ABSTRACT

ERGONOMIC EVALUATION OF SHOULDER MUSCLE ACTIVATION DURING LIGHT WEIGHT HAND TOOL EXERTION TASK

by
Gul Ahmed

A study was conducted to evaluate the effect of shoulder muscle activation during hand exertion tasks using a light weight hand tool by working individuals. Electromyography (EMG) of trapezius, supraspinatus, triceps, and pectoralis major was conducted for 45^o, 0^o and -45^o arm angles, for three different reaches i.e. normal, maximum and extreme and three different push forces low, medium and high. Ten volunteers participated in the experimental study. The effects of push force and reach distance were found to be statistically significant for all four muscles. However the effect of change of angle was not found to be statistically significant, except for triceps. The only interaction effect that was found to be significant was between force and reach for all four muscles.

The interaction effect between force and reach shows higher trapezius and supraspinatus activity at low force and extreme reach levels and hence shows that the postures which require lower forces and farther reach levels are potentially more likely to cause or enhance injuries in shoulder muscles. This study for the first time used a shoulder and arm muscle activation pattern for manual tasks with a downward push force and it is relevant to the work in medical imaging sonography.

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To my beloved parents

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LIST OF SYMBOLS

BLS	Bureau of Labor Statistics
EMG	Electromyography
MSD	Musculoskeletal Disorder
MVC	Maximum Voluntary Contraction
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration

CHAPTER 1

INTRODUCTION

1.1 Background

Musculoskeletal disorders (MSD) are one of the most common types of workplace illnesses. They are recognized as a major cause of workers' absences. OSHA defined work related musculoskeletal disorders (WMSDs) are caused or enhanced by activities at the workplace and are characterized by pain or discomfort of nerves, tendons, muscles, and supporting structures of the body (Burnett and Campbell-Kyureghyan 2010). For example, 73% of all compensable claims in the health care industry between 1994 and 1998 in British Columbia, Canada resulted from WMSDs with the direct costs of these claims approaching $113 million (Burnett and Campbell-Kyureghyan 2010).

Medical Sonography is one of the areas where WMSDs are frequently encountered. Over the past ten years, studies have indicated an 80% incidence rate of musculoskeletal symptoms among sonographers (Horkey and King 2004). The above mentioned 80% of sonographers have been scanning in pain/discomfort for almost half of their career and 20% of them would ultimately end their career for the same reason. According to a study, between 84% and 93% of sonographers in United States, Canada and Australia have reported work related musculoskeletal injuries (Bravo *et al*. 2005). Another study suggests that while the prevalence of neck and upper limb pain for the general population is 13% to 22%, for sonographers it is between 63% and 91% (Village and Trask 2007). Injury rates compiled from questionnaires suggest that 65 to 91% of sonographers were affected by some kind of Musculoskeletal pain (Burnett and Campbell-Kyureghyan 2010).

One of the major causes of injuries to sonographers is believed to be the static and sustained muscle contraction at shoulders, upper back and upper extremities, which is required to maintain the extended arm position during medical sonography (Bastian *et al*. 2009). Additional risk factors identified are application of downward push force on the transducer, repetitive movements of the shoulder, arm, forearm, wrist, hand and fingers along with awkward postures of the upper arm (Village and Trask 2007; Burnett and Campbell-Kyureghyan 2010). Varying degrees of a downward pushing force are needed to manipulate the image, which also vary with scan type and depth of adipose tissue (Burnett and Campbell-Kyureghyan 2010).

Ergonomic factors, such as the reach distance and orientation of a sonographer with respect to the patient position determines the upper arm elevation and rotation requirement of the sonographer during scans. Since the scan times last anywhere between 12 to 30 minutes (Village and Trask 2007), low level activation of shoulder and upper arm muscles from sustained arm elevation may induce muscle fatigue. Failure to address ergonomic issues on a workstation may cost up to $580,000 in revenue loss, medical bills, average cost of a worker's compensation claims and new staff recruitment. Temporary staffing from an agency can cost an additional $80,000 (Society of Diagnostic Medical Sonography. 2003).

Two EMG based studies on Sonography have been reported in the literature that quantified muscular load in the shoulder region. Village and Trask (2007), measured surface EMG of three neck/shoulder muscles (trapezius, supraspinatus and infraspinatus) for three sonographers performing seven scans on patients. They collected EMG data from three sonographers performing abdominal carotid, echocardiogram, abdominal, renal and leg scans totaling 183 minutes. They determined 10, 50 and 90 percentile amplitude of probability distribution functions (APDFs) of EMGs to characterize the static, median and peak muscle activity during scanning. The mean 10 percentile APDF of all three shoulder muscles exceeded 3% MVC corresponding to a ‘‘low’’ risk rating for shoulder–neck MSDs. Also, for two of the seven sonographers, static, median and peak trapezius activity exceeded the limits of muscle activity corresponding to risk of shoulder MSDs. During their study, they observed long durations of static and awkward shoulder abduction and outward rotation of upper arm and high and sustained grip forces, which were consistent with the high prevalence of neck and upper limb musculoskeletal disorders and symptoms. Their study provided a detailed quantification of objective risk factors in terms of EMG and posture evaluation, and suggested strongly the need of effective control measures on posture to reduce the risk of injury.

