observed during auditory warning with the mean of 1.962% of MVC.

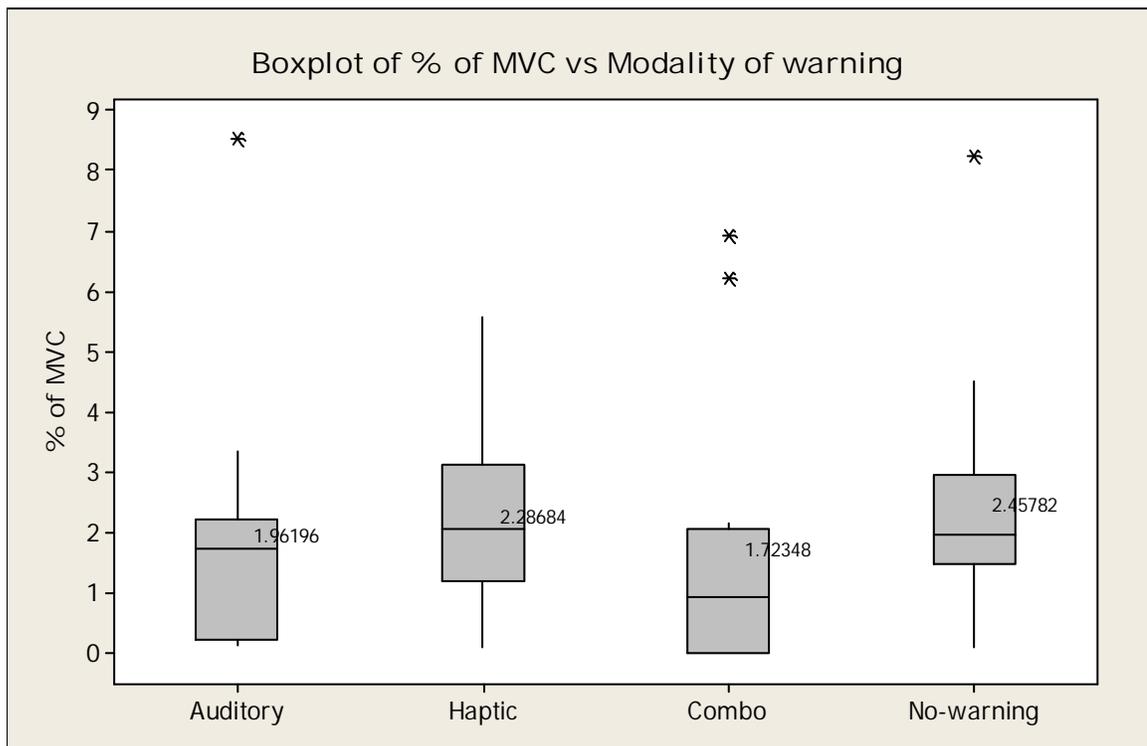


Figure 35. Box plot of % of MVC for Tibialis Anterior Muscle

Figure 35. shows the box plot of the percentage of MVC for four modalities of warning, which suggest that the greater variability in percentage of MVC was the auditory warning at $\pm 2.305\%$ of MVC and the least amount of variability, was the haptic warning condition at $\pm 1.581\%$ of MVC.

No significant differences were observed between gender for the tibialis anterior muscle $F_{1, 33} = 0.56$, $p = 0.472$ and also no significant differences were observed between modality of warning for tibialis anterior muscle $F_{3, 33} = 0.55$, $p = 0.655$. Since, there are no significant impact of gender and modality of warning in the percentage of MVC for tibialis anterior, the interaction between gender and modality of warning was not considered for ANOVA analysis. Table 19. shows the summary of the ANOVA procedure for biceps brachii.

Table 19. ANOVA of % of MVC for Tibialis Anterior.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Gender	1	6.316	6.316	6.316	0.56	0.472
PARTICIPANT (Gender)	10	112.871	112.871	11.287	4.76	0.000
Modality of Warning	3	3.882	3.882	1.294	0.55	0.655
ERROR	33	78.323	78.323	2.373		
Total	47	201.393				

Figure 36. shows the main effect plot for the tibialis anterior. The graph shows that the percentage of MVC of the male is less compared to the male participants, but they are not statistically different by the above ANOVA analysis. The graph also confirms that the percentage of MVC between the modality of the warning is not significantly different.

