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## Quantification of Stabilization Efforts of Shoulder Muscles using Surface Electromyography

Hamad Nasser Alasim

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# **Quantification of Stabilization Efforts of Shoulder Muscles using Surface Electromyography**

**Hamad Nasser Alasim**

Thesis submitted to the Benjamin M. Statler College of  
Engineering and Mineral Resources at  
West Virginia University in partial fulfillment  
of the requirement for the degree of

**Master of Science  
in  
*Industrial Engineering***

Ashish D. Nimbarte, Ph.D., Chair  
Majid Jaridi, Ph.D.  
Xiaopeng Ning, Ph.D.

**Department of Industrial and Management Systems Engineering**

Morgantown, West Virginia

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## **ABSTRACT**

### **Quantification of Stabilization Efforts of Shoulder Muscles using Surface Electromyography**

**Hamad Nasser Alasim**

Shoulder musculoskeletal disorders (MSDs) put a huge burden on both employers and employees due to lost work days, healthcare costs and human suffering. Static and heavy industrial work, submaximal repetitive movement and arm elevation are frequently associated with shoulder MSDs. Previous studies indicated that factors such as force exertion levels, posture and hand gripping can influence the activation and fatigability of shoulder muscles. In this study, we explored the inter-muscle difference in shoulder activation during isometric/static force exertions. We suspected that shoulder muscles' attempt to stabilize the glenohumeral joint using the concavity compression mechanism may explain differences in the muscle activation pattern during shoulder exertions. Ten right-hand dominant male participants performed a 60 second static shoulder exertion using three force levels (10, 7.5 and 5 lbs.) in five directions (back, down, left, right and up). Results showed that muscle activity and fatigability were affected by force level and force exertion direction. Muscle exertion and fatigability were highly affected by 10lbs. force exertion. The findings of this study suggest that, during static shoulder exertion, pulling in up and right directions result in the highest muscle activity and fatigability.

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## List of Acronyms

MSD	Musculoskeletal Disorders
GHJ	Glenohumeral joint
ACJ	acromioclavicular joint
SCJ	sternoclavicular joint
MVC	Maximum Voluntary Contraction
EMG	Electromyography
SEMG	Surface electromyography
PB	Pulling up
PD	Pulling down
PL	Pulling left
PR	Pulling right
PU	Pulling up
MF	Median frequency
M	Slope value
TM	Total slope value
MAV	Mean absolute value
NMAV	Normalized mean absolute value
TNMAV	Total normalized mean absolute value
PAR-Q	Physical activity readiness questionnaire
SD	Standard deviation
ANOVA	Analysis of variance
lbs.	Pound

## Chapter 1: Introduction

Shoulder musculoskeletal disorders (MSDs) put a huge burden on both employers and employees due to lost work days, healthcare costs and human suffering. The Bureau of Labor Statistics (BLS) reported that in 2012 over 27,000 shoulder-related occupational injuries and illnesses caused a day or more away from work, with a median of 12 lost days (BLS, 2014). The cost per shoulder MSD claim varies from a few hundred to several thousand dollars. In a recent report on worker compensation data in the state of Maryland, it was reported that the cost per shoulder injury was higher, averaging \$25,378 per claim compared to the average cost of \$22,447 per lower back injury claim. Several Permanent Partial Disability (PPD) awards due to shoulder injuries were also reported, with costs ranging between \$253,230 (against Montgomery County Board of Education) and \$307,286 (against Browning Ferris Industries) (Warnken, 2012). The exact nature of the injuries was unknown for legal reasons.

Static and heavy industrial work, submaximal repetitive movement and arm elevation are some of the activities which are frequently associated with shoulder MSDs (Alizadehkhayat et al., 2011). Specialty trade contractors, food manufacturing, building material and garden equipment and supplies dealers, air transportation, warehousing and storage, nursing and residential care facilities are the occupations with the highest number of workers suffering from shoulder MSDs (BLS, 2014).

Most of the existing studies that deal with the prevention of shoulder MSDs primarily focus on evaluating the effects of stress (due to work-related factors such as force, posture and repetition) on internal shoulder strain measured using pain/discomfort, muscle activation and joint loading. A few such studies are reviewed in the next chapter. The results of these studies indicate that the

shoulder strain is affected by a multitude of factors including the magnitude of force exertion, direction of force exertion, posture used, nature of exertion (static vs. dynamic) etc. All these studies are valuable and add to the body of knowledge on shoulder MSD prevention. However, there is a lack of research on workplace assessment/evaluation tools that can predict the risk of shoulder MSDs.

Developing a workplace assessment/evaluation tool for shoulder joints is challenging for several reasons. The shoulder is the most complex, yet most mobile, part of the human body, the joint is susceptible to injury due to repetitive submaximal exertion as well as heavy forceful arm exertion and there is a lack of research on how this joint is stabilized during physical workplace exertions. One study, focused on concavity compression, a shoulder stabilizing mechanism, to develop a strain index (Cutlip, 2014). A biomechanical model of the shoulder complex was used to develop the strain index. Biomechanical models provide good approximations; however, they exhibit several limitations due to their lack of physiological realism. Cutlip (2014) showed a reasonably strong relationship between the strain index and the ratings of perceived exertion. The purpose of this study was to further evaluate the role of concavity compression in shoulder stabilization using physiological data. Specifically, the activation pattern of the shoulder muscles was studied by using surface electromyography.

## Chapter 2: Background and Literature Review

The shoulder complex consists of three joints including the glenohumeral joint (GHJ), acromioclavicular joint (ACJ) and sternoclavicular joint (SCJ) (Figure 1). While most of these joints provide passive strength to the shoulder complex, the GHJ is responsible for the motion of the shoulder during workplace exertions. The GHJ is a ball-and-socket joint between the humeral head and the scapula's glenoid fossa. The surface of the glenoid fossa is only one third of the humeral head, meaning a small part of the humeral head is in contact with the glenoid fossa in any position of the joint. In order to maintain the stability of the GHJ, the humeral head must be held against the glenoid fossa. The shoulder muscles compress the humeral head while providing forces to compensate the moment due to the application of external force. This mechanism, which compresses the humeral head against the glenoid fossa, is called the concavity compression mechanism (Figure 2). The muscles have to resist the translational forces which push the humeral head away from the glenoid fossa to facilitate concavity compression.

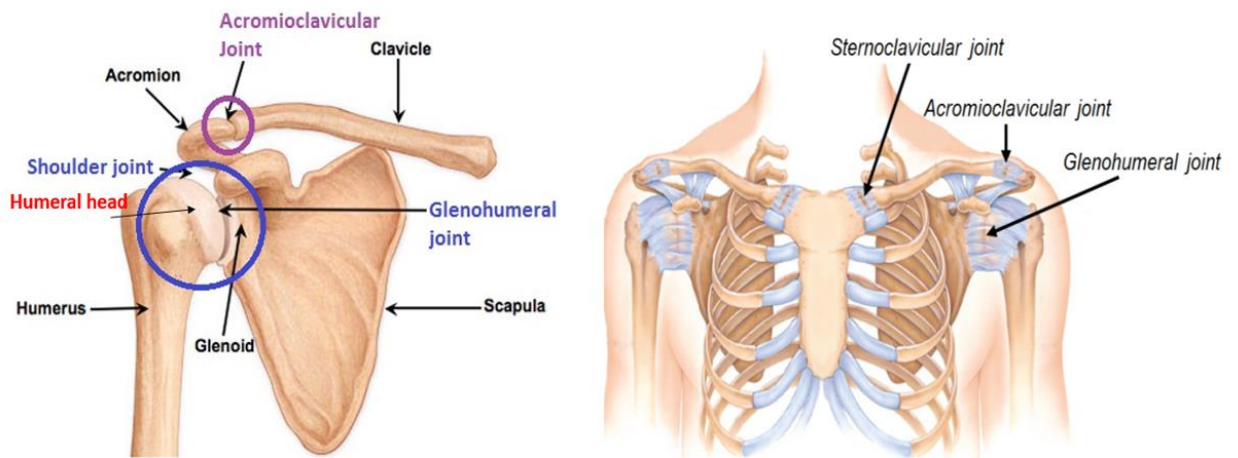
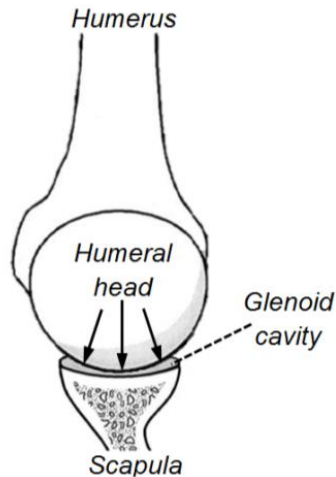


Figure 1: Human shoulder complex (Cutlip, 2004).



*Figure 2: Concavity compression mechanism (Cutlip, 2014).*

There are several muscles that are activated during exertions performed by the shoulder complex. The deltoid muscles (anterior, middle and posterior) are considered primary shoulder movers during elevation and abduction. The rotator cuff muscles include supraspinatus, infraspinatus, teres minor, teres major and subscapularis play a multifunctional role in achieving shoulder mobility and stability. They are referred as the dynamic ligaments of the GHJ (Müntener, 1982). The infraspinatus and subscapularis play major roles in scapular plane abduction, generating forces equal to three times the supraspinatus force (Escamilla et al., 2009). The biceps brachii and triceps brachii are the arm muscles that enter into the shoulder complex and facilitate upper and lower arm motions during shoulder exertions. The trapezius is a shoulder elevator muscle that also participates in the rotation of the scapula to extend the reach upwards.

Among these muscles, the rotator cuff muscles are considered the primary GHJ stabilizing muscles. These muscles not only facilitate the dynamic motion of the GHJ, but also add to the passive stability of the shoulder due to their location and orientation around the GHJ. The rotator cuff muscles are located closer to the center of GHJ rotation and act in association with the

underlying capsular ligament structures to resist GHJ shear stresses. Individual rotator cuff muscles have independent actions that, in combination, contribute to the overall stability of the GHJ during the mid- and end-ranges of motion (Lugo et al., 2008). Wuelker et al., (1998) found that when forces from rotator cuff muscles decreased by 50%, it will result in a roughly 50% increase in displacement of the humeral head anterior in response to external loading at all GHJ positions. Itoi et al. (1993) found that biceps brachii muscle activity could also assist in GHJ stability. Lee (2003) measured deltoid muscle activity interaction with GHJ stability. He found that in the scapular plane, and with 60° of glenohumeral elevation, GHJ stability increased because of deltoid activity. In the coronal plane, with 60° glenohumeral elevation, the GHJ stability decreased because of deltoid activity.

A few studies have looked at the activity of shoulder muscles by simulating static workplace exertions. Sporrang et al (1995, 1996) performed studies to evaluate the activity of shoulder muscles during hand gripping tasks. The muscles studied were the supraspinatus, infraspinatus, the middle portion of the deltoid and the descending part of the trapezius. Human participants performed hand gripping tasks at 30% and 50% of maximal voluntary contraction levels using a hand dynamometer in eight postures characterized by shoulder flexions of 30°, 60°, 90° and 120° in the sagittal plane and abduction of 30°, 60°, 90° and 120° in the scapular plane. The EMG activity of the muscles was compared with and without hand gripping. It was observed that the hand gripping significantly increased the activity of the supraspinatus muscle in humeral flexion from and above 60° degrees. A similar but smaller increase was observed for the infraspinatus muscle. For the deltoid muscles, an increase in activity was observed for positions lower than 90°; in higher arm positions, a decrease in activity was observed. The gripping task had no effect on the activity of the trapezius muscle.

In a similar study, Antony and Keir (2010) evaluated the effect of load and gripping forces on the activity of shoulder muscles. Fifteen postures, characterized by abduction angles of 0°, 30°, 60°, 90° and 120° in the sagittal, frontal and mid-sagittal frontal planes, were studied. It was observed that the load in the hand increased activity of most of the shoulder muscles. During gripping exertion, an increase in activity was observed for the infraspinatus, trapezius, and biceps brachii muscles. A decrease in activity was observed among anterior and middle deltoid muscles. A similar conclusion regarding an increase in activity of the supraspinatus and infraspinatus muscles during a gripping task was also reported by Alizadehkhayat et al. (2011). In their study, muscle activity was measured in a standardized sitting and arm position using fine-wire electrodes during a controlled gripping task at 50% of maximum voluntary contraction (MVC).

Brookham et al. (2010) studied the effect of different postures during light tool usage and forward pushing exertion on the activity of shoulder muscles. Fifteen postures characterized by shoulder flexion angles of 0°, 60°, 70°, 80° and 90° in three shoulder rotations (humeral rotations), -45°, 0° and 45°, were evaluated. The muscles studied were the right superior, middle and inferior trapezius, all deltoid portions, pectoralis major, infraspinatus and latissimus dorsi. To simulate hand tool use, a gripping task at 30% MVC was performed and a force of  $13 \pm 2$  N was used for the forward pushing exertion. All tasks were performed in a seated position with shoulder abduction and elbow flexion maintained at 90°. In general, an increase in the shoulder flexion angle was associated with an increase in muscle activation. The postures with internal and external rotation influenced the activity of the inferior trapezius muscle more than other muscles.

Several other studies on shoulder muscle activation looked at fatigue development due to workplace alike exertions. Takala et al (1993) investigated the relationship between holding time and EMG changes. The study participants held a suspended weight using 90° arm abduction in

the sagittal plane until exhaustion. Male participants held a different weight than female participants (4 kg for men and 2.5 kg for women). Larger EMG changes were observed in male participants than in female participants. The infraspinatus and anterior deltoid muscles showed faster EMG changes and signs of fatigue than the upper trapezius. Minning et al. (2007) also reported similar findings regarding faster fatigue development of the deltoid muscle compared to other shoulder muscles. The upper trapezius, middle deltoid, serratus anterior and lower trapezius muscles were investigated in their study. The participants performed static lifting tasks at 90° arm elevation using 60% MVC load until exhaustion. Kai et al. (2012) compared the fatigability of the infraspinatus and deltoid muscles during resisted arm elevation (30% MVC) performed at various postures in the sagittal and scapular planes. Faster fatigue development was observed for the infraspinatus in the sagittal plane than in the scapular plane.

Arwert et al., (1997) studied the relation between electromyography of shoulder muscles and force direction while performing static exertions. Fourteen muscles including supraspinatus, infraspinatus, teres major, all deltoid and latissimus dorsi were studied. Three postures were used: 90° scapular shoulder abduction with 90° elbow flexion and forearm in horizontal position; 90° anteflexion of the humerus shoulder abduction with 90° elbow flexion and forearm in horizontal position; 90° anteflexion of the humerus shoulder abduction with 90° elbow flexion and forearm in vertical position. 14 N was the exerted force for 3 seconds in all eight force directions (0° ,45° ,90° ,135° ,180° ,225° ,270° ,315°). A relationship found between teres major and latissimus dorsi muscles since they have been activated simultaneously. Teres major and latissimus were active in downward and forward forces. Rotator cuff muscles and all deltoid muscles role in stabilizing the glenohumeral joint was obvious from the continues activation during exertion.



In summary, existing studies indicate that factors such as force exertion level, posture and hand gripping influence the activation and fatigue of shoulder muscles. Different muscles exhibit different activation and fatigue patterns depending on the conditions of posture, force and hand gripping used. However, no previous study clearly explained the inter-muscle difference in the activation or fatigability pattern when subjected to different demands (work/exertion). It was suspected that shoulder muscles' attempt to stabilize the GHJ using concavity compression may explain the differences in muscle activation pattern during arm exertions. This forms the basis for conducting this study. In this study, the SEMG data recorded from shoulder muscles was examined to understand their role in stabilizing the shoulder using concavity compression.

## **Chapter 3: Study Rationale**

### **3.1 Problem Statement**

The socioeconomic impact of shoulder MSDs is huge in terms of lost work days, lost productivity and healthcare costs. Shoulder MSDs are prevalent among workers in several occupations including, but not limited to, nursing, material handling, janitorial work, transportation and manufacturing. Despite the high socioeconomic impact and widespread occurrence of shoulder MSDs, currently no workplace assessment/evaluation tool exists that can predict the risk of developing these MSDs. Such a tool could prove beneficial to preventing work-related shoulder MSDs. However, development of a workplace assessment/evaluation tool is a long, multi-step process.

The long-term goal of the research proposed in this study is to aid in the development of a workplace assessment/evaluation tool. Results of a previous study (Cutlip, 2014) showed some promise in utilizing concavity compression, a shoulder stabilizing mechanism, as a governing mechanism in developing such a tool; however, the problem with the previous study (or problem statement for this study) is that the findings heavily relied on the outputs of a biomechanical model and lacked comparison with true physiological data. Therefore, the purpose of this study is to further evaluate concavity compression as a suitable governing mechanism in developing a workplace assessment/evaluation tool by utilizing true physiological (muscle activation) data.

## 3.2 Objective and Hypotheses

The main objective of this research is to study the shoulder muscle activation pattern during static arm exertions. The arm exertions were performed in five directions: pulling right (PR), pulling left (PL), pulling back (PB), pulling down (PD) and pulling up (PU). Three force exertion levels were used: 5 lbs., 7.5 lbs. and 10 lbs. The muscle activation pattern was used to quantify joint loading and fatigue development.

The following hypotheses were tested in this study:

Null hypotheses:

H<sub>01</sub>: The direction of force exertion has no effect on the muscle activation pattern and fatigability.

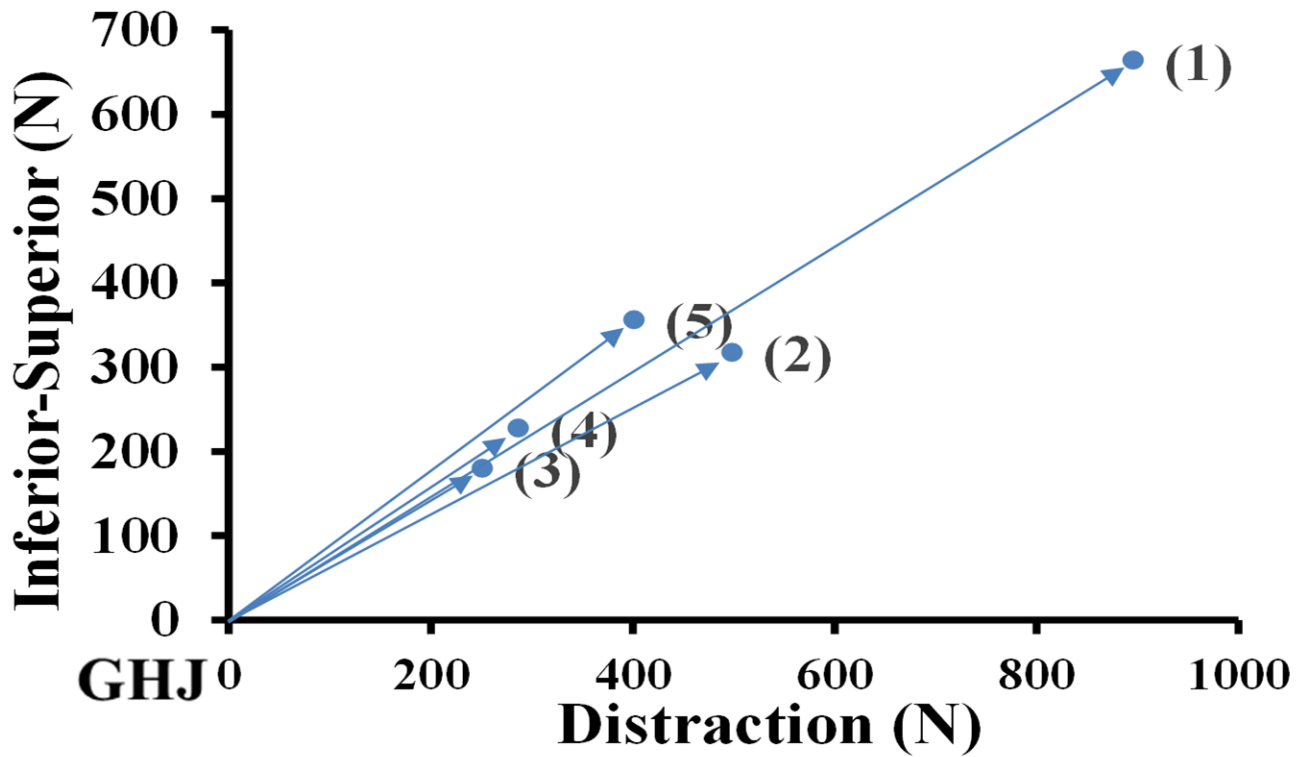
H<sub>02</sub>: The magnitude of force exertion has no effect on the muscle activation pattern and fatigability.

H<sub>03</sub>: The direction and magnitude of force exertion have no interaction effect on the muscle activation pattern and fatigability.

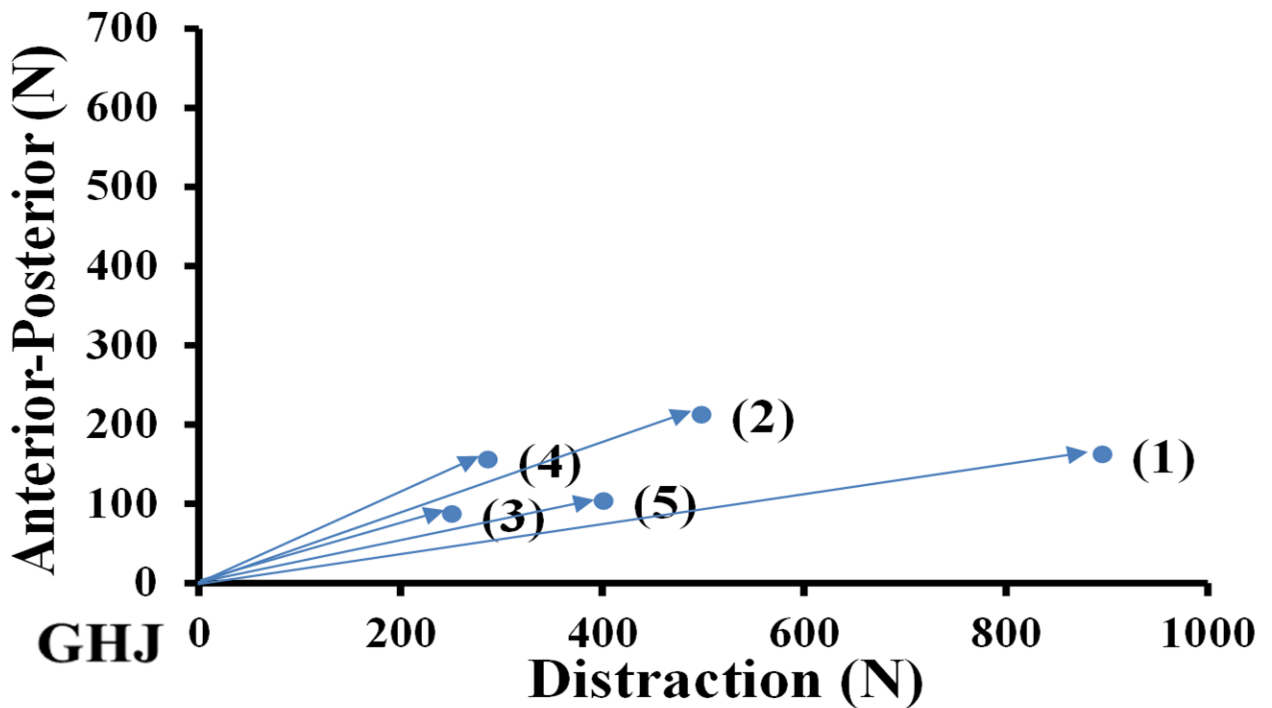
Alternate hypotheses:

The results from a previous study (Cutlip, 2014) were summarized in Figure 3. The vectors in this figure represent locations of the resultant force vectors at the GHJ in the frontal and transverse planes. It can be observed from the figure that the orientation and magnitude of these vectors is affected by the direction of force exertion. Thus, based on these findings, the following alternate hypotheses will be tested:

H<sub>A1</sub>: The direction of force exertion has an effect on the muscle activation pattern. Specifically, pulling exertions performed in the right direction will result in the highest muscle loading and faster fatigue development, followed by the exertions performed in the up and left directions.



1) pulling right, 2) pulling left, 3) pulling back, 4) pulling down and 5) pulling up.



1) pulling right, 2) pulling left, 3) pulling back, 4) pulling down and 5) pulling up.

Figure 3: Force magnitude for frontal and transverse plane.

The lowest muscle loading and slow fatigue development were observed for pulling exertions performed in the back and down directions.

H<sub>A2</sub>: The magnitude of force exertion has an effect on the muscle activation pattern and fatigability.

H<sub>A3</sub>: The direction and magnitude of force exertion have interaction effect on the muscle activation pattern and fatigability.

## **Chapter 4: Methodology**

### **4.1 Approach**

A laboratory-based study was performed to quantify the effect of static arm exertions on the shoulder muscle activation pattern. Human subjects performed static arm exertions in five directions using three different weights. SEMG data was recorded from nine shoulder muscles. The SEMG data were used to quantify shoulder muscle loading and fatigue. The relationship between muscle loading and fatigue and the concavity compression vector were evaluated by testing the SEMG data.

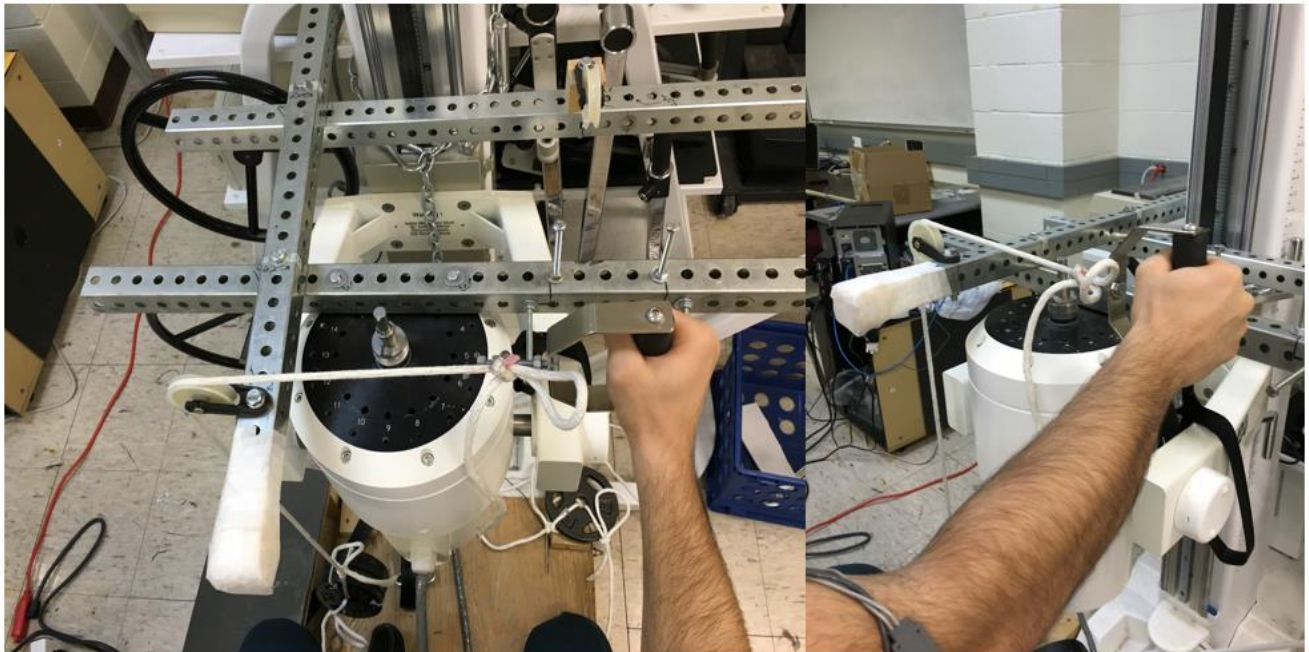
### **4.2 Participants**

Ten healthy, right-hand dominant male participants between the ages of 18 and 40 were recruited for the study. The primary inclusion criteria for this study required that the participants were free from any type of musculoskeletal, degenerative or neurological disorder and that they had neither a history of shoulder pain nor any current pain. The Physical Activity Readiness Questionnaire (PAR-Q, Canadian Society for Exercise Physiology) (Appendix A) was used to screen participants for cardiac and other health problems (e.g., dizziness, chest pain and heart trouble). Participants who met the inclusion criteria were asked to read and sign a consent form approved by the local Institutional Review Board (Appendix B).

## 4.3 Equipment

### 4.3.1 Custom-Made Force Exertion Device

This device consists of a wooden chair equipped with a four-point harness to secure participants in a standard sitting posture. The chair was attached to a column and base assembly, and the column was fitted with a height-adjustable base. A peripheral assembly consisting of a set of perforated steel tubes was attached to this base, and several pulleys were mounted on the perforated steel tubes. Rope was used to hang weights of different magnitudes from the pulleys, and human participants pulled the other end of the rope using a D-handle. A set of perforated steel tubes and pulleys allow the experimenter to control the direction of pulling. Different weights can be attached to the rope to control the magnitude of force exertion. Figure 4 and Figure 5 can illustrate the experiment setup.



*Figure 4: Experiment device while performing pulling right (PR) task.*

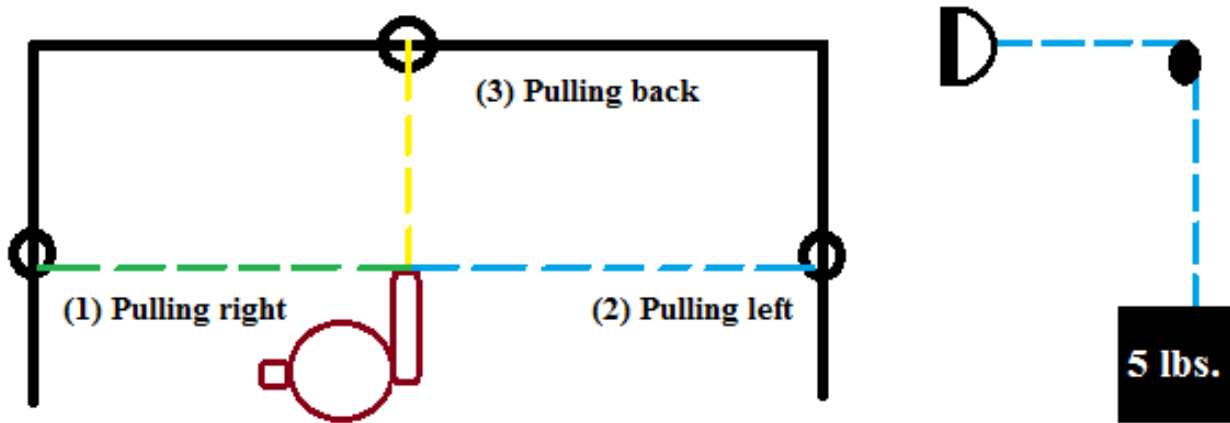


Figure 5: Upper view for experiment device shows (PR, PL and PB) tasks.

#### 4.3.2 Surface Electromyography (SEMG) system

EMG signals were used to study muscle activation pattern by analyzing the electrical signal generated during muscular contractions (Acierno et al., 1995). EMG data can be recorded using surface or intramuscular EMG electrodes. The surface electrodes are employed when collecting data from superficial muscles. In the current study, surface electrodes were used to record EMG data from shoulder muscles.



Figure 6: Telemyo 2400 T G2 EMG system receiver and transmitter.



A Telemetry 2400 T G2 EMG system (Noraxon Inc., AZ, USA) was used for data collection. The system consists of a Telemetry 2400R G2 receiver (Figure 6), Telemetry 2400T G2 transmitter with 16 channels (Figure 6), pre-amplified lead wires (Figure 7) and disposable, self-adhesive Ag/AgCl snap/clips electrodes (Figure 7). The bipolar Ag/AgCl pre-gelled surface electrodes were of 1 cm diameter, with an inter-electrode distance of 2 cm. The pre amplifier on the lead wires has a band-pass of 10-1000 Hz (gain of 500), CMRR >100 dB and input impedance >100 M $\Omega$ . The electrodes were attached to the pre-amplified lead wires and then connected to the Telemetry 2400T G2 transmitter. The Telemetry 2400T G2 transmitter was mounted on the participants using a pouch and belt clip. The G2 transmitter transmitted the EMG data wirelessly to the Telemetry 2400R G2 receiver. The system can sample EMG data at a frequency of up to 1500 Hz.



*Figure 7: Pre-amplified lead wires and Ag/AgCl snap/clips electrodes.*

#### **4.4 Experimental Design**

A two-factor replicated block design was used in this research. Factor 1, direction of force exertion, was treated at five levels: PR, PL, PB, PD and PU. Factor 2, force exertion level, was treated at three levels: 5 lbs., 7.5 lbs. and 10 lbs.

The force exertion levels were obtained based on the findings of preliminary testing. During this testing we found that forces greater than 10 lbs. were very difficult to pull in certain directions. We also found that forces not greater than 2 lbs. were not perceived differently by the human participants. Therefore, a force difference of 2.5 lbs. was maintained between the force exertion levels. The duration of each exertion was controlled at 60 seconds. This trial length was determined based on the findings of the preliminary study. Over 60 seconds, the participants had trouble pulling in certain directions.

Two repetitions were collected for each experimental condition. Thus, each participant performed 30 experimental trials (5 directions  $\times$  3 weights  $\times$  2 repetitions). The trial order was randomized. Rest periods of up to two minutes were provided between experimental trials.

#### **4.5 Muscle Selection**

Based on previous SEMG studies on the shoulder complex and the role of individual muscles in shoulder stabilization, the following nine shoulder muscles were tested in this study: the supraspinatus, infraspinatus, teres major, anterior deltoid, middle deltoid, posterior deltoid, biceps, triceps and latissimus dorsi were studied. It is very important to select the appropriate muscles which have the highest activation in shoulder task. According to few studies that include shoulder static exertions and shoulder stability, the supraspinatus and infraspinatus were the major rotator cuff muscles. The deltoid, biceps and triceps muscles played important roles in stabilizing the shoulder joint during static arm exertions. (Hawkes et al., 2015; Itoi et al., 1993).

## 4.6 Experimental Data Collection Procedure

After participants arrived to the laboratory, they were provided with a tour of the experimental setup. Equipment, data collection procedures and specifics of the experimental tasks were explained to the participants, and their signatures were obtained on a consent form approved by the local Institutional Review Board (Appendix B). A set of anthropometric measures such as height, weight and age were recorded for each participant. After that, EMG data collection preparation began. Participants prepared for EMG data collection by shaving the skin in the areas where SEMG electrodes were placed and then rubbing and cleaning the skin with 70% alcohol prior to the placement of the electrodes. Table 1 shows the electrode location for the shoulder muscles. Next, the MVCs were recorded for each muscle. Table 2 describes the exertion used to record the MVC for each muscle.

Participants then began the experimental trials. They were seated and secured into the wooden chair of the force exertion device using the four-point harness. A few practice trials were then performed to get the participants acquainted with the setup. During the actual trials, the position of the pulley, rope and D-handle were adjusted such that the participant could grasp it using a 15- 20° flexed elbow joint and a 70- 80° flexed shoulder joint. In each trial, participant was required to hold a D-shape handle attached to one of the weight levels which are (10, 7.5, 5 lb.) for 60 second with a 15°- 20° flexed elbow joint and a 70°- 80° flexed shoulder joint. participant performed this task in five different directions which are right, left, front, up and down. Each trial had two repetitions. A 2 minutes' rest time was provided between trials. A total of 30 trials were performed. The SEMG data was recorded continuously during the exertion. In addition, after the completion of each exertion, the participants were asked to numerically rate their perceived exertion using Borg's CR-10 scale (Appendix C). The Borg CR-10 scale contains

two columns: one for subjective categories ranging from “nothing at all” to “extremely strong” and the other for numerical ratios ranging from 1 to 10 that are associated with the different categories.