In the second EMG-based study, Murphey and Milkowski (2006) evaluated the effects of various commonly found arm postures related to the sonography task. Twenty-two experienced sonographers participated in the study. Researchers measured EMG from the trapezius and suprascapular fossa of the shoulder region at upper arm postures of (i) two levels of shoulder flexion (0° & 50°), (ii) two levels of shoulder abduction (30° and 75°), and (iii) one level of shoulder abduction at 30° with a soft support under the elbow. Their study showed large and statistically significant reductions in muscle activity can be obtained by modifying the scanning technique and workstation arrangement. The trapezius muscle activity decreased 65% by changing from a 50° forward shoulder flexion, (which is effected by the medial reach requirement by a sonographer) to a neutral (0° flexion) position. The right suprascapular fossa activity was reduced by 46% when the abduction (reaching laterally) was reduced from 75° to 30°. They found an even more dramatic reduction of 78% by providing support under the forearm at the same 30° abduction level. The total reduction from 75° abduction to 30° abduction with support was demonstrated to be an 88% decrease in muscular activity. Based on the above results, the authors recommended using an adjustable ergonomic chair, exam table heights, and an adjustable ultrasound console to achieve improved patient positioning. The study showed that when sonographers utilize extended reach, either laterally or medially, stressful forces in the muscles of the shoulder joint increase. The further away the reach was, the greater the force was required by the shoulder muscles to counter the action of gravity on the extended arm. Although, the above study identified the favorable upper postures that minimize shoulder muscle stress, this study did not take into account the combined effect of arm reach and downward push force that the sonographers need to apply on the transducer to obtain an image.

A simple biomechanical model of shoulder joint (Figure 1.1) provides insight on how the activities of the shoulder muscles are influenced by the upward push force at the hand from the transducer. When the arm is abducted (or extended) the center of gravity of the arm segment shifts by a distance d from the shoulder joint (Figure 1.1a). To maintain rotational equilibrium of the shoulder joint, a reactive torque T1 must be generated by the shoulder muscle complex to counter the rotational moment ($T1=W*d$) from the abducted (or extended) arm. However, when an upward force P (up to a certain magnitude) acts on the distal end of the hand (Figure 1.1b), the reactive muscle torque (T2) should decrease ($T2<T1$), as $T2=W*d-P*L$. For increasing P, the rotational moment due to P ($P*L$) may exceed that of the arm weight ($P*L>W*d$), and the magnitude of the muscle reaction torque T2 could again be increasing in the opposite (counter clockwise) direction of T1. A considerable amount of hand force (mean = 39N, standard deviation = 29N) was measured by Village and Trask (2007) from holding and pushing the transducer by the sonographers. Thus, although the EMG patterns observed by Murphey and Milkowski (2006) identified the harmful ergonomic factors in sonography, they did not investigate the combined effect of arm posture and push force, which is inherent to the sonography task.

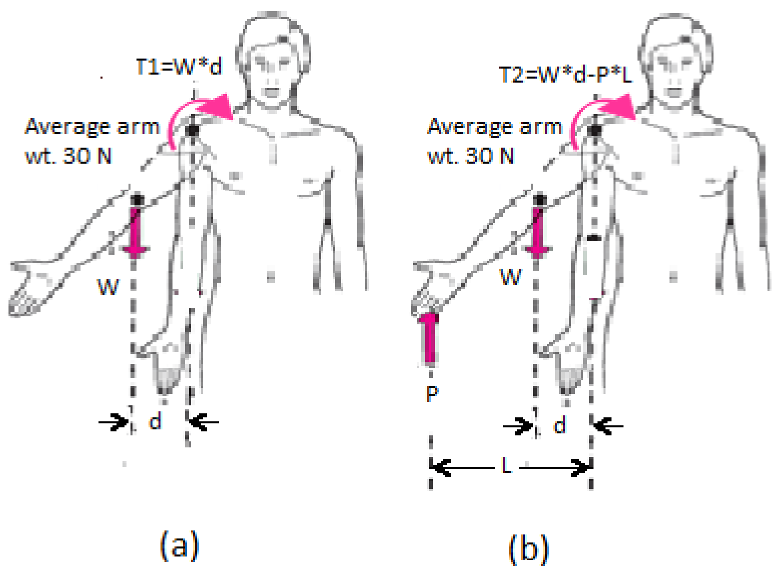

Figure 1.1 Biomechanical model of shoulder joint: (a) abducted arm and (b) abducted arm with an upward force is acting on distal end of hand.

Combined effects of shoulder posture and hand force, on shoulder/arm muscle activity in terms of EMG have been investigated for industrial tasks by several researchers (Brookham *et al.* 2010; Sengupta, and Das 2004; Sporrong, *et al.*1998). Brookham *et al.* 2010 identified the least stressful shoulder postures in terms of EMG from seven shoulder muscles when subjects performed the simulated light hand tool task in 15 shoulder postures (3 humeral rotations x 5 flexions) with a 13N horizontal hand force against a vertical work surface. Sengupta and Das (2004) found that physiological costs in terms of heart rate and

EMG from four upper body muscles were reduced significantly when repetitive manual handling tasks were performed in smaller reach distances. In their study, the force acting on the hand was a gravitational force of a box being handled over a horizontal work surface. Sporrong, *et al.*(1998) evaluated five different shoulder postures and found that the precision requirement from a light hand tool increases the shoulder muscle activity significantly. In their study the subjects carried a special positioning tool which exerted a downward force on the hand.