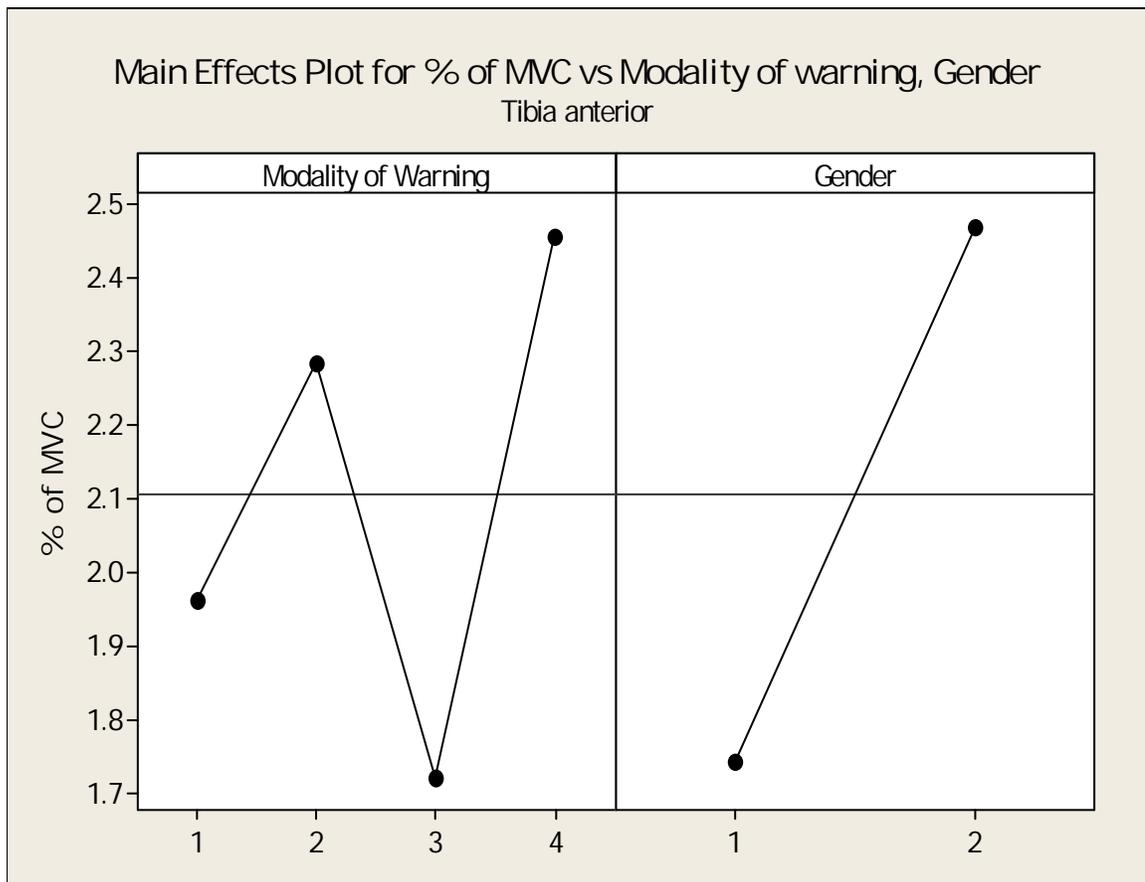


Figure 36. Main Effects Plot for % of MVC for the Tibialis Anterior
Where Modality of warning, 1= Auditory, 2 = Haptic, 3 = Combo and 4 = No-warning
Gender, 1 = Male, 2 = Female

First Warning Event

The first warning resulted in 12 data points with three data points for each modality of warning. The higher percentage of MVC was observed during combo warning with the mean of 15.783% of MVC. The lower percentage of MVC was observed during haptic warning with the mean of 13.101% of MVC. Figure 37 shows the box plot of the percentage of MVC for each warning condition

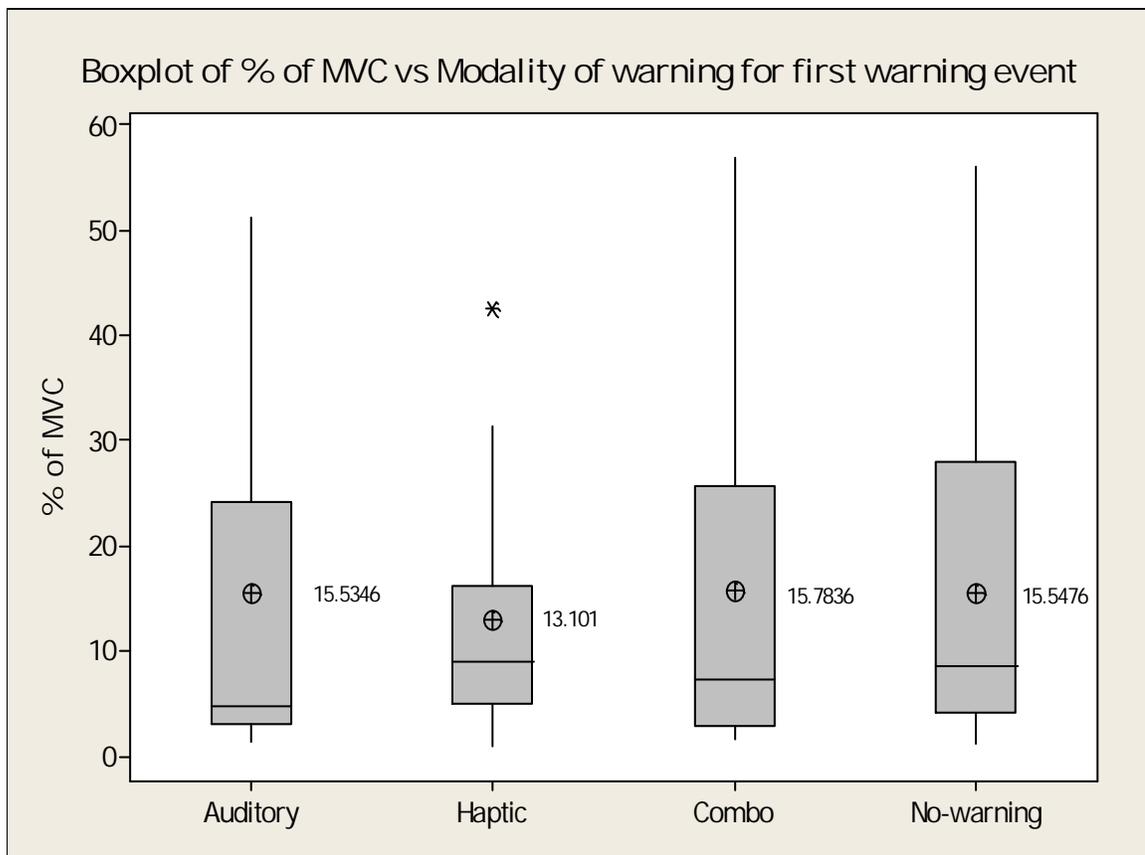


Figure 37. Box plot of % of MVC for the First Warning Event

Table 20. has been provided to summarize the ANOVA procedure. No significant differences were found between modality of warning, $F_{3, 32} = 0.31$, $p = 0.815$ and

significant differences were found between muscle fibers $F_{3, 32} = 52.24$, $p < 0.001$. Furthermore, there is no interaction between the modality of warning and muscle fibers factor $F_{9, 32} = 0.72$, $p = 0.686$. Tukey's HSD test reveals that percentage of MVC in deltoid is greater than biceps muscle $p < 0.001$, pronator teres $p < 0.001$ and tibialis anterior $p < 0.001$. Also, pronator teres has more percentage of MVC than the tibialis anterior.

Table 20. ANOVA of % of MVC for the First Warning Event

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Modality of Warning	3	57.67	57.67	19.22	0.31	0.815
Muscle Fibers	3	9584.23	9584.23	3194.74	52.24	0.000
Modality of Warning* Muscle Fibers	9	396.93	396.93	44.10	0.72	0.686
ERROR	32	1956.78	1956.78	61.15		
Total	47	11995.61				

Figure 38. shows the main effect plot of the percentage of MVC for the first warning event.