*Table 1: EMG locations of shoulder muscles.*

	<b>Muscle</b>	<b>Electrodes position</b>
<b>1</b>	Supraspinatus	Midpoint and two fingers-breadths anterior to the scapular spine.
<b>2</b>	Infraspinatus	Midpoint and two fingers-breadths below and parallel to the scapular spine.
<b>3</b>	Teres Major	Middle of the muscle belly.
<b>4</b>	Anterior deltoid	Two to three fingers- breadths below the acromion process, over the muscle belly, in line with the fibers.
<b>5</b>	Middle deltoid	Midline of the lateral surface of the arm, one fourth of the distance between the acromion and the elbow.
<b>6</b>	Posterior deltoid	Two fingers-widths behind the angle of the acromion, over the muscle belly, in line with the fibers.
<b>7</b>	Biceps	Midpoint between the acromioclavicular and elbow joint.
<b>8</b>	Triceps	Midpoint between acromion of the scapula and the ulna olecranon.
<b>9</b>	Latissimus dorsi	Approximately 4 cm below the inferior tip of the scapula, half the distance between the spine and lateral edge of the torso.

Table 2: MVC posture and action for each muscle.

	<b>Muscle</b>	<b>MVC posture</b>	<b>MVC action</b>
1	Supraspinatus	Arm will be abducted at 20 degrees in frontal plane; elbow will be flexed at 90 degrees; and no shoulder flexion.	Arm will be resisting the abduction, while subject will sit on a chair and will push against a wall.
2	Infraspinatus	Arm will be abducted at 50 degrees in frontal plane; elbow will be flexed at 90 degrees; and hand will be in 90 degrees pronation.	Arm will be resisting the External rotation of the shoulder.
3	Teres major	Arm will be abducted at 50 degrees in frontal plane; elbow will be flexed at 90 degrees; and hand will be in 90 degrees pronation.	Arm will be resisting the Internal rotation of the shoulder.
4	Anterior deltoid	Arm will be abducted at 20 degrees in frontal plane; elbow will be flexed at 90 degrees; and no shoulder flexion.	Arm will be resisting the horizontal flexion.
5	Medial deltoid	Arm will be abducted at 90 degrees in frontal plane; elbow will be flexed at 90 degrees; and no shoulder flexion.	Arm will be resisting the abduction.
6	Posterior deltoid	Arm will be abducted at 20 degrees in frontal plane; elbow will be flexed at 90 degrees; and no shoulder flexion.	Arm will be resisting the horizontal extension.
7	Biceps	No shoulder abduction; elbow will be flexed at 90 degrees; and hands will be supinated at 90 degrees.	Arm will be resisting the vertical flexion.
8	Triceps	No shoulder abduction; elbow will be flexed at 90 degrees; and hands will be supinated at 90 degrees.	Arm will be resisting the vertical extension.
9	Latissimus dorsi	Arm straight, abduct 30 degrees in the coronal plane, and internally rotated 45 degrees.	Extension and internal rotation.

## 4.7 Data Analysis

The EMG data were processed to estimate the following dependent variables (muscle load, muscle fatigue and subjective discomfort rating):

### 4.7.1 Muscle load

The raw SEMG data were filtered using 10 Hz to 400 Hz band pass filter and a 60 Hz notch filter to eliminate noise. The signal was demeaned and full wave rectified. The resulting signal were averaged to determine mean absolute values (MAV). The MAV data were normalized using EMG recorded during MVC exertion to determine normalized MAV (NMAV). The total muscle load during an exertion were estimated using the following equation:

$$NMAV_{total} = \sum_{i=1}^9 NMAV_i$$

Where,  $NMAV_i$  is the normalized activation of the  $i^{\text{th}}$  muscle. A total of 9 muscles are evaluated in this study. In addition to the total NMAV which is the summation of all muscles, each individual muscle load was considered as a dependent variable too.

### 4.7.2 Muscle fatigue

The time domain EMG data were transformed to frequency domain using fast Fourier transformation. Spectral analysis was performed using a window size of 5 seconds to estimate median frequency with a total of 12 windows. The median frequency data for each exertion was assumed to follow a linear regression data and fitted with linear regression line to estimate the

slope of the line ( $M_i$ ) (Dedering et al., 1999; Strimpakos et al., 2005; Hummel et al., 2005; Oliveira et al., 2009; Alizadehkhayat et al., 2011). Total muscle fatigue was estimated using the following equation:

$$M_{total} = \sum_{i=1}^9 M_i$$

In addition to the total M which is the summation of all muscles, each individual muscle M was considered as a dependent variable too.

For the dependent variable related to the subjective discomfort rating, data obtained from the individual participant after each trial was used.

#### 4.8 Statistical Analysis

This research evaluates the total muscle load and fatigue of shoulder muscles during static arm exertions performed in five different directions under three weight conditions. The following statistical model was used to study the effect of independent variables (direction) and load (weight) on the dependent variables:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + \varepsilon_{ijk} \begin{cases} i = 1, \dots, a \\ j = 1, \dots, b \\ k = 1, \dots, n \\ l = 1, 2 \end{cases},$$

Where:

$y$  represents the dependent variables related to muscle load, fatigue and discomfort ratings.

$\mu$  is the overall mean common to all treatments.

$\alpha_i$  is the effect of exertion direction (PR, PL, PB, PD and PU), so  $i = 1, 2, 3, 4, 5$ .

$\beta_j$  is the effect of load (weight) level at 5 lbs., 7.5 lbs., and 10 lbs., so  $j = 1, 2, 3$ .

$\gamma_k$  is the effect of participants (block), and represents the number of participants recruited in the study. Ten participants were recruited in this study, so  $k = 1, 2, 3 \dots 10$ .

$(\alpha\beta)_{ij}$  is the interaction effect of exertion direction and load level.

$\varepsilon_{ijk}$  is a random error term.

In this model, the exertion direction ( $\alpha_i$ ) and weight level ( $\beta_j$ ) are treated as fixed factors.

It was assumed that each factor and the two-way interaction factors have no effect on the muscle load and fatigue. That is:

$$\sum_{i=1}^a \alpha_i = 0, \quad \sum_{j=1}^b \beta_j = 0,$$

$$\sum_{i=1}^a \sum_{j=1}^b (\alpha\beta)_{ij} = 0.$$



Participants ( $\gamma_k$ ) were treated as a random factor that was assumed to be a normally and independently distributed (NID)  $(0, \sigma_y^2)$  random variable. The random error ( $\varepsilon_{ijk}$ ) was also assumed to also follow NID  $(0, \sigma^2)$ .

The appropriate F tests were applied in testing if the means of the fixed factor effects were equal to zero:

$$H_0: \alpha_i = 0, \beta_j = 0 \text{ and } (\alpha\beta)_{ij} = 0,$$

$$H_1: \text{at least one } \alpha_i \neq 0, \beta_j \neq 0 \text{ and } (\alpha\beta)_{ij} \neq 0.$$

In addition, F tests were performed in testing the hypotheses of the random factor,

$H_0: \sigma_\gamma^2$ . The Type I error probability,  $\alpha = 0.05$ , and power of the test  $(1-\beta)$ , which equals 0.90, were chosen for hypotheses testing and sample size determination. These were previously discussed in section 4.2.

Significant effects were further evaluated by conducting a comparison between means using Tukey's Honestly Significant Difference (HSD) all-pairwise comparison test. For fixed factors, such as direction of force exertion and load, when the null hypothesis was rejected then the factors' effects were estimated using Minitab 17 statistical analysis software (Minitab Inc., PA, USA).

### 4.8.1 Data Normality

The normality assumption for all dependent variables except for  $M_{supraspinatus}$  data was found to be not true. Therefore, the equality of variance test was performed. The equality of variance test was true for most of the dependent variables except for  $NMAV_{infraspinatus}$ ,  $NMAV_{middle\ deltoid}$ ,  $NMAV_{anterior\ deltoid}$ ,  $NMAV_{posterior\ deltoid}$ ,  $NMAV_{bicep}$ ,  $M_{teres\ major}$  and TM. See appendix (D). The dependent variables that met the equality of variance was analyzed using general linear ANOVA. If the sufficiency of the linear model was not affirmed by using normal probability plots of residuals between the raw data and fitted values, the Johnson transformation was applied (Table 3, Figure 8).  $M_{infraspinatus}$ ,  $M_{middle\ deltoid}$ ,  $M_{posterior\ deltoid}$ ,  $NMAV_{supraspinatus}$ ,  $NMAV_{teres\ major}$ ,  $NMAV_{triceps}$ , and  $NMAV_{latissimus\ dorsi}$  data did not meet the data normality distribution.

Table 3: Johnson transformation family.

Johnson Family	Transformation Function
SB	$\gamma + \eta \times \ln\left[\frac{(x - \varepsilon)}{(\lambda + \varepsilon - x)}\right]$
SU	$\gamma + \eta \times \sinh^{-1}\left[\frac{(x - \varepsilon)}{\lambda}\right]$ Where, $\sinh^{-1}(x) = \ln[x + \sqrt{1 + x^2}]$
SL	$\gamma + \eta \times \ln(x - \varepsilon)$

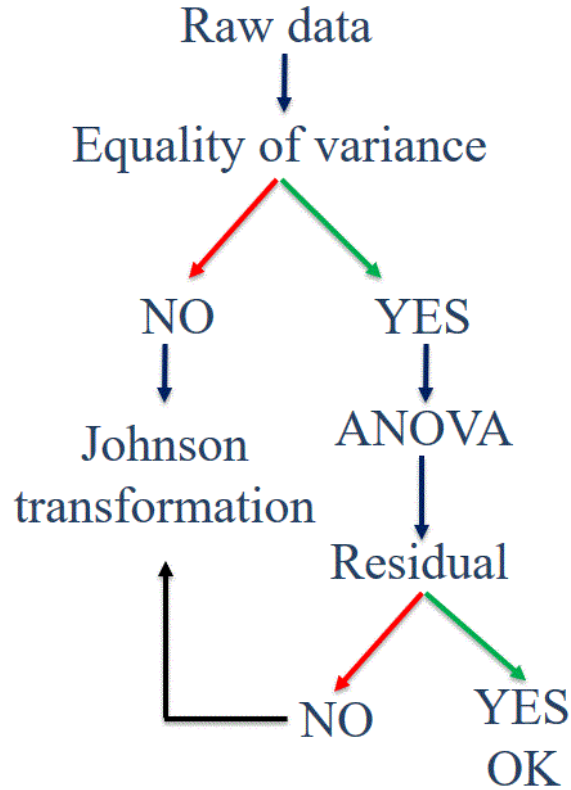


Figure 8: Illustration of the process used to perform statistical analysis.

Finally, the Johnson transformation was applied to the  $M_{infraspinatus}$ ,  $M_{teres\ major}$ ,  $M_{middle\ deltoid}$ ,  $M_{posterior\ deltoid}$ ,  $TM$ ,  $NMAV_{supraspinatus}$ ,  $NMAV_{teres\ major}$ ,  $NMAV_{anterior\ deltoid}$ ,  $NMAV_{posterior\ deltoid}$ ,  $NMAV_{bicep}$ ,  $NMAV_{tricep}$  and  $NMAV_{latissimus\ dorsi}$  data in order to achieve normality. A bounded (SB) type distribution Johnson transformation achieved normality for  $M_{infraspinatus}$ ,  $NMAV_{supraspinatus}$ ,  $NMAV_{teres\ major}$ ,  $NMAV_{anterior\ deltoid}$ ,  $NMAV_{posterior\ deltoid}$ ,  $NMAV_{bicep}$  and  $NMAV_{latissimus\ dorsi}$  data. Also, a bounded (SU) type distribution Johnson transformation achieved normality for  $M_{teres\ major}$ ,  $M_{middle\ deltoid}$ ,  $M_{posterior\ deltoid}$ ,  $TM$  and  $NMAV_{tricep}$  data. Table 4 shows the optimal transformation function and parameter values for all transformed raw data.

Table 4: Johnson transformation.

	Johnson transform type	Johnson transformation function	$\gamma$	$\eta$	$\varepsilon$	$\lambda$	p-value before transformation	p-value after transformation
<b>M Infraspinatus</b>	SB	$-1.5766 + 1.09558 \times \ln\left[\frac{(x + 4.06686)}{(0.366255 - x)}\right]$	-1.5766	1.09558	4.06686	0.366255	<0.005	0.959094
<b>M Teres major</b>	SU	$1.40006 + 1.26292 \times \sinh^{-1}\left[\frac{(x - 0.0521897)}{0.380748}\right]$	1.40006	1.26292	0.0521897	0.380748	<0.005	0.439864
<b>M Middle deltoid</b>	SU	$1.22404 + 1.21468 \times \sinh^{-1}\left[\frac{(x - 0.00676503)}{0.29702}\right]$	1.22404	1.21468	0.00676503	0.29702	<0.005	0.989716
<b>M Posterior deltoid</b>	SU	$1.28858 + 1.31359 \times \sinh^{-1}\left[\frac{(x - 0.00203363)}{0.31806}\right]$	1.28858	1.31359	0.00203363	0.31806	<0.005	0.562281
<b>Total M NMAV Supraspinatus</b>	SU	$2.347 + 1.39986 \times \sinh^{-1}\left[\frac{(x - 0.166531)}{1.30482}\right]$	2.347	1.39986	0.166531	1.30482	<0.005	0.901577
<b>NMAV Teres major</b>	SB	$3.15424 + 0.933155 \times \ln\left[\frac{(x - 0.131077)}{(196.205 - x)}\right]$	3.15424	0.933155	0.131077	196.205	<0.005	0.622031
<b>NMAV Anterior deltoid</b>	SB	$1.43894 + 0.847714 \times \ln\left[\frac{(x - 0.647975)}{(60.7376 - x)}\right]$	1.43894	0.847714	0.647975	60.7376	<0.005	0.977591
<b>NMAV Posterior deltoid</b>	SB	$1.22166 + 0.481705 \times \ln\left[\frac{(x - 0.319075)}{(78.6941 - x)}\right]$	1.22166	0.481705	0.319075	78.6941	<0.005	0.12699
<b>NMAV Bicep</b>	SB	$1.53906 + 0.604884 \times \ln\left[\frac{(x - 0.383474)}{(69.8451 - x)}\right]$	1.53906	0.604884	0.383474	69.8451	<0.005	0.875149
<b>NMAV Tricep</b>	SU	$1.2986 + 0.590796 \times \ln\left[\frac{(x - 0.303751)}{(58.6284 - x)}\right]$	1.2986	0.590796	0.303751	58.6284	<0.005	0.473572
<b>NMAV Latissimus dorsi</b>	SU	$-1.8708 + 0.825356 \times \sinh^{-1}\left[\frac{(x - 0.864504)}{0.862481}\right]$	-1.8708	0.825356	0.864504	0.862481	<0.005	0.586
	SB	$2.16552 + 0.987277 \times \ln\left[\frac{(x - 1.68571)}{(97.1743 - x)}\right]$	2.16552	0.987277	1.68571	97.1743	<0.005	0.893428

The transformed data met the normality and equality of variance assumption for most of the dependent variables. The results of the Johnson transformation are presented in Appendix E. However, NMAV (infraspinatus) and NMAV (middle deltoid) could not be transformed to normality using a Johnson transformation. Therefore, a nonparametric analysis was performed using Kruskal-Wallis test.

## Chapter 5: Results

Ten healthy, right-hand dominant male participants were recruited for this research. The average height, weight and age of the participants were  $173.5 \pm 5.42$  cm,  $168.1 \pm 18.19$  lbs. and  $26.9 \pm 2.424$  years. Table 5 shows this anthropometric data for each participant.

*Table 5: Participants anthropometric data.*

<b>Subject number</b>	<b>Height (cm)</b>	<b>Weight (lbs.)</b>	<b>Age</b>
<b>1</b>	175	163	31
<b>2</b>	170	189	30
<b>3</b>	170	150	27
<b>4</b>	178	162	28
<b>5</b>	173	180	24
<b>6</b>	180	185	24
<b>7</b>	182	195	27
<b>8</b>	173	140	27
<b>9</b>	164	162	27
<b>10</b>	170	155	24
<b>Average</b>	174	168	27
<b>STD</b>	5.4	18.2	2.4

### 5.1 Subjective discomfort data

Data for the individual subjective discomfort ratings are summarized in Appendix I. The mean scores of subjective discomfort for each force level showed an increasing trend towards the highest force level, which is 10 lbs (Figure 9). The mean scores of subjective discomfort for direction showed that the PU and PR directions had the highest discomfort rating, followed by the PD direction. The PL and PB directions had the lowest discomfort ratings of all directions. A baseline discomfort of 1 (nothing at all) was recorded frequently at the 5 lbs. force level, and recorded in the PL and PB directions for different force levels. A mean discomfort of 4 (slight

discomfort) was commonly reported at different force levels and different pulling directions. A mean subjective discomfort of 10 (very severe) was reported in the PU and PR directions. Some participants who reported a discomfort of 10 could not complete the trial, and stopped before reaching the 60 second mark. This situation occurred when participant was pulling 10 lbs. in the up direction, and it also occurred when pulling the same force level in the right direction.

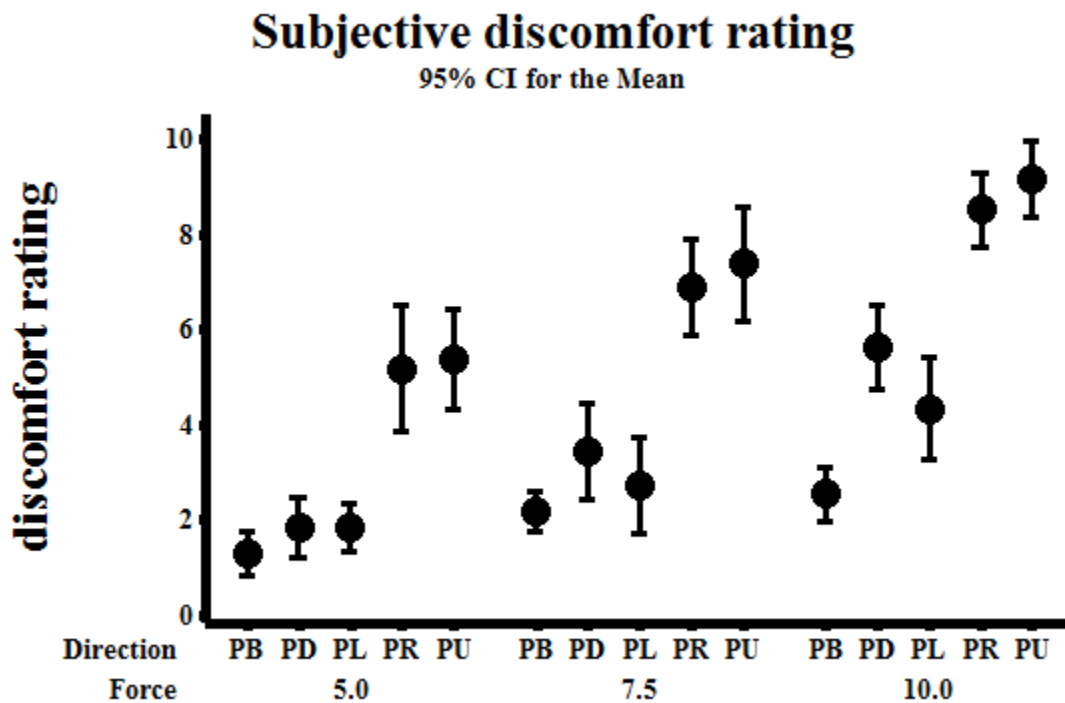


Figure 9: Subjective discomfort scores at different force levels and directions. Error bars represent standard deviations.

Further statistical analysis was performed on the subjective discomfort data to investigate whether the different force levels, different directions or the interaction between them had a significant effect on discomfort. ANOVA analysis showed that the main effect of force level was significant for the discomfort rating ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was significant for the discomfort rating ( $p\text{-value} \leq 0.001$ ) (Table 6). In addition, the interaction effect of force level and direction was significant for the discomfort rating ( $p\text{-value} \leq 0.001$ ). Discomfort

ratings for the PB, PD, PL, PR and PU directions increased by approximately 60%, 200%, 100%, 60% and 80%, respectively, at the 10lbs. force level compared to the 5 lbs. force level. Results of post hoc analysis showed that at 5 lbs. force level, PU and PR directions were higher than PB, PD and PL directions. Similar results were found at the 7.5 lbs. force level. However, at 10 lbs. force level, PU and PR directions were higher than PD and PL directions, and PB direction was lower than PD and PL directions.

*Table 6: ANOVA results table for discomfort rating.*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	119.86	13.318	18.51	0
<b>Force</b>	2	216.17	108.087	150.25	0
<b>Direction</b>	4	686.13	171.532	238.45	0
<b>Force*Direction</b>	8	25.39	3.174	4.41	0
<b>Error</b>	126	90.64	0.719		
<b>Total</b>	149	1138.19			

## **5.2 Electromyography**

Electromyography data for supraspinatus, infraspinatus, teres major, anterior deltoid, middle deltoid, posterior deltoid, biceps, triceps and latissimus dorsi muscles were expressed in terms of median frequency (M) and normalized mean absolute activation (NMAV) data.

### **5.2.1 Median Frequency**

Median frequency data for each exertion was fitted with linear regression to estimate the slope of the line ( $M_i$ ). The slope values used for performing statistical analysis are presented in Appendix J. Table 17 shows the median frequency slope values and standard deviations, and it also shows the main and interaction effects for each muscle. Figure 10 shows the median frequency slope values for each muscle.



For the supraspinatus muscle, ANOVA analysis showed that the main effect of the force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ). In addition, the interaction effect of force level and direction was significant ( $p\text{-value} = 0.006$ ) (Table 7). In all force exertion directions except BP, the slope value decreased by 100% or more at the 10 lbs. force level compared to the 5 lbs. force level. Results of post hoc analysis showed that at 5 lbs. force level, no differences were found between all force directions. Similar results were found for the 7.5 lbs. force level. However, at 10 lbs. force level, PU and PR directions were lower than PB, PD and PL directions.

Table 7: ANOVA results table for  $M_{supraspinatus}$

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	0.9284	0.10316	1.65	0.108
<b>Force</b>	2	2.1716	1.0858	17.39	0
<b>Direction</b>	4	2.0556	0.5139	8.23	0
<b>Force*Direction</b>	8	1.4319	0.17899	2.87	0.006
<b>Error</b>	122	7.6195	0.06246		
<b>Total</b>	145	14.2085			

For the infraspinatus muscle, ANOVA analysis showed that the main effect of force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ). In addition, the interaction effect of force level and direction was significant ( $p\text{-value} = 0.047$ ) (Table 8). The slope value for the PR and PU directions decreased by 50% and 150% respectively at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the other directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Results of post hoc analysis showed that at 5 lbs. force level, PU and PR directions were lower than PB, PD and PL directions. Similar results were found for the 7.5 lbs. force level. However, in at 10 lbs. force level, PL, PU and PR directions were lower than PB and PD directions.

Table 8: ANOVA results table for  $M_{infraspinatus}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	15.912	1.768	4.01	0
<b>Force</b>	2	11.729	5.8643	13.3	0
<b>Direction</b>	4	69.806	17.4514	39.56	0
<b>Force*Direction</b>	8	7.211	0.9014	2.04	0.047
<b>Error</b>	124	54.695	0.4411		
<b>Total</b>	147	160.145			

For the teres major muscle, ANOVA analysis showed that the main effect of force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ). In addition, the interaction effect of force level and direction was significant ( $p\text{-value} = 0.043$ ) (Table 9). Slope value for the PR and PU directions decreased around 60% and 175% at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the other directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that at 5 lbs. force level, PL, PU and PR directions were lower than PB and PD directions. However, at 7.5 lbs. force level, PU and PR directions were lower than PB, PD and PL directions. Similar results were found for the 10 lbs. force level.

Table 9: ANOVA results table for  $M_{teres\ major}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	7.207	0.8008	2.03	0.042
<b>Force</b>	2	10.899	5.4495	13.79	0
<b>Direction</b>	4	77.787	19.4468	49.21	0
<b>Force*Direction</b>	8	6.551	0.8189	2.07	0.043
<b>Error</b>	123	48.608	0.3952		
<b>Total</b>	146	152.269			

For the middle deltoid muscle, ANOVA analysis showed that the main effect of force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq$

0.001). In addition, the interaction effect of force level and direction was significant (p-value = 0.015) (Table 10). Slope value for the PR and PU directions was decreased by approximately 350% and 125%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the other directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that at 5 lbs. force level, PB, PL, PU and PR directions were lower than PD directions. At 7.5 lbs. force level, PB, PL, PU and PD directions were lower than PR directions. Similar results were found for the 10 lbs. force level.

*Table 10: ANOVA results table for  $M_{middle\ deltoid}$*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	27.051	3.0056	6.12	0
<b>Force</b>	2	15.652	7.8262	15.94	0
<b>Direction</b>	4	26.122	6.5305	13.3	0
<b>Force*Direction</b>	8	9.861	1.2326	2.51	0.015
<b>Error</b>	123	60.409	0.4911		
<b>Total</b>	146	138.597			

For the anterior deltoid muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ) (Table 11). In addition, the interaction effect of force level and direction was significant (p-value = 0.006). Slope value for the PD, PR and PU directions was decreased by approximately 200%, 400% and 200%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the PB and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that at 5 lbs. force level, PU direction was lower than PB, PD, PL and PR directions. Similar results were found for the 7.5 and 10 lbs. force levels.

Table 11: ANOVA results table for  $M_{\text{anterior deltoid}}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	2.086	0.2317	1.72	0.091
<b>Force</b>	2	6.326	3.163	23.49	0
<b>Direction</b>	4	12.735	3.1838	23.64	0
<b>Force*Direction</b>	8	3.099	0.3874	2.88	0.006
<b>Error</b>	121	16.296	0.1347		
<b>Total</b>	144	40.3			

For the posterior deltoid muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ) (Table 12). In addition, the interaction effect of force level and direction was significant (p-value = 0.001). Slope value for the PD, PR and PU directions was decreased by approximately 100%, 400% and 90%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the PB and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Results of post hoc analysis showed that at 5 lbs. force level, no differences were found between all force directions. Similar results were found for the 7.5 lbs. force level. However, at 10 lbs. force level, PR direction was lower than PB, PD, PL and PU directions.

Table 12: ANOVA results table for  $M_{\text{posterior deltoid}}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	11.05	1.228	2.3	0.02
<b>Force</b>	2	16.28	8.1388	15.22	0
<b>Direction</b>	4	12.04	3.0093	5.63	0
<b>Force*Direction</b>	8	14.57	1.8212	3.41	0.001
<b>Error</b>	121	64.69	0.5346		
<b>Total</b>	144	118.79			

For the bicep muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ). However, the interaction effect of force level and direction was not significant (p-value = 0.401) (Table 13). Slope value for the PR, PD and PU directions was decreased by roughly 180%, 100% and 100% for 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the other directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that at 10 lbs. force level was different than the other force levels. In addition, it showed that the PR and PD directions were lower than PB, PL and PU directions.

*Table 13: ANOVA results table for  $M_{bicep}$*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	1.6244	0.18049	1.87	0.064
<b>Force</b>	2	1.633	0.8165	8.45	0
<b>Direction</b>	4	2.9236	0.73091	7.56	0
<b>Force*Direction</b>	8	0.8145	0.10181	1.05	0.401
<b>Error</b>	116	11.2151	0.09668		
<b>Total</b>	139	18.318			

For the tricep muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ). In addition, the interaction effect of force level and direction was significant (p-value  $\leq 0.001$ ) (Table 14). Slope value for the PD, PR and PU directions was decreased by approximately 200%, 250% and 150%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the PB and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Results of post hoc analysis showed that in the at 5 lbs. force level, no differences were found between all force directions. However, at 7.5 lbs. force

level, PU and PR directions were lower than PB, PD and PL directions. At 10 lbs. force level, PD and PU directions were lower than PB and PL directions, and PR direction was lower than PD and PU directions.

Table 14: ANOVA results table for  $M_{triceps}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	5.966	0.66285	6.84	0
<b>Force</b>	2	4.766	2.38285	24.58	0
<b>Direction</b>	4	7.712	1.928	19.89	0
<b>Force*Direction</b>	8	2.965	0.3706	3.82	0
<b>Error</b>	124	12.021	0.09694		
<b>Total</b>	147	33.468			

For the latissimus dorsi muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ). However, the interaction effect of force level and direction was not significant (p-value = 0.09) (Table 15). Slope value for the PR and PU directions decreased by around 100% and 150%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the other directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that the force level of 10 lbs. was different than the other force levels. In addition, post hoc analysis showed that the PR and PU directions were lower than PB, PD and PL directions.

Table 15: ANOVA results table for  $M_{latissimus\ dorsi}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	4.971	0.5523	5.08	0
<b>Force</b>	2	1.814	0.9069	8.34	0
<b>Direction</b>	4	4.535	1.1336	10.42	0
<b>Force*Direction</b>	8	1.541	0.1926	1.77	0.09
<b>Error</b>	117	12.727	0.1088		
<b>Total</b>	140	25.175			

Finally, for total M, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ). However, the interaction effect of force level and direction was not significant (p-value = 0.377) (Table 16). Slope value for the PR and PU directions was decreased by roughly 150% for both at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, slope values for the PB, PD and PL directions had a smaller change at the 10lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that each force level was different than others. Moreover, post hoc analysis showed that PL direction was lower than PB and PD directions, and PR and PU were lower than PL direction.

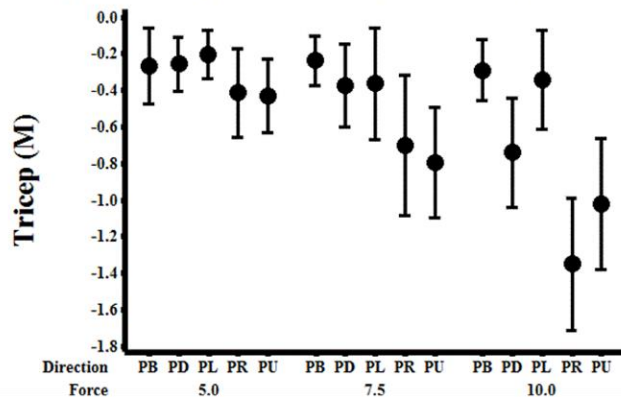
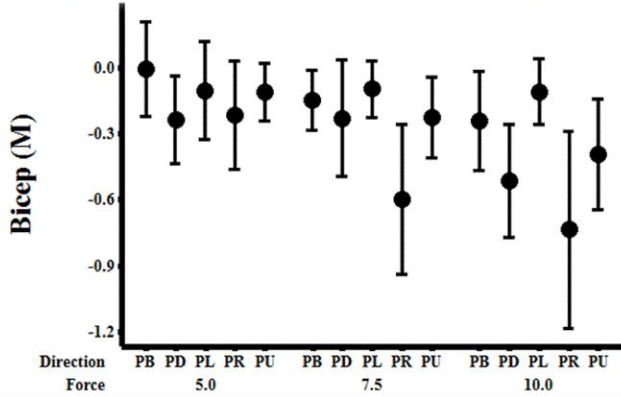
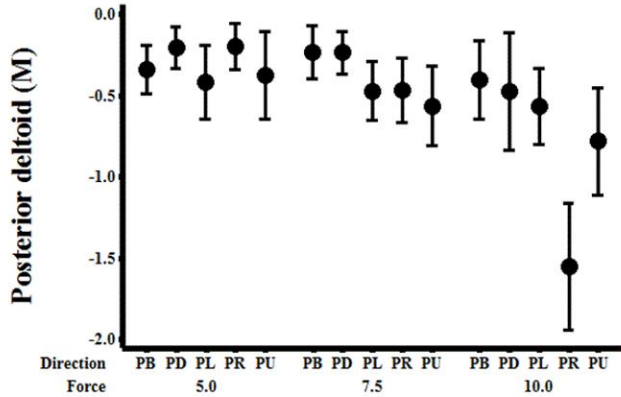
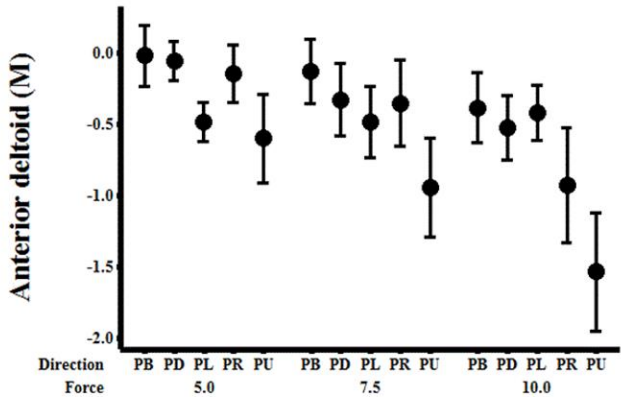
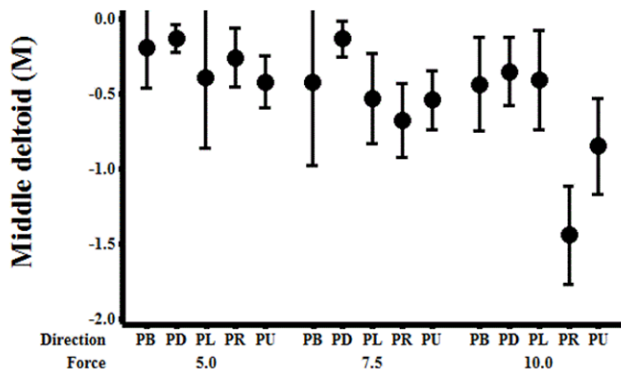
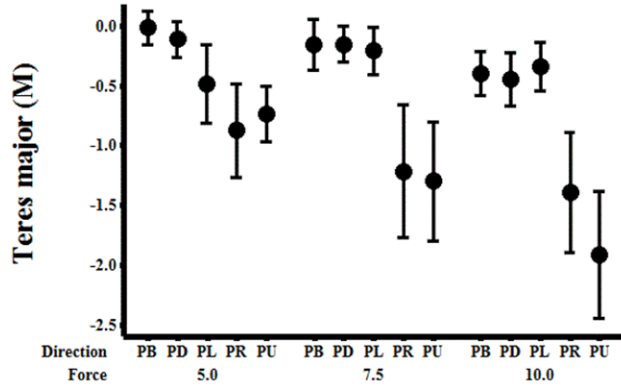
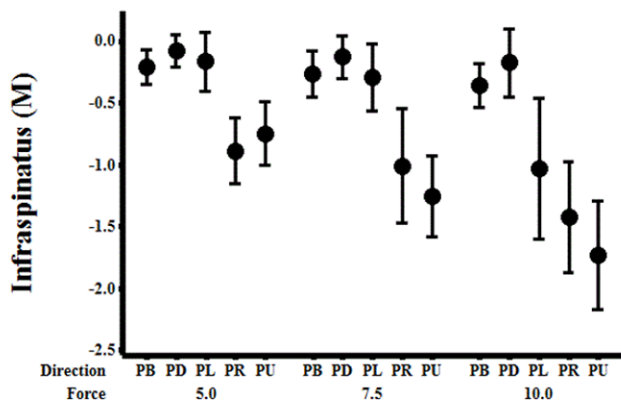
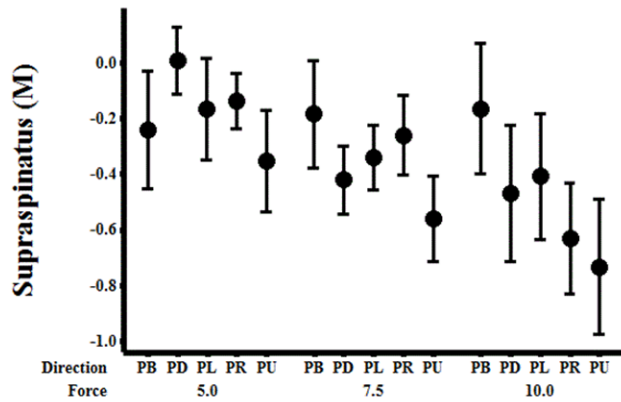
*Table 16: ANOVA results table for TM*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	15.051	1.6723	5.8	0
<b>Force</b>	2	27.483	13.7414	47.63	0
<b>Direction</b>	4	60.351	15.0879	52.3	0
<b>Force*Direction</b>	8	2.509	0.3136	1.09	0.377
<b>Error</b>	126	36.353	0.2885		
<b>Total</b>	149	141.746			

Table 17: Median frequency slope values mean, SD, main and interaction effect.