Although, the above studies provide useful results regarding the design of workstations and work methods, the findings of these studies would not be pertinent to sonography work, since the latter involves pushing the transducer downward on an approximately horizontal plane. A sonographer exerts a gripping force and a downward pushing force on the transducer, and, as a result, the arm of the sonographer is subjected to a vertically upward force, as shown in Figure 1.1b. Burnett and Campbell-Kyureghyan (2010) have discussed variations of the push force with various sonography scan types. Work postures involving the use of a transducer with a downward pressure along with an awkward posture have been regarded as “most painful” ones (Friesen *et al*. 2006). Although the push force or downward pressure has been shown to be one of the most important potential causes of shoulder injuries, the push force has not been investigated in conjunction with shoulder posture.

Further research is needed to study the effects of the sonography task on shoulder muscle activation during various upper limb postures, to determine if hazardous levels of activation can be avoided by postural control. The objective of this study is to document the influence of shoulder flexion and humeral rotation on shoulder muscle activity (in terms of

EMG) during submaximal downward pushing tasks similar to the sonography task. Electromyography is regarded as one of the most objective and accurate methods of directly measuring muscular stress, as evidenced from the research studies discussed in this section.

1.2 Objectives and Hypotheses

The specific objectives of this study are:

1. Conduct a literature review related to musculoskeletal injuries in the field of Medical Sonography.

2. To systematically evaluate the effect that reach distance, humeral rotation and downward force have on an upper extremity muscle EMG when a light downward push is exerted on a horizontal plane. Muscular loads involved are monitored by measuring electromyography (EMG) of four shoulder muscles (middle trapezius, triceps, pectoralis major and supraspinatus) while applying a vertically downward push force that would be measured through a strain gage.

It is hypothesized that:

1. EMG will be significantly affected by the reach distance

2. EMG will be significantly affected by humeral rotation

3. EMG will be significantly affected by the exerted push force

CHAPTER 2

LITERATURE REVIEW

The following two sections describe the current biomechanical and psychophysical research on Sonography Profession related MSDs of Sonographers.

2.1 Biomechanical Studies

Village and Trask (2007) investigated the postural loads involved in performing ultrasound sonography scans to identify the extent of abduction and outward rotation of the shoulder, unsupported shoulder postures and neck bending/twisting. They conducted a video-based postural analysis at six hospital facilities involving a total of 11 different ultrasound sonographers for 24 full scans totaling 528 minutes of scan duration.

Their video analysis results showed that on average sonographers spent 66% of the scanning time with the shoulder abducted more than 30^o and 45% of the time at more than 45^o. The static or unsupported arm postures of the right shoulder to hold the weight of the arm and transducer was found to be on average for 73% of scanning time. According to Jarvholm *et al.* (1988, 1989), a 30^o shoulder abduction causes significant impedance of blood flow in the supraspinatus muscle. High shoulder abduction coupled with prolonged unsupported static upper arm posture was identified as significant risk factors for MSDs at the shoulder region. On average, sonographers spent 63% of their scanning time with the shoulder outwardly rotated more than 30^o and 43% of the time at more than 45^o. This shoulder posture loads specifically the supraspinatus muscle (Village and Trask 2007). They found that the neck was bent forward, laterally or twisted more than 20^o for an average of 37% of the scanning time.

In their second part of the study they measured muscle loads in terms of electromyography (EMG) of three neck/shoulder muscles (trapezezius, supraspinatus and infraspinatus) as well as the gripping force of the flexicarpi ulnaris holding the transducer. They collected EMG during one full shift at one of the six hospital facilities, when three sonographers performed 2–3 scans each (a total of seven scans) on patients.

All three shoulder muscles were found to work 90% of the time statically at or above a mean contraction of 3% to 10% of MVC, which corresponds to a medium risk rating for shoulder-neck MSDs. Mean forearm flexor (FCU) EMG was 3.96 kg (SD 2.94), with occasional peak forces as high as 27.6 kg. The study confirmed that ergonomic risk factors, such as long durations of static loads on shoulder muscles are accurate representatives of high prevalence of neck and shoulder injuries and symptoms as reported by many studies conducted on Sonographers.

Brookham *et al.* (2010) investigated the effects of light hand tool exertion task on the activation of nine shoulder muscles (right superior, middle and inferior trapezius, anterior, middle and posterior deltoid, pectoralis major, infraspinatus and latissimus dorsi) during different shoulder flexion postures and three angles of humeral rotation. Tasks were performed at 15 different postures: shoulder flexion of 0^o, 60^o, 70^o, 80^o, and 90^o, and humeral rotation of -45^o, 0^o, and 45^o. The elbow was flexed to 90^o during all postures. Subjects performed two simultaneous tasks - producing a gripping force of 30% MVC and exerted a forward push force at 13N with a hand dynamometer. The subjects exerted a force horizontally, similar to a drilling task.