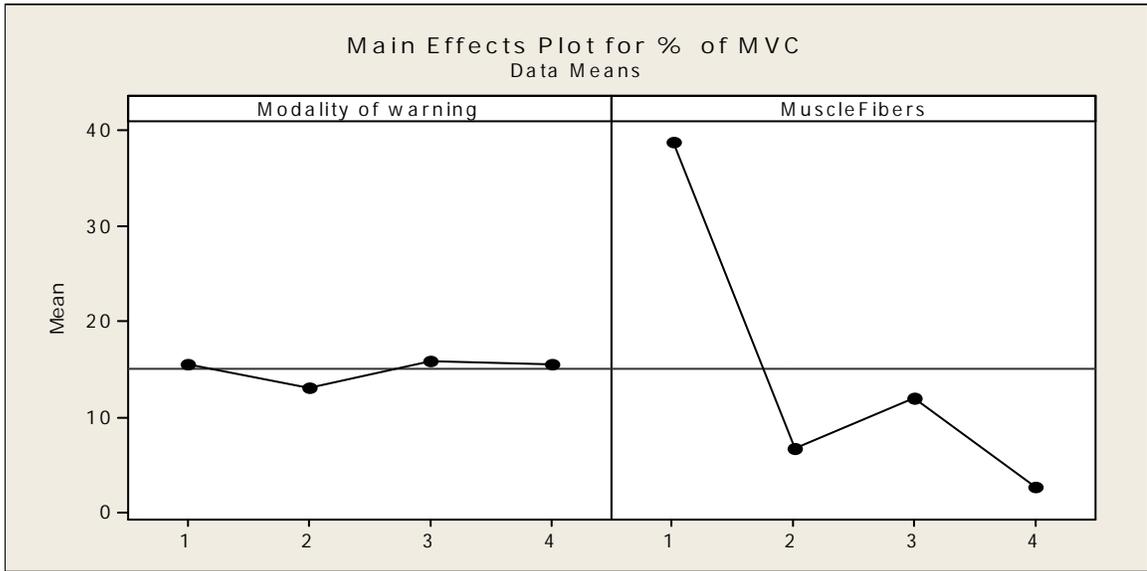


Figure 38. Main effect plot of % of MVC for the First Warning Event

Figure 39 shows an example of graphical representation the muscle activity (in mV) of deltoid muscle during auditory warning.

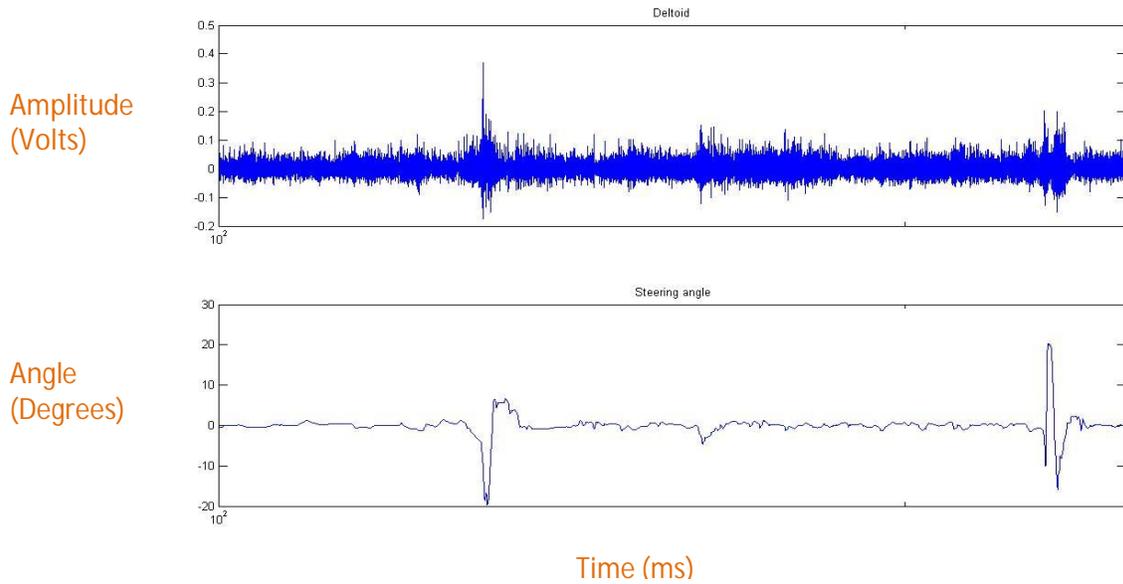


Figure 39. Example of EMG activity for Deltoid Muscle during Auditory warning for a Subject

CHAPTER 5

DISCUSSION

In phase I part of the study, with six (three male and three female) participants, it was found that abductor pollicis brevis, trapezoid muscles have no significant RMS EMG amplitude with respect to steering activity and soleus muscle also has no significant RMS EMG amplitude with respect to braking activity. Meanwhile, deltoid, biceps brachii, pronator teres muscles have significant RMS EMG amplitude with respect to steering activity and tibialis anterior has significant RMS EMG amplitude with respect to braking activity.

In phase II of the study, with the EMG electrodes placed over deltoid, biceps brachii, pronator teres and tibialis anterior muscles, twelve different (six male and six female) participants received four different warning modalities such as the auditory signal (rumble strip sound), haptic signal (seat vibration), the combined modalities of both Haptic and auditory during roadway lane departure and no-warning condition during the road-way lane departure. Major findings include that there is a significant difference in EMG (mV) at MVC between the four muscle groups. In the four muscle groups, deltoid and biceps brachii muscles have more mV at MVC than the pronator teres and tibialis anterior. Furthermore, male participants have greater EMG (mV) at MVC than the female participants. There is a significant difference in reaction between modalities of warning. The auditory and combo warning has faster reaction time than the haptic warning. There is no significant difference in time to return to lane between modalities of

warnings. In the deltoid muscle, there is a significant difference in percentage of MVC between the modality of warnings. Auditory warning has more mean percentage of MVC than the haptic, combo and no-warning modalities. Also, combo warning has higher mean percentage of MVC than the haptic warning. But, in the case of the biceps brachii, pronator teres and tibialis anterior muscles there are no significant differences found in the percentage of MVC between modalities of warnings. Furthermore, there is no significant difference found between male and female participants in the percentage of MVC for all four muscle fibers (deltoid, biceps brachii, pronator teres and tibialis anterior). Finally, there is no significant difference in the percentage of MVC between modality of warning during the first event warning. But there is a significant difference in % of MVC between muscle fibers during first warning event. Deltoid has more % of MVC than biceps brachii, pronator teres and tibialis anterior muscles. Pronator teres has more % of MVC than tibialis anterior muscle