M	Load			P - value	Direction					P- value	Interaction P-value
	5 lbs.	7.5 lbs.	10 lbs.		PB	PD	PL	PR	PU		
<b>Supraspinatus</b>	-0.1811 (±0.2479)	-0.3531 (±0.2390)	-0.4812 (±0.3647)	≤ <b>0.001</b>	-0.1958 (±0.2914)	-0.2981 (±0.3075)	-0.3076 (±0.2610)	-0.3422 (±0.2978)	-0.5490 (±0.3090)	≤ <b>0.001</b>	<b>0.006</b>
<b>Infraspinatus</b>	-0.4239 (±0.4434)	-0.5957 (±0.6116)	-0.942 (±0.817)	≤ <b>0.001</b>	-0.2742 (±0.2375)	-0.1275 (±0.2755)	-0.503 (±0.656)	-1.107 (±0.593)	-1.245 (±0.624)	≤ <b>0.001</b>	<b>0.047</b>
<b>Teres major</b>	-0.4303 (±0.4781)	-0.591 (±0.713)	-0.897 (±0.809)	≤ <b>0.001</b>	-0.1862 (±0.2959)	-0.2326 (±0.2839)	-0.3371 (±0.3406)	-1.167 (±0.668)	-1.314 (±0.773)	≤ <b>0.001</b>	<b>0.043</b>
<b>Mid deltoid</b>	-0.2808 (±0.3760)	-0.4549 (±0.4681)	-0.6812 (±0.5722)	≤ <b>0.001</b>	-0.355 (±0.552)	-0.2030 (±0.2354)	-0.4442 (±0.5087)	-0.772 (±0.599)	-0.6029 (±0.3713)	≤ <b>0.001</b>	<b>0.015</b>
<b>Ant deltoid</b>	-0.2613 (±0.3669)	-0.4572 (±0.4619)	-0.7709 (±0.6087)	≤ <b>0.001</b>	-0.1747 (±0.3223)	-0.2981 (±0.3469)	-0.4613 (±0.2638)	-0.4712 (±0.5436)	-1.025 (±0.626)	≤ <b>0.001</b>	<b>0.006</b>
<b>Post deltoid</b>	-0.3025 (±0.2668)	-0.3919 (±0.2796)	-0.7373 (±0.5841)	≤ <b>0.001</b>	-0.3261 (±0.2624)	-0.3022 (±0.3376)	-0.4856 (±0.2881)	-0.718 (±0.681)	-0.5716 (±0.4187)	≤ <b>0.001</b>	<b>0.001</b>
<b>Bicep</b>	-0.1331 (±0.2826)	-0.2508 (±0.3223)	-0.3911 (±0.4226)	≤ <b>0.001</b>	-0.1324 (±0.2780)	-0.3318 (±0.3421)	-0.1012 (±0.2312)	-0.5014 (±0.4965)	-0.2463 (±0.2906)	≤ <b>0.001</b>	0.401
<b>Tricep</b>	-0.3144 (±0.2676)	-0.4978 (±0.4385)	-0.7485 (±0.5732)	≤ <b>0.001</b>	-0.2645 (±0.2211)	-0.4558 (±0.3771)	-0.3021 (±0.3405)	-0.821 (±0.604)	-0.7486 (±0.4703)	≤ <b>0.001</b>	≤ <b>0.001</b>
<b>Latissimus dorsi</b>	-0.2079 (±0.3430)	-0.2741 (±0.3901)	-0.4565 (±0.4883)	≤ <b>0.001</b>	-0.1829 (±0.2828)	-0.1358 (±0.3258)	-0.2451 (±0.4108)	-0.4189 (±0.3007)	-0.601 (±0.568)	≤ <b>0.001</b>	0.090
<b>Total M</b>	-2.455 (±1.610)	-3.723 (±2.479)	-6.020 (±3.866)	≤ <b>0.001</b>	-1.980 (±1.330)	-2.339 (±1.944)	-3.090 (±1.371)	-6.064 (±3.606)	-6.855 (±3.178)	≤ <b>0.001</b>	0.377





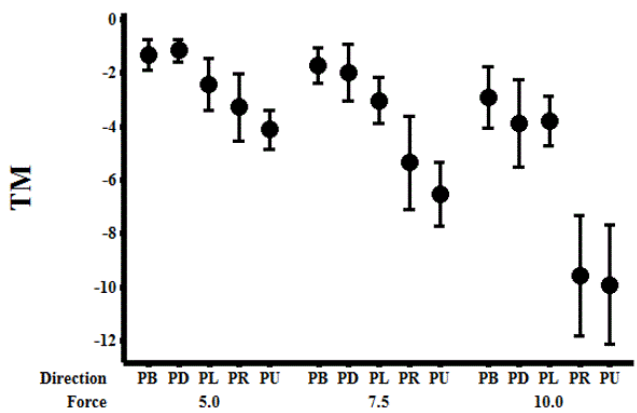
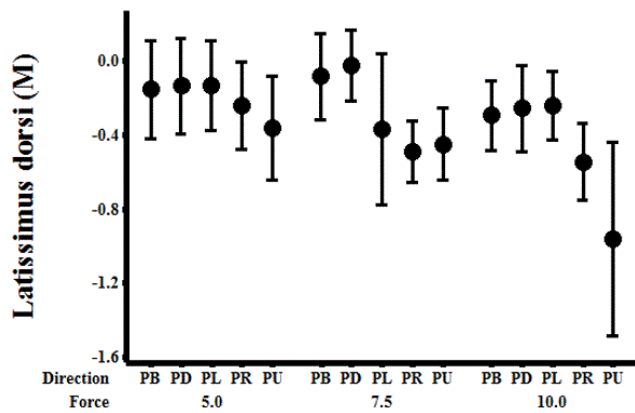


Figure 10: Raw data charts for median frequency slope values. Error bars represents standard deviation.

### 5.2.2 Normalized mean absolute values

The raw data used for performing statistical analysis are presented in Appendix K. Table 26 shows the NMAVs and deviations, as well as the main and interaction effects for each muscle. Figure 11 shows the changes in NMAVs for each muscle.

For the supraspinatus muscle, ANOVA analysis showed that the main effect of the force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ). However, the interaction effect of force level and direction was not significant ( $p\text{-value} = 0.984$ ) (Table 18). Muscle activation for the PR and PU directions was increased by approximately 100% and 60%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PB, PD and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that each force level was different than other force levels. In addition, post hoc analysis showed that the PR and PD directions were different than the PU and PL directions, and both of them were different than PB direction.

Table 18: ANOVA results table for  $NMAV_{supraspinatus}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	33.893	3.7659	10.72	0
<b>Force</b>	2	16.855	8.4276	23.98	0
<b>Direction</b>	4	58.538	14.6345	41.64	0
<b>Force*Direction</b>	8	0.662	0.0828	0.24	0.984
<b>Error</b>	126	44.282	0.3514		
<b>Total</b>	149	154.231			

For the infraspinatus muscle, Kruskal-Wallis one-way analysis showed that the main effect of force level was significant ( $p\text{-value} = 0.003$ ), and the main effect of direction was also

significant ( $p\text{-value} \leq 0.001$ ). Muscle activation for the PR and PU directions was increased by roughly 100% and 66%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PB, PD and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level.

For the teres major muscle, ANOVA analysis showed that the main effect of force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ) (Table 19). However, the interaction effect of force level and direction was not significant ( $p\text{-value} = 0.88$ ). For all force exertion directions, muscle activation increased by roughly 100% at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that each force level was different than other force levels. In addition, post hoc analysis showed that the PR, PB and PD directions were different than PU and PL directions.

*Table 19: ANOVA results table for  $NMAV_{teres\ major}$*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	56.054	6.2282	19.71	0
<b>Force</b>	2	30.815	15.4075	48.76	0
<b>Direction</b>	4	9.015	2.2536	7.13	0
<b>Force*Direction</b>	8	1.171	0.1463	0.46	0.88
<b>Error</b>	126	39.814	0.316		
<b>Total</b>	149	136.867			

For the middle deltoid muscle, Kruskal-Wallis one-way analysis showed that the main effect of force level was significant ( $p\text{-value} = 0.011$ ), and the main effect of direction was significant ( $p\text{-value} \leq 0.001$ ). Muscle activation for the PR and PU directions was increased by roughly 200% and 100%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PB, PD and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level.

For the anterior deltoid muscle, ANOVA analysis showed that the main effect of force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ). However, the interaction effect of force level and direction was not significant ( $p\text{-value} = 0.703$ ) (Table 20). Muscle activation for the PR and PU directions was increased by roughly 150% and 50%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PB and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that the force level of 5 lbs. was different than the other force levels. In addition, post hoc showed that each force exertion direction was different than the others. PU direction was the highest followed by PR direction, and PB and PD directions were lower than PL direction.

Table 20: ANOVA results table for  $NMAV_{\text{anterior deltoid}}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	7.186	0.7985	4.24	0
<b>Force</b>	2	3.85	1.9251	10.22	0
<b>Direction</b>	4	117.778	29.4444	156.26	0
<b>Force*Direction</b>	8	1.034	0.1293	0.69	0.703
<b>Error</b>	125	23.554	0.1884		
<b>Total</b>	148	153.244			

For the posterior deltoid muscle, ANOVA analysis showed that the main effect of force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ). However, the interaction effect of force level and direction was not significant ( $p\text{-value} = 0.29$ ) (Table 21). Muscle activation for the PD, PR and PU directions was increased by roughly 100%, 150% and 70%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PB and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that each force

level was different than the other force levels. In addition, it showed that PR direction was the highest followed by PU and PD directions, and PB and PL directions were the lowest.

*Table 21: ANOVA results table for  $NMAV_{posterior\ deltoid}$*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	19.467	2.163	8.61	0
<b>Force</b>	2	10.787	5.3937	21.48	0
<b>Direction</b>	4	93.375	23.3437	92.95	0
<b>Force*Direction</b>	8	2.461	0.3077	1.23	0.29
<b>Error</b>	125	31.392	0.2511		
<b>Total</b>	148	154.262			

For the bicep muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ). However, the interaction effect of force level and direction was not significant (p-value = 0.141) (Table 22). Muscle activation for the PL, PR and PU directions was increased by roughly 100% for all at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the other directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that the force level of 10 lbs. was different than other force levels. In addition, it showed that PU direction was the highest followed by PL direction, and PB and PD directions were the lower than PR direction.

*Table 22: ANOVA results table for  $NMAV_{bicep}$*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	16.526	1.8362	12.32	0
<b>Force</b>	2	6.643	3.3214	22.29	0
<b>Direction</b>	4	96.475	24.1187	161.84	0
<b>Force*Direction</b>	8	1.867	0.2334	1.57	0.141
<b>Error</b>	126	18.778	0.149		
<b>Total</b>	149	140.288			

For the tricep muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ). In addition, the interaction effect of force level and direction was significant (p-value = 0.022) (Table 23). Muscle activation for the PD, PR and PU directions was increased by roughly 150%, 50% and 50%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PB and PL directions had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that at a force level of 10 lbs. the PB, PD and PL directions were different than the PR and PU directions. At a force level of 7.5 lbs. PU direction was different than other directions. At a force level of 5 lbs., no difference was found between the directions of force exertion. Results of post hoc analysis for interaction effect showed that at 5 lbs. force level, PD direction was higher than PR and PU directions, and PB and PL were the lowest. However, in the interaction between 7.5 lbs. force level and force directions, PD, PR and PU directions were higher than PL and PB directions. Similar results were found for the 10 lbs. force level.

*Table 23: ANOVA results table for  $NMAV_{tricep}$*

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	29.812	3.3124	12.25	0
<b>Force</b>	2	11.037	5.5185	20.4	0
<b>Direction</b>	4	64.21	16.0524	59.35	0
<b>Force*Direction</b>	8	5.082	0.6352	2.35	0.022
<b>Error</b>	126	34.078	0.2705		
<b>Total</b>	149	144.218			

For the latissimus dorsi muscle, ANOVA analysis showed that the main effect of force level was significant (p-value  $\leq 0.001$ ), and the main effect of direction was also significant (p-value  $\leq 0.001$ ). However, the interaction effect of force level and direction was not significant (p-

value = 0.262) (Table 24). Muscle activation for the PB, PD, PR and PU directions was increased by roughly 100%, 175%, 100% and 50%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PL direction had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Post hoc analysis showed that each force level was different than the other force levels. In addition, it showed that the PL direction was lower than the PB, PU, PR and PD directions.

Table 24: ANOVA results table for  $NMAV_{latissimus\ dorsi}$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
<b>Subject</b>	9	65.097	7.233	22.52	0
<b>Force</b>	2	28.879	14.4397	44.96	0
<b>Direction</b>	4	29.594	7.3986	23.04	0
<b>Force*Direction</b>	8	3.279	0.4099	1.28	0.262
<b>Error</b>	126	40.467	0.3212		
<b>Total</b>	149	167.316			

Finally, for TNMAV, ANOVA analysis showed that the main effect of force level was significant ( $p\text{-value} \leq 0.001$ ), and the main effect of direction was also significant ( $p\text{-value} \leq 0.001$ ). In addition, the interaction effect of force level and direction was significant ( $p\text{-value} \leq 0.001$ ) (Table 25). Muscle activation for the PD, PR and PU directions was increased by roughly 100%, 100% and 60%, respectively, at the 10 lbs. force level compared to the 5 lbs. force level. On the other hand, muscle activation for the PL direction had a smaller change at the 10 lbs. force level compared to the 5 lbs. force level. Results of post hoc analysis showed that at 5 lbs. force level and force directions, PU and PR directions were higher than PB, PD and PL directions. Similar results were found for the 7.5 and 10 lbs. force levels.

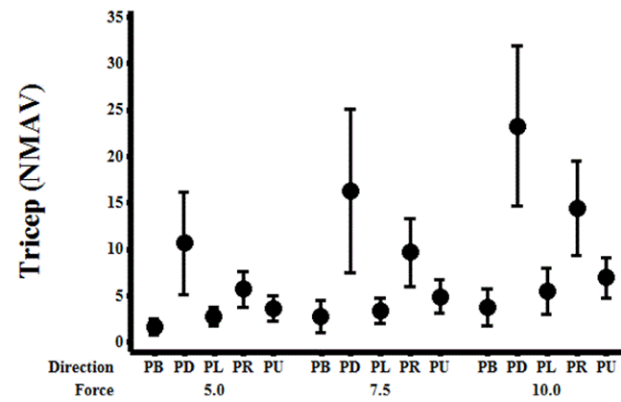
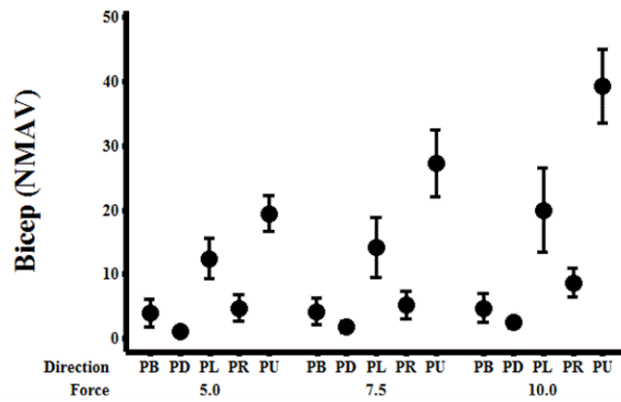
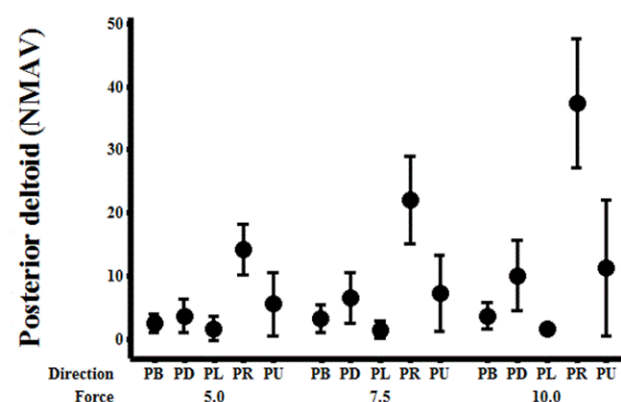
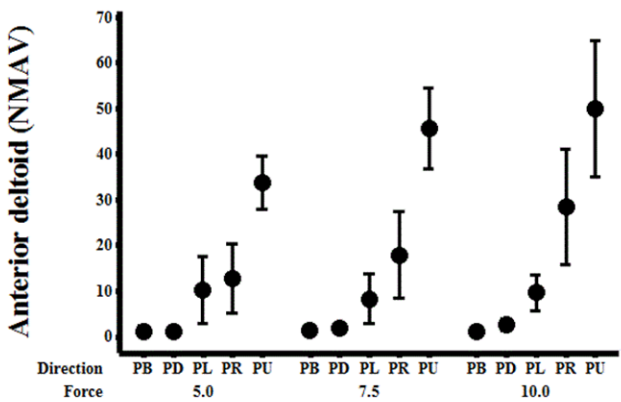
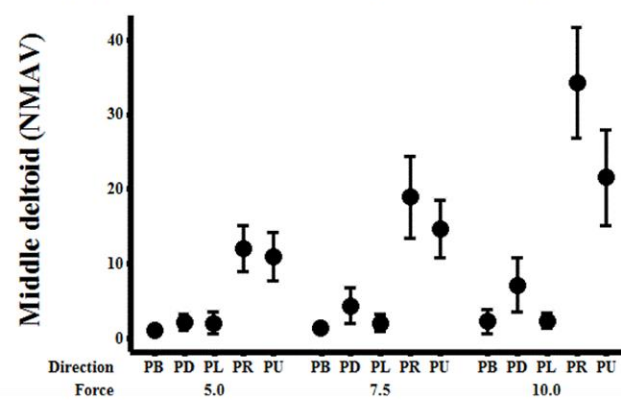
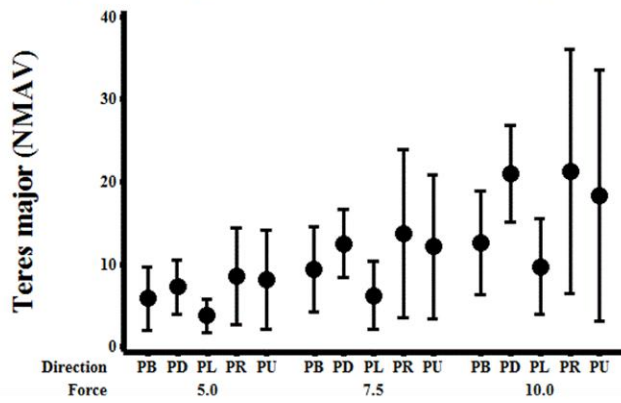
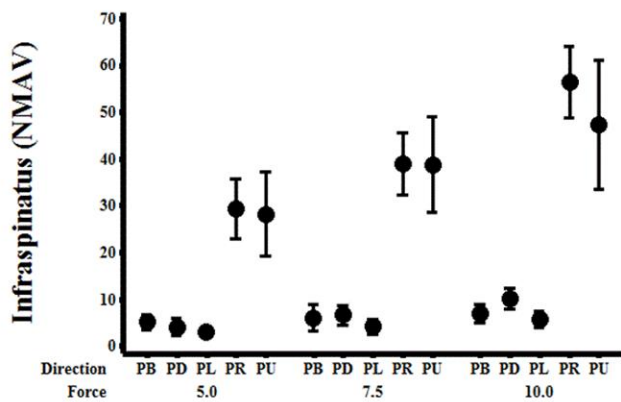
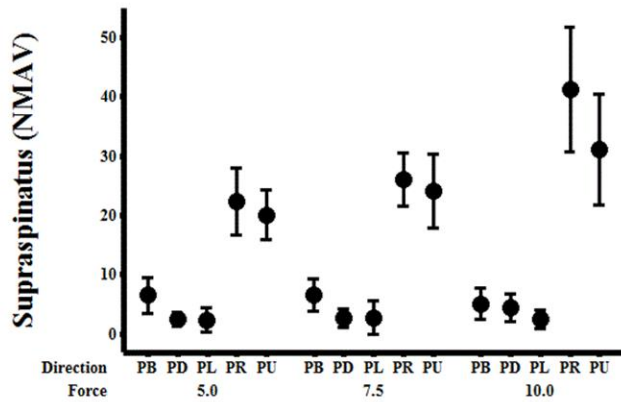


Table 25: ANOVA results table for TNMAV

<b>Source</b>	<b>DF</b>	<b>Adj SS</b>	<b>Adj MS</b>	<b>F-Value</b>	<b>P-Value</b>
<b>Subject</b>	9	70774	7863.7	12.47	0
<b>Force</b>	2	144207	72103.5	114.32	0
<b>Direction</b>	4	347382	86845.5	137.69	0
<b>Force*Direction</b>	8	35327	4415.9	7	0
<b>Error</b>	126	79470	630.7		
<b>Total</b>	149	677160			

Table 26: Normalized mean absolute values, SD, main and interaction effect.

NMAV	Load			P-value	Direction					P-value	P-value for Interaction
	5 lbs.	7.5 lbs.	10 lbs.		PB	PD	PL	PR	PU		
<b>Supraspinatus</b>	10.72 (±9.71)	12.40 (±11.48)	16.85 (±17.93)	≤ <b>0.001</b>	6.009 (±3.306)	3.165 (±2.184)	2.500 (±2.476)	29.85 (±11.89)	25.09 (±9.21)	≤ <b>0.001</b>	0.984
<b>Infraspinatus</b>	13.93 (±13.55)	18.92 (±17.77)	24.72 (±23.41)	<b>0.003</b>	6.006 (±2.635)	6.968 (±3.463)	4.226 (±1.986)	41.56 (±13.96)	37.73 (±14.40)	≤ <b>0.001</b>	-
<b>Teres major</b>	6.713 (±5.392)	10.79 (±8.33)	16.57 (±12.87)	≤ <b>0.001</b>	9.27 (±6.56)	13.58 (±7.78)	6.55 (±5.46)	14.54 (±13.58)	12.86 (±12.99)	≤ <b>0.001</b>	0.880
<b>Mid deltoid</b>	6.01 (±6.36)	8.61 (±9.10)	13.50 (±15.31)	<b>0.011</b>	1.390 (±0.701)	4.410 (±4.306)	2.456 (±1.751)	23.25 (±13.97)	15.34 (±7.69)	≤ <b>0.001</b>	-
<b>Ant deltoid</b>	11.84 (±13.55)	15.07 (±18.17)	16.68 (±19.83)	≤ <b>0.001</b>	1.201 (±0.975)	1.903 (±1.202)	9.40 (±6.66)	19.71 (±13.41)	42.58 (±12.28)	≤ <b>0.001</b>	0.703
<b>Post deltoid</b>	5.521 (±5.925)	8.11 (±9.04)	12.18 (±14.69)	≤ <b>0.001</b>	3.159 (±2.301)	6.74 (±5.57)	1.581 (±1.602)	23.98 (±12.47)	8.05 (±9.12)	≤ <b>0.001</b>	0.290
<b>Bicep</b>	8.34 (±7.28)	10.59 (±10.22)	15.05 (±14.45)	≤ <b>0.001</b>	4.324 (±2.418)	1.823 (±1.020)	15.55 (±6.54)	6.281 (±3.063)	28.66 (±9.93)	≤ <b>0.001</b>	0.141
<b>Tricep</b>	4.863 (±4.478)	7.16 (±6.70)	10.32 (±8.67)	≤ <b>0.001</b>	2.706 (±2.004)	16.45 (±9.70)	3.867 (±2.336)	9.70 (±5.40)	5.136 (±2.471)	≤ <b>0.001</b>	<b>0.022</b>
<b>Latissimus dorsi</b>	7.824 (±6.015)	10.516 (±6.271)	15.26 (±9.22)	≤ <b>0.001</b>	13.16 (±8.18)	12.27 (±7.86)	4.697 (±1.626)	13.20 (±8.95)	12.68 (±7.39)	≤ <b>0.001</b>	0.262
<b>Total NMAV</b>	75.76 (±50.41)	102.0 (±66.9)	138.9 (±89.7)	≤ <b>0.001</b>	47.23 (±17.50)	65.94 (±29.73)	50.82 (±18.76)	180.7 (±66.0)	183.0 (±51.9)	≤ <b>0.001</b>	≤ <b>0.001</b>



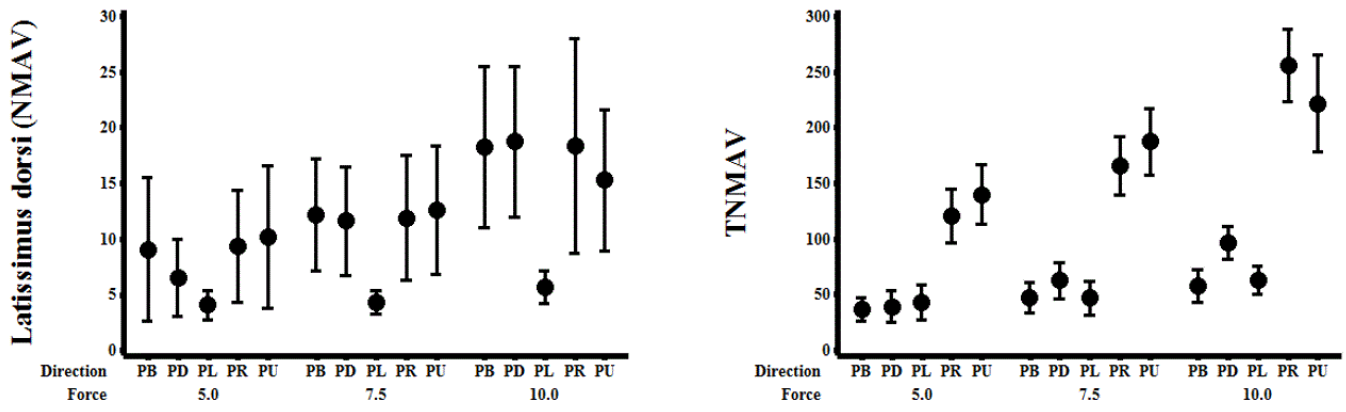


Figure 11: Raw data charts normalized mean absolute values. Error bars represents standard deviation.

## **Chapter 6: Discussion and Conclusion**

In this study, the activation pattern of the shoulder muscles was examined using SEMG under different force exertion demands. We suspected that shoulder muscles' attempt to stabilize the GHJ using concavity compression may explain the differences in muscle activation pattern during arm exertions. The results indicate that the level of force exertion had an effect on the muscle activation pattern. The 5 lbs. force level had the smallest effect on muscle activation and fatigability, followed by the 7.5 lbs. force level. The 10 lbs. force level had the highest effect on muscle activation and fatigability. In fact, several of the participants could not complete all 10 lbs. force level exertions trials. The discomfort ratings were also affected by the level of force exertion. The 5 lbs. force level had the smallest effect on discomfort rating, followed by the 7.5 lbs. force level. The 10 lbs. force level had the highest effect on discomfort ratings.

The results also indicate that the direction of force exertion had an effect on the muscle activation pattern. The PB and PL directions of force exertion had the smallest effect on muscle activation, followed by the PD direction. The PR and PU directions of force exertion had the largest effect on muscle activation. In addition, the directions of force exertion had an effect on muscle fatigability. The PB direction of force exertion had the smallest effect on muscle fatigability, followed by the PD and PL directions. The PR and PU directions of force exertion had the highest effect on muscle fatigability. In fact, several of the participants could not complete all PR and PU direction force exertion trials. The discomfort ratings were also affected by the direction of force exertion. The PB and PL directions of force exertion had the smallest effect on discomfort rating, followed by the PD direction. The PR and PU directions of force exertion had

the highest effect on discomfort rating. The interaction between direction and level of force exertion was also significant for the muscle activation, muscle fatigability, and discomfort rating.

High muscles activation on PR and PU directions were common in both rotator cuff muscles and non-rotator cuff muscles. Among rotator cuff muscles, PR and PU directions caused the highest muscle activation for all force levels. On the other hand, PB, PD and PL caused almost the same lower muscle activation for all force levels. In 10 lbs. force level, supraspinatus and infraspinatus muscle activation at PR and PU directions was higher than muscle activation at PB, PD and PL directions by a range of 350% to 500%. In addition to PR and PU directions, PD direction caused high muscle activation for teres major muscle. Teres major muscle activation in PR, PU and PD force directions and 10 lbs force levels increased by 100% compared to the muscle activation in PR, PU and PD directions and the 5 lbs. force level. Among non-rotator cuff muscles, PR and PU directions (or at least one of them) caused the highest muscle activation for all force levels. On the other hand, PB, PD, PL caused in general the lowest muscle activation for all force levels. In 10 lbs. force level, middle deltoid and anterior deltoid muscle activation at PR and PU directions was higher than muscle activation at PB, PD and PL directions by a range of 200% to 500%. Posterior deltoid muscle activation at PR direction was higher than muscle activation at PB, PD, PL and PU directions by 300%. For bicep and tricep muscles, muscle activation was high at PU and PD directions, respectively. And it was higher than muscle activation at other force directions by 150%. Latissimus dorsi muscle activation was the same for all directions except the PL direction. Findings of study, in terms of muscle activation for different direction is comparable with a study performed by Arwert et al., 1997. Similar to our findings Arwert et al., (1997) also reported the highest activation of teres major and latissimus dorsi muscles in pulling down direction. On the other hand, Arwert et al., (1997) found that supraspinatus' highest activation

was in pulling up direction compared to the pulling right direction found in our study. Also, they found that infraspinatus was activated in all direction and in our study, infraspinatus was found to be mainly activated in pulling up and pulling right directions. This difference in experimental setup could be the reason for this. In the study performed by Arwert et al., (1997), they did not use a hand grip instead they directly connected strain-gauge two-dimensional force transducer to participants' elbow.

Similarly, high muscles fatigability on PR and PU directions were common in both rotator cuff muscles and non-rotator cuff muscles. Among rotator cuff muscles, PR and PU directions caused the highest muscles fatigue for all force levels. On the other hand, in general PB, PD and PL caused almost the same small muscles fatigue for all force levels. In 10 lbs. force level, supraspinatus and teres major muscles fatigue at PR and PU directions was higher than PB, PL and PD directions by a range of 100% to 200%. For infraspinatus muscle, PL, PR and PU directions was higher than PB and PD directions by 200%. Among non-rotator cuff muscles, PR and PU directions (or at least one of them) caused the highest negative slope for all force levels. On the other hand, PB, PD, PL caused in general the small negative slope for all force levels. middle deltoid, posterior deltoid and tricep muscles fatigue at PR direction was higher than PB, PL, PD and PU directions by 200%. For anterior deltoid, muscle fatigue at PR and PU directions was higher than PB, PL and PD directions by a range of 100% to 200%. Finally, latissimus dorsi muscle fatigue in PU direction was higher than PB, PL, PD and PR directions by 200%.

The alternate hypotheses tested in this study were based on a biomechanical modelling study performed by Cutlip (2014). When the biomechanical results were compared with the physiological result from this study, they are found to be in good agreement. The results in Cutlip (2014) were that the PL exertion direction had the highest muscle biomechanical demand followed

by the PU and PL directions. The lowest muscle biomechanical demand was observed in the PD and PB directions. The relationship between the direction of force exertion and muscle fatigability was also affected by the level of force exertion.

It is clear that the PR and PU exertion directions had the highest muscle activation and caused the largest negative slopes. In the PR and PU directions, rotator muscles have to resist the translational forces which push the humeral head away from the glenoid fossa to facilitate concavity compression. In other words, while participants were trying to pull in left direction, the reaction forces pushed their humeral head away from the glenoid fossa. To prevent joint instability, rotator cuff muscles contribute to pulling the humeral head back to the glenoid fossa. Blasier et al. (1992) reported that each of the rotator cuff muscles significantly contributed to GHJ stability, with no significant difference between one another.

Rotator cuff muscles in the PR and PU directions had higher muscle activation compared to other directions of force exertion at the same force level. It is well-known that glenohumeral joint stability is a primary job for the supraspinatus and infraspinatus muscles; therefore, in order to maintain joint stability and to contribute to concavity compression, muscle activity is expected to increase with hand exertions. Sigholm et al. (1984) and Sporrang et al. (1995, 1996) had similar findings regarding the supraspinatus and infraspinatus muscle activation during hand exertions. In Sporrang et al. (1995, 1996), it was observed that hand gripping significantly increased the activity of the supraspinatus muscle in humeral flexion from and above 60°. A similar, but lesser, increase was observed for the infraspinatus muscle. However, in the latter case there were no signs of muscles fatigue during hand gripping tasks.

Some of the non-rotator cuff muscle such as middle deltoid and posterior deltoid muscles had high muscle activation and exhibited the largest negative slopes in the PR and PU exertion



directions. However, the anterior deltoid's largest muscle activation and largest negative slope were in the PU direction. The activation of deltoid muscle was affected by the exertion direction, and thus contributed to concavity compression in stabilizing the GHJ. This is in agreement with the findings of Sigholm et al. (1984). They found that, while holding a 2 kg load in the shoulder abduction posture or shoulder flexion posture, deltoid muscle activity increased. Even though the deltoid muscles play an important role in shoulder abduction (Kronberg et al., 1990), they also contribute to GHJ stability, especially the middle deltoid and posterior deltoid muscles. On the other hand, some studies have found a muscle activity reduction for deltoid muscles in correlation with the increase in infraspinatus muscle activity (MacDonell and Keir, 2005). However, those previous studies tested the muscles in different shoulder flexion angles and/or different shoulder abduction angles, which could affect the muscle activation (Sporrong et al., 1996). Also, bicep muscle activation in the PR direction supports the findings of Itoi et al. (1993). They found that biceps brachii muscle activity could also assist in GHJ stability.

The action of shoulder muscles can be characterized into three vectors which are compressive force, anterior-posterior shear force and superior-inferior shear force. Despite the fact that compressive forces work to push the humeral head into the glenoid fossa for stabilizing the GHJ, anterior-posterior shear force and superior-inferior shear force can contribute to stabilize the GHJ or destabilize it (Labriola et al., 2005). That means that not all activated muscles in pulling up and pulling right directions are contributed in GHJ stability. Some of shoulder muscles may be considered as destabilized muscles such as deltoid muscles. Lee and An (2002), have found out that deltoid muscle activity contributes to GHJ stability based on shoulder abduction plane. Deltoid muscle activity contributed to increase GHJ stability in a 60 degree of shoulder abduction in mid-sagittal frontal plane. On the other hand, deltoid muscle activity contributed to

decrease GHJ stability in a 60 degree of shoulder abduction in the frontal plane. Labriola et al., (2005) studied the contribution of individual shoulder muscle in GHJ stability by using a model. When supraspinatus, infraspinatus, or teres minor muscles magnitude was increased, the action vectors were less anteriorly directed, which contribute to improve GHJ stability. On the other hand, GHJ stability tend to decrease when activation vector was more anteriorly directed with increases in deltoid muscle activation. However, subscapularis, teres major and latissimus dorsi muscles had no effects on activation vector for the resultant force.