The results suggested that in order to reduce risky levels of inferior trapezius activation, light hand tool tasks should be performed at neutral elevation and 45^o internal rotation, or for slightly higher activations (but still low risk) at 60° shoulder flexion and 45° internal rotation. Another important finding of the study was that light hand tool tasks cause shoulder muscle activation at levels close to or exceeding the recommended threshold of 10-14% MVC for long lasting intermittent or dynamic work.

The experimental set up of Brookham *et al*'s study (Figure 2.1) was very similar to the Sonography task, but with a different plane of force exertion. In sonography mostly a downward pushing force is exerted instead of a force in the horizontal direction. A very different set of muscles come into action when the direction of the applied force is changed, even for very similar tasks. Further research is needed to find the differences involved for such a change.

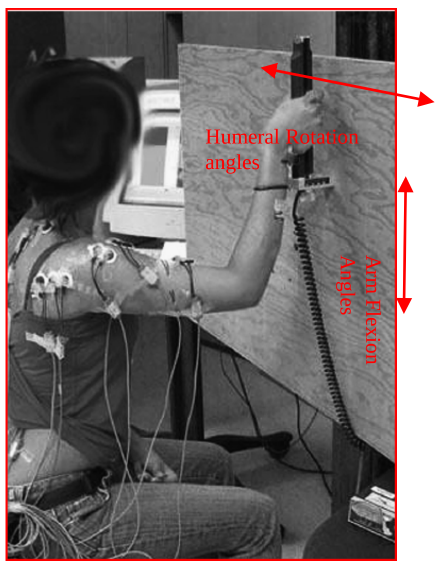

Figure 2.1 Experimental set up employed by Brookham *et al*. (2010) to evaluate shoulder muscles activity for sub-maximal tasks performed in horizontal direction.

Sporrong *et al*. (1998) examined the effect of light manual precision work on shoulder muscle activity. They used EMG to study seven shoulder muscles for 10 subjects, in five different arm positions, consisting of different arm and elbow flexion angles. The subject held a light stick with a total weight of 100g and moved the tip of the stick through a labyrinth, without touching it, for approximately 10 seconds (Figure 2.2). Later, the EMG activity of the shoulder muscles was compared with and without the precision work.

The statistical outcome showed a significant increase of EMG activity in all except one arm position. The tendency for an increase of EMG activity in most positions was similar in most of subjects, despite some individual differences. There was an increase of 68% in trapezius muscle EMG activity for all 10 subjects and in all arm positions. Mean EMG activity increase for deltoideus anterior, levator scapulae, rhomboideus major, middle deltoideus, supraspinatus and infraspinatus by 64%, 78%, 71%, 70%, 86%, and 83% respectively. The authors suggested that the increased hand activity was due to requirement of increased stability in the shoulder especially in the supraspinatus and infraspinatus, which were considered as the dominant stabilizers of the shoulder during flexion (and latissimus dorsi in the late part of the movement).

The results of the study showed that even a rather light hand activity could significantly increase shoulder muscle activity. The study also emphasized, in view of current results, that precision work in awkward shoulder positions should be avoided. This is a very fundamental article providing statistical evidence of an important phenomenon.

In another study, Bravo *et al*. (2005) evaluated the activity of shoulder muscles in reference to the non-scanning arm. Left upper trapezius muscles were chosen for this purpose. This arm is continuously in elevated position to reach the ultrasound equipment control panel. One of the purposes of this study was to achieve reproducible results for evaluating the efficacy of using voice-activated control panel controls to reduce muscle activity.

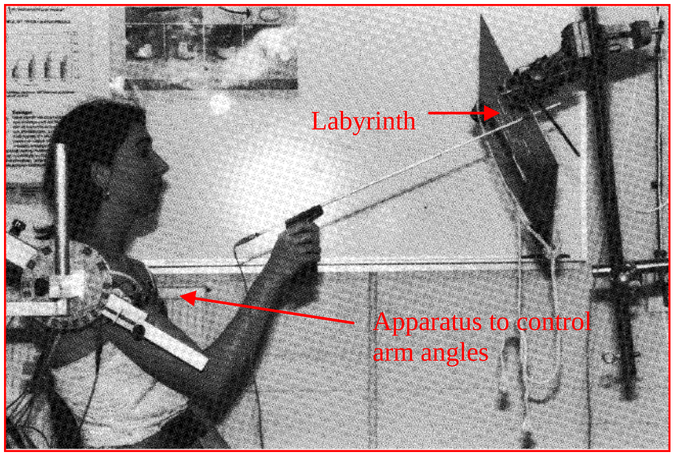

Figure 2.2 Experimental set up employed by Sporrong et al. (1998).

Surface EMG was used to compare muscle activity. As a first step an EMG of the upper trapezius muscles measured the activity level of the muscle while accessing the control panel. The study used 34 subjects, consisting of 4 men and 30 women at varying age, experience etc. First MVC was measured for the muscle group and then measurement were taken for a forward shoulder flexion at 44^o, 55^o and 70^o from the trunk, sustained for 10 seconds. The data were analyzed using ANOVA.