A summary of statistical analysis is provided in table 21 with the dependent variable and its statistical method, modality significance, gender significance and briefing of significance. Many findings of this research coincide with the past research, while some of the findings contrast with past research. Numerous studies had found that males have more strength than the females, which coincide with the finding of this study such as the EMG (mV) generated in the EMG during MVC is higher for males than females. However, this study has measured mV at MVC for the muscles with respect to the driving position. The main reason for the higher mV at MVC for the males is due to their larger muscle fibers (Miller, MacDougall, Tarnopolsky & Sale, 1993)

Table 21. Statistical Analysis Summary

Dependent variable	Statistical method	Modality significance	Gender Significance	Briefing of Significance
mV at MVC	ANOVA/ Tukey's	Yes	Yes	Deltoid and biceps brachii have more mV at MVC over pronator teres and tibialis anterior; Male has more mV at MVC than females
Reaction Time	ANOVA/ Tukey's	Yes	-	Auditory and combo have faster reaction time than haptic
Time to return to lane	ANOVA	No	-	-
% of MVC (Deltoid)	ANOVA/ Tukey's	Yes	No	Auditory has more mean % of MVC than haptic, combo and no-warning; Combo has more mean % of MVC than haptic
% of MVC (Biceps brachii)	ANOVA	No	No	-
% of MVC (Pronator teres)	ANOVA	No	No	-
% of MVC (Tibialis anterior)	ANOVA	No	No	-
% of MVC (First Warning Event)	ANOVA/ Tukey's	Yes	-	Deltoid has more % of MVC than biceps brachii, pronator teres and tibialis anterior. Pronator teres has more % of MVC than tibialis anterior

Reaction time of auditory and combo warning are faster than the haptic warning which suggest that rumble strip noise has more influence for the driver to react quickly to the distraction. These findings contrast with the previous studies by Kozak et al., (2006) and Stanley et al., (2007) which suggest that haptic warning has better reaction time than other warnings. However, the time to return to lane is not significantly differ among warning modalities which reveals that the faster reaction time did not influence the driver to come back quickly in to the road. All the warning modalities took the approximately same time to come back to road.

Stanley et al., (2007) has found that greater maximum steering response was produced in auditory warning than the haptic or combination warnings, which is reflected in this study by auditory warning generating high percentage of MVC for deltoid muscle than the haptic, combination with the addition of no-warning condition. But this study also found that combination warning has high percentage of MVC than the haptic warning which may suggest that combination warning might have greater maximum steering response than the haptic warning. However, other than the deltoid muscle there is no significant difference found in percentage of MVC between modality of warning other muscles such as biceps brachii, pronator teres and tibialis anterior.

The main aim of this study was to find the possible startle/panic responses due to the auditory, haptic and combination warnings compared to the no-warning condition. The results of this study suggest that there are no potential startle/panic responses perceived by human participants since there is no significant difference found in percentage of MVC between no-warning modality compared to the auditory, haptic and

combination modality. The only significant difference was found in auditory warning for deltoid muscle which may be most likely due to the greater maximum steering response. In the case of response of driver only to the first warning event also did not find any significant differences in their muscle contraction between modalities of warnings. This reveals that driver that the unexpected warning may not have a greater influence to panic the driver. This suggests that warning systems may well help the driver in bringing back attention to the road with their natural response to such lane departure circumstances. In the case of incorrect maneuver there was no significant difference among the modalities. But there is a significant difference found among the first and second distraction which may be due to the expectancy of the participants of distraction to be in the same distraction. Also, reaction time varied among the warning modalities which may increase the muscle activity among modalities, since there is no change in time to return to lane may well did not vary the muscle activity. In conclusion, this study may well reveal that warning systems are unlikely to impede driving response by startling or panicking them.

Furthermore, this study was conducted in a simulator environment which might give lenience to drivers. Drivers know that there is no danger to their life, if they involve in an accident during the lane departure. This thought might have influenced the behavior of drivers to the lane departures. Further research is needed in real driving conditions (without any traffic to reduce the possible danger) to completely understand the possible startle/panic responses. Also, the distraction provided is a forced distraction such that the memorizing the letters of index card placed behind the shoulders. Natural distraction may different produce different response from the human participants.

The mean percentage of MVC for tibialis anterior was approximately less than 2.5% of MVC in all modalities. This result reveals that, for the speed limit of 55mph which was used in this study, the driver did not reduce the speed by big margin or applied brake after the issuance of warnings when they are off the road. There is a potential chance of driver startling/panicking when they are at a high speed, which brings the new research thoughts about checking the driver responses to different speed limits.

There is also no significant difference found in the percentage of MVC between male and female participants in all muscle groups. Even though, there is no significant difference statistically from ANOVA analysis, while looking at the main effect plot, females have more percentage of MVC than males by very less margin in exception of tibialis anterior. The study conducted by Kofler et al., (2001) also found that females have more probability of auditory startle responses than males and also they found that human participants tend to habituate the sound burst with the repeated simulation except for the orbicularis oculi (near eyes) muscle. In such a case of habituation by drivers to the lane departure warning systems, a better understanding of startle response might be measured from the orbicularis oculi by the blink response. Furthermore, the muscles discarded from the phase I study are completely dependent on the conditions of steering wheel and braking pedal of the simulator used for this experiment. The RMS EMG amplitude for muscle groups might vary for a different simulated car.