The highest fatigue for all muscles was found to be in PR and PU exertion directions at the 10 lbs. force level, where the negative slope value was equal to -11. This was followed by the PR and PU exertion directions and the 7.5 lbs. force level, which produced a negative slope value of -6. The slope values for other exertion directions at the 10 lbs. force level were almost the same as the slope value in the PR and PU exertion directions at the 5 lbs. force level, which was equal to -4. The slope value for the PD and PL exertion directions at the 10 lbs. force level was equal to -3, followed by the PB exertion direction at the 10 lbs. force level, which had a negative slope value equal to -1. In addition, the highest fatigue for a specific muscle found was for the teres major. The slope value for the teres major was roughly equal to -2 for interactions at both the PR and PU exertion directions at the 10 lbs. force level. This was followed by the infraspinatus muscle's slope value, which was approximately equal to -1.75 for interactions in the PL, PR and PU exertion directions at the 10 lbs. force level. The middle deltoid, posterior deltoid and tricep had their highest negative slope value (-1.5) in the PR exertion direction at the 10 lbs. force level. For the tricep, the slope value for the PD exertion direction at the 10 lbs. force level was equal to -0.8, smaller than the PR and PU fatigues. This means that, even though muscles exert more in other directions, the PR and PU directions had the highest fatigability. The anterior deltoid and

latissimus dorsi had almost the same negative slope values, at -1.5 and -1.1 respectively, for the PR exertion direction at the 10 lbs. force level.

A relationship was found between muscle fatigability and MVC in different directions for several of the muscles. However, fatigability cannot be predicted based on muscle activation. For example: the posterior deltoid muscle had the highest negative slope value for the PR direction, followed by the PU direction. At the same time, this muscle had the highest muscle activity in the PR direction, followed by the PU direction. On the other hand, the tricep muscle had the highest negative slope value in the PR direction, followed by the PU direction, but it had the highest muscle activity in the PD direction.

A relationship was also found between subjective (discomfort) and objective (EMG) data. Participants' discomfort ratings supported both the muscle activation and fatigability results, and they considered the PR and PU directions at the 10 lbs. force level to be the most strenuous exertion. In fact, some of the participants could not complete some of the PR and PU direction force exertion trials. The PR and PU directions at the 7.5 lbs. force level were considered to be the second most strenuous exertions. Furthermore, participants' discomfort ratings show that the PD and PL directions at the 10 lbs. force level and the PR and PU directions at the 5 lbs. force level produced almost the same level of discomfort. A similar finding was made in muscle activation and fatigability results.

In occupational application, an MVC of 30% or more is considered to be occupationally hazardous. Only two exertion directions resulted in this level of activation. The PR and PU exertion directions had 30% muscle activation or more, and can thus be considered the most hazardous directions. In the PR direction at the 10 lbs. force level, the supraspinatus, infraspinatus, middle deltoid and posterior deltoid muscles exert more than 30% MVC. In the PU direction at

10 lbs. force level, the supraspinatus, infraspinatus and bicep muscles exert more than 30% MVC. In the PU direction at each of the force levels, the anterior deltoid muscles exert more than 30% MVC. In the PR and PU directions at the 7.5 lbs. force level, the infraspinatus muscle exerted more than 30% MVC.

Muscle co-contraction improves joint stability in the human body, especially during in dynamic force exertions (Xu, 2014). Some studies (Van der Helm, 1994; Happee and Van der Helm, 1995) indicate that the concavity compression mechanism in the GHJ is basically muscle co-contraction, particularly when the reaction/resultant force of shoulder muscles is pushing the humeral head to the glenoid fossa to stabilize the GHJ and prevent it from dislocating. Forster et al. (2004) define muscle co-contraction as the occurrence of antagonistic muscle activity. The activity of agonist and antagonistic muscle groups and arm abduction angle play important roles in muscle co-contraction during dynamic exertions; however, the shoulder elevation plane has no influence on muscle co-contraction (Xu et al., 2014; Antony et al., 2010). Muscle co-contraction is hard to predict in static muscle exertions and therefore cannot be used to explain findings of this current study.

## **6.1 Future work and limitation**

Shoulder muscles' action can be characterized into three vectors which are compressive force, anterior-posterior shear force and superior-inferior shear force. The compressive forces work to push the humeral head into the glenoid fossa for stabilizing the GHJ. Future studies should investigate the exact compressive forces direction that provide GHJ stability by pushing glenohumeral head to the glenoid fossa.

One of the limitation we had in this study is gender diversity. Only male participants were used for data collection in this study. Inclusion of female participant could provide additional insight into the gender specific strategies used by the shoulder muscles to stabilize the joint. Resting time of 2 minutes was provided between trials. It is possible that 2 minutes may not have been enough for participants to fully recover from the preceding exertion. Future studies should better control/study the effect of gender and rest period on fatigability and overall stability of the shoulder complex.

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## **Appendix A: PAR-Q**

# PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. <b>Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?</b>
<input type="checkbox"/>	<input type="checkbox"/>	2. <b>Do you feel pain in your chest when you do physical activity?</b>
<input type="checkbox"/>	<input type="checkbox"/>	3. <b>In the past month, have you had chest pain when you were not doing physical activity?</b>
<input type="checkbox"/>	<input type="checkbox"/>	4. <b>Do you lose your balance because of dizziness or do you ever lose consciousness?</b>
<input type="checkbox"/>	<input type="checkbox"/>	5. <b>Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?</b>
<input type="checkbox"/>	<input type="checkbox"/>	6. <b>Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?</b>
<input type="checkbox"/>	<input type="checkbox"/>	7. <b>Do you know of <u>any other reason</u> why you should not do physical activity?</b>

**If  
you  
answered**

## YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

## NO to all questions

- If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
  - take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

### DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

**PLEASE NOTE:** If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

**Informed Use of the PAR-Q:** The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

**No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.**

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME \_\_\_\_\_

SIGNATURE \_\_\_\_\_

DATE \_\_\_\_\_

SIGNATURE OF PARENT  
or GUARDIAN (for participants under the age of majority) \_\_\_\_\_

WITNESS \_\_\_\_\_

**Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.**

## **Appendix B: Consent Form**

**Only Minimal Risk  
Consent Information and HIPAA Form**

Principal Investigator	Dr. Ashish Nimbarte
Department	ENGINEERING-Industrial and Management Systems Engineering
Protocol Number	1511900923
Study Title	Effect of force and direction on shoulder complex
Co-Investigator(s)	Hamad Alasim
Sponsor (if any)	N/A

**Contact Persons**

In the event you experience any side effects or injury related to this research, you should contact Dr. Ashish Nimbarte at (304) 293-9473. If you have any questions, concerns, or complaints about this research, you can contact Dr. Ashish Nimbarte (304)293-9473.

For information regarding your rights as a research subject, to discuss problems, concerns, or suggestions related to the research, to obtain information or offer input about the research, contact the Office of Research Compliance at (304) 293-7073.

In addition, if you would like to discuss problems, concerns, have suggestions related to research, or would like to offer input about the research, contact the Office of Research Integrity and Compliance at 304-293-7073.

**Introduction**

You, \_\_\_\_\_, have been asked to participate in this research study, which has been explained to you by Mr. Hamad. This study is being conducted by Dr. Ashish Nimbarte (PhD) and Hamad Alasim in the Department of Industrial and Management System Engineering at West Virginia University.

**Purpose(s) of the Study**

The purpose of this study is to find out if static hand load exertions in five different directions, which are front, right, left, up and down direction, can develop shoulder fatigue and shoulder instability.

**Description of Procedures**

Upon arrival, the procedures of the experiment will be explained to you in detail and you will be asked to sign an informed consent form. Next, basic anthropometric data including age, body weight, height and elbow height will be measured. You will be then given a ~10 minutes training session in order to become familiar with the tasks to be performed and also to warm-up your shoulder muscles. Surface EMG electrodes will be placed over the skin at the following muscles: supraspinatus, infraspinatus, teres major, anterior deltoid, middle deltoid, posterior deltoid, biceps and triceps. You will be asked to perform maximum voluntary contraction (MVC) exertions in order to measure the maximum exertion using EMG from all selected muscles. Each maximum voluntary contraction trial will be five seconds long and a one-minute rest

period will be provided between exertions in order to reduce the chance of fatigue and injury. Then you will move to the testing area and perform designated tasks. In each trial you are required to hold a D-shape handle attached to one of the weight levels which are (10, 7.5, 5 lb.) for 60 second with a 15°- 20° flexed elbow joint and a 70°- 80° flexed shoulder joint. You will perform this task in five different directions which are right, left, front, up and down. Each trial will have two repetitions. A 3 minutes' rest time is will be provided between trials. A total of 30 trials will be performed. After the completion of each task, you will be asked to numerically rate your perceived exertion caused by the hand load exertion using Borg's CR-10 scale. The Borg CR-10 scale contains two columns, one for subjective categories ranging from "nothing at all" to "extremely strong" and the other for numerical ratios ranging on a scale of 0 to 10 that are associated with the different categories. The purpose of performing static hand load exertions during those trials was to generate fatigue in the shoulder muscles. During performing static hand load exertions, you will be seated in the wooden chair in upright position and buckle up with the four-point harness to prevent any upper body movement which could interfere with the data collection.

### **Discomforts**

There is a minimal risk for shoulder muscles strain and fatigue while performing the maximum exertions. Therefore, you will be required to complete a warm up before these tasks and sufficient rest between trials.

### **Alternatives**

You do not have to participate in this study.

### **Benefits**

You may not receive any direct benefit from this study. The knowledge gained from this study may eventually benefit others.

### **Financial Considerations**

You will not receive any compensation for participation in the study and will not incur any costs related to the study. It is very important for you to understand that neither the investigator nor WVU or it associated affiliates has the funds set aside to pay for the cost work wages or any care or treatment that might be necessary because you get hurt or sick taking part in this study. Any injuries that may result from this study would not be eligible for workers' Compensation as this is not a job related injury. Understand that any treatments necessary will be billed to the participant or to your personal health insurance, and you may wish to consult your insurance provider before participating in this study.

### **Confidentiality**

Any information about you that is obtained as a result of your participation in this research will be kept as confidential as legally possible. Your research records and test results, just like hospital records, may be subpoenaed by court order or may be inspected by the study sponsor or federal regulatory authorities (including the FDA if applicable) without your additional consent.

### **Voluntary Participation**

Participation in this study is voluntary. You are free to withdraw your consent to participate in this study at any time.

Refusal to participate or withdrawal will not affect [your class standing or grades, as appropriate] and will involve no penalty to you. Refusal to participate or withdrawal will not affect your future care, or your employee status at West Virginia University.

In the event new information becomes available that may affect your willingness to participate in this study, this information will be given to you so that you can make an informed decision about whether or not to continue your participation.

You have been given the opportunity to ask questions about the research, and you have received answers concerning areas you did not understand.

Upon signing this form, you will receive a copy.

I willingly consent to participate in this research.

## Signatures

Signature of Subject

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Printed Name

Date

Time

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The participant has had the opportunity to have questions addressed. The participant willingly agrees to be in the study.

Signature of Investigator or Co-Investigator

---

Printed Name

Date

Time

---

### Approval Letter Expedited

**Action Date** 02/02/2016  
**To** Ashish Nimbarte  
**From** WVU Office of Research Integrity and Compliance  
**Approval Date** 02/02/2016  
**Expiration Date** 02/01/2017  
**Subject** Protocol Approval Letter  
**Protocol Number** 1511900923  
**Title** Effect of Force and Direction on shoulder Complex.

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The above-referenced research study was reviewed by the West Virginia University Institutional Review Board IRB and was approved in accordance with 46 CFR 46.101b.

It has been determined that this study is of minimal risk and meets the criteria as defined by the expedited categories listed below:

- Category 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subjects privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.
- Category 7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. [NOTE: Some research in this category may be exempt from the DHHS regulations for the protection of human subjects. See Exempt Categories and 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.]



Documents reviewed and/or approved as part of this submission:

**Subject Name.pdf:** 2016-01-20-05:00

**Hamad's Consent OMR .pdf:** 2016-01-25-05:00

**Dear Dr.pdf:** 2016-01-25-05:00

Documents for use in this study are available in the WVUkc system in the Notes and Attachments section of your protocol.

The Office of Research Integrity and Compliance is here to provide assistance to you from the initial submission of an IRB protocol and all subsequent activity. Please feel free to contact us by phone at 304.293.7073 with any question you may have. Thank you.

WVU Office of Research Integrity and Compliance

Date:02/02/2016

Signed:



**Sarah Stutler**

**IRB Administrator**

iving regulations apply:

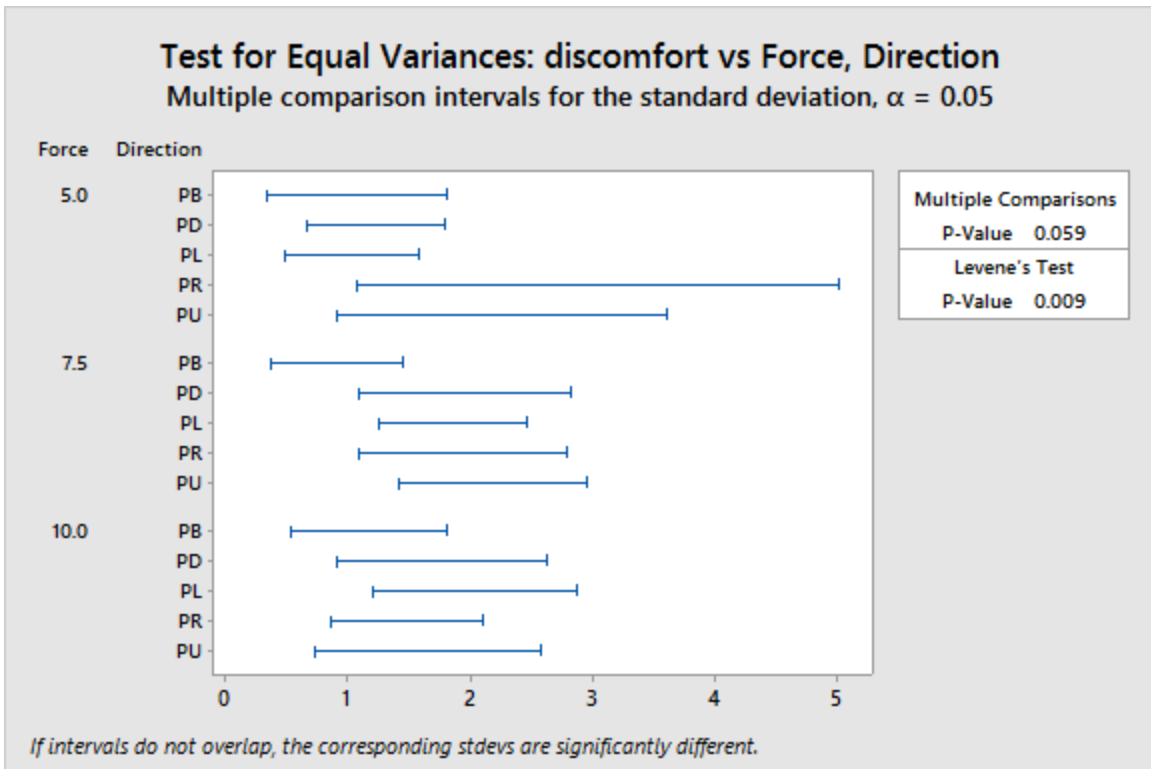
1. Unanticipated or serious adverse events/side effects encountered in this research study must be reported to the IRB within five (5) days via the Notify IRB action.
2. Any modifications to the study protocol or informed consent form must be reviewed and approved by the IRB prior to implementation via submission of an amendment.
3. You may not use a modified informed consent form until it has been approved and validated by the IRB.

## **Appendix C: Borg's CR-10 scale**

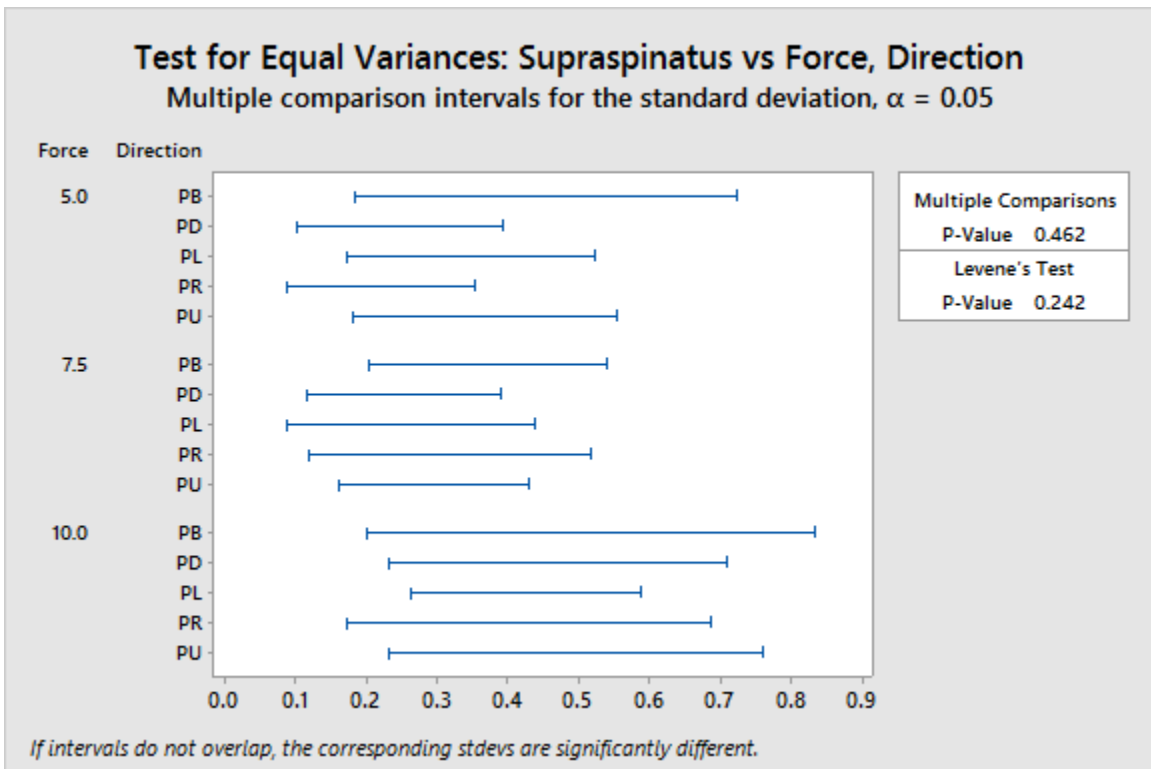
*Table 27: Borg's CR-10 scale*

<b>Number</b>	<b>Severity</b>
1	Nothing at all
2	Just Noticeable
3	Very Slight
4	Slight
5	Slight Moderate
6	Moderate
7	Some difficulty
8	Moderate Severe
9	Severe
10	Very Severe

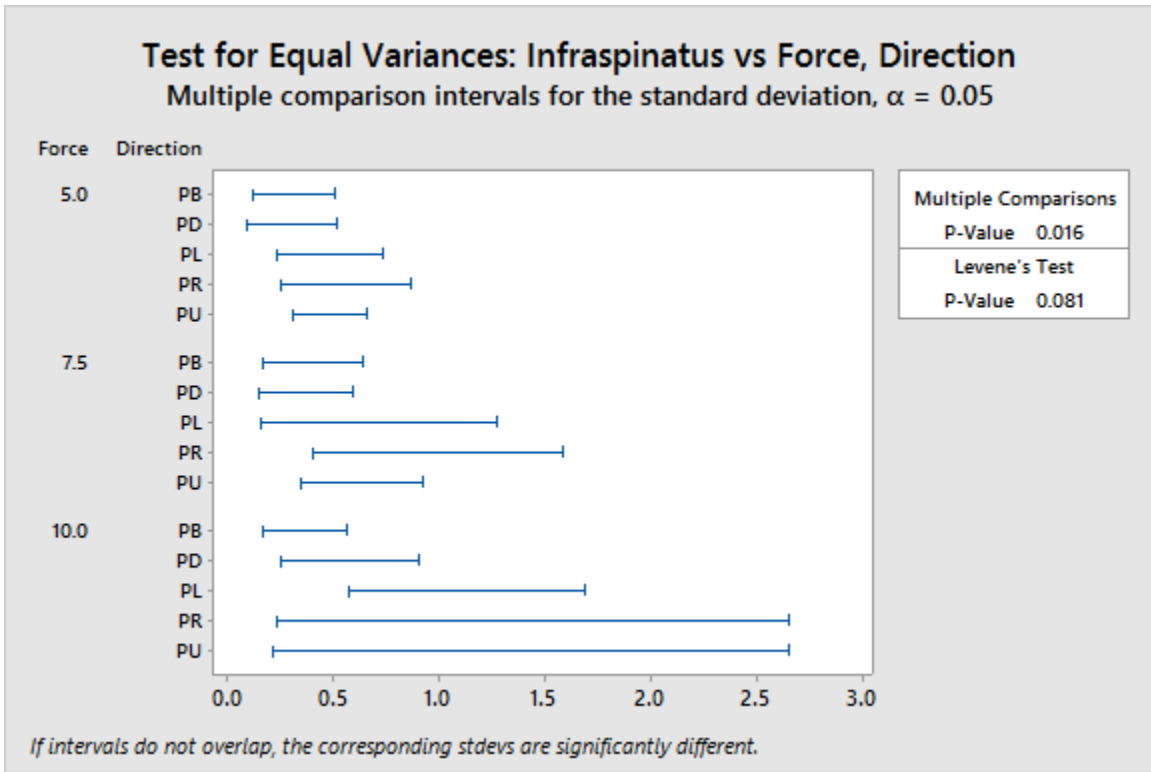
## **Appendix D: Equality of variance**



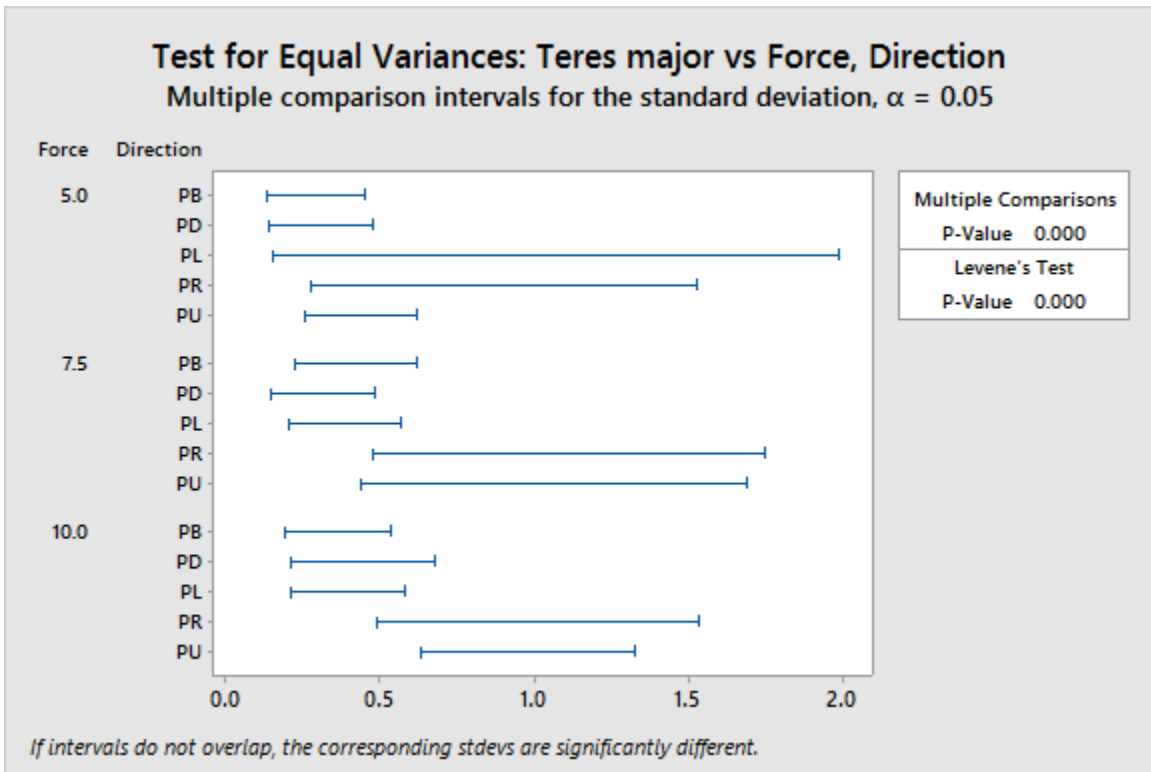
Equality of variance test for discomfort rating



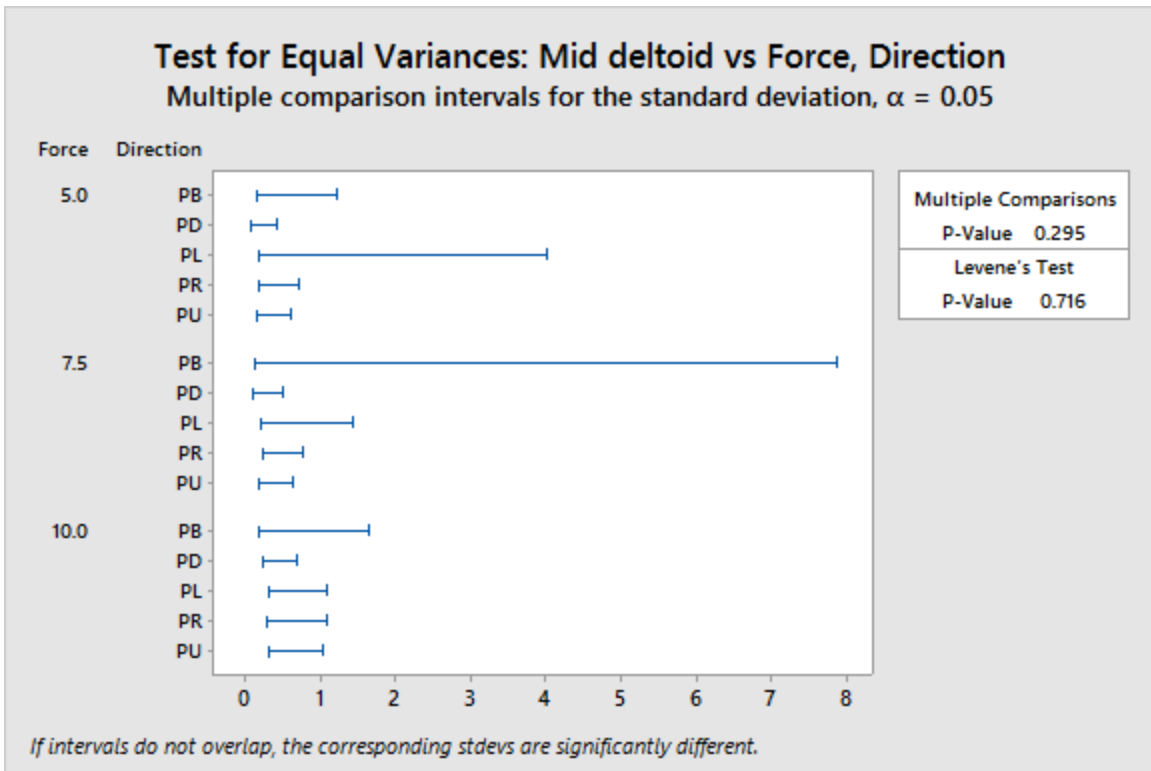
Equality of variance test for M (supraspinatus)



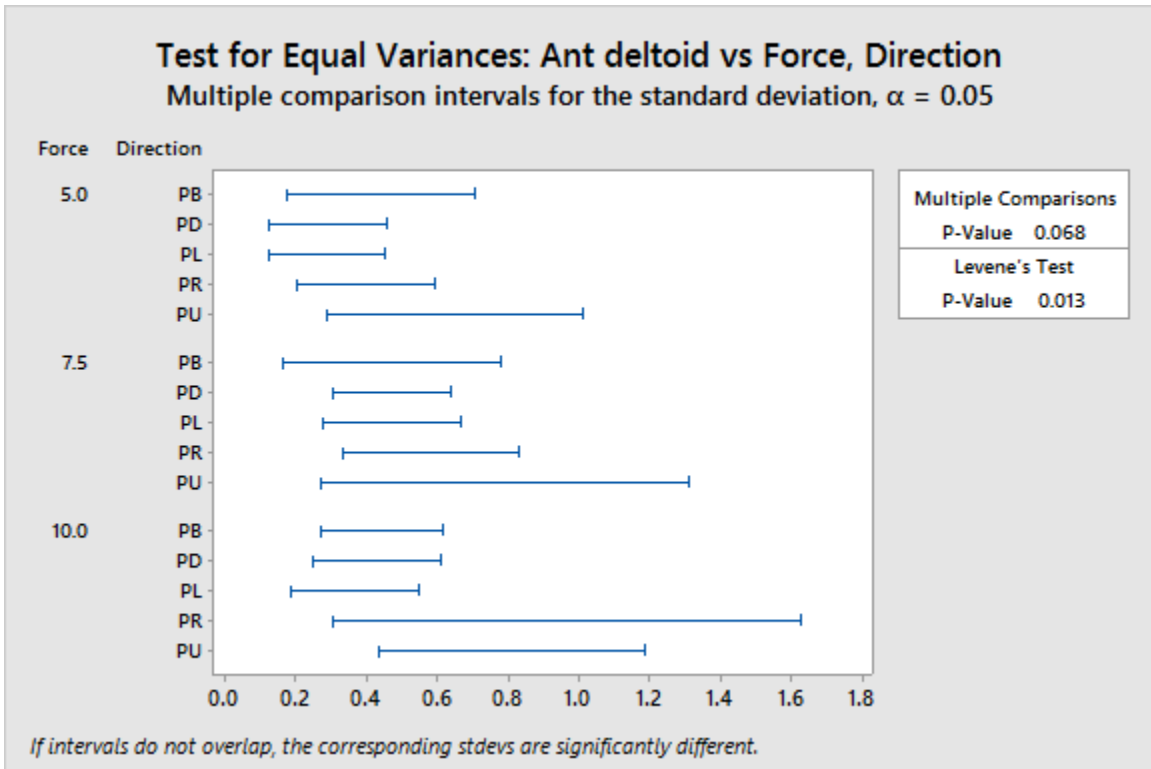
Equality of variance test for M (infraspinatus)



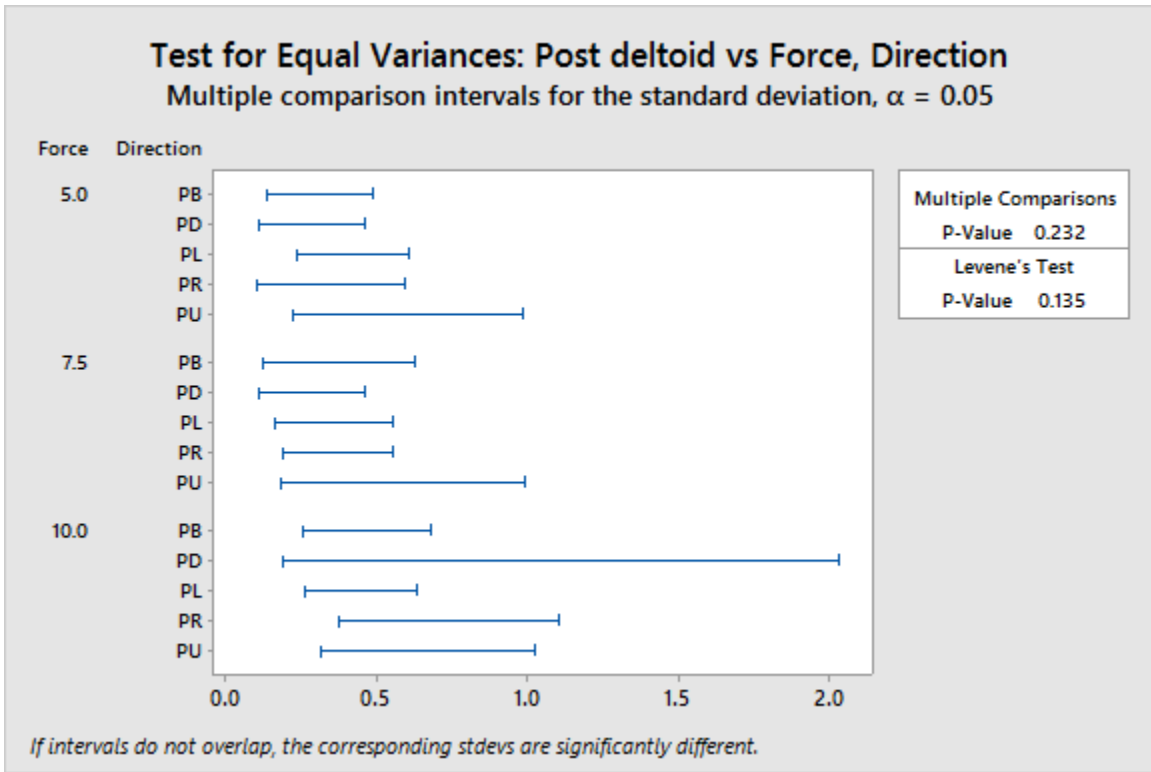
Equality of variance test for M (teres major)



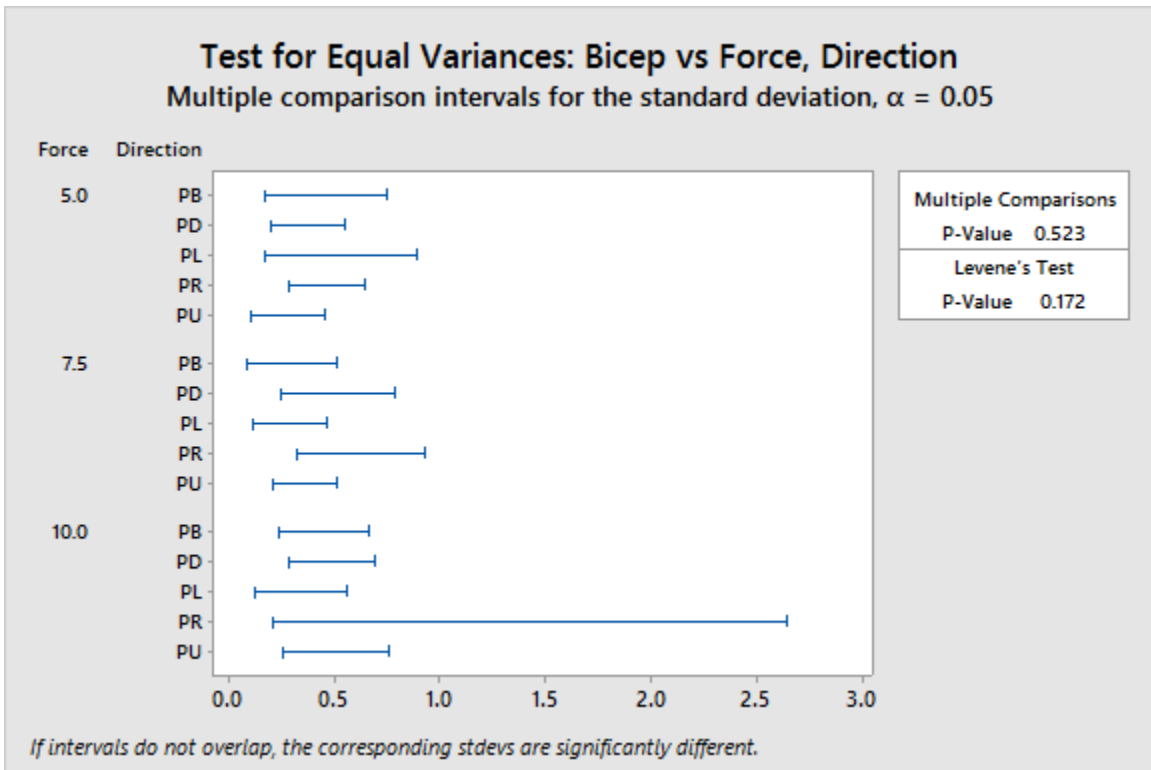
Equality of variance test for M (middle deltoid)