Results showed that the expected time to reach maximum shoulder muscle fatigue decreased with increasing reach, indicating that there was an increase in muscle electrical activity with an increase in forward flexion. 21% of the subjects exhibited percentages of MVC recruitment at 70^o forward shoulder flexion that exceeded the recommended 15% to 20% of MVC. 9% of subjects showed greater than the recommended MVC at both 44^o and 55^o of flexion. This means that these subjects were more prone to muscle fatigue and injury because of low blood flow through the muscles and hence reduced removal of waste products. The authors emphasized the use of ergonomic interventions and engineering control and they concluded that the use of a voice-activated control panel would reduce muscular effort by reducing the frequency of reaches for the control panel as well as the necessity to maintain an extended reach. The study did not consider various rotation angles, which are frequently used by sonographers with the scanning arm. More muscles might also have been included to evaluate the impact of the intervention on them.

Murphey and Milkowski (2006) compared EMG measurement, for upper trapezius muscles and rotator cuff for standard and improved postures for both right and left sides. The study used 22 subjects (sonographers), consisting of 6 males and 16 females. Adaptive cushions used to support the scanning arm in 30^{o} supported position. A 64% reduction in mean exertion of the left upper trapezius muscle was found, for extended versus a neutral position, which may be achieved by using an adjustable control panel or a similar intervention.

For the right rotator cuff, three different positions were analyzed; 75^{o} angle of abduction, which is very common to sonographers, 30^{o} angle of abduction, which is the recommended posture and 30^{o} abduction with the addition of a support cushion placed under the right forearm.

Reducing the angle from 75^{o} to 30^{o} resulted in a 46% decrease in firing of the muscles tested. The firing reduced further to 78% by supporting the forearm. The overall reduction between the first position and third one (a position of 30 degrees abduction with the addition of support cushions) was 88% decrease of muscle activity. This study concluded that shoulder muscle activity can be dramatically reduced through proper technique and equipment.

Although the outcome of the study was very obvious, it confirmed that reach plays a very important role in shoulder muscle activity and the later may be greatly reduced by keeping the reach angles as small as possible.

2.2 Psychophysical Studies

In the field of Medical Sonography questionnaires or surveys are a common method to assess the prevalence of work related MSDs and the existence of perceived risk factors for injuries. Burnett and Campbell-Kyureghyan (2010) investigated sonography scan-specific risk factors for shoulder muscles through such questionnaires. They also performed job evaluations and tried to quantify those evaluations through quantitative analysis of upper extremity joint biomechanics.

They used the Standardized Nordic Questionnaire (SNQ), (which was developed to analyze low back, neck, shoulder and general complaints for use in epidemiological studies) and customized it to gather specific details related to the trunk and upper extremities. Questions about lifetime prevalence, work-relatedness, causality, severity and duration of MSDs were also included.

All seven respondents of the survey perceived sustained shoulder abduction, sustained transducer usage and scanning large or obese patients to be risk-factors for occupational injury. Six responders reported musculoskeletal pain in at least one upper extremity joint. Although sample size was small, this high injury rate was quite consistent with that found in the other studies.

Second part of the study constituted an ergonomic analysis for five scan types, chosen on the basis of high frequency of scans at the facility where the evaluation was performed, and because they involved a variety of extremity and trunk postures and various push force requirements. The RULA (Rapid Upper Limb Assessment) method was employed for evaluation and electrogonio-meters were used to measure joint angles. Video taping was performed for all scan types. The evaluation was translated into a score, which was categorized into four levels. Level 4 indicated that investigations and changes were required immediately, and level 1 indicated that further changes may not be needed. Goniometers were used for angle measurements, while the push force was measured through a digital push/pull strain gage (Ergo FET 300). Minitab 15 was used to perform statistical analysis to compare the push force between different scan types.

The statistical analysis showed no significant differences between push forces exerted for different scan types. Neither was significant the statistical difference found for push forces among different subjects. Peak abduction angles exceeded 68^{o} for all scans, which was way more than the suggested acceptable limit of 20^{o}. Peak wrist flexion angles exceeded 51^{o} for all scans, while the acceptable limits found in literature, are 15^{o} to 40^{o}. Excessive and repetitive push force applications along with awkward wrist positions was found in 4 out of 5 scan types, which may be related to Carpal Tunnel Syndrome in sonographers. It was noted that all scan types have similar levels of risks with respect to postures and push force, with two of them having much longer duration than the others. The study concluded that although all investigated scan types involved injury risk, the level of risk or specific type of risk varied with scan type. This fact may be used while designing or employing a certain type of intervention or while evaluation the risk of MSDs.

The study used goniometers to record the angles, which may be used for wrist angle measurement. However the humeral movement around the shoulder is very intricate and may not be very accurately measured through them. A method employing a 3D movement recording system might be a better choice. A larger sample size might have also further validated the results.

Horkey and King (2004) performed a study on the effects of interventions on prevalence of MSDs and if interventions were used by sonographers. Interventions were categorized into engineering controls, administrative controls, and individual controls (i.e. job risk identification, training, and education). Examples of ergonomic interventions that have been reported in the literature include adjustability of chairs, beds, and equipment, varying posture throughout the day, reducing the amount of reaching to, and over the patient, alternating between standing and sitting when scanning, alternating scan hands, rotating between scan types, doing stretching exercises, providing education programs on proper posture and technique while scanning, and taking frequent rest breaks. A survey was conducted among 300 randomly selected registered cardiac sonographers, and 81 of them responded to the survey. The results showed that the majority of sonographers were aware of most of the recommendations and that the majority of sonographers were not implementing approximately half of the recommendations. Engineering control were most commonly reported interventions not being implemented. Responders reported these interventions were not implemented due to budget restraints. The study concluded that a high rate of MSD incidence still persists among sonographers despite awareness and implementation of majority of interventions which implies that the right solution for reducing Sonographers MSDs was still unknown.