The result obtained from the initial power analysis was observed only from a single participant. The results of that power analysis suggested the use of twelve participants. But the final analysis showed very less power level for the biceps brachii,

pronator teres and tibialis anterior which suggest the use of more participants in the future study. Finally, video recordings of the driving scenario also did not provide any evidence of sudden blinking of eyes. The driver normally turned back to the drive after they received the warning in the forced lane departure.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to (1) determine the appropriate muscle group which are active while driving a simulated by doing simple actions like steering and braking the vehicle (2) determine the response of the distracted driver on a sudden issuance of warnings (auditory, haptic, combo) compared to the no-warning conditions. This study concluded that the deltoid, biceps brachii and pronator teres muscles are best active while steering the vehicle and the tibialis anterior is best active while applying brake to the vehicle under the given experimental setup of the DriveSafety™ 500C simulator. In the above selected muscles, there are no significant differences in the percentage of MVC between modality of warnings except for the deltoid muscle. The higher percentage of MVC in deltoid muscle for the auditory warning condition may be due to the maximum steering response of the auditory warning compared to other modalities of warning as found by Stanley et al., (2007). Also, there are no significant differences among the warning during the first warning event. This concludes that there might not be a potential startle/panic responses perceived by the driver during issuance of warnings in roadway lane departure. The auditory and combo has faster reaction time than the haptic warning and there is no difference in the time to return to lane between modalities.

Furthermore, the EMG (mV) generated at the MVC is high for males compared to females for all the above muscles. In these muscles, deltoid and biceps brachii has more

EMG (mV) at MVC than the pronator teres and tibialis anterior muscles. Even though, the EMG (mV) at MVC varies between males and females, while calculating the response as a percentage of MVC, there is no significant difference for the various modalities of warnings. This concludes that the manufacturer of warning systems may not need to consider gender while manufacturing these systems. Finally, the above study in general provides some evidence that warning systems are more advantageous in helping distracted drivers during roadway lane departure rather than startling/panicking drivers. However, this study requires future in-depth analysis to provide more evidence to the findings. Also, studies about startle/panic responses due to warning systems itself are still in its initial stages and these results may prompt further research in this area.

Future research might include:

- 1) As startle/panic responses are well perceived in the real driving conditions, conducting study in real driving condition assisted with the proper safety measures can provide better support for the measurement of startle/panic responses.
- 2) The human beings have the tendency to get habituated to the repeated activities which initiates to study about finding the habituation period of the drivers to the warning systems.
- 3) The expectancy of the drivers to the warnings is high, since the same driver is used for all four different types of warnings. In the future studies, different participants should be used for the different warnings.
- 4) Consideration of different speed levels in the driving scenario.

- 5) Natural distraction task than the forced lane departure.
- 6) Measurement of EMG activities in the facial muscles such as the muscles associated with the blinking of eyes.
- 7) More human participants to provide more statistical power level.
- 8) Providing different modality of warnings in the single drive scenario in a randomized order.
- 9) Measuring EMG activity on both sides of the body.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPLICATION

MONTANA STATE UNIVERSITY
Institutional Review Board Application for Review
(revised 11/17/08)

[Include copies of PI's and Co-PI's "Completion Certificate(s)" as proof that all have received the education and instructions for researchers using human subjects. The preferred instruction and education is that from the National Cancer Institute: <http://Cancer.gov> - Human Participant Protections Education for Research Teams/cme.cancer.gov/clinicaltrials/learning/humanparticipant-protections.asp

THIS AREA IS FOR INSTITUTIONAL REVIEW BOARD USE ONLY. DO NOT WRITE IN THIS AREA.

Application Number:

Approval Date:

Disapproved:

IRB Chair's Signature:

Submit 14 copies of this application (including the signature copy), along with 14 copies of the subject consent form and 14 copies of all other relevant Materials, to Institutional Review Board, 960 Technology Blvd., Room 127, Montana State University, Bozeman, MT 59717-3610. (Please staple, bind or clip together the application form, surveys, etc. as 14 individual packets; one complete packet for each board member.) Submit one copy of grant contract proposal for the office file. For information and assistance, call 994-6783 or contact the Institutional Review Board Chair, Mark Quinn at 994-5721.

PLEASE TYPE YOUR RESPONSES IN BOLD

Date:

I. Investigators and Associates (list all investigators involved; application will be filed under name of first

person listed)

NAME: **ANBURAJ MUTHUMANI**

TITLE:
GRADUATE STUDENT

DEPT: INDUSTRIAL AND MANAGEMENT PHONE #: 4066007719

ENGINEERING

ADDRESS: Room no: 402 - Roberts Hall, Montana State University, Bozeman, MT- 59715

E-MAIL ADDRESS: anburaj1985@yahoo.co.in

DATE TRAINING COMPLETED: 02/11/2009 and Certificate is on file

Do you as PI, any family member or any of the involved researchers or their family members have consulting agreements, management responsibilities or substantial equity (greater than \$10,000 in value or greater than 5% total equity) in the sponsor, subcontractor or in the technology, or serve on the Board of the Sponsor? _____ YES
__x__ NO

If you answered Yes, you will need to contact the Director of the Technology Transfer Office, Dr. Rebecca Mahurin at 406-994-7868.

II. Title of Proposal:

STUDY OF STARTLE/PANIC RESPONSES DUE TO AUDITORY AND HAPTIC WARNINGS FROM ROADWAY LANE DEPARTURE SYSTEMS

III. Beginning Date for Use of Human Subjects:

3rd week of March 2009

IV. Type of Grant and/or Project (if applicable)

Research Grant:

Contract:

Training Grant:

Classroom Experiments/Projects:

Thesis Project: **Master's Thesis**

Other (Specify):

V. Name of Funding Agency to which Proposal is Being Submitted (if applicable):

VI. Signatures

Submitted by Investigator

Typed Name: **ANBRUAJ MUTHUMANI**

Signature:

Date:

Faculty sponsor (for student)

Typed Name: **Dr. ROBERT MARLEY**

Signature:

Date:

VII. Summary of Activity. Provide answers to each section and add space as needed. Do not refer to an accompanying grant or contract proposal.

A. RATIONALE AND PURPOSE OF RESEARCH (What question is being asked?)

In order to improve traffic safety, car manufacturers are creating driver support systems that are intended to detect hazards and warn drivers. However, it is not clear if the warning themselves may be a potential hazard in terms of distracting or startling drivers. This distraction and startle might impede drivers from quickly and appropriately responding to the original traffic hazard. So this study is intended to better understand how human subjects react to such a warning (Auditory signal and haptic signal)

to warn of a possible hazard.

- B. **RESEARCH PROCEDURES INVOLVED.** Provide a short description of sequence and methods of procedures that will be performed with human subjects. Include details of painful or uncomfortable procedures, frequency of procedures, time involved, names of psychological tests, questionnaires, restrictions on usual life patterns, and follow up procedures.