Equality of variance test for M (anterior deltoid)

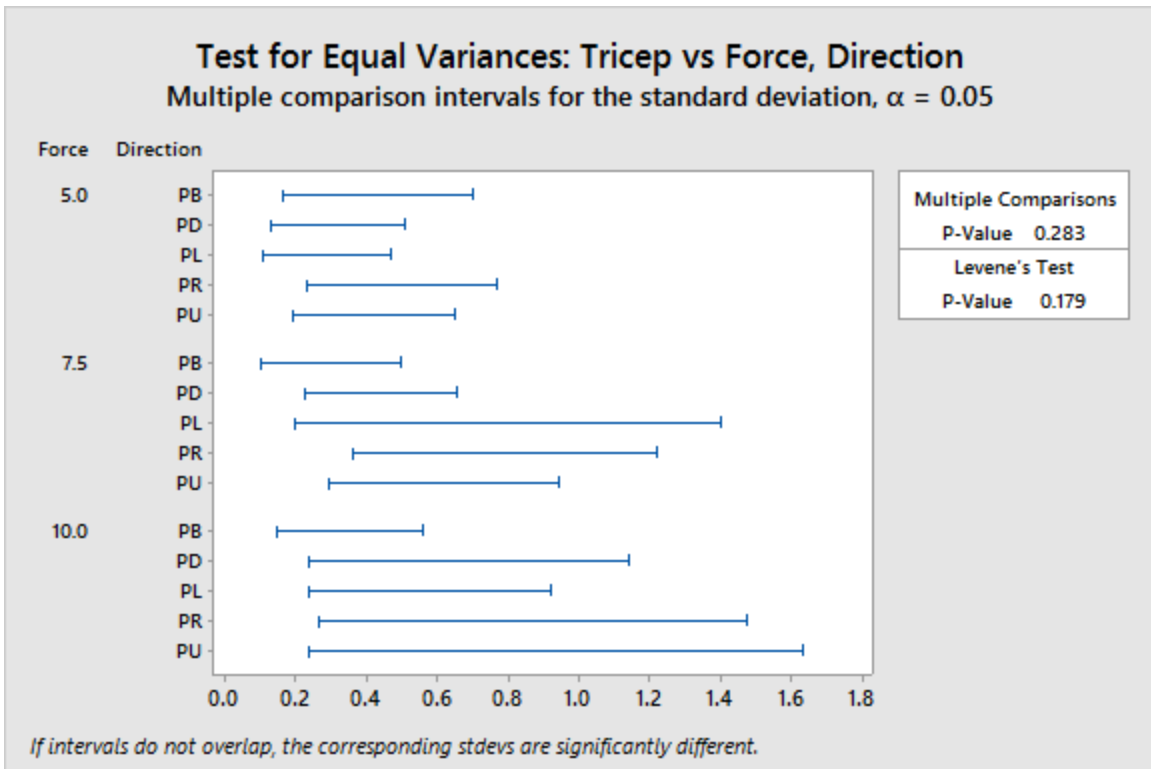


Equality of variance test for M (posterior deltoid)

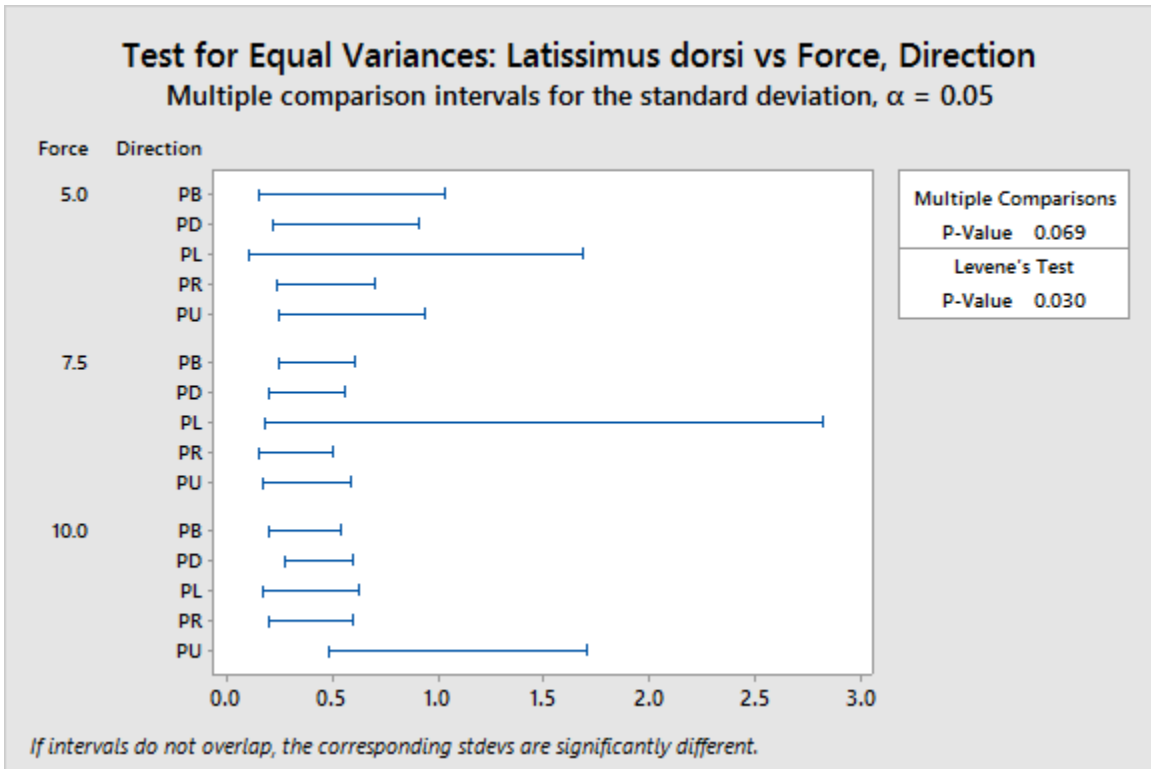


Equality of variance test for M (bicep)

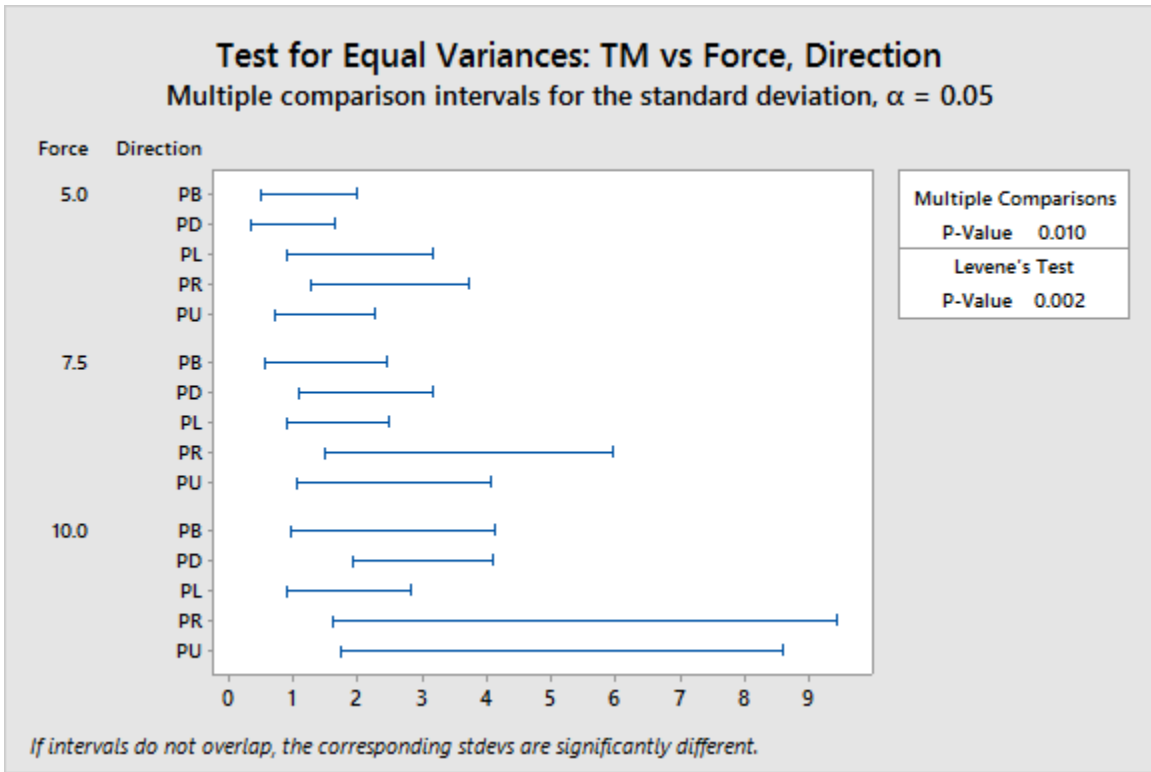




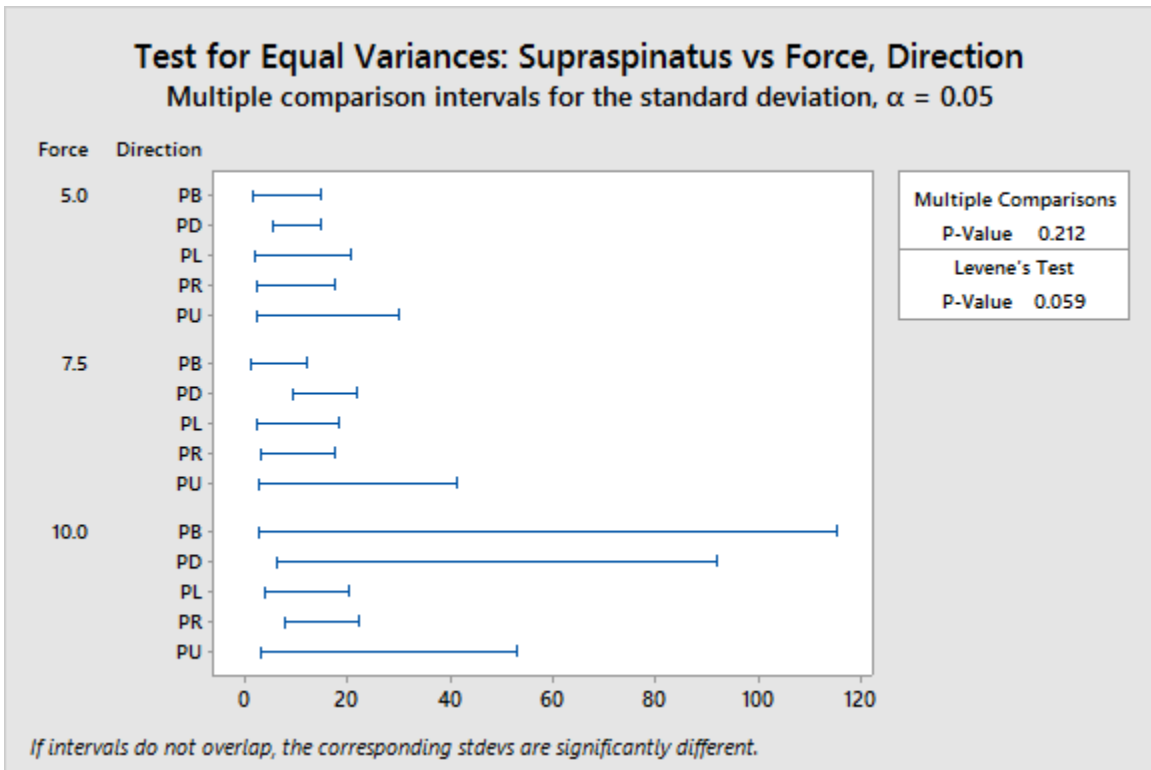
Equality of variance test for M (tricep)



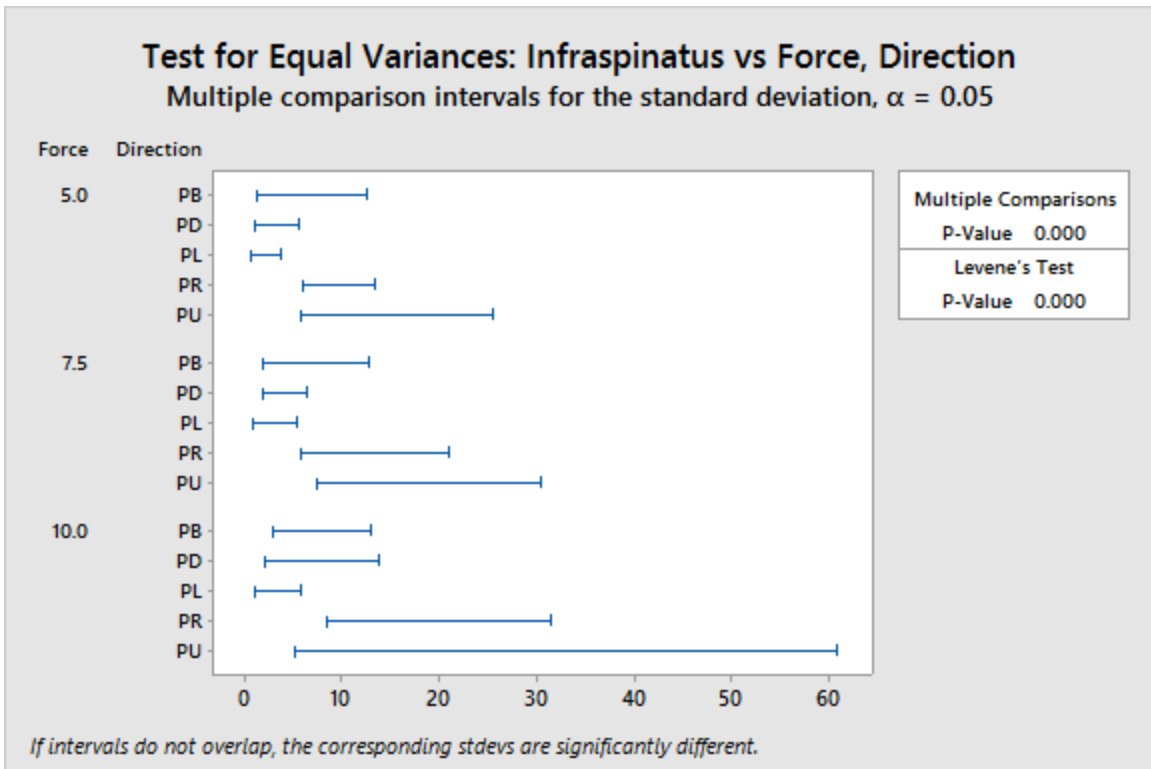
Equality of variance test for M (latissimus dorsi)



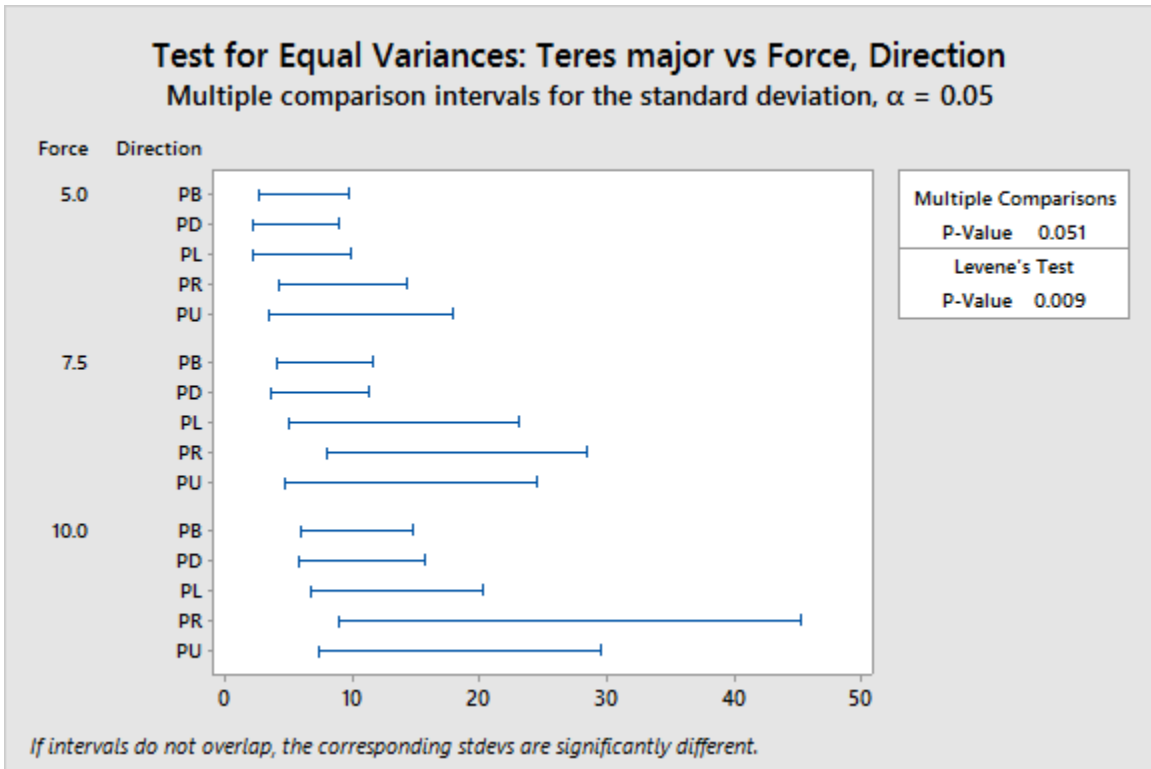
Equality of variance test for TM



Equality of variance test for NMAV (supraspinatus)



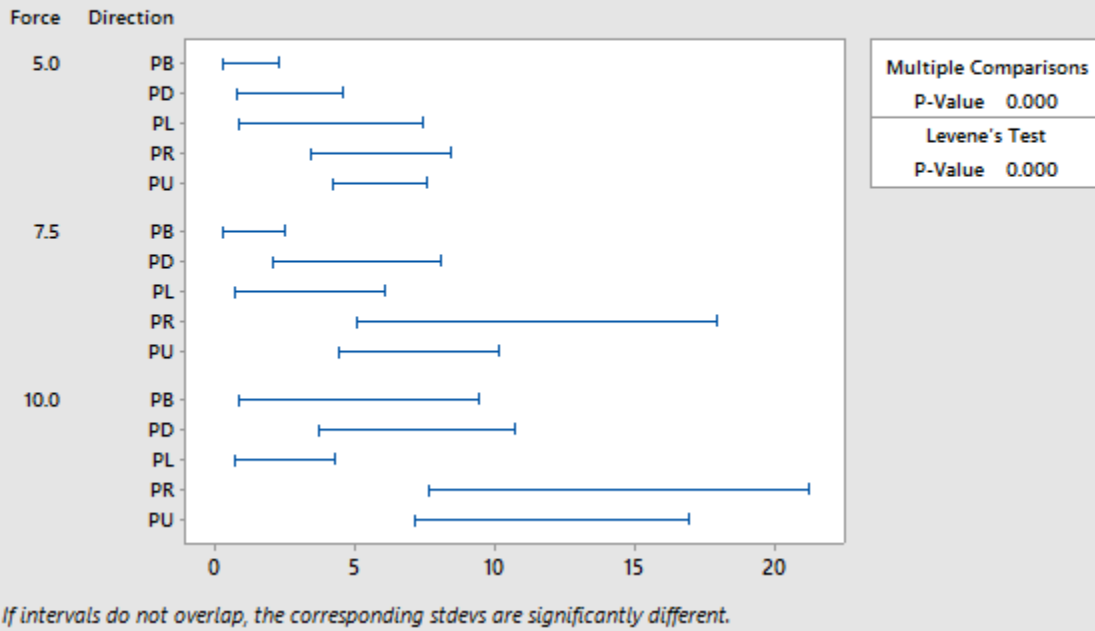
Equality of variance test for NMAV (infraspinatus)



Equality of variance test for NMAV (teres major)

### Test for Equal Variances: Mid deltoid vs Force, Direction

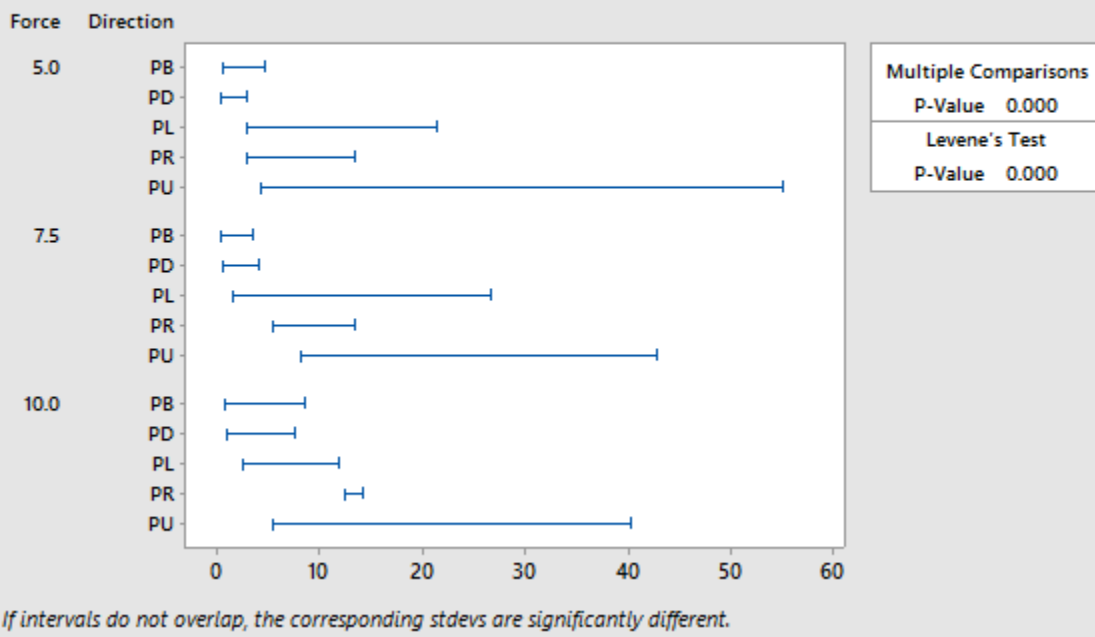
Multiple comparison intervals for the standard deviation,  $\alpha = 0.05$



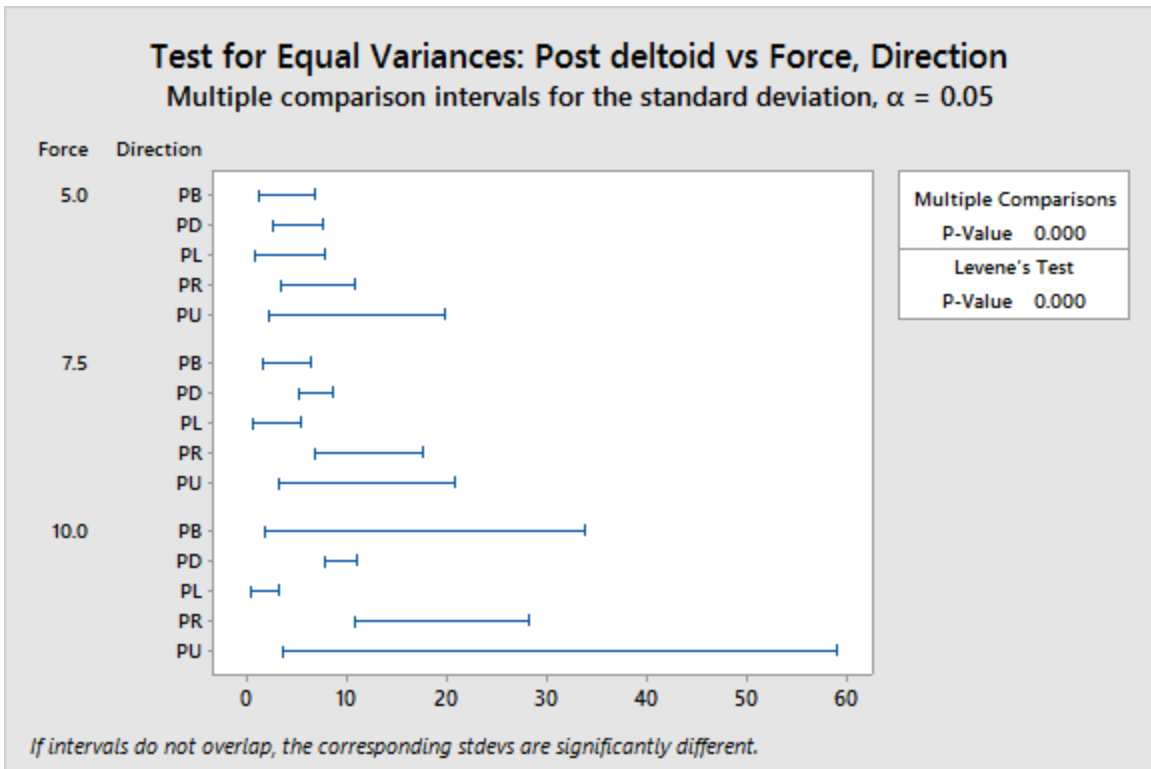
Equality of variance test for NMAV (middle deltoid)

### Test for Equal Variances: Ant deltoid vs Force, Direction

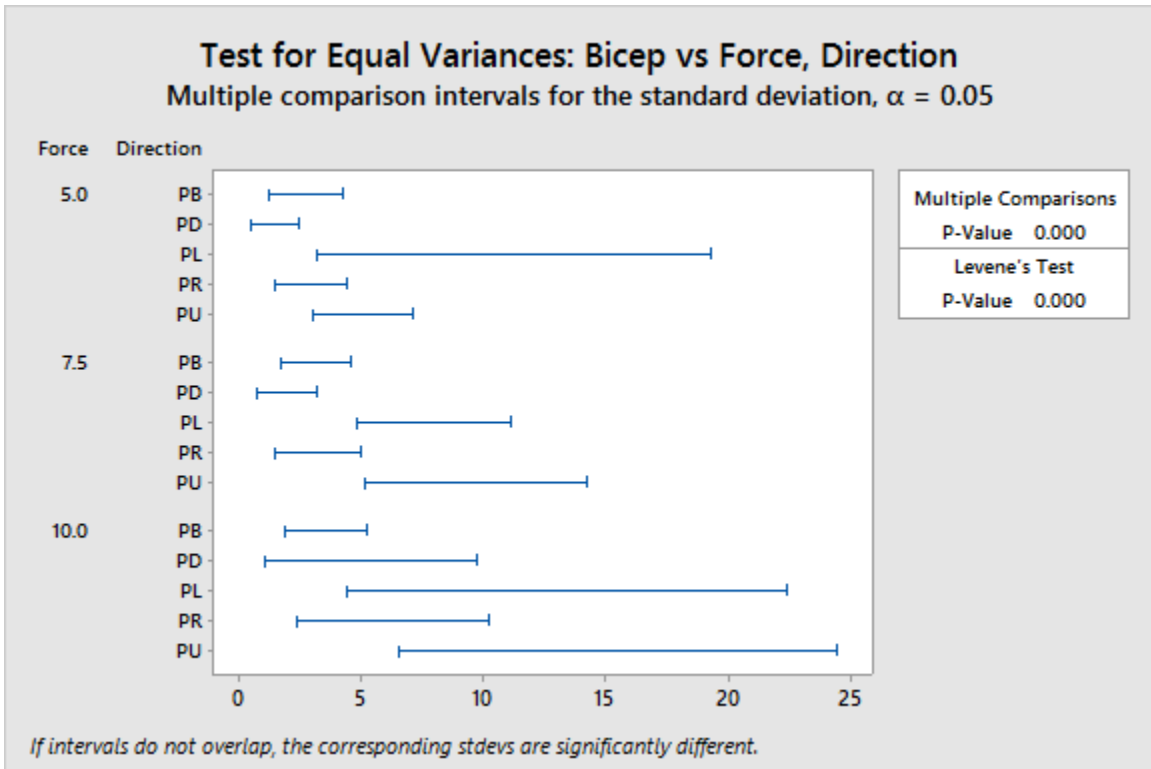
Multiple comparison intervals for the standard deviation,  $\alpha = 0.05$



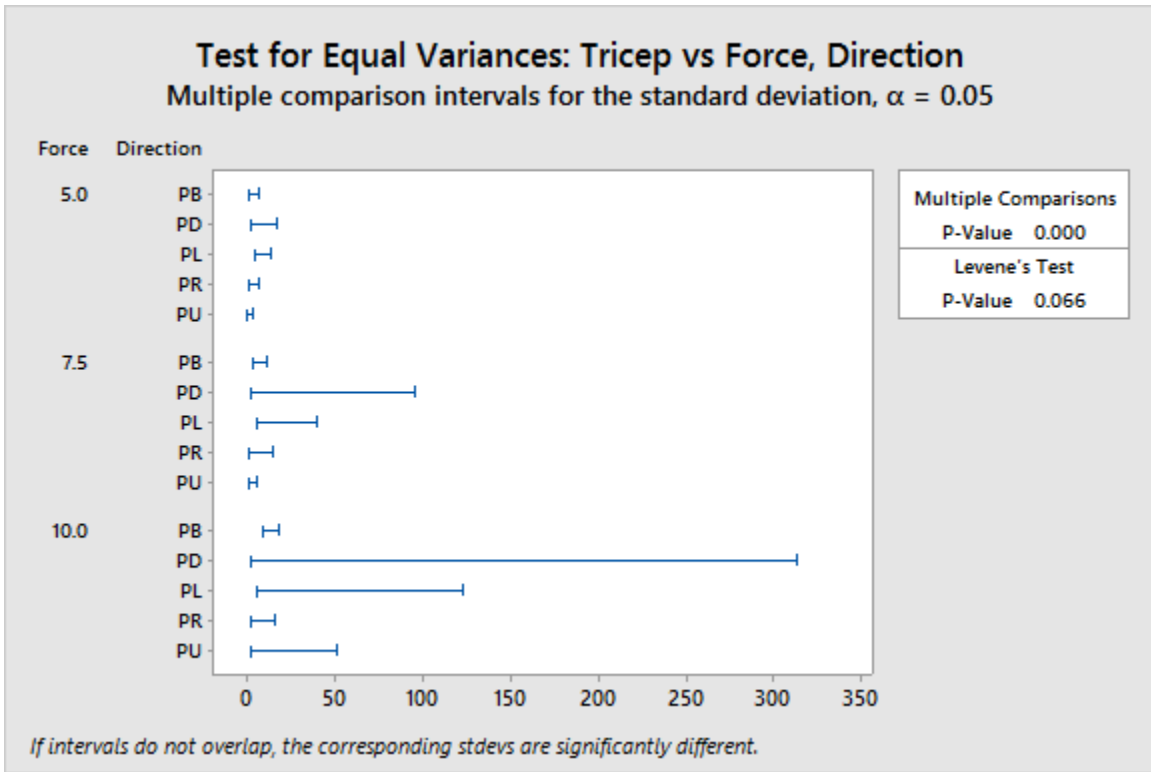
Equality of variance test for NMAV (anterior deltoid)



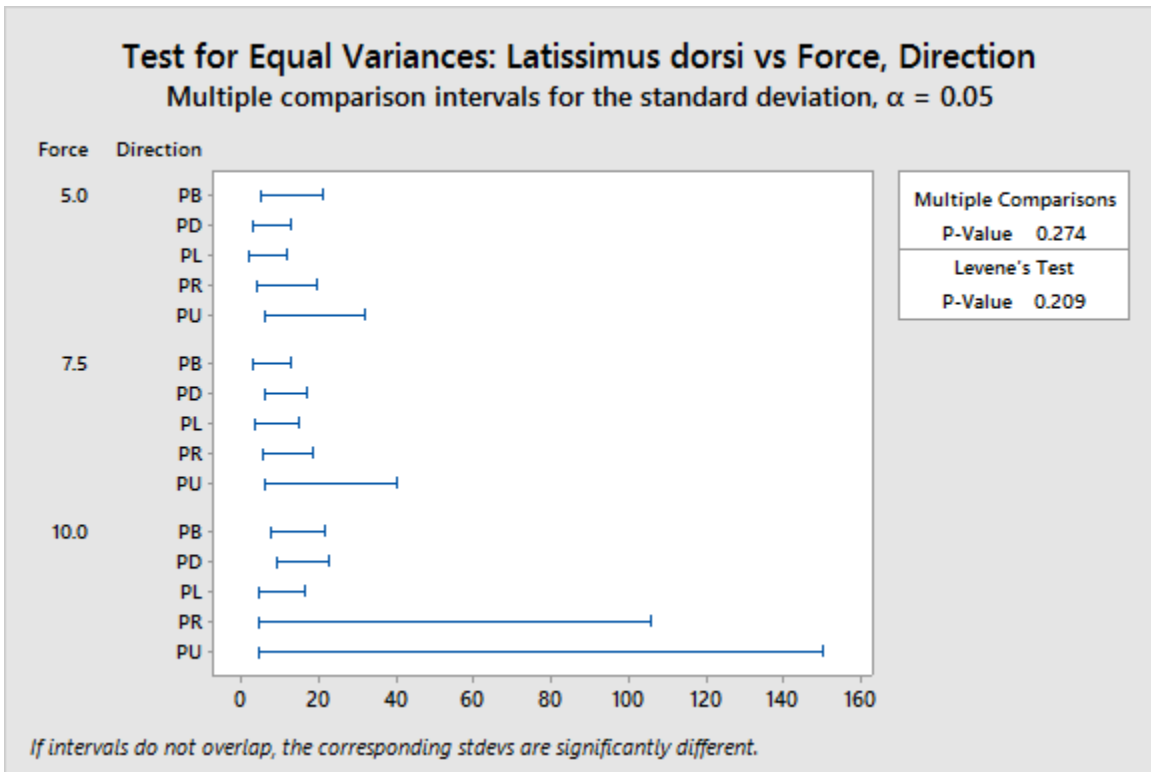
Equality of variance test for NMAV (posterior deltoid)



Equality of variance test for NMAV (bicep)