Friesen *et al*. (2006) conducted a study to compare MSDs and workplace ergonomics among rural-based sonographers compared to urban-based sonographers. A questionnaire consisting of 115 questions was sent to 20 sonographers related to general health status, history of work-related injury, perceived risks for injury, preferred equipment models, and overall work environment. The 12 sonographers, who responded, reported experiencing pain most frequently in the neck and shoulders. The most painful or stressful work posture involved the use of the transducer with downward pressure, firm grip, and flexed wrist combined with shoulder abduction and forearm pronation or supination. 81% of them reported pain in the neck and shoulder that involves the upper trapezius and shoulder muscles.

Based on the survey results, rural-based sonographers appeared to have greater work stress and risk of musculoskeletal injuries. Among a variety of factors identified as contributing towards increased risk of MSDs were outdated equipment, longer reach and strong grip requirements for scanning obese patients, and push force requirement. Heavy work load (number of scans per day) also contributed to more injuries. The reason for heavy loads may be the lack of strong support networks and inadequate political power due to their small number.

The second part of study tested a biomechanical software ErgoWatch 4D-WatBak for assessing the load on the spine and upper extremity joint. An on-site video-taped ergonomic and biomechanical evaluations was done for Sonographers, performing various scans on simulated clients in a work environment. They demonstrated a wide range of joint angles during the scanning procedure. (Trunk flexion 5^o to 10^o, shoulder abduction 10^o to 60^o, and shoulder flexion 30^o to 110^o). They used joint torque per unit of applied force in a worse-case scenario by combining joint angle data with anthropometric data of limb segment lengths. The highest load moment was obtained when the moment arm about the shoulder was highest i.e. for largest shoulder abduction and smallest elbow flexion. This result indicated that mechanical stress on shoulders could be reduced by being as close to the patients as possible to reduce the reach and hence moment arm. This may also be achieved by having some degree of flexion in the elbow.

The authors concluded that the software could only be used for load assessments in sagittal planes and not for multi-plane joint evaluation, and hence, it was minimally effective. The authors did not provide experimental procedure details and method of analysis. Also, the use of a device to exactly measure the push force could have been more useful.

CHAPTER 3

EXPERIMENTAL METHODS

3.1 Participants

Ten volunteers, with no pre-existing musculoskeletal disorders, were randomly selected by posting fliers on bulletin boards in NJIT campus buildings. Demographics of the participants are provided in Table 3.1. The participants' height ranged from 170 cm to 185 cm with a mean of 177.8 cm, body weight ranging from 134 lb to 211 lb with a mean of 171.0 lb and age ranged from 18 to 56, with a mean of 26.5 years.

Table 3.1 Anthropometric and demographic data of participants

Demographic Data			
Sub #	**Height (cm)**	**Weight (lb)**	**Age (years)**
1	170	160	32
2	177	202	22
3	183	200	56
4	175	149	18
5	183	147.18	25
6	183	210.98	32
7	170	151.8	19
8	170	170	22
9	180	134.2	18
10	185	185.46	21
Average	**177.8**	**171**	**26.5**
St Dev	**5.99**	**26.89**	**11.57**

3.2 Electromyography (EMG)

The experiment was done in NJIT's Safety Lab. EMG activity of the four shoulder muscles was monitored using type SX230 bipolar differential surface electrodes, manufactured by Biometrics Ltd. These electrodes were adhered to the participant's skin with Biometrics Ltd medical grade adhesive tape. The design of these electrodes includes a pre-amplifier. The area of the skin, where an electrode was to be attached, was first cleaned and abraded and then an electrode conductive gel was applied. EMG was measured for right side of each subject. EMG activity was transmitted through an 8-channel remote patient data acquisition unit, which was attached to subjects' belts. This acquisition unit was connected to a DLK800 Base unit. The Base unit was connected to the PC, which processes data using Biometrics Datalink Pc Software Version 2.0 as well as stored it. The EMG hardwire configuration is illustrated in Figure 3.1. EMG was recorded at a rate of 1000 Hz for the entire experimental procedure.

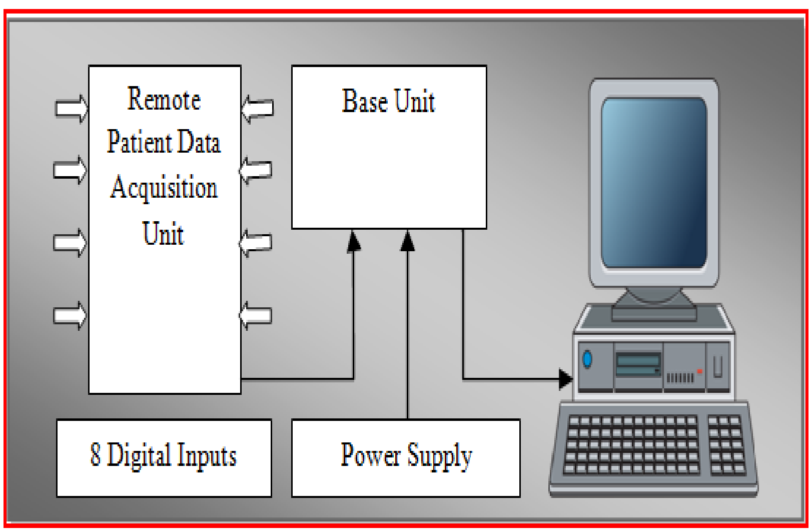

Figure 3.1 Biometrics Datalink hardware system configuration.