Driver behavior will be observed in a driving simulator with a simulated driver support system that provides warnings to drivers about virtual hazards. This study consists of two phases of experiment.

In phase I of the experiment, six participants will be used with equal proportion of both genders. Prior to experiment there will be a practice session to drive in a high-fidelity driving simulator on a rural road by involving three short trips each lasting approximately five minutes. The participants experiencing any discomfort during practice session will not be considered for further study. After a rest period, the participant will be attached with electromyography (EMG) electrodes on the upper and lower extremities of the body which will be connected to a data acquisition box to collect the EMG data. Then participants will be asked to drive through a scenario of rural road for approximately 10 minutes. The rural road will be a curvilinear road with no traffic approximately two miles. The normal muscle activity of participants while driving and doing simple actions like steering the wheel, braking etc., will be collected using the attached EMG electrodes. This data will be used to isolate the muscles active during driving.

In Phase II of the experiment, 12 participants will be used with equal proportion of both genders. Experiment will consist of four sessions approximately lasting for two hours. Prior to experiment, practice session will be conducted with the same driving simulator as in phase I and the driver with discomfort will not be considered for further study. The muscles identified in the phase I will be attached with EMG electrodes. In the first session participants will drive on a rural road of approximately 10 minutes. The rural road is straight two-lane highway with no traffic. After approximately driving through three minutes, participants will be presented with a distracter task where they will look over their shoulder and read an index card of letters. At this time the experimenter will issue a gradual wind gust (East to West, or West to East), to take them out of the lane. Once out

of lane, participants will be issued a warning, in the form of haptic seat vibration, auditory, haptic and auditory combined or sometimes no-warning. At this time the muscle activity of driver to bring back the car in to lane will be measured using EMG. Again after approximately eight minutes into the drive the participant will do the same distracter task and the same warning signal will issued at this time without the wind gust. Muscle activity will be again measures using EMG.

The same procedure will be followed in the next three remaining sessions with the randomly chosen warning systems excluding the warnings used in the previous session. The whole experiment will be conducted at same time (different day) for each subject. During the both phase of the study the participant will be asked to wear loose clothes to ensure necessary space to attach EMG in your body.

- C. DECEPTION - If any deception (withholding of complete information) is required for the validity of this activity, explain why this is necessary and attach debriefing statement.

None

D. SUBJECTS

1. Approximate number and ages

How Many Subjects: **18**

Age Range of Subjects: **20-30**

How Many Normal/Control: **within subject design**

Age Range of Normal/Control: **within subject design**

2. Criteria for selection:

3 - 5 years experience in driving the car.

3. Criteria for exclusion:

Any high discomfort experienced due to driving in driving simulator.

4. Source of Subjects (including patients):

Students of Montana State University

5. Who will approach subjects and how? Explain steps taken to avoid coercion.

The principal investigator will ask student permission in Industrial and Mechanical department and through advertisement in the notice boards of the university campus. Students who are interested will be explained with the testing procedure that is to be followed in the experiment. Only interested students who consent will be selected based on their schedule.

6. Will subjects receive payments, service without charge, or extra course credit?
Yes or **No**
(If yes, what amount and how? Are there other ways to receive similar benefits?)

No financial compensation will be given

7. Location(s) where procedures will be carried out.

Driving simulator lab, Western Transportation Institute, Bozeman, MT – 59715

E. RISKS AND BENEFITS (ADVERSE EFFECTS)

1. Describe nature and amount of risk and/or adverse effects (including side effects), substantial stress, discomfort, or invasion of privacy involved.

Subject might feel dizziness due to driving in a simulator. Subject might feel soreness or itching in muscles where EMG will be kept.

2. Will this study preclude standard procedures (e.g., medical or psychological care, school attendance, etc.)? If yes, explain.

No

3. Describe the expected benefits for individual subjects and/or society.

No direct benefits other than experience with driving a simulator and the research process.

F. ADVERSE EFFECTS

1. How will possible adverse effects be handled?

By investigator(s): **First aid supplies will be available in the testing area to attend the emergency. Appropriate emergency personnel will be contacted if necessary.**

Referred by investigator(s) to appropriate care:

Other (explain):

2. Are facilities/equipment adequate to handle possible adverse effects? **Yes**
or No

(If no, explain.)

3. Describe arrangements for financial responsibility for any possible adverse effects.

MSU compensation (explain): none

Sponsoring agency insurance: none

Subject is responsible: yes

Other (explain):

G. CONFIDENTIALITY OF RESEARCH DATA

1. Will data be coded? **Yes** or No
2. Will master code be kept separate from data? **Yes** or No
3. Will any other agency have access to identifiable data? Yes or **No**

(If yes, explain.)

4. How will documents, data be stored and protected?

Locked file:

Computer with restricted password: **Will be stored in computer and with password protection**

Other (explain):

VIII. Checklist to be completed by Investigator(s)

- A. Will any group, agency, or organization be involved? Yes or **No**

(If yes, please confirm that appropriate permissions have been obtained.)

- B. Will materials with potential radiation risk be used (e.g. x-rays, radioisotopes)?
Yes or **No**

1. Status of annual review by MSU Radiation Sources Committee (RSC).
Pending or Approved

(If approved, attach one copy of approval notice.)

2. Title of application submitted to MSU RSC (if different).

C. Will human blood be utilized in your proposal? Yes or **No**

(If yes, please answer the following)

1. Will blood be drawn? Yes or No

(If yes, who will draw the blood and how is the individual qualified to draw blood?

What procedure will be utilized?)

2. Will the blood be tested for HIV? Yes or No

3. What disposition will be made of unused blood?

4. Has the MSU Occupational Health Officer been contacted? Yes or No

D. Will non-investigational drugs or other substances be used for purposes of the research? Yes or **No**

Name:

Dose:

Source:

How Administered:

Side effects:

E. Will any investigational new drug or other investigational substance be used? Yes or **No**

[If yes, provide information requested below and one copy of: 1) available toxicity data; 2) reports of animal studies; 3) description of studies done in humans; 4) concise review of the literature prepared by the investigator(s); and 5) the drug protocol.]