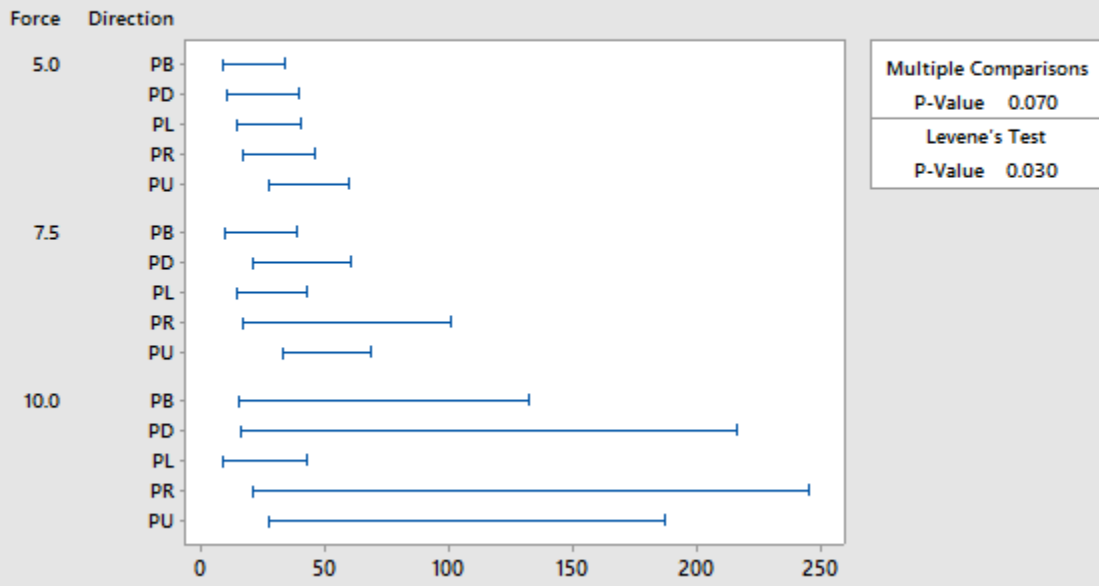
Equality of variance test for NMAV (tricep)



Equality of variance test for NMAV (latissimus dorsi)

### Test for Equal Variances: TNMAV vs Force, Direction

Multiple comparison intervals for the standard deviation,  $\alpha = 0.05$

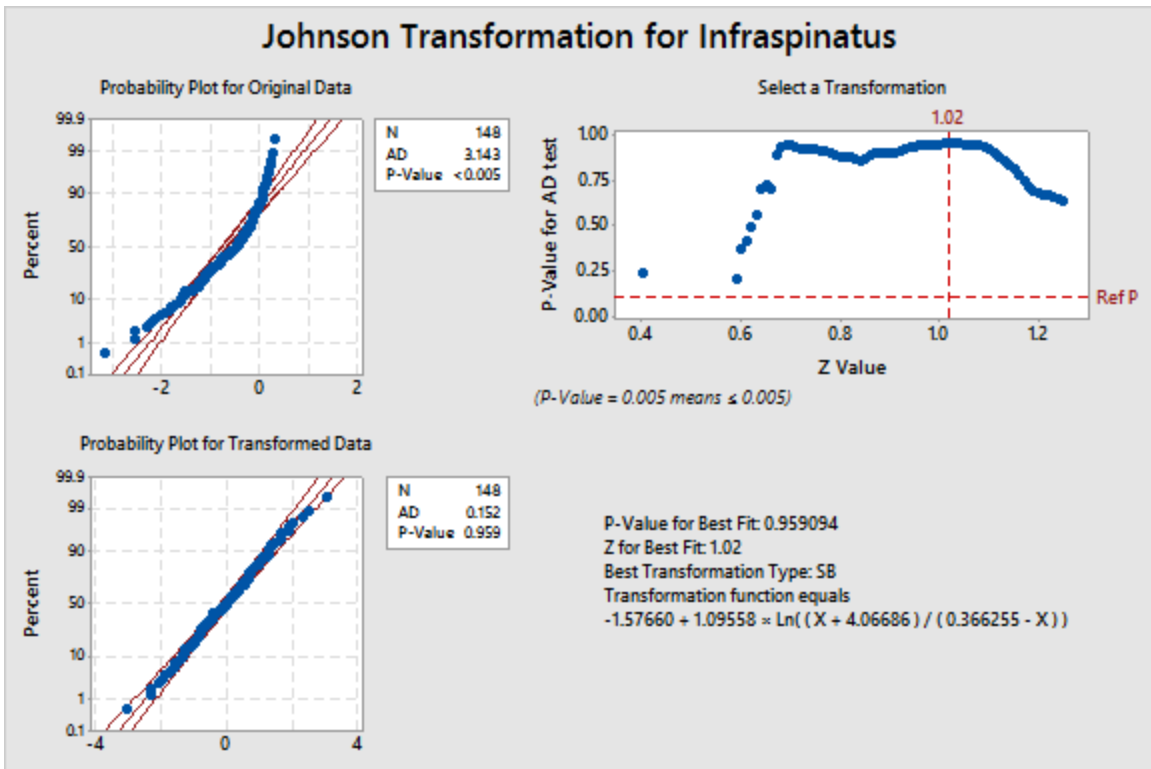


*If intervals do not overlap, the corresponding stdevs are significantly different.*

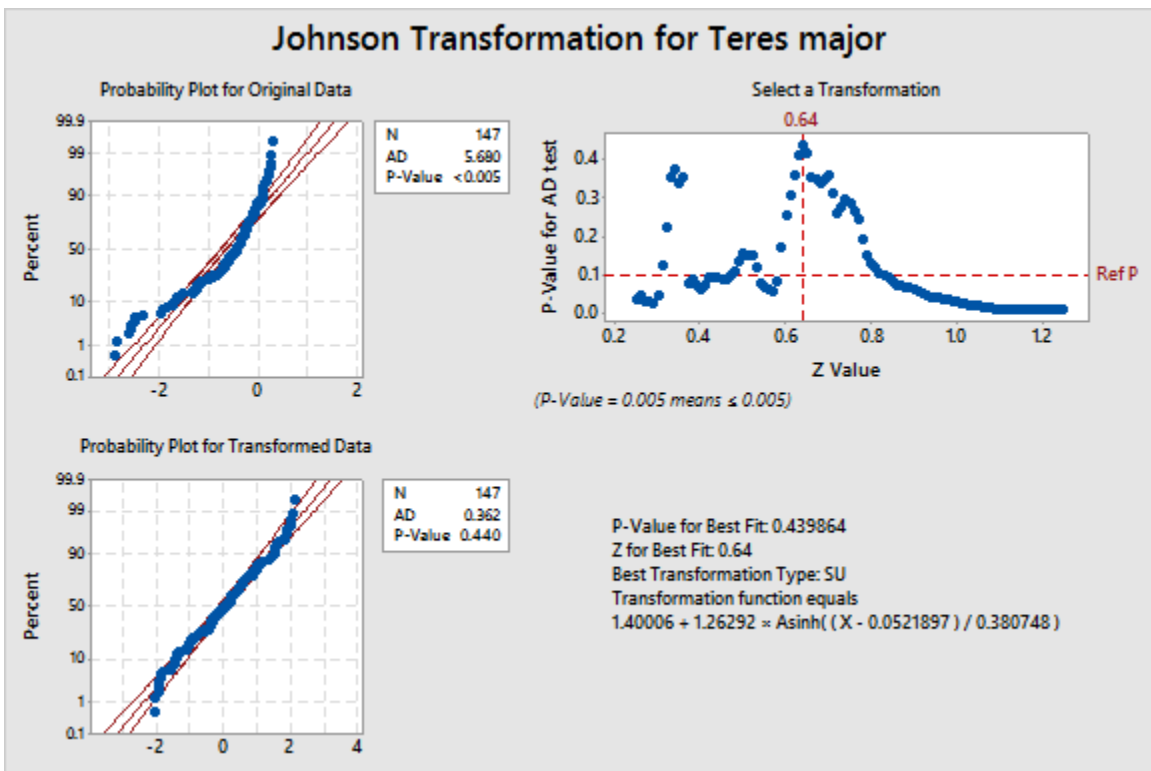
Equality of variance test for TNMAV

## **Appendix E: Johnson transformation**

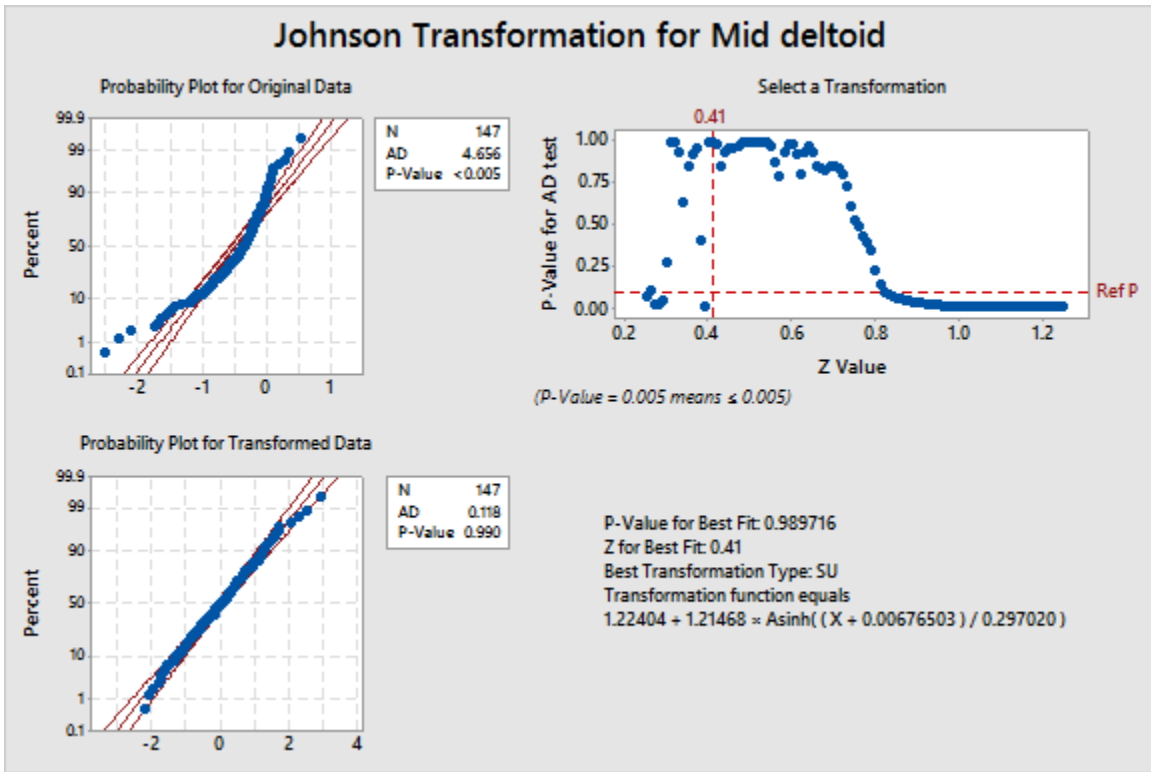




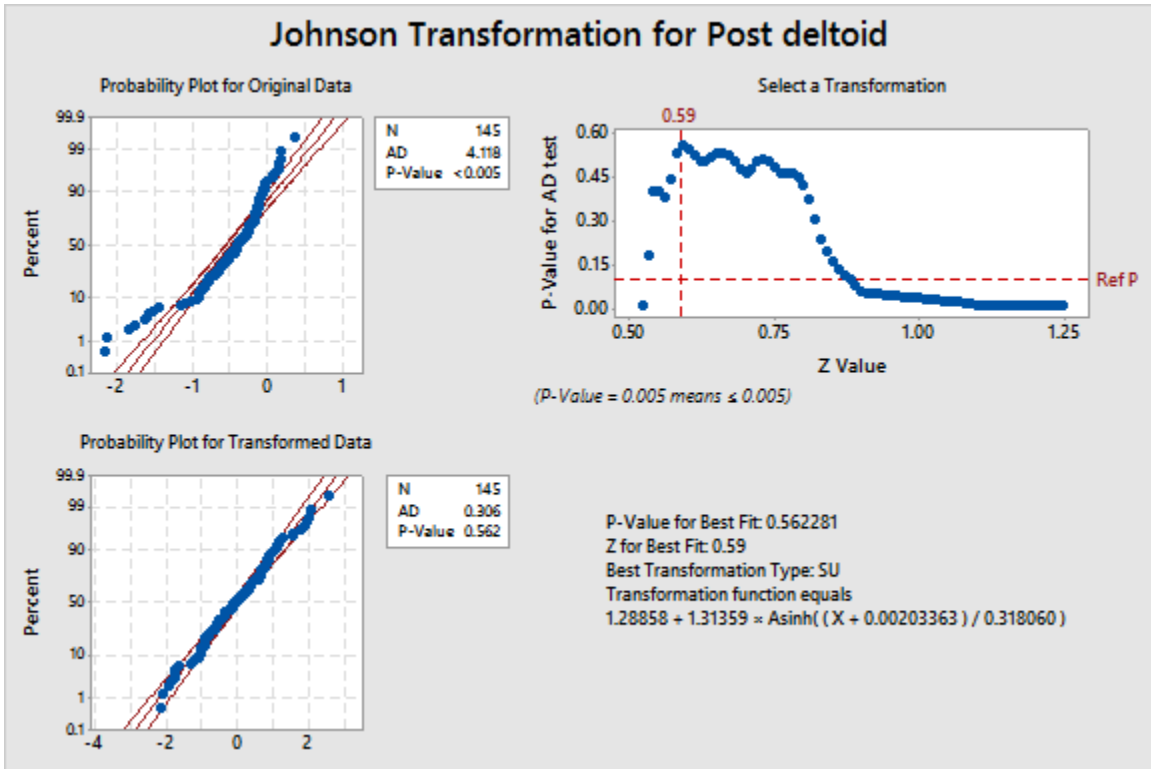
Johnson transformation for M (infraspinatus)



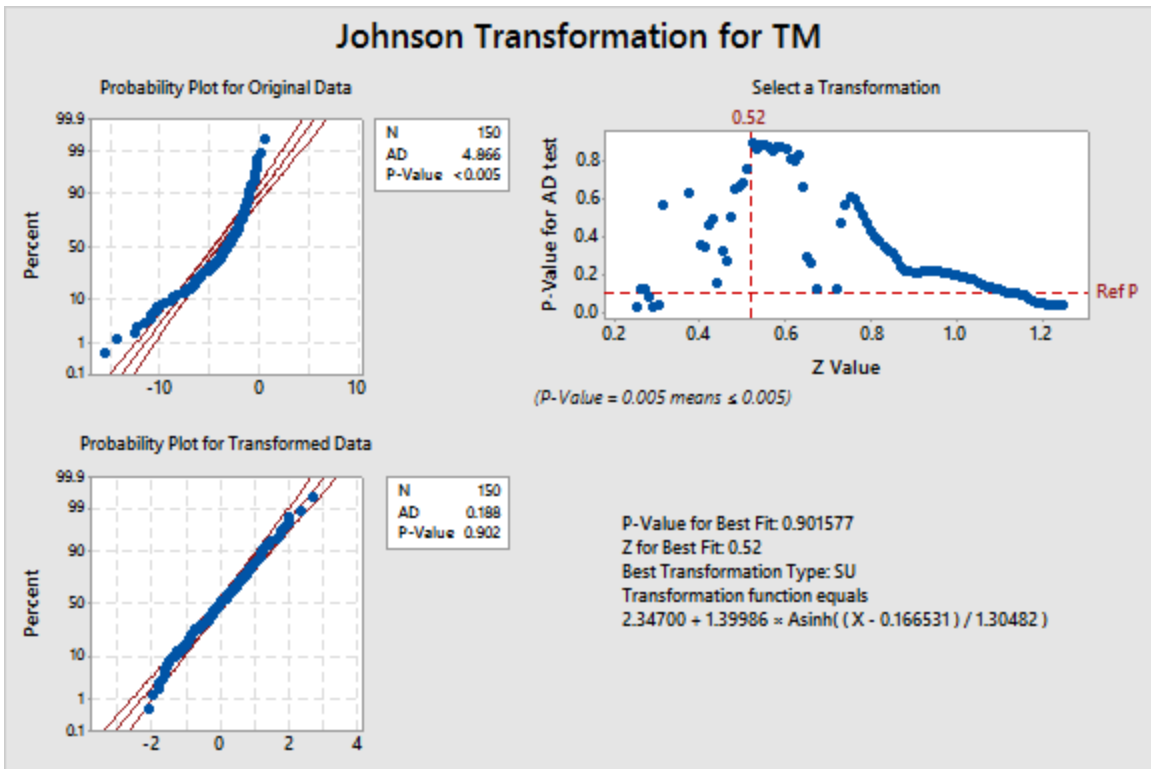
Johnson transformation for M (Teres major)



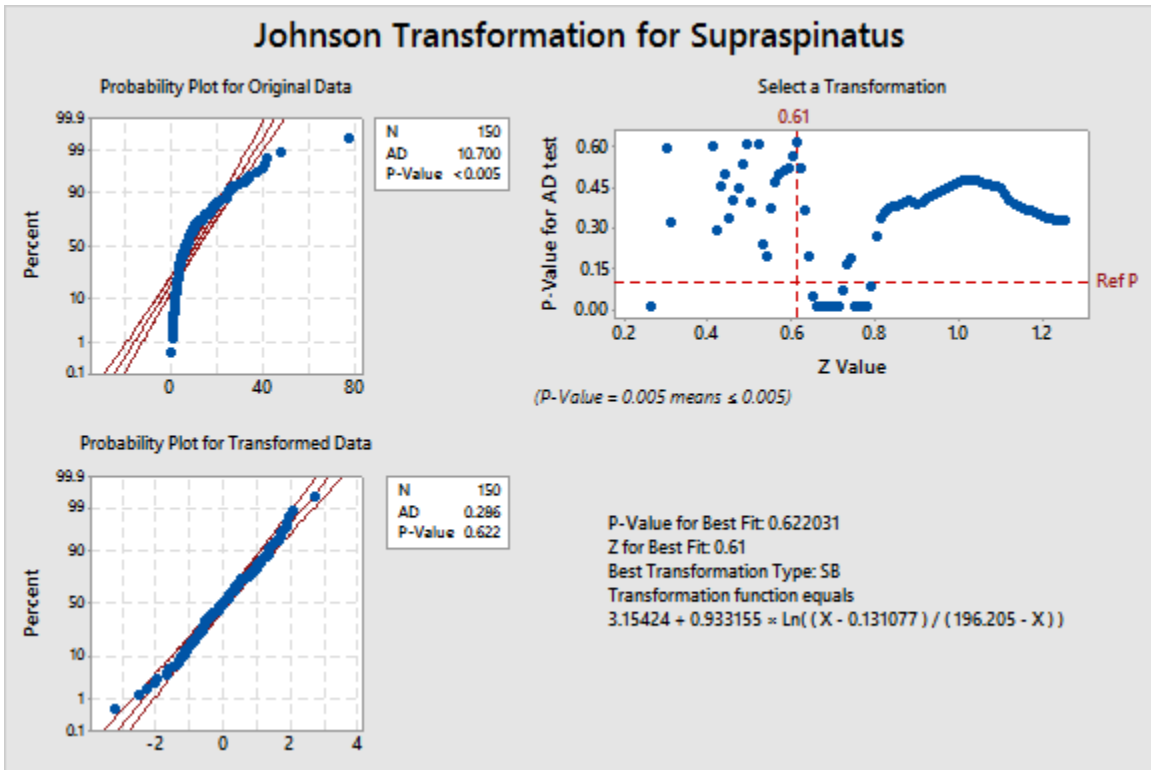
Johnson transformation for M (middle deltoid)



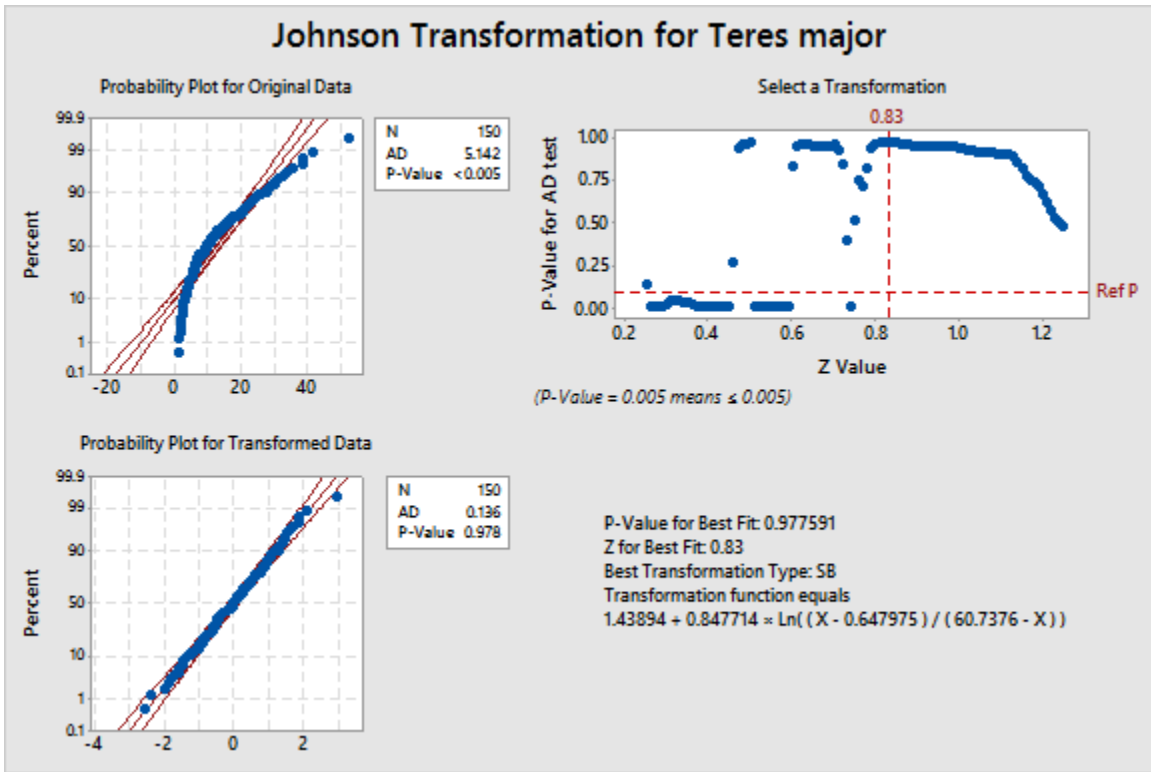
Johnson transformation for M (posterior deltoid)



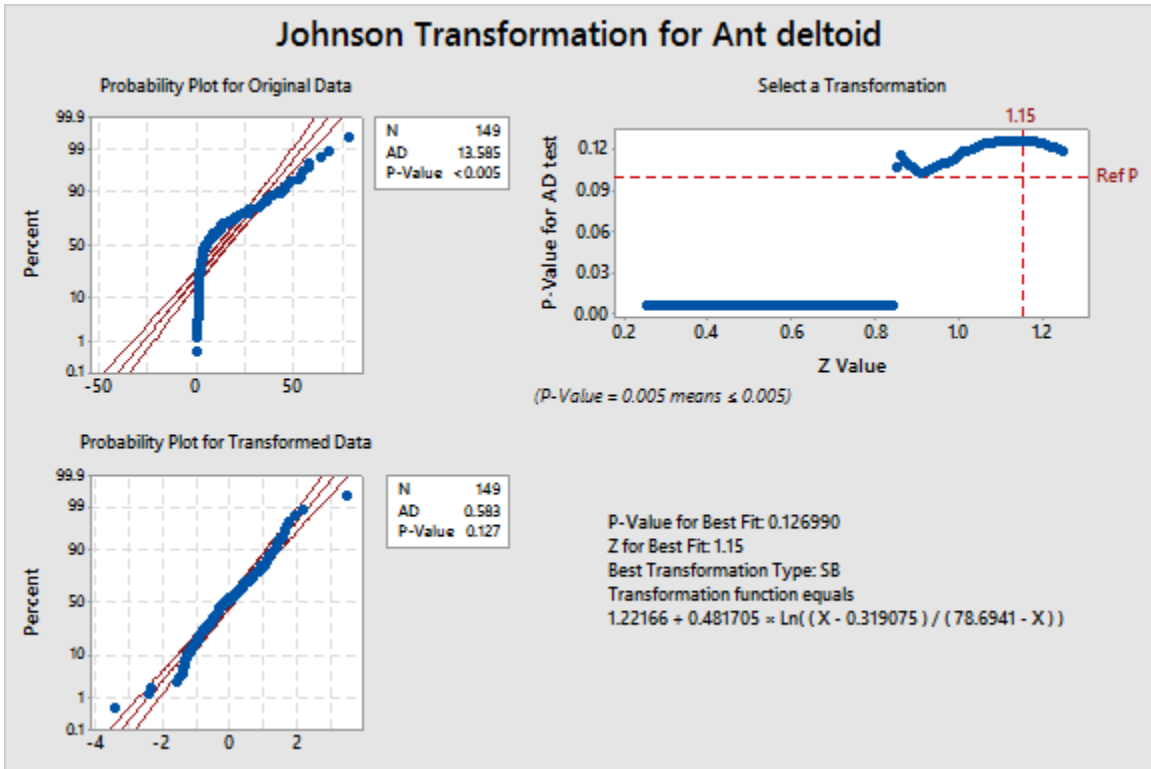
Johnson transformation for TM



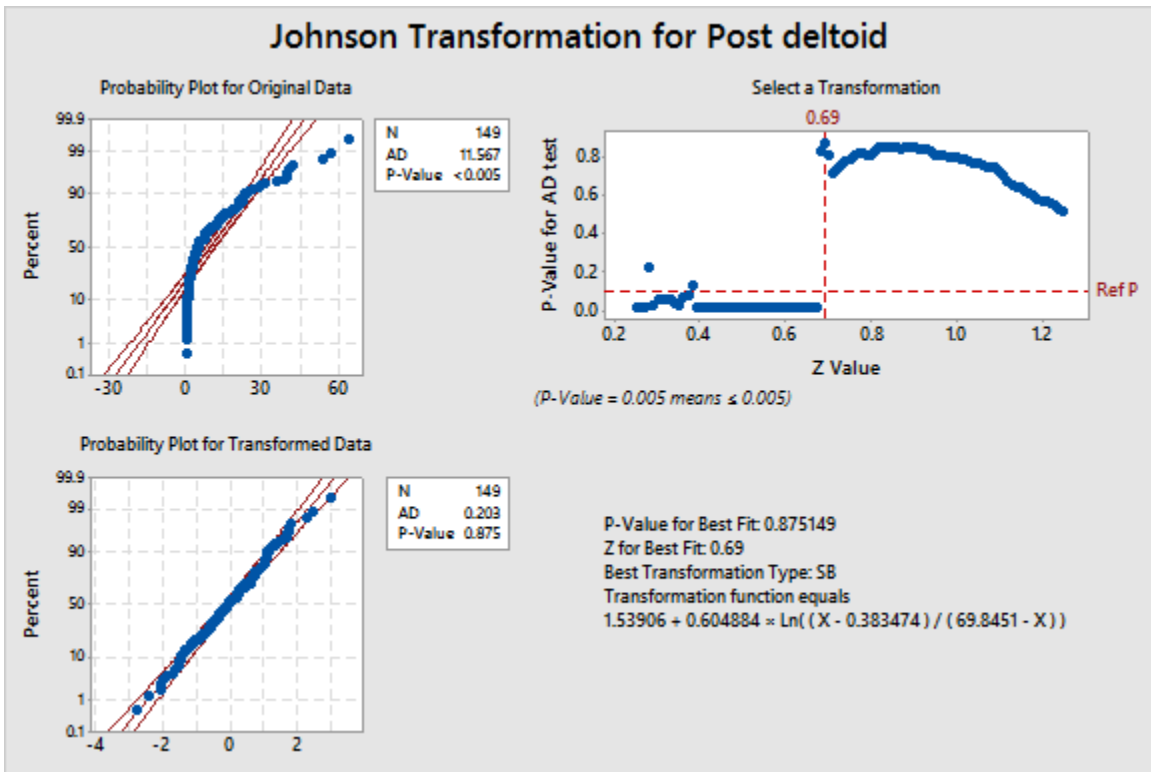
Johnson transformation for NMAV (supraspinatus)



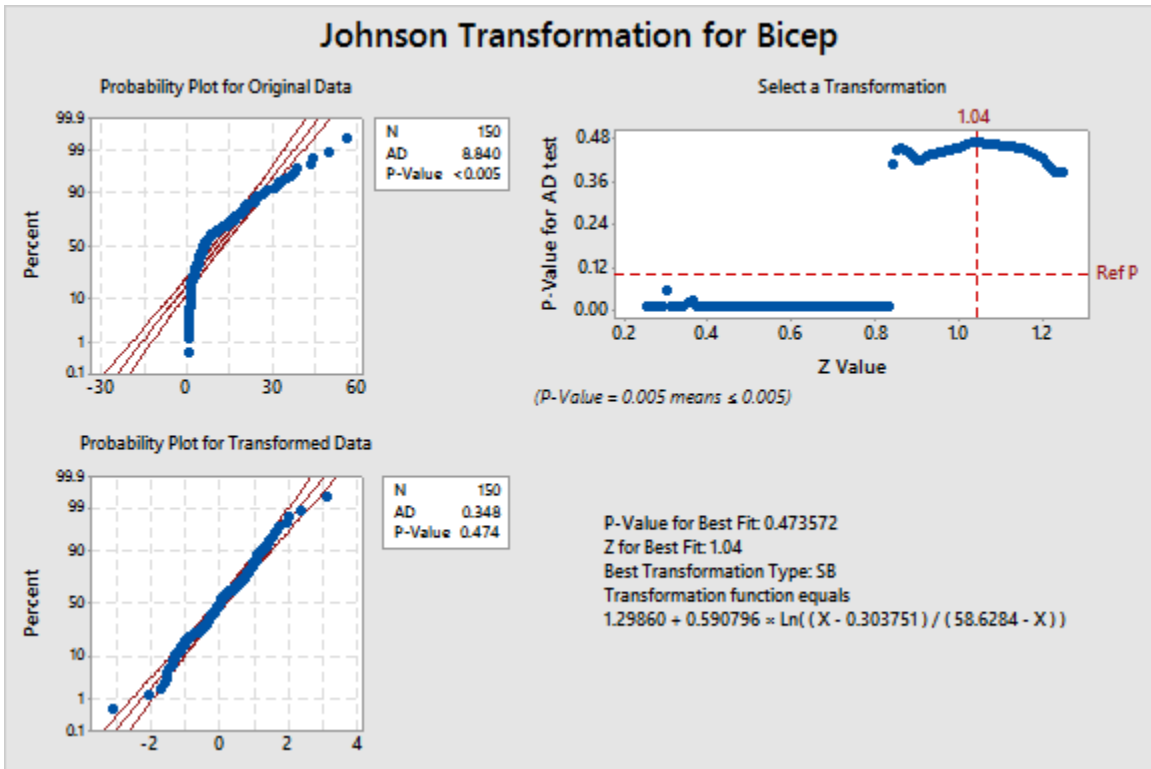
Johnson transformation for NMAV (terese major)



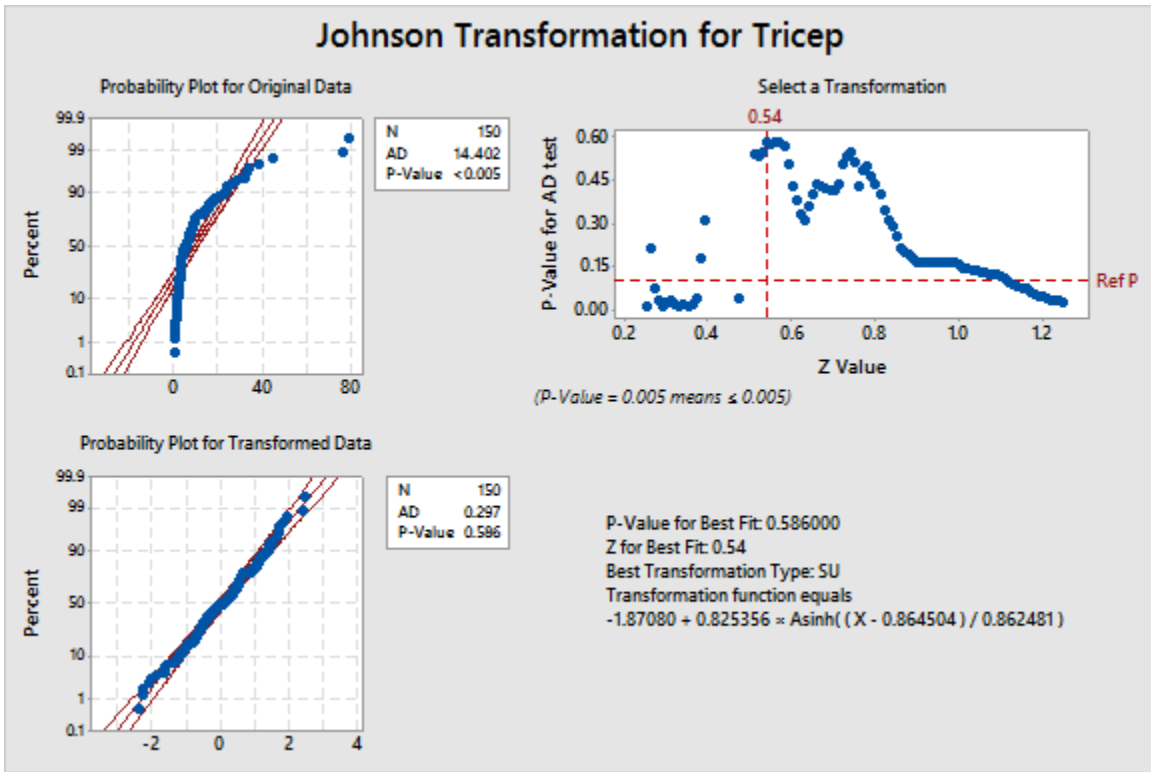
Johnson transformation for NMAV (anterior deltoid)



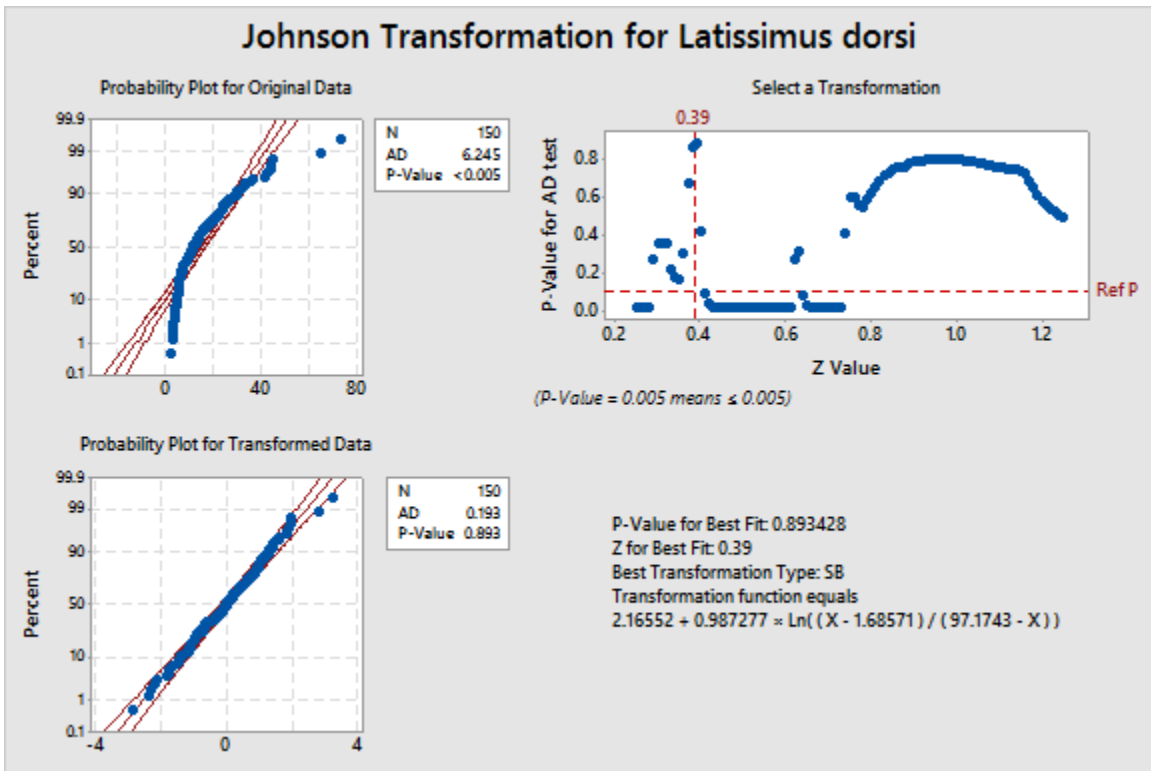
Johnson transformation for NMAV (posterior deltoid)