3.3 Experimental Design

A plastic handle was attached to the strain gage to simulate the sonography probe, as shown in the Figure 3.2. The strain gage was connected to the Biometrics Data Acquisition Unit. Calibration of the strain gage was performed prior to experiment for zero, 5, 10, and 15 pounds. The instrument was reset, using the Biometrics Software, at no load to get a zero calibration. Load calibrations were achieved by putting three metal plates of known weights, 5 pound each, onto the strain gage.

Figure 3.2 Strain gage with installed handle to simulate sonography probe.

A repeated measures experimental design was adopted for this study. All participants were exposed to the same experimental conditions in randomized order. The three independent variables were arm reach, arm rotation and downward push force. The dependant variable observed was surface EMG of middle trapezius, suprascapular fossa, anterior triceps, and pectoralis major muscles. The suprascapular fossa reflected the activity of the supraspinatus and upper trapezius muscles and it

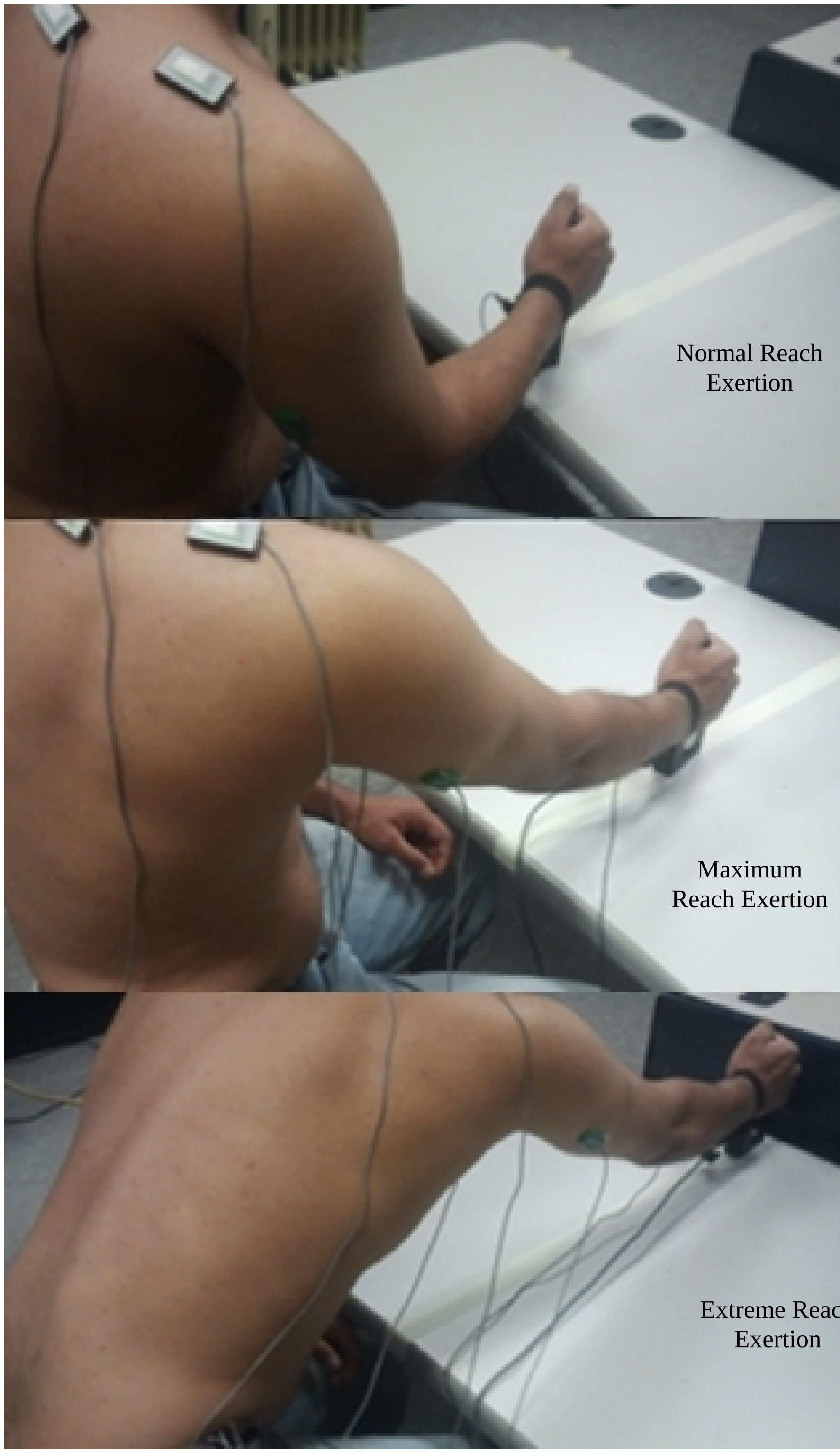

Figure 3.3 Illustration of normal, maximum and extreme reach positions.

was used as a proxy for evaluating the muscular activity of the rotator cuff (Murphey and Milkowski 2006).