Name:

Dose:

Source:

How Administered:

IND Number:

Phase of Testing:

F. Will an investigational device be used? Yes or **No**

(If yes, provide name, source description of purpose, how used, and status with the U.S. Food and Drug Administration FDA). Include a statement as to whether or not device poses a significant risk. Attach any relevant material.)

G. Will academic records be used? Yes or **No**

H. Will this research involve the use of:

Medical, psychiatric and/or psychological records Yes or **No**

Health insurance records Yes or **No**

Any other records containing information regarding personal health and illness
Yes or **No**

If you answered "Yes" to any of the items under "H.", you must complete the **HIPAA worksheet.**

I. Will audio-visual or tape recordings or photographs be made? **Yes** or No

The driving behavior will be recorded in video tape to see actual startle response in face. The recordings will be stored in computer with password protection

J. Will written consent form(s) be used? **Yes** or No

(If no, explain.)

APPENDIX B

SIMULATOR SICKNESS PRE-SCREENING FORM

SIMULATOR SICKNESS PRE-SCREENING QUESTIONNAIRE

A. This study will require you to drive in a simulator. In the past, some participants have felt uneasy after participating in studies using the simulator. To help identify people who might be prone to this feeling, we would like to ask the following questions.

- Do you or have you had a history of migraine headaches? yes no
If yes, please describe: _____

- Do you or have you had a history of claustrophobia? yes no
If yes, please describe: _____

- Do you or have you had a history of frequent or severe motion sickness? yes no
If yes, please describe: _____

- Do you or have you had a history of any health problems (e.g., seizures, diabetes, heart problems, vertigo) that affect your ability to drive? yes no
If yes, please describe: _____

- If you are a female, are you or is there a possibility that you might be pregnant? yes no

The investigator has explained to me that I may be at a higher risk for problems related to simulator exposure.

Subject Initials Date Investigator Initials

B. Please tell us how you feel right now. Are you experiencing any of the following?

Eye Strain:	<input type="checkbox"/> none	<input type="checkbox"/> slight	<input type="checkbox"/> moderate	<input type="checkbox"/> severe	
Temperature increase:	<input type="checkbox"/> none	<input type="checkbox"/> slight	<input type="checkbox"/> moderate	<input type="checkbox"/> severe	
Dizziness:	<input type="checkbox"/> none	<input type="checkbox"/> unsteady	<input type="checkbox"/> slight	<input type="checkbox"/> moderate	<input type="checkbox"/> severe
Headache:	<input type="checkbox"/> none	<input type="checkbox"/> lightheaded	<input type="checkbox"/> slight	<input type="checkbox"/> moderate	<input type="checkbox"/> severe
Nausea:	<input type="checkbox"/> none	<input type="checkbox"/> uneasy	<input type="checkbox"/> slight	<input type="checkbox"/> moderate	<input type="checkbox"/> severe

*Part A. If a participant answered Yes to any of the questions above, indicate to them they may be at a higher risk for problems resulting from simulator exposure (may trigger migraines for migraine sufferers, the confined space may be a challenge for claustrophobics, and motion sickness may be exacerbated.) **If a subject answered Yes to two or more questions, they will not be eligible to participate.** Ask subject to initial and date this form. Attach to signed consent form.*

Part B. If participant answers **slight or higher to two or more questions**, they should not participate today.

APPENDIX C

POST-EXPERIMENT SIMULATOR INDUCED DISCOMFORT FORM

POST-EXPERIMENT SIMULATOR INDUCED DISCOMFORT QUESTIONNAIRE

There is a small risk associated with driving in the driving environment simulator. The driver may experience feelings of dizziness and increased body temperature, which are symptoms of a temporary condition called 'Simulator Induced Discomfort' (SID).

To verify the extent of SID occurrence, we are tracking the severity of any discomfort felt by those who drive in the driving environment simulator.

Sex:

male

female

Age: _____

Are you wearing prescription glasses or contact lenses?

no

glasses

contact lenses

What is your exposure to the driving environment simulator?

first time

second time

more than two times

Please tell us how you feel right now. Are you experiencing any of the following?

Eye Strain: none slight moderate severe

Temperature increase: none slight moderate severe

Dizziness: none unsteady slight moderate severe

Headache: none lightheaded slight moderate severe

Nausea: none uneasy slight moderate severe

If the participant answers slight or higher to two or more questions, they should not continue.

APPENDIX D

STUDENT CONSENT FORM _ PHASE I

STUDENT CONSENT FORM
PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Active Muscles during Driving

INTRODUCTION

You are being asked to participate in a study to examine the startle/panic responses perceived by human drivers. You will be asked to drive through a scenario of rural road for approximately 15 minutes in the driving simulator with electromyography (EMG) electrodes attached to the upper and lower extremities of the body.

PROCEDURE

If you agree to participate, you will then practice to drive in a high-fidelity driving simulator. After a rest period, then you will be attached with EMG electrodes on the upper and lower extremities of the body which will be connected to a data acquisition box to collect the EMG data. Then you will be asked to drive through a scenario of rural road for approximately 10 minutes. During this session you will be asked to wear loose clothes to ensure necessary space to attach EMG in your body. A female investigator will be allotted to place EMG electrodes for female participants and male investigator will be allotted to place EMG electrodes for male participants.

RISKS

The risks involved in participating in this study are 1) you might feel dizziness due to driving in a simulator 2) you might feel soreness or itching in muscles where EMG will be kept.

BENEFITS

There is no direct benefit other than experience with driving a simulator and the research process.

PARTICIPATION

Study participation is voluntary. The decision by you to not participate in this study will not impact your future relationship with MSU. You will be able to withdraw from the study at any time and for any reason without penalty.

INJURY AND COMPENSATION

No special medical arrangements have been made regarding participation in this study. In the event of your participation results in injury, appropriate emergency personnel will be contacted. However, there is no compensation available for injury; you are responsible for all medical costs. Further, information may be obtained by contacting Robert Marley at 406-994-2272 or principal investigator, Anburaj Muthumani at 406-600-7719

CONFIDENTIALITY

Your confidentiality will be fully protected. You will be assigned a code number and all measures will be catalogued under that number instead of your name. All records by which a given participant can be related to the code number will be kept in a locked file. Your driving performance scores will only be reported as group averages.