Johnson transformation for NMAV (bicep)



Johnson transformation for NMAV (tricep)



Johnson transformation for NMAV (latissimus dorsi)

## **Appendix F: Analysis of variance**

Table 28: Expected mean squares for A and B as fixed variables and C as a random variable

Factor	F	F	R	R	E(MS)
	<i>a</i>	<i>b</i>	<i>c</i>	<i>n</i>	
	<i>i</i>	<i>j</i>	<i>k</i>	<i>l</i>	
$\tau_i$	0	<i>b</i>	<i>c</i>	<i>n</i>	$\sigma^2 + bn\sigma_{\tau\gamma}^2 + bcn \sum \frac{\tau_i^2}{(a-1)}$
$\beta_j$	<i>a</i>	0	<i>c</i>	<i>n</i>	$\sigma^2 + an\sigma_{\beta\gamma}^2 + acn \sum \frac{\beta_j^2}{(b-1)}$
$\gamma_k$	<i>a</i>	<i>b</i>	1	<i>n</i>	$\sigma^2 + abn\sigma_{\gamma}^2$
$(\tau\beta)_{ij}$	0	0	<i>c</i>	<i>n</i>	$\sigma^2 + n\sigma_{\tau\beta\gamma}^2 + cn \sum \sum \frac{(\tau\beta)_{ij}^2}{(a-1)(b-1)}$
$(\tau\gamma)_{ik}$	0	<i>b</i>	1	<i>n</i>	$\sigma^2 + bn\sigma_{\tau\gamma}^2$
$(\beta\gamma)_{jk}$	<i>a</i>	0	1	<i>n</i>	$\sigma^2 + an\sigma_{\beta\gamma}^2$
$(\tau\beta\gamma)_{ijk}$	0	0	1	<i>n</i>	$\sigma^2 + n\sigma_{\tau\beta\gamma}^2$
$\varepsilon_{(ijk)}$	1	1	1	1	$\sigma^2$

### General Linear Model: discomfort rating versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

#### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	119.86	13.318	18.51	0.000
Force	2	216.17	108.087	150.25	0.000
Direction	4	686.13	171.532	238.45	0.000
Force*Direction	8	25.39	3.174	4.41	0.000
Error	126	90.64	0.719		
Total	149	1138.19			

#### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.848154	92.04%	90.58%	88.71%



## General Linear Model: MF (Supraspinatus) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	0.9284	0.10316	1.65	0.108
Force	2	2.1716	1.08580	17.39	0.000
Direction	4	2.0556	0.51390	8.23	0.000
Force*Direction	8	1.4319	0.17899	2.87	0.006
Error	122	7.6195	0.06246		
Total	145	14.2085			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.249910	46.37%	36.26%	23.34%

## General Linear Model: MF (Infraspinatus) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	15.912	1.7680	4.01	0.000
Force	2	11.729	5.8643	13.30	0.000
Direction	4	69.806	17.4514	39.56	0.000
Force*Direction	8	7.211	0.9014	2.04	0.047
Error	124	54.695	0.4411		
Total	147	160.145			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.664148	65.85%	59.51%	51.39%

## General Linear Model: MF (Teres major) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	7.207	0.8008	2.03	0.042
Force	2	10.899	5.4495	13.79	0.000
Direction	4	77.787	19.4468	49.21	0.000
Force*Direction	8	6.551	0.8189	2.07	0.043
Error	123	48.608	0.3952		
Total	146	152.269			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.628639	68.08%	62.11%	54.37%

## General Linear Model: MF (Mid deltoid) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	27.051	3.0056	6.12	0.000
Force	2	15.652	7.8262	15.94	0.000
Direction	4	26.122	6.5305	13.30	0.000
Force*Direction	8	9.861	1.2326	2.51	0.015
Error	123	60.409	0.4911		
Total	146	138.597			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.700804	56.41%	48.26%	37.91%

## General Linear Model: MF (Ant deltoid) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	2.086	0.2317	1.72	0.091
Force	2	6.326	3.1630	23.49	0.000
Direction	4	12.735	3.1838	23.64	0.000
Force*Direction	8	3.099	0.3874	2.88	0.006
Error	121	16.296	0.1347		
Total	144	40.300			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.366981	59.56%	51.88%	41.96%

## General Linear Model: MF (Post deltoid) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	11.05	1.2280	2.30	0.020
Force	2	16.28	8.1388	15.22	0.000
Direction	4	12.04	3.0093	5.63	0.000
Force*Direction	8	14.57	1.8212	3.41	0.001
Error	121	64.69	0.5346		
Total	144	118.79			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.731167	45.54%	35.19%	22.02%

## General Linear Model: MF (Bicep) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	1.6244	0.18049	1.87	0.064
Force	2	1.6330	0.81650	8.45	0.000
Direction	4	2.9236	0.73091	7.56	0.000
Force*Direction	8	0.8145	0.10181	1.05	0.401
Error	116	11.2151	0.09668		
Total	139	18.3180			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.310937	38.78%	26.64%	10.77%

## General Linear Model: MF (Tricep) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	5.966	0.66285	6.84	0.000
Force	2	4.766	2.38285	24.58	0.000
Direction	4	7.712	1.92800	19.89	0.000
Force*Direction	8	2.965	0.37060	3.82	0.000
Error	124	12.021	0.09694		
Total	147	33.468			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.311353	64.08%	57.42%	48.94%

## General Linear Model: MF (Latissimus dorsi) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	4.971	0.5523	5.08	0.000
Force	2	1.814	0.9069	8.34	0.000
Direction	4	4.535	1.1336	10.42	0.000
Force*Direction	8	1.541	0.1926	1.77	0.090
Error	117	12.727	0.1088		
Total	140	25.175			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.329811	49.45%	39.51%	27.00%

## General Linear Model: TM versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	15.051	1.6723	5.80	0.000
Force	2	27.483	13.7414	47.63	0.000
Direction	4	60.351	15.0879	52.30	0.000
Force*Direction	8	2.509	0.3136	1.09	0.377
Error	126	36.353	0.2885		
Total	149	141.746			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.537135	74.35%	69.67%	63.65%

## General Linear Model: NMAV (Supraspinatus) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	33.893	3.7659	10.72	0.000
Force	2	16.855	8.4276	23.98	0.000
Direction	4	58.538	14.6345	41.64	0.000
Force*Direction	8	0.662	0.0828	0.24	0.984
Error	126	44.282	0.3514		
Total	149	154.231			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.592827	71.29%	66.05%	59.31%

## General Linear Model: NMAV (Teres major) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	56.054	6.2282	19.71	0.000
Force	2	30.815	15.4075	48.76	0.000
Direction	4	9.015	2.2536	7.13	0.000
Force*Direction	8	1.171	0.1463	0.46	0.880
Error	126	39.814	0.3160		
Total	149	136.867			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.562122	70.91%	65.60%	58.77%

## General Linear Model: NMAV (Ant deltoid) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	7.186	0.7985	4.24	0.000
Force	2	3.850	1.9251	10.22	0.000
Direction	4	117.778	29.4444	156.26	0.000
Force*Direction	8	1.034	0.1293	0.69	0.703
Error	125	23.554	0.1884		
Total	148	153.244			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.434092	84.63%	81.80%	78.17%

## General Linear Model: NMAV (Post deltoid) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	19.467	2.1630	8.61	0.000
Force	2	10.787	5.3937	21.48	0.000
Direction	4	93.375	23.3437	92.95	0.000
Force*Direction	8	2.461	0.3077	1.23	0.290
Error	125	31.392	0.2511		
Total	148	154.262			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.501132	79.65%	75.91%	71.06%

## General Linear Model: NMAV (Bicep) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	16.526	1.8362	12.32	0.000
Force	2	6.643	3.3214	22.29	0.000
Direction	4	96.475	24.1187	161.84	0.000
Force*Direction	8	1.867	0.2334	1.57	0.141
Error	126	18.778	0.1490		
Total	149	140.288			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.386042	86.61%	84.17%	81.03%

## General Linear Model: NMAV (Tricep) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	29.812	3.3124	12.25	0.000
Force	2	11.037	5.5185	20.40	0.000
Direction	4	64.210	16.0524	59.35	0.000
Force*Direction	8	5.082	0.6352	2.35	0.022
Error	126	34.078	0.2705		
Total	149	144.218			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.520057	76.37%	72.06%	66.51%



## General Linear Model: NMAV (Latissimus dorsi) versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	65.097	7.2330	22.52	0.000
Force	2	28.879	14.4397	44.96	0.000
Direction	4	29.594	7.3986	23.04	0.000
Force*Direction	8	3.279	0.4099	1.28	0.262
Error	126	40.467	0.3212		
Total	149	167.316			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.566715	75.81%	71.40%	65.72%

## General Linear Model: TNMAV versus sub, Force, Direction

Factor	Type	Levels	Values
sub	Random	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
Force	Fixed	3	5.0, 7.5, 10.0
Direction	Fixed	5	PB, PD, PL, PR, PU

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
sub	9	70774	7863.7	12.47	0.000
Force	2	144207	72103.5	114.32	0.000
Direction	4	347382	86845.5	137.69	0.000
Force*Direction	8	35327	4415.9	7.00	0.000
Error	126	79470	630.7		
Total	149	677160			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
25.1140	88.26%	86.12%	83.37%

## **Appendix G: Kruskal-Wallis test**

## Kruskal-Wallis Test: NMAV (Infraspinatus) versus Force

149 cases were used  
1 cases contained missing values

Kruskal-Wallis Test on Infraspinatus

Force	N	Median	Ave Rank	Z
5.0	50	5.852	60.3	-2.95
7.5	50	9.049	74.9	-0.02
10.0	49	12.373	90.1	2.99
Overall	149		75.0	

H = 11.82 DF = 2 P = 0.003

## Kruskal-Wallis Test: NMAV (Infraspinatus) versus Direction

149 cases were used  
1 cases contained missing values

Kruskal-Wallis Test on Infraspinatus

Direction	N	Median	Ave Rank	Z
PB	30	5.526	53.5	-3.06
PD	30	7.377	55.7	-2.74
PL	30	3.705	27.7	-6.72
PR	30	38.300	122.0	6.67
PU	29	36.337	117.6	5.92
Overall	149		75.0	

H = 113.38 DF = 4 P = 0.000

### **Kruskal-Wallis Test: NMAV (Middle deltoid) versus Force**

Kruskal-Wallis Test on Mid deltoid

Force	N	Median	Ave Rank	Z
5.0	50	2.849	62.7	-2.55
7.5	50	4.828	75.0	-0.10
10.0	50	7.610	88.8	2.65
Overall	150		75.5	

H = 9.00 DF = 2 P = 0.011

### **Kruskal-Wallis Test: NMAV (Middle deltoid) versus Direction**

Kruskal-Wallis Test on Mid deltoid

Direction	N	Median	Ave Rank	Z
PB	30	1.150	33.0	-5.99
PD	30	2.965	63.4	-1.70
PL	30	1.781	44.6	-4.36
PR	30	19.127	123.3	6.73
PU	30	15.216	113.2	5.31
Overall	150		75.5	

H = 105.05 DF = 4 P = 0.000

## **Appendix H: Tukey Pairwise comparisons**

## Comparisons for MF (Supraspinatus)

### Tukey Pairwise Comparisons: Response = MF (Supraspinatus), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
5.0 PD	9	0.010713	A
5.0 PR	10	-0.135945	A B
10.0 PB	10	-0.163085	A B
5.0 PL	9	-0.170668	A B C
7.5 PB	10	-0.182940	A B C
5.0 PB	10	-0.241495	A B C
7.5 PR	10	-0.259485	A B C D
7.5 PL	9	-0.320884	A B C D
5.0 PU	10	-0.352615	A B C D E
10.0 PL	10	-0.407525	B C D E
7.5 PD	10	-0.420215	B C D E
10.0 PD	9	-0.450856	B C D E
7.5 PU	10	-0.561455	C D E
10.0 PR	10	-0.631245	D E
10.0 PU	10	-0.732980	E

Means that do not share a letter are significantly different.

## Comparisons for MF (Infraspinatus)

### Tukey Pairwise Comparisons: Response = MF (Infraspinatus), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
10.0 PD	10	0.90079	A
5.0 PD	9	0.88430	A
5.0 PL	10	0.82605	A
7.5 PD	10	0.82327	A
5.0 PB	10	0.58284	A B
7.5 PB	10	0.48366	A B C
7.5 PL	9	0.38001	A B C
10.0 PB	10	0.27721	A B C
5.0 PU	10	-0.32877	B C D
7.5 PR	10	-0.48898	C D E
10.0 PL	10	-0.52363	C D E
5.0 PR	10	-0.52470	C D E
7.5 PU	10	-0.94880	D E
10.0 PR	10	-1.13420	D E
10.0 PU	10	-1.47205	E

Means that do not share a letter are significantly different.

## Comparisons for MF (Teres major)

### Tukey Pairwise Comparisons: Response = MF (Teres major), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
5.0 PB	10	1.20377	A
5.0 PD	10	0.93964	A B
7.5 PB	10	0.85334	A B
7.5 PD	10	0.81414	A B
7.5 PL	10	0.69517	A B
10.0 PL	10	0.36103	A B C
10.0 PB	10	0.22225	B C
10.0 PD	10	0.13602	B C D
5.0 PL	9	0.12432	B C D
5.0 PU	10	-0.37869	C D E
5.0 PR	9	-0.50045	C D E F
7.5 PR	9	-0.84745	D E F
7.5 PU	10	-0.94708	E F
10.0 PR	10	-1.05360	E F
10.0 PU	10	-1.48249	F

Means that do not share a letter are significantly different.

## Comparisons for MF (Mid deltoid)

### Tukey Pairwise Comparisons: Response = MF (Mid deltoid), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
5.0 PD	10	0.76916	A
7.5 PD	10	0.76779	A B
5.0 PB	9	0.63942	A B
5.0 PR	10	0.42243	A B C
7.5 PB	10	0.37583	A B C
5.0 PL	10	0.29503	A B C D
10.0 PD	10	0.19662	A B C D
10.0 PL	10	0.10493	A B C D
10.0 PB	10	0.04143	A B C D
5.0 PU	10	-0.05313	A B C D
7.5 PL	10	-0.21094	A B C D
7.5 PU	10	-0.31798	B C D
7.5 PR	9	-0.55037	C D E
10.0 PU	10	-0.78973	D E
10.0 PR	9	-1.48400	E

Means that do not share a letter are significantly different.

## Comparisons for MF (Ant deltoid)

### Tukey Pairwise Comparisons: Response = MF (Ant deltoid), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
5.0 PB	9	0.01545	A
5.0 PD	10	-0.04919	A B
7.5 PB	8	-0.08074	A B
5.0 PR	10	-0.13935	A B
7.5 PD	10	-0.32398	A B
7.5 PR	10	-0.34801	A B
10.0 PB	9	-0.37319	A B C
10.0 PL	9	-0.42822	A B C
5.0 PL	10	-0.48104	A B C
7.5 PL	10	-0.48150	A B C
10.0 PD	10	-0.52110	A B C
5.0 PU	10	-0.59753	B C
10.0 PR	10	-0.92636	C
7.5 PU	10	-0.94284	C
10.0 PU	10	-1.53530	D

Means that do not share a letter are significantly different.

## Comparisons for MF (Post deltoid)

### Tukey Pairwise Comparisons: Response = MF (Post deltoid), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
5.0 PR	10	0.60565	A
5.0 PD	10	0.55851	A
7.5 PB	9	0.51196	A
7.5 PD	10	0.46300	A
5.0 PB	10	0.16162	A B
5.0 PU	10	0.16046	A B
10.0 PB	10	0.09331	A B
10.0 PD	10	0.02424	A B
5.0 PL	9	-0.01892	A B
7.5 PR	9	-0.09842	A B
7.5 PL	9	-0.16745	A B
7.5 PU	10	-0.29779	A B
10.0 PL	10	-0.31509	A B
10.0 PU	10	-0.68075	B C
10.0 PR	9	-1.60083	C

Means that do not share a letter are significantly different.



## Comparisons for MF (Bicep)

### Tukey Pairwise Comparisons: Response = MF (Bicep), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
5.0	47	-0.134849	A
7.5	44	-0.249179	A B
10.0	49	-0.395608	B

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

### Tukey Pairwise Comparisons: Response = MF (Bicep), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PL	30	-0.101177	A
PB	26	-0.121537	A B
PU	29	-0.244540	A B
PD	28	-0.331466	B C
PR	27	-0.500673	C

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

## Comparisons for MF (Tricep)

### Tukey Pairwise Comparisons: Response = MF (Tricep), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
5.0 PL	10	-0.20272	A
7.5 PB	9	-0.23251	A B
5.0 PD	10	-0.25496	A B
5.0 PB	9	-0.25758	A B C
10.0 PB	10	-0.28936	A B C
10.0 PL	10	-0.34235	A B C D
7.5 PL	10	-0.36126	A B C D
7.5 PD	10	-0.37273	A B C D
5.0 PR	10	-0.41253	A B C D
5.0 PU	10	-0.43148	A B C D
7.5 PR	10	-0.69980	B C D E
10.0 PD	10	-0.73976	C D E
7.5 PU	10	-0.79315	D E
10.0 PU	10	-1.02117	E F
10.0 PR	10	-1.35000	F

Means that do not share a letter are significantly different.

## Comparisons for MF (Latissimus dorsi)

### Tukey Pairwise Comparisons: Response = MF (Latissimus dorsi), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
5.0	46	-0.186679	A
7.5	46	-0.285607	A
10.0	49	-0.462065	B

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

### Tukey Pairwise Comparisons: Response = MF (Latissimus dorsi), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PD	30	-0.135752	A
PB	25	-0.135913	A
PL	30	-0.245063	A B
PR	28	-0.438098	B C
PU	28	-0.602424	C

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

## Comparisons for TM

### Tukey Pairwise Comparisons: Response = TM, Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
5.0	50	0.496373	A
7.5	50	0.058270	B
10.0	50	-0.547624	C

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

### Tukey Pairwise Comparisons: Response = TM, Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PB	30	0.701540	A
PD	30	0.626073	A
PL	30	0.147412	B
PR	30	-0.598959	C
PU	30	-0.864369	C

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

## Comparisons for NMAV (Supraspinatus)

### Tukey Pairwise Comparisons: Response = NMAV (Supraspinatus), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
10.0	50	0.430612	A
7.5	50	-0.006792	B
5.0	50	-0.389893	C

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

## Tukey Pairwise Comparisons: Response = NMAV (Supraspinatus), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PD	30	0.914883	A
PR	30	0.521204	A
PU	30	-0.171670	B
PL	30	-0.398637	B C
PB	30	-0.809235	C

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

## Comparisons for NMAV (Teres major)

## Tukey Pairwise Comparisons: Response = NMAV (Teres major), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
10.0	50	0.538699	A
7.5	50	-0.036756	B
5.0	50	-0.571275	C

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

## Tukey Pairwise Comparisons: Response = NMAV (Teres major), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PD	30	0.304687	A
PR	30	0.177918	A B
PB	30	-0.068040	A B C
PU	30	-0.135591	B C
PL	30	-0.394527	C

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

## Comparisons for NMAV (Ant deltoid)

### Tukey Pairwise Comparisons: Response = NMAV (Ant deltoid), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
10.0	49	0.160551	A
7.5	50	0.018308	A
5.0	50	-0.229064	B

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

### Tukey Pairwise Comparisons: Response = NMAV (Ant deltoid), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PU	29	1.37235	A
PR	30	0.51992	B
PL	30	-0.11363	C
PD	30	-0.70663	D
PB	30	-1.15569	E

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

## Comparisons for NMAV (Post deltoid)

### Tukey Pairwise Comparisons: Response = NMAV (Post deltoid), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
10.0	49	0.306044	A
7.5	50	-0.063939	B
5.0	50	-0.353388	C

Means that do not share a letter are significantly different.

### Tukey Simultaneous 95% CIs

## Tukey Pairwise Comparisons: Response = NMAV (Post deltoid), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PR	29	1.23899	A
PU	30	0.15407	B
PD	30	0.08820	B
PB	30	-0.49693	C
PL	30	-1.16981	D

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

### Comparisons for NMAV (Bicep)

## Tukey Pairwise Comparisons: Response = NMAV (Bicep), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
10.0	50	0.317852	A
7.5	50	-0.040809	B
5.0	50	-0.182116	B

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

## Tukey Pairwise Comparisons: Response = NMAV (Bicep), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PU	30	1.26617	A
PL	30	0.61139	B
PR	30	-0.18959	C
PB	30	-0.62740	D
PD	30	-0.90236	D

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

## Comparisons for NMAV (Tricep)

### Tukey Pairwise Comparisons: Response = NMAV (Tricep), Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping
10.0 PL	10	1.33180	A
7.5 PL	10	1.04777	A B
10.0 PB	10	0.98464	A B C
5.0 PL	10	0.65185	A B C D
7.5 PB	10	0.36537	B C D E
5.0 PD	10	0.21681	C D E F
10.0 PR	10	0.11908	D E F G
10.0 PD	10	0.06900	D E F G
5.0 PB	10	-0.10904	D E F G
7.5 PD	10	-0.21854	E F G H
7.5 PR	10	-0.36123	E F G H
10.0 PU	10	-0.48143	F G H
5.0 PR	10	-0.68027	G H I
7.5 PU	10	-0.98531	H I
5.0 PU	10	-1.31854	I

Means that do not share a letter are significantly different.

## Comparisons for NMAV (Latissimus dorsi)

### Tukey Pairwise Comparisons: Response = NMAV (Latissimus dorsi), Term = Force

Grouping Information Using the Tukey Method and 95% Confidence

Force	N	Mean	Grouping
10.0	50	0.530913	A
7.5	50	-0.040747	B
5.0	50	-0.543134	C

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

### Tukey Pairwise Comparisons: Response = NMAV (Latissimus dorsi), Term = Direction

Grouping Information Using the Tukey Method and 95% Confidence

Direction	N	Mean	Grouping
PB	30	0.285739	A
PU	30	0.251095	A
PR	30	0.170686	A
PD	30	0.100879	A
PL	30	-0.896679	B

Means that do not share a letter are significantly different.

## Tukey Simultaneous 95% CIs

## Comparisons for TNMAV

### Tukey Pairwise Comparisons: Response = TNMAV, Term = Force\*Direction

Grouping Information Using the Tukey Method and 95% Confidence

Force*Direction	N	Mean	Grouping				
10.0 PR	10	237.569	A				
10.0 PU	10	216.100	A				
7.5 PU	10	173.272		B			
7.5 PR	10	143.604		B	C		
5.0 PU	10	129.642			C	D	
10.0 PD	10	119.761			C	D	E
5.0 PR	10	100.209				D	E F
10.0 PB	10	86.189					E F G
10.0 PL	10	86.058					E F G
7.5 PD	10	75.181					F G H
7.5 PL	10	67.367					F G H
7.5 PB	10	53.804					G H
5.0 PL	10	51.474					G H
5.0 PD	10	47.639					G H
5.0 PB	10	40.429					H

Means that do not share a letter are significantly different.



## **Appendix I: Subjective discomfort ratings raw data**

Table 29: Subjective discomfort ratings

Force	10 lbs.					7.5 lbs.					5lbs.				
	Subject number	PU	PB	PR	PL	PD	PU	PB	PR	PL	PD	PU	PB	PR	PL
<b>1</b>	10	2	10	4	7	10	3	9	3	5.5	7	1	7.5	2	2
<b>2</b>	10	3.5	10	5.5	7	8	2	8	4.5	4	6.5	1	7	1.5	3
<b>3</b>	9	3	8.5	5	6	5.5	2	6	4.5	5	5.5	1	4.5	2	1
<b>4</b>	7.5	2.5	8	3	5	6	1.5	6	1	2.5	4	1	3.5	1	1
<b>5</b>	7.5	2	7	2.5	3.5	5.5	2	5.5	2	2.5	4	1	4	1	1.5
<b>6</b>	10	3	8.5	5	6	8.5	3	7.5	3	4.5	6	2.5	6	3	3
<b>7</b>	8	1.5	7	4	4	5.5	1.5	4.5	1	1	2.5	1	1.5	1	1
<b>8</b>	10	2	9	2	6	9	2	8	1	2	7	1	7	2	1
<b>10</b>	10	4	9.5	6.5	7	7.5	3	8	4	4	6	2.5	6	2.5	3
<b>11</b>	10	2	8	6	5	8.5	2	6.5	3.5	3.5	5.5	1	5	2.5	2
<b>Avg.</b>	9.2	2.55	8.55	4.35	5.65	7.4	2.22	6.9	2.75	3.45	5.4	1.3	5.2	1.85	1.85
<b>STD</b>	1.11	0.79	1.09	1.51	1.25	1.66	0.586	1.41	1.42	1.42	1.47	0.63	1.87	0.7	0.88

## **Appendix J: Median frequency slope raw data**

**S:** Subject. **F:** Force. **D:** Direction. **SS:** Supraspinatus. **IS:** Infraspinatus. **TM:** Teres major. **MD:** Middle deltoid. **AD:** Anterior deltoid. **PD:** posterior deltoid. **Bi:** Bicep, **Tri:** Tricep. **LD:** Latissimus dorsi.

<b>S</b>	<b>F</b>	<b>D</b>	<b>SS</b>	<b>ID</b>	<b>TM</b>	<b>MD</b>	<b>AD</b>	<b>PD</b>	<b>Bi</b>	<b>Tri</b>	<b>LD</b>	<b>TM</b>
1	10	PU	-0.7393	-1.5786	-2.9191	-0.8274	-2.3762	-0.3560	-0.4869	-1.1822	-1.9810	-12.4465
1	10	PB	0.1909	-0.1014	-0.7007	-0.7552	*	-0.3854	-0.0021	-0.2563	-0.1413	-2.1515
1	10	PR	-0.0764	-1.2091	-1.3313	*	0.2091	*	*	-0.8127	*	-3.2204
1	10	PL	-0.1175	-0.3832	0.0354	-0.1717	-0.4990	-0.1742	-0.1749	-0.3140	-0.2713	-2.0703
1	10	PD	*	-0.0011	-0.3144	-0.4861	-0.1336	0.1818	-0.0755	-0.1812	-0.0518	-1.0616
1	7.5	PU	-0.6893	-1.2310	-2.5762	-0.2702	-1.5405	-0.5345	-0.3560	-1.4703	*	-8.6678
1	7.5	PB	0.2252	-0.2406	0.0853	-0.2119	*	-0.1703	*	-0.3878	0.2395	-0.4605
1	7.5	PR	-0.2580	-1.1142	*	*	-0.0476	*	-0.0109	-0.2013	*	-1.6320
1	7.5	PL	*	-0.2594	0.0679	-0.3720	-0.3336	-0.2462	0.1241	-0.3721	-0.6895	-2.0808
1	7.5	PD	-0.4416	0.1843	0.1322	-0.0238	0.2598	0.1207	-0.0521	0.2133	0.0853	0.4781
1	5	PU	0.1039	-0.2637	-0.4584	0.0095	-1.2563	-0.1759	-0.2899	-0.3577	-1.0906	-3.7790
1	5	PB	-0.0049	-0.0615	-0.0727	-0.1469	-0.0168	-0.3182	-0.2350	-0.1175	-0.2657	-1.2392
1	5	PR	0.0626	-0.6853	-0.9979	0.1102	0.1944	-0.0934	0.1318	-0.2664	-0.2416	-1.7857
1	5	PL	-0.3776	-0.2025	-0.5790	-0.4178	-0.5325	-0.3717	-0.0955	0.0469	-0.1826	-2.7122
1	5	PD	0.1084	-0.2035	-0.4559	-0.3423	0.1588	-0.3738	-0.1336	-0.0755	-0.5637	-1.8811
2	10	PU	-1.2429	-3.1571	-2.8557	-0.8500	-2.0693	-1.4536	-0.4179	-1.4936	-2.1393	-15.6793
2	10	PB	-0.1347	-0.1860	-0.0825	-0.0769	-0.2308	-0.0888	-0.0948	-0.2672	0.0601	-1.1015
2	10	PR	-0.6867	-1.0167	-0.7455	-1.4313	-1.2567	-1.6312	-0.2418	-0.9615	-0.7703	-8.7416
2	10	PL	-0.1469	-0.8888	-0.1168	-0.4168	-0.5878	-0.4923	-0.0815	-0.3144	-0.7007	-3.7458

2	10	PD	-0.0238	-0.1395	-0.1752	-0.1493	-0.2714	-0.1399	-0.2577	-0.4965	0.1423	-1.5109
2	7.5	PU	-0.7131	-1.8350	-1.9901	-0.8215	-0.9575	-0.8481	-0.1675	-1.2659	*	-8.5985
2	7.5	PB	-0.3227	-0.2937	-0.2595	-0.0067	-0.3559	-0.1297	-0.0521	-0.4937	0.2091	-1.7048
2	7.5	PR	-0.2696	-0.7689	-0.8161	-0.3616	-0.2032	-0.3256	*	-0.1934	-0.6860	-3.6243
2	7.5	PL	-0.2315	-0.3301	-0.2913	-0.4343	-0.6322	-0.1196	-0.0920	-0.4280	-1.0357	-3.5945
2	7.5	PD	-0.1808	0.0626	0.0465	-0.1532	-0.0339	-0.0273	-0.1581	-0.2116	-0.1490	-0.8046
2	5	PU	-0.4039	-1.0025	-1.2007	-0.7479	-0.6734	-0.5728	-0.0444	-0.7734	-0.3910	-5.8098
2	5	PB	-0.2196	-0.0322	0.2552	-0.2084	-0.5853	-0.1084	-0.0623	-0.3266	*	-1.2876
2	5	PR	-0.0042	-0.8081	-0.7140	0.0713	-0.1252	0.0591	0.1738	0.1294	-0.3514	-1.5693
2	5	PL	-0.2451	0.0612	-0.0490	-0.4860	-0.6101	-0.4248	-0.0347	-0.2290	0.1937	-1.8238
2	5	PD	0.1650	*	-0.1916	-0.2727	-0.0161	-0.1021	-0.5990	-0.4559	0.0140	-1.4584
3	10	PU	-0.7070	-1.5643	-1.5577	-1.7525	-2.2189	-0.3983	-0.1469	-1.1025	-0.9413	-10.3892
3	10	PB	0.1657	-0.4203	-0.4430	-0.3290	-0.6888	-0.8231	0.3517	-0.4143	-0.5042	-3.1053
3	10	PR	-0.5801	-1.1336	-0.7441	-1.1021	-0.7073	-1.1459	-0.9259	-0.8892	-0.4434	-7.6715
3	10	PL	-0.2438	-0.9909	-0.2280	-0.5846	-0.5350	-0.8189	-0.3881	-0.3196	-0.0839	-4.1927
3	10	PD	-0.5070	0.1881	-0.3650	-0.4070	-0.5238	-0.5109	-0.6298	-0.7406	-0.2220	-3.7178
3	7.5	PU	-0.5650	-1.3738	-1.2693	-0.9728	-1.0144	-0.4112	-0.0784	-0.7458	-0.1469	-6.5774
3	7.5	PB	-0.1906	-0.7913	-0.5238	-0.3133	-0.4361	-0.3494	0.0455	*	0.2140	-2.3448
3	7.5	PR	-0.2430	-0.9903	-1.1133	-0.6777	0.1339	-0.6707	-1.1825	-0.8007	-0.3889	-5.9330
3	7.5	PL	-0.3619	-0.2724	0.2291	-0.6231	-0.0200	-0.8937	-0.2336	-0.2843	-0.2168	-2.6765
3	7.5	PD	-0.6091	-0.2455	-0.2518	-0.0871	-0.7049	-0.2227	0.1322	-0.6472	0.1091	-2.5269
3	5	PU	-0.6374	-0.6193	-1.0382	-0.6462	-0.7699	-1.1053	0.0518	-0.2832	-0.0682	-5.1158

3	5	PB	-0.8002	-0.2500	-0.0771	*	0.0527	-0.1079	-0.0651	-0.0354	0.3200	-0.9628
3	5	PR	-0.1598	-0.4766	-0.6706	-0.1511	0.3601	-0.2962	0.1647	-0.3126	0.0049	-1.5371
3	5	PL	-0.0951	-0.2028	-0.3580	-0.2350	-0.3056	*	-0.2469	-0.1755	0.0360	-1.5829
3	5	PD	-0.2161	0.0678	-0.0524	-0.2238	0.2503	-0.2615	-0.3685	-0.3420	-0.8392	-1.9854
4	10	PU	-0.1206	-1.8636	-2.6311	-0.4053	-0.9734	-0.7081	-0.9102	-0.3850	-0.4469	-8.4441
4	10	PB	0.0958	-0.6011	-0.6574	-0.4238	-0.8140	-0.4227	-0.6899	-0.7214	-0.3731	-4.6073
4	10	PR	-0.7556	-2.5615	-2.5049	-0.9818	-0.8434	-0.7350	-0.6909	-1.6042	-0.2860	-10.9633
4	10	PL	-0.5983	-2.1483	0.1028	-0.1525	-0.0483	-0.4227	0.0437	-0.3696	-0.1329	-3.7260
4	10	PD	-0.6322	-0.1175	-0.3654	0.0748	-0.3280	-0.2238	-0.2011	-0.7392	-0.4063	-2.9386
4	7.5	PU	-0.3147	-1.5224	-1.8542	-0.3969	0.0476	-0.7745	-0.4193	-0.3042	-0.7658	-6.3042
4	7.5	PB	-0.4594	0.0797	-0.3252	-0.8025	0.0256	-0.0633	-0.2095	-0.1140	0.2028	-1.6657
4	7.5	PR	-0.5325	-1.7249	-1.7406	-0.2542	-0.5484	-0.1182	-0.4141	-1.1652	-0.2618	-6.7598
4	7.5	PL	-0.3825	*	-0.1833	-0.2458	-0.8493	-0.4333	-0.1874	-0.0997	-0.1476	-2.5288
4	7.5	PD	-0.5633	-0.6122	-0.3717	-0.2532	-0.6640	-0.4329	*	-0.1906	-0.2133	-3.3011
4	5	PU	-0.2228	-1.1539	-0.9448	-0.4214	0.2091	-0.2846	-0.0769	0.0633	0.1063	-2.7256
4	5	PB	-0.0937	-0.3559	0.0853	-0.0280	0.0413	-0.1594	0.3545	*	-0.2280	-0.3839
4	5	PR	-0.4004	-1.2441	-1.7266	-0.2168	-0.4665	-0.2507	-0.4389	-0.2371	-0.2811	-5.2620
4	5	PL	-0.0434	-0.7892	-0.5909	-0.1018	-0.3993	-0.4007	0.0574	-0.4930	-0.0679	-2.8287
4	5	PD	-0.1920	-0.0780	0.0797	-0.0231	-0.0014	0.1577	-0.5280	-0.1598	-0.2693	-1.0141
5	10	PU	-0.5748	-1.3843	-1.1682	-0.2497	-0.5902	-0.1350	-0.2329	0.0416	-0.1217	-4.4151
5	10	PB	-0.4350	-0.1752	-0.4090	-0.2819	0.0260	-0.7494	-0.6497	0.0204	0.1149	-2.5389
5	10	PR	-0.3769	-1.0703	-0.6336	-0.9252	-0.6745	-0.9493	-0.7497	-1.0698	-0.1418	-6.5911