CONSENT

You are welcome to ask any questions about this study and its procedures prior to consenting to participate. Additional questions about human subject research and protection can be answered by the Chairman of the Institutional Review Board, Mark Quinn, and (406) 994-4707.

AUTHORIZATION:

I have read the above and understand the discomforts, inconvenience, and risk of this study.

I, _____ (print Name), agree to participate in this research. I understand that I withdraw from the study at any time. I agree to comply with the requirements of the study protocol. I have received a copy of this consent form records.

SIGNED: _____

INVESTIGATOR: _____

DATE: _____

APPENDIX E

STUDENT CONSENT FORM _ PHASE II

STUDENT CONSENT FORM
PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Responses of driver to sudden warnings in roadway lane departure

INTRODUCTION

You are being asked to participate in a study to examine the startle/panic responses perceived by human drivers. You will be asked to drive through a scenario of rural road for approximately 15 minutes in the driving simulator with electromyography (EMG) attached to the upper and lower extremities of the body.

PROCEDURE

If you agree to participate, you will take part in four experimental sessions. Each experimental session will last approximately for 30 minutes.

Prior to start of the experiment you will practice to drive in a high-fidelity driving simulator. After a rest period, you will be attached with EMG electrodes on the upper and lower extremities of the body which will be connected to a data acquisition box to collect the necessary data. Then you will be asked to drive several sessions through a scenario of rural road for approximately 10 minutes each.

During each session you will be asked to wear loose clothes to ensure necessary space to attach EMG in your body. A female investigator will be allotted to place EMG electrodes for female participants and male investigator will be allotted to place EMG electrodes for male participants. At the end of the final session you will be filling a questionnaire about your experience. Total participation time is approximately 2 hours.

RISKS

The risks involved in participating in this study are 1) you might feel dizziness due to driving in a simulator 2) you might feel soreness or itching in muscles where EMG will be kept.

BENEFITS

There is no direct benefit other than experience with driving a simulator and the research process.

PARTICIPATION

Study participation is voluntary. The decision by you to not participate in this study will not impact your future relationship with MSU. You will be able to withdraw from the study at any time and for any reason without penalty.

INJURY AND COMPENSATION

No special medical arrangements have been made regarding participation in this study. In the event of your participation results in injury, appropriate emergency personnel will be contacted. However, there is no compensation available for injury; you are responsible

for all medical costs. Further, information may be obtained by contacting Robert Marley at 406-994-2272 or principal investigator, Anburaj Muthumani at 406-600-7719

CONFIDENTIALITY

Your confidentiality will be fully protected. You will be assigned a code number and all measures will be catalogued under that number instead of your name. All records by which a given participant can be related to the code number will be kept in a locked file. Your driving performance scores will only be reported as group averages.

CONSENT

You are welcome to ask any questions about this study and its procedures prior to consenting to participate. Additional questions about human subject research and protection can be answered by the Chairman of the Institutional Review Board, Mark Quinn, and (406) 994-4707.

AUTHORIZATION:

I have read the above and understand the discomforts, inconvenience, and risk of this study.

I, _____ (print Name), agree to participate in this research. I understand that I withdraw from the study at any time. I agree to comply with the requirements of the study protocol. I have received a copy of this consent form records.

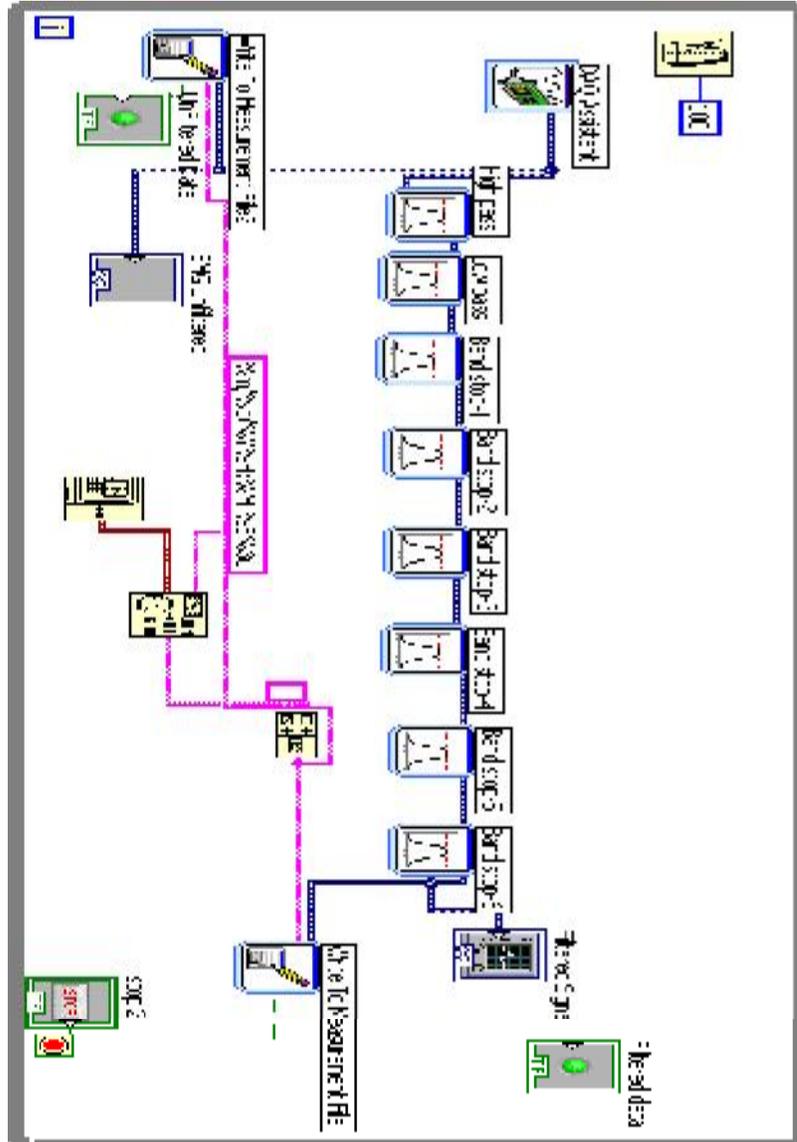
SIGNED: _____

INVESTIGATOR: _____

DATE: _____

APPENDIX F

LABVIEW FILTERING PROCESS CODE



APPENDIX G
LABVIEW TCL CODE