5	10	PL	-0.1374	0.2055	-0.6650	-0.1170	-0.1126	-0.9168	0.0073	0.2801	-0.2564	-1.7123
5	10	PD	0.0294	0.0056	0.0336	-0.1025	-0.1126	-0.2161	-0.2920	-0.3011	-0.0133	-0.9689
5	7.5	PU	-0.3560	-1.0965	-0.5920	-0.2916	-0.5056	-0.2472	0.1549	-0.0046	-0.3007	-3.2392
5	7.5	PB	-0.6396	-0.5199	0.1997	0.1119	*	*	*	0.0744	*	-0.7735
5	7.5	PR	-0.1105	-0.8028	-0.4895	-0.3969	-0.3014	-0.2839	-0.7137	-0.2374	-0.2098	-3.5458
5	7.5	PL	-0.2413	-1.1427	-0.3517	0.0748	-0.2916	*	0.2664	0.6371	-0.1231	-1.1721
5	7.5	PD	-0.1357	0.0399	0.1783	-0.0343	-0.0591	-0.2637	0.1713	-0.1948	0.4490	0.1511
5	5	PU	-0.2559	-0.8032	-0.3140	-0.3402	-0.3532	-0.1713	-0.2797	-0.3707	0.0368	-2.8513
5	5	PB	-0.3119	-0.4168	0.1797	0.2804	*	-0.4958	*	0.2615	*	-0.5029
5	5	PR	-0.1266	-1.2217	-0.4210	-0.1955	-0.1707	-0.1574	-0.4860	-0.6413	0.1350	-3.2850
5	5	PL	0.1804	0.1455	-1.5248	-0.0367	-0.4700	-0.8371	-0.1269	-0.0895	-0.0098	-2.7689
5	5	PD	0.0175	0.0154	-0.0315	-0.1899	0.0252	-0.1231	0.1213	0.0843	-0.0874	-0.1681
6	10	PU	-0.9500	-1.6221	-1.1976	-1.2284	-1.3689	-0.8913	-0.7151	-1.4574	-1.6311	-11.0616
6	10	PB	-0.2374	-0.0938	-0.0825	-0.4951	0.0119	-0.5168	-0.3354	-0.1168	-0.5287	-2.3945
6	10	PR	-0.4682	-1.1098	-1.2560	-1.6556	-1.4133	-1.7769	-0.8196	-1.3479	-0.6039	-10.4511
6	10	PL	-0.7615	-0.4021	-0.3899	-0.5269	-0.7546	-0.4007	-0.1598	0.1546	0.0399	-3.2010
6	10	PD	-0.3661	0.0699	-0.5431	-0.2871	-0.5067	-0.2577	-0.8305	-0.6032	-0.6178	-3.9421
6	7.5	PU	-0.4804	-0.9360	-0.6007	-0.8895	-1.4811	-0.8315	-0.5277	-0.6829	-0.5682	-6.9979
6	7.5	PB	-0.0221	0.0668	-0.1091	-0.3018	-0.2997	-0.1920	-0.3616	-0.2559	-0.1567	-1.6319
6	7.5	PR	-0.3769	-0.3734	-0.2608	-0.5909	-0.7095	-0.5920	-0.0986	-0.4643	-0.5598	-4.0261
6	7.5	PL	-0.6801	-0.0091	-0.3720	-0.6256	-0.2325	-0.5451	-0.2888	-0.3472	-1.6318	-4.7322
6	7.5	PD	-0.4423	-0.2612	-0.2203	-0.3021	-0.0577	-0.2532	-0.5028	-0.1276	0.1088	-2.0584

6	5	PU	-0.4804	-1.1112	-0.7046	-0.7207	-0.4941	-0.2773	-0.2962	-0.1990	-0.8896	-5.1728
6	5	PB	-0.2696	-0.1395	-0.2290	-0.3060	-0.1930	-0.4444	-0.2934	-0.4983	-0.4357	-2.8088
6	5	PR	-0.1014	-0.5615	-0.2888	-0.3259	-0.2221	-0.1581	-0.0199	-0.2203	-0.7119	-2.6098
6	5	PL	*	0.2406	-0.1895	-0.2074	-0.3290	-0.1860	-0.1493	-0.3231	-1.0451	-2.1887
6	5	PD	-0.0203	0.1437	-0.2095	-0.0784	-0.0035	-0.1245	*	-0.1476	0.1280	-0.3119
7	10	PU	-0.3231	-0.9643	-1.3147	-0.5637	-1.0343	-1.0329	-0.1741	-0.9706	-0.2780	-6.6556
7	10	PB	-0.4825	-0.4881	-0.3878	0.0004	-0.3112	0.1479	-0.3535	-0.5731	-0.4039	-2.8518
7	10	PR	-0.7823	-1.0294	-1.7028	-2.3014	-1.8005	-2.1330	-1.5892	-2.4449	-0.5787	-14.3622
7	10	PL	-0.5955	-1.8294	-0.3741	-0.8741	*	-0.9514	-0.2469	-1.1084	-0.0189	-5.9986
7	10	PD	-0.8524	-0.7456	-0.6453	-0.6021	-0.6363	-0.7877	-0.1939	-0.6637	-0.7337	-5.8605
7	7.5	PU	-0.6671	-0.6609	-1.2301	-0.6238	-0.8476	-0.7969	0.0598	-0.9221	-0.5102	-6.1986
7	7.5	PB	-0.1595	-0.3301	0.0742	0.0133	0.4343	-0.3738	*	-0.3413	-0.4276	-1.1104
7	7.5	PR	-0.4309	-1.5246	-1.6518	-1.1791	-1.0528	-0.8791	-1.0127	-1.6437	-0.6327	-10.0072
7	7.5	PL	-0.2647	0.0685	-0.6088	-0.6371	-1.0629	-0.6171	-0.2682	-0.9221	0.0329	-4.2793
7	7.5	PD	-0.4826	-0.2703	-0.0990	-0.0643	-0.1063	-0.2787	0.0531	-0.6322	-0.3339	-2.2140
7	5	PU	-0.5049	-0.4598	-0.9427	-0.3570	-0.7039	-0.5060	*	-0.5269	-0.3171	-4.3181
7	5	PB	-0.2283	-0.5112	-0.2598	-0.1451	0.2532	-0.4294	-0.2794	-0.4203	*	-2.0203
7	5	PR	-0.1483	-0.8140	-0.8602	-0.8161	-0.5206	-0.6913	-0.6269	-1.0727	-0.2406	-5.7904
7	5	PL	-0.3343	-0.4906	-0.4413	-0.5350	-0.7241	-0.6182	-0.1542	-0.4392	-0.0955	-3.8322
7	5	PD	-0.0049	-0.0566	0.1028	-0.0769	-0.1028	-0.5077	0.1231	-0.3308	-0.1322	-0.9860
8	10	PU	-0.8067	-1.5497	-2.5689	-0.8808	-1.5518	-1.5385	-0.7958	-1.5619	-0.2832	-11.5371
8	10	PB	-0.0360	-0.1186	-0.0192	-0.0759	-0.1322	0.0650	-0.0143	-0.0819	-0.3441	-0.7570



8	10	PR	-0.6651	-1.6549	-2.3511	-1.6818	-1.1958	-1.8500	-1.1336	-1.7210	-0.3385	-12.5917
8	10	PL	0.0017	-0.8566	-0.4675	-0.6700	-0.3811	-0.9199	-0.2154	-0.4287	0.0133	-3.9241
8	10	PD	-0.3601	0.3028	-0.2640	-0.9182	-0.7556	-1.6203	-0.6231	-0.9472	0.1752	-5.0105
8	7.5	PU	-0.7518	-1.2427	-1.2675	-0.2780	-1.2969	-0.9116	-0.6378	-0.8490	-0.1741	-7.4091
8	7.5	PB	-0.1007	-0.1490	0.2315	-0.2154	-0.0857	-0.7011	-0.0483	-0.1706	-0.1661	-1.4052
8	7.5	PR	-0.1843	-1.1199	-1.6692	-1.1196	0.2074	-0.1552	-0.5916	-1.3853	-0.2343	-6.2521
8	7.5	PL	-0.3060	-0.1469	0.0916	-0.4308	-0.6563	-0.5311	-0.0423	-0.3832	0.1112	-2.2937
8	7.5	PD	-0.6091	0.1297	-0.1913	0.2070	-0.6130	-0.5105	-0.3455	-0.5227	0.2825	-2.1728
8	5	PU	-0.4591	-0.3693	-0.2755	-0.1686	-1.0570	-0.6511	-0.1403	-0.5403	-0.0864	-3.7474
8	5	PB	-0.6119	0.1413	-0.1049	-0.1441	0.4091	-0.7483	0.0329	-0.4937	*	-1.5196
8	5	PR	-0.2171	-0.9465	*	-0.2479	0.0042	-0.1108	-0.1710	-0.6357	0.3608	-1.9641
8	5	PL	0.1895	0.1056	*	-0.1801	-0.7608	-0.0514	0.5476	-0.0581	0.0382	-0.1695
8	5	PD	-0.0469	-0.1399	0.1990	0.0336	-0.4060	-0.2535	-0.2993	-0.6196	0.4545	-1.0780
10	10	PU	-0.7306	-2.3167	-1.7747	-0.5434	-1.3436	-0.6588	0.2800	-1.1594	-0.6838	-8.9309
10	10	PB	0.0636	-0.5822	-0.7326	-0.4259	-0.6280	-0.6175	-0.2070	-0.1140	-0.1063	-3.3497
10	10	PR	-0.8195	-2.5613	-1.9424	-1.3466	-0.4114	-1.5909	0.4933	-1.6324	-0.9912	-10.8023
10	10	PL	-0.9326	-2.2269	-0.7049	0.5503	-0.1846	-0.0108	0.3636	-0.4601	-0.6378	-4.2438
10	10	PD	-0.7021	-0.8556	-0.9979	-0.0035	-1.0038	-0.3011	-0.8997	-1.6553	-0.2018	-6.6206
10	7.5	PU	-0.2109	-2.0305	-1.2934	-0.5605	-0.6507	-0.4486	-0.0259	-0.9871	-0.7238	-6.9311
10	7.5	PB	-0.3336	-0.3063	-0.6588	0.0476	-0.1305	-0.0294	-0.0874	-0.1046	-0.5301	-2.1330
10	7.5	PR	-0.3769	-1.9301	-2.4888	-0.6720	-0.1168	-0.5874	*	-0.7035	-0.7105	-7.5860
10	7.5	PL	-0.1587	-0.1930	-0.0899	-0.4486	-0.0493	-0.5934	-0.0455	-0.7252	-0.0018	-2.3053

10	7.5	PD	-0.2469	-0.1333	-0.4843	-0.2238	-0.6311	-0.1514	-0.4776	-0.7091	-0.3727	-3.4301
10	5	PU	-0.0028	-1.2365	-0.9210	-0.5145	-0.0855	-0.3381	0.2119	-0.9334	-0.3805	-4.2002
10	5	PB	-0.1287	-0.1203	0.2706	-0.0381	-0.0538	-0.1717	0.5238	-0.5538	-0.1140	-0.3860
10	5	PR	0.0203	-1.6238	-1.6539	-0.2378	-0.3892	-0.0763	-0.7759	-0.6735	-0.5584	-5.9683
10	5	PL	-0.2962	-0.0315	-0.2591	0.3608	-0.5332	-0.0371	-0.0776	-0.2657	-0.2042	-1.3437
10	5	PD	*	-0.4388	-0.3742	0.0224	-0.2664	-0.1696	-0.1028	-0.1297	0.0657	-1.3934
11	10	PU	-1.1350	-1.3196	-1.1503	-1.1874	-1.8266	-0.6256	-0.3249	-0.9409	-1.1182	-9.6284
11	10	PB	-0.8214	-0.7713	-0.4388	-1.4969	-0.6567	-0.6378	-0.4172	-0.3692	-0.6941	-6.3032
11	10	PR	-1.1018	-0.8913	-0.6916	-1.5277	-1.1700	-2.1608	-0.9703	-1.0165	-0.7532	-10.2829
11	10	PL	-0.5438	-0.7755	-0.5965	-1.1135	-0.6490	-0.5161	-0.2200	-0.5434	-0.3172	-5.2748
11	10	PD	-0.8154	-0.4210	-0.8070	-0.6192	-0.9395	-0.8301	-1.1238	-1.0700	-0.6224	-7.2482
11	7.5	PU	-0.8665	-0.6416	-0.3049	-0.2871	-1.1819	0.1867	-0.2497	-0.7000	-0.4042	-4.4490
11	7.5	PB	0.1734	-0.1322	-0.2311	-2.5168	-0.1367	-0.0549	-0.2906	-0.3305	-0.3182	-3.8375
11	7.5	PR	0.1878	0.2588	-0.7011	-0.8428	-0.8418	-0.5651	-0.7591	-0.2033	-0.7240	-4.1906
11	7.5	PL	-0.4333	-0.3528	-0.5315	-1.5619	-0.6874	-0.2504	-0.1860	-0.6881	0.0350	-4.6563
11	7.5	PD	-0.4909	-0.1668	-0.2224	-0.3700	-0.6298	-0.3108	-0.8668	-0.7049	-0.1749	-3.9371
11	5	PU	-0.6629	-0.4388	-0.5105	-0.3004	-0.7913	0.3500	-0.1067	-0.3937	-0.5206	-3.3747
11	5	PB	0.2538	-0.3256	-0.1626	-1.0049	-0.0420	-0.3808	-0.0035	-0.2046	-0.1944	-2.0644
11	5	PR	-0.2846	-0.5074	-0.5126	-0.5724	-0.0581	-0.1804	-0.0790	-0.1951	-0.5315	-2.9209
11	5	PL	-0.4567	-0.4769	-0.3413	-2.1060	-0.1458	-0.8154	-0.7304	-0.0011	0.0182	-5.0552
11	5	PD	0.2731	-0.0224	-0.1164	-0.1336	-0.1301	-0.2714	-0.3315	-0.3731	-0.0825	-1.1877

## **Appendix K: Normalized mean absolute values raw data**

**S:** Subject. **F:** Force. **D:** Direction. **SS:** Supraspinatus. **IS:** Infraspinatus. **TM:** Teres major. **MD:** Middle deltoid. **AD:** Anterior deltoid. **PD:** posterior deltoid. **Bi:** Bicep, **Tri:** Tricep. **LD:** Latissimus dorsi.

S	F	D	SS	IS	TM	MD	AD	PD	Bi	Tri	LD	TNMA V
1	10	PU	11.2707	46.2376	38.5113	32.1507	*	20.8333	36.7188	8.7735	24.8096	219.305 5
1	10	PB	6.3425	7.2772	21.0032	0.7665	0.7299	0.5585	5.6250	6.2320	21.5452	70.0801
1	10	PR	14.4751	41.3366	38.5113	18.6765	11.5166	28.3918	10.5469	10.0442	23.2318	196.730 8
1	10	PL	9.2044	4.8960	21.6181	2.3015	7.2275	1.1345	21.0156	5.7238	7.1328	80.2542
1	10	PD	17.6796	11.4851	22.0388	1.8585	0.8412	5.2924	4.4043	6.5967	13.2699	83.4665
1	7.5	PU	6.8177	36.3366	30.2265	21.4890	57.8199	13.6404	24.7266	3.1271	16.9750	211.158 7
1	7.5	PB	3.9116	5.8960	19.6278	0.8585	2.6682	0.7485	5.6445	6.4862	10.7835	56.6249
1	7.5	PR	7.7348	29.7525	31.1003	11.2684	6.8246	18.9474	8.4375	2.9061	22.1980	139.169 6
1	7.5	PL	3.2707	3.3267	14.6764	1.6397	8.3531	0.7149	12.0313	8.7735	4.9238	57.7101
1	7.5	PD	10.1436	7.1634	12.5566	1.2610	2.7275	2.3173	2.5859	5.2707	9.7443	53.7704
1	5	PU	5.3481	24.4059	22.8155	18.1066	44.9052	9.7076	20.0586	1.6022	15.0163	161.966 1
1	5	PB	2.1878	5.4257	14.0777	0.9522	4.1588	0.4868	6.4063	3.6906	3.4712	40.8571
1	5	PR	4.1657	20.9901	20.5825	7.6103	3.4479	13.3626	5.7188	2.3757	12.3504	90.6039
1	5	PL	3.2707	2.1683	7.2977	1.2794	2.9739	0.5848	10.4297	5.7569	4.5647	38.3262
1	5	PD	6.0331	3.0644	9.0291	1.0625	1.7014	1.6140	2.5391	8.3099	4.0424	37.3959
2	10	PU	9.0845	*	26.0749	31.8421	68.4028	39.8381	32.4380	2.6338	10.8037	221.117 9
2	10	PB	2.8451	6.3938	6.1997	1.8158	0.8073	5.3198	7.3760	22.3944	15.3299	68.4819
2	10	PR	27.1831	60.0237	41.6089	40.4135	32.6910	*	8.0992	3.4577	10.7107	224.187 8
2	10	PL	3.6761	5.5872	6.6782	4.0996	16.0590	3.1964	19.3802	17.1271	4.4078	80.2115

2	10	PD	19.6479	7.4259	20.6657	1.3853	1.2049	2.8806	1.4773	4.6197	13.9594	73.2666
2	7.5	PU	6.0000	49.3476	17.3370	19.1729	47.2222	22.8543	20.4752	1.7465	10.1354	194.2911
2	7.5	PB	2.3099	5.1186	6.6990	1.4323	0.6997	4.1316	6.2190	13.5211	7.9780	48.1092
2	7.5	PR	13.7324	47.8055	30.6519	23.1391	21.4931	39.1700	5.0661	2.6338	8.8917	192.5835
2	7.5	PL	3.4507	7.6453	6.5742	6.3158	19.6354	5.4251	15.6198	13.2394	5.2876	83.1934
2	7.5	PD	14.0845	3.8553	9.6879	0.9962	0.9045	2.0830	1.1260	3.9648	5.6684	42.3707
2	5	PU	4.3099	40.6880	10.4022	15.2632	38.8889	18.8866	17.7479	1.5563	6.8782	154.6212
2	5	PB	1.7887	4.3060	6.3037	0.9098	0.5347	2.7611	4.0909	7.7465	7.0474	35.4889
2	5	PR	8.2394	39.4425	14.7018	13.4774	12.9340	23.3401	3.3182	2.9507	6.9459	125.3500
2	5	PL	3.1268	4.6679	3.9667	7.1992	19.7917	7.2874	16.5083	7.9577	4.1709	74.6766
2	5	PD	8.8732	2.8055	5.4785	0.7068	0.6510	1.1619	0.7748	7.9245	5.1269	33.5032
3	10	PU	14.2138	51.7574	19.5413	30.1347	43.3884	7.7902	38.7847	2.7673	32.4332	240.8111
3	10	PB	7.9874	10.2970	14.5872	2.1094	1.1570	4.9888	4.2118	23.5849	32.9198	101.8435
3	10	PR	24.5283	50.6436	52.0183	50.3367	36.6116	53.7946	8.7500	8.4277	17.6718	302.7826
3	10	PL	8.4277	3.8540	10.3211	1.9731	5.7521	0.8415	23.5069	17.3944	19.1031	91.1737
3	10	PD	40.5031	9.9257	30.2752	12.1549	3.1074	17.5000	3.8715	8.5535	40.9351	166.8265
3	7.5	PU	10.4403	37.8218	16.0550	22.6431	77.9339	5.7143	30.4861	1.9874	28.8168	231.8987
3	7.5	PB	2.0189	7.8960	9.6330	1.0488	0.9091	2.5536	5.4896	15.3459	15.0095	59.9045
3	7.5	PR	17.1069	36.4604	32.5229	33.9394	26.7355	35.5357	5.1840	7.0440	13.9218	208.4507
3	7.5	PL	7.7987	3.3094	3.8106	1.7391	5.8182	0.8549	20.8681	23.2704	14.3130	81.7823
3	7.5	PD	25.4088	8.8119	19.8165	7.8451	2.1777	12.8571	3.0104	6.2516	26.0496	112.2288
3	5	PU	6.7296	25.5198	11.8807	15.1684	63.5950	3.8460	24.4097	1.4151	20.6107	173.1750

3	5	PB	1.4340	4.7723	5.5688	0.7525	0.9380	2.2612	3.9722	7.0440	7.3092	34.0522
3	5	PR	10.0000	25.6436	15.5963	17.0202	12.7273	15.0446	6.8299	4.1258	10.0477	117.0354
3	5	PL	4.3899	1.9010	2.3312	1.1953	3.1405	0.9844	16.9444	16.7296	11.8130	59.4293
3	5	PD	19.0566	4.0446	11.8349	2.1700	1.2066	3.4509	2.8576	4.8102	11.4790	60.9104
4	10	PU	5.7664	58.9200	5.7763	28.5714	53.9200	4.8753	23.6644	2.5036	29.4521	213.4495
4	10	PB	2.5036	4.8800	13.8584	3.1217	1.8120	6.2742	4.8288	9.1241	35.1884	81.5912
4	10	PR	14.4526	62.8000	9.5205	45.9259	35.8000	39.4737	10.8390	3.3869	43.4932	265.6918
4	10	PL	3.8102	5.5280	5.6438	2.9339	12.0000	1.0928	14.0411	34.2138	5.0428	84.3065
4	10	PD	26.4964	8.8440	14.8858	16.7989	5.7840	20.0000	1.7363	2.9197	29.6233	127.0884
4	7.5	PU	3.8978	40.6000	3.8014	16.8254	32.9200	2.7909	18.9384	1.6715	27.8168	149.2621
4	7.5	PB	1.7664	3.1400	4.2603	1.9868	1.7520	2.0512	3.5514	7.0292	18.3219	43.8592
4	7.5	PR	7.5182	38.0000	4.7352	25.3439	23.9600	20.6510	3.4332	3.1387	21.5753	148.3555
4	7.5	PL	3.3212	3.5400	3.0068	2.1376	3.5440	0.8075	11.0616	23.5036	5.8990	56.8213
4	7.5	PD	25.4015	4.8480	10.2740	11.0847	3.8680	14.2105	1.4229	2.7007	23.9726	97.7829
4	5	PU	3.0438	33.3200	3.1393	13.4656	26.9200	2.2936	18.4247	1.8321	26.8836	129.3226
4	5	PB	2.2336	4.4760	6.8493	2.4497	1.5000	4.6537	2.7637	4.4161	24.2295	53.5716
4	5	PR	5.1314	38.6000	4.3174	19.5767	20.9200	14.1551	6.5428	2.5839	22.6884	134.5157
4	5	PL	3.5839	3.0000	2.4795	3.3492	13.6600	0.9183	14.1438	14.0876	7.2517	62.4740
4	5	PD	17.5912	4.4560	5.6826	5.5079	2.3160	9.1413	1.0445	4.3653	14.4606	64.5656
5	10	PU	4.9461	31.5909	5.8116	14.0525	53.7267	12.6173	26.3324	3.1101	5.1392	157.3268
5	10	PB	3.6534	18.4091	24.4863	0.9662	1.0652	5.2963	0.8983	8.7963	31.4561	95.0272
5	10	PR	11.3349	31.2879	8.6986	29.3058	18.1677	41.8765	1.6877	19.0164	10.5996	171.9751

5	10	PL	19.7658	3.6439	27.8082	1.3358	1.7391	2.2494	7.7650	24.1606	18.2441	106.7121
5	10	PD	33.9110	10.8333	22.5000	7.8612	2.7888	17.7284	0.9327	3.4567	23.4690	123.4810
5	7.5	PU	3.9719	25.8333	4.4075	12.4765	45.4658	11.3333	18.9398	2.3981	5.3961	130.2226
5	7.5	PB	5.9672	14.3939	16.6438	0.8630	0.9845	4.1235	1.6447	7.2787	11.0921	62.9914
5	7.5	PR	9.3677	22.1212	5.2158	22.7580	11.0559	31.3086	1.2364	4.7588	5.5396	113.3619
5	7.5	PL	9.0211	2.6780	23.3562	0.9812	1.3851	2.4543	4.9857	26.0422	18.0086	88.9123
5	7.5	PD	33.6300	8.5985	14.4521	4.6379	1.8261	12.0741	0.7736	2.7166	6.7024	85.4112
5	5	PU	2.7541	21.4773	3.8082	10.2814	31.5217	9.5062	14.3266	1.9953	4.9422	100.6131
5	5	PB	2.0328	13.5985	10.3425	0.9118	0.8820	3.5580	1.4670	3.3349	8.9936	45.1211
5	5	PR	5.7611	19.8864	4.5171	14.9343	8.0745	21.1852	0.9814	2.4075	4.9379	82.6854
5	5	PL	2.7166	1.9053	8.3527	0.8462	1.1646	1.3481	5.5014	14.3326	3.8630	40.0305
5	5	PD	17.1429	4.9583	6.5548	2.4146	1.1149	7.2099	0.7908	7.1250	5.2184	52.5296
6	10	PU	7.5625	59.6667	27.6052	15.5130	52.2936	8.1849	44.3709	5.5500	10.2147	230.9615
6	10	PB	6.5625	12.3733	20.3407	1.5043	2.2018	4.3445	0.9056	20.5625	20.9509	89.7463
6	10	PR	21.2500	65.4667	23.6974	19.9130	36.0321	29.2437	6.2748	7.0000	13.4356	222.3133
6	10	PL	7.2500	6.8533	19.5391	0.9730	5.5275	0.8319	11.8709	32.2248	8.5583	93.6289
6	10	PD	16.0625	13.6000	23.7475	1.8452	2.7317	5.1681	2.1325	3.9688	13.2209	82.4770
6	7.5	PU	5.9500	39.4000	16.1824	10.3913	34.6789	4.5546	34.6854	5.7813	9.5092	161.1331
6	7.5	PB	7.8750	14.1000	16.8337	2.6930	3.1376	6.6807	1.1921	9.4375	22.7301	84.6796
6	7.5	PR	9.6875	39.2667	13.2265	9.3043	18.0275	14.0924	3.6093	4.2250	5.7301	117.1693
6	7.5	PL	4.3750	5.7133	12.6253	0.8209	3.6399	0.5655	8.6589	8.2500	5.7853	50.4341
6	7.5	PD	11.3125	10.5067	15.5812	1.7748	2.2339	4.6723	1.4172	3.3438	12.0552	62.8975

6	5	PU	3.5375	25.9333	11.0721	5.8783	27.3165	2.3950	24.1060	3.0250	5.6227	108.886 4
6	5	PB	4.5000	9.7467	10.5461	1.0739	1.3280	3.0916	1.0596	5.8813	17.4847	54.7118
6	5	PR	7.9375	29.6667	10.5711	6.3652	12.9587	9.6303	4.0894	2.4250	6.3865	90.0304
6	5	PL	2.9625	3.7667	6.9790	0.5870	3.1422	0.4412	6.7053	7.5000	2.8773	34.9611
6	5	PD	7.6875	8.0667	12.6253	1.1322	1.4404	3.1849	0.9983	4.4027	9.1411	48.6790
7	10	PU	4.5734	18.5169	6.2264	5.9540	45.8861	3.4821	49.8599	0.8464	10.2574	145.602 7
7	10	PB	0.8703	5.6271	9.7170	0.5818	0.6535	0.8584	6.8207	9.0102	18.9338	53.0729
7	10	PR	9.3174	55.0847	10.7311	28.5349	21.5981	40.3061	6.8768	2.4642	21.5441	196.457 5
7	10	PL	3.4812	8.8941	5.6604	2.0426	5.3639	2.1301	33.8375	15.4375	4.9853	81.8326
7	10	PD	23.9932	8.5551	21.5330	3.4157	2.4652	7.9464	2.8852	2.8396	21.5441	95.1774
7	7.5	PU	3.0068	18.4322	5.5967	5.4600	42.8006	3.6888	31.9328	0.6382	8.4926	120.048 7
7	7.5	PB	0.7065	4.8729	6.3443	0.5187	0.7310	1.2844	4.7759	3.6519	10.9265	33.8122
7	7.5	PR	7.4403	31.8220	6.1321	15.3578	12.0411	22.1556	3.8473	1.6519	12.8309	113.279 0
7	7.5	PL	1.7816	4.0805	2.5495	1.3203	4.7152	1.1964	21.5126	9.7952	3.4007	50.3521
7	7.5	PD	9.9659	5.0085	9.4575	1.1354	1.1693	2.9592	1.6008	1.9488	11.6912	44.9366
7	5	PU	1.9590	16.5254	3.7830	5.2215	33.7025	3.4439	20.4202	0.4505	6.8162	92.3222
7	5	PB	0.5870	4.6525	1.6509	0.4855	0.6408	1.6365	4.4958	2.8430	6.5993	23.5914
7	5	PR	3.0648	19.7458	3.3703	9.3952	7.1203	13.1122	2.4202	1.1195	7.6985	67.0468
7	5	PL	1.6007	2.3983	2.6014	0.8535	2.8022	0.7806	13.2493	3.1877	2.6875	30.1612
7	5	PD	3.7201	2.0508	3.4104	0.4514	0.6772	0.9477	0.9468	2.6030	2.2537	17.0612
8	10	PU	2.8464	46.3576	2.5606	15.3933	25.3036	4.5546	43.4870	0.4494	10.1244	151.076 9
8	10	PB	0.9120	4.8013	6.2976	1.1133	0.3603	7.6580	0.6453	9.3446	12.3632	43.4956



8	10	PR	11.6667	67.5497	4.3339	38.2022	16.7713	56.8966	4.5691	1.8071	8.9801	210.7767
8	10	PL	2.3034	1.7406	5.3806	1.2022	4.2206	1.4914	12.8357	16.6212	3.5050	49.3007
8	10	PD	32.2097	7.3289	11.0813	7.3596	2.1660	20.3736	1.9339	1.7566	12.5871	96.7966
8	7.5	PU	2.0787	32.3400	1.8962	10.9082	57.3887	3.2241	26.4529	0.6685	6.4925	141.4498
8	7.5	PB	1.6948	4.5585	4.5934	1.1863	0.3664	7.5862	0.3367	5.4869	9.7761	35.5853
8	7.5	PR	6.5169	53.2009	2.7768	17.0412	9.1296	26.1207	2.0150	1.1479	6.4925	124.4415
8	7.5	PL	1.2903	1.2561	2.3875	0.9597	3.2389	1.0991	6.0721	13.9700	2.7960	33.0698
8	7.5	PD	17.1348	4.2936	5.8910	5.0187	1.1235	12.8592	0.8287	1.1985	6.7910	55.1390
8	5	PU	1.2416	16.6336	1.1782	6.6199	32.0850	2.2514	15.9920	0.2715	4.1269	80.4000
8	5	PB	0.3427	4.1280	2.0502	0.8034	0.3239	5.1149	0.7285	3.4831	5.8706	22.8454
8	5	PR	3.6330	31.7881	1.8287	10.9738	5.5870	15.2155	1.4529	1.0899	4.0498	75.6186
8	5	PL	1.1948	0.9857	1.2820	0.8493	3.2186	1.0129	8.2565	8.9513	2.6244	28.3754
8	5	PD	10.5993	2.9139	2.9585	2.7154	0.7004	8.4770	0.4960	10.0000	5.3980	44.2584
10	10	PU	36.9565	60.4723	10.6494	20.9655	54.3253	4.5801	31.4953	3.4261	15.2212	238.0916
10	10	PB	5.7950	7.4025	12.5649	2.2897	0.7336	1.8268	6.2617	32.6957	16.7257	86.2954
10	10	PR	41.4286	49.8973	16.2987	37.6897	15.8478	24.5144	10.1090	9.3913	16.8142	221.9909
10	10	PL	3.5714	6.3912	9.1916	5.2310	10.6903	1.5682	28.2710	28.2772	4.6681	97.8601
10	10	PD	8.5714	14.1684	33.5065	10.3103	2.3201	7.6640	3.0078	7.8783	32.2124	119.6392
10	7.5	PU	29.7516	60.0103	8.2143	15.6552	36.5052	3.2415	20.4984	2.1043	12.6991	188.6798
10	7.5	PB	6.8323	5.9959	12.6623	1.7586	0.6886	1.1772	5.6698	15.6522	13.2301	63.6669
10	7.5	PR	24.1615	39.2710	10.6818	20.3793	10.2076	12.6247	7.2586	4.1391	11.3717	140.0953
10	7.5	PL	2.6149	4.1632	4.2662	2.9241	6.0052	0.8753	19.0498	44.5217	3.3451	87.7658

10	7.5	PD	5.7453	9.2864	22.0779	6.0276	1.3875	4.2257	3.9097	5.9739	14.7345	73.3686
10	5	PU	23.4161	45.4312	7.0130	12.6897	26.4360	2.6614	14.4860	1.4957	11.0177	144.6467
10	5	PB	5.4845	4.0349	4.1591	1.2517	0.5796	0.6181	3.6044	6.9826	5.6018	32.3166
10	5	PR	20.1863	31.9815	7.1591	12.8276	8.2180	7.2178	5.3427	4.0522	9.7788	106.7640
10	5	PL	3.6522	3.5883	2.3149	2.9828	10.9343	0.8097	16.7913	22.6957	3.7035	67.4726
10	5	PD	4.6770	6.7710	11.6558	3.2138	0.8581	2.5696	0.9735	5.2016	8.8717	44.7922
11	10	PU	5.8065	48.7023	15.6034	21.0811	48.4333	22.7461	56.0729	27.4597	72.8302	343.2570
11	10	PB	47.1774	16.5649	28.3333	8.3398	6.6000	23.0570	3.9615	31.8952	43.8994	172.2571
11	10	PR	32.2581	75.9542	18.3621	33.6486	40.7667	63.7306	16.4170	8.3468	64.0881	362.7842
11	10	PL	21.0484	6.4542	28.9368	1.8649	4.2067	2.3420	14.7368	78.8696	20.3145	95.3022
11	10	PD	76.6129	21.2214	35.3448	8.8803	7.8000	22.2539	9.8583	76.6129	41.6352	229.3881
11	7.5	PU	4.0726	25.8397	9.0517	11.7375	27.4333	12.5648	37.8745	3.3185	44.4025	204.5707
11	7.5	PB	3.4153	4.7481	9.1379	1.6583	1.3533	7.2539	1.2348	2.6169	18.6164	48.8085
11	7.5	PR	14.2339	33.0916	6.2069	10.7915	12.1667	21.1658	5.5061	13.7097	29.1195	139.1352
11	7.5	PL	17.8629	4.6412	25.2011	1.9498	2.7267	1.7435	15.6275	11.4516	15.5975	83.6242
11	7.5	PD	39.9597	11.1450	17.1552	4.2085	4.1933	14.5855	4.1134	38.4274	26.0377	123.9014
11	5	PU	2.3911	21.7557	7.2414	7.0849	19.9667	6.9171	23.1377	2.3427	36.0377	150.4697
11	5	PB	12.2581	4.3969	9.8276	1.8417	1.5067	8.3679	1.2510	2.8871	25.1572	61.7377
11	5	PR	10.1210	30.1145	5.3017	7.8764	8.3867	17.0207	3.7166	7.4597	23.9623	112.4409
11	5	PL	17.9032	2.8359	12.8448	1.8224	1.9600	1.7746	27.2874	15.6855	12.5346	78.8301
11	5	PD	24.4355	6.2786	8.2759	2.4749	2.5367	10.1036	2.3684	18.0242	17.0440	72.6954