The three reach lengths were adopted as described by Sengupta and Das (2004) as a) the normal reach on a work surface, which was attained by the sweep of the forearm, while the upper arm and torso are kept close to vertical, b) the maximum reach on the work surface, which was attained by the movement of extended arm with a vertical torso, and c) the extreme reach, that is the farthest possible distance from where the task could be performed; i.e. torso can be bent while the arm was extended. Figure 3.3 illustrate the three arm reaches. Arm rotation angles were selected as -45^{o} internal rotation, neutral, and 45^{o} external rotation as selected by Brookham *et al*. (2010).

3.4 Electrode Placement

The electrode placement for middle trapezius, suprascapular fossa, triceps and pectoralis major muscles are illustrated in Figure 3.4 and the placement sites were according to the recommendations from Village and Trask (2007), and Cram & Kasman (1998).

For the middle trapezius muscle, the electrode was placed 2 cm laterally from the mid-point of a line from the spinous process of C7 to the acromion process of the scapula. For the supraspinatus muscle the electrode was placed directly above the spine of the scapula, over the suprascapular fossa, after palpating the spine of the spacula, locating its lateral distal aspect. For the triceps muscles electrode was placed over the belly of the muscle. For the pectoralis major muscle, electrode was placed horizontally on the chest wall over the muscle mass that arises approximately 2 cm out from the auxiliary fold.

3.5 Experimental Procedure

Subjects were seated in an adjustable height office chair in front of an adjustable height table. The chair height was adjusted such that the knee angle remains 90^o and feet were touching the floor. The table height was adjusted for each participant so that table surface is up to seated elbow level.

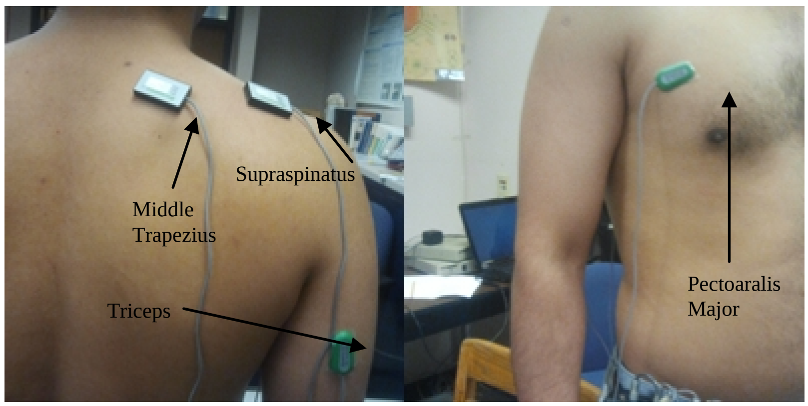

Figure 3.4 Electrode placement

A masking tape is attached on the floor underneath the chair to mark -45^o, neutral (or 0^o) and 45^o angles. The order of humeral rotation was randomly selected. At each of these humeral rotation, the subject extended his arm to normal, maximum and extreme reach condition (in randomized order), while holding the transducer and pressing it on the table at three levels of downward push force (Figure 3.3) for approximately 5 seconds. The three levels of push force were obtained by: a) placing the arm on the strain gage and recording the baseline reading from the weight of the hand and arm, b) a downward push force approximately equal to baseline reading plus 5 lbs, and c) a downward push force approximately equal to baseline reading plus 10 lbs. Henceforth, the above three force levels will be referred to as low, medium and high push force, respectively. The subject maintained the force levels from the real-time feedback on the force level in the computer screen and they practiced the trials prior to actual experiment. For each combination of rotation angle and reach trial, EMG and force data were collected digitally at 1000 Hz and stored in separate digital files for further analysis.

EMG data for maximal voluntary contractions (MVCs) were collected for each of four muscle groups. Calibration of the middle trapezius and supraspinatus was followed according to Village and Trask (2007). Each subject was asked to elevate their shoulder as hard as possible against a resistance provided manually by research assistant. Supraspinatus calibration was achieved by restricting the participant's wrist while the arm was laterally abducted at a 45^o angle, and asking the participant to abduct against the resistance with full effort. For the MVC of the pectoralis major, participants were asked to pull their arm medially with full effort and participants were asked to push the forearm downward, as hard as possible, to find out MVC of the triceps muscle.

3.6 Processing of EMG and Force Data

A typical EMG activity for trapezius muscle in millivolt (mv), superimposed by the push force recording is shown in the Figure 3.5. In this trial, the EMG amplitude increased as the level of push force was increased. EMG and force data were processed in the 'Datalog' PC software version 8.0, provided by Biometrics Ltd. For each force level, a representative window of 2-3 second was selected, and the average force level within the window represented the applied force. For the selected window, the individual muscle EMG data were first filtered by applying the RMS (Root Mean Square) filter with a time constant of 50ms, and then were averaged to obtain the respective muscle EMG activity. Similarly, the EMG data of maximum voluntary contraction (MVC) for each muscle was first applied with the RMS filter and then were averaged over a 2-3 seconds time window to obtain the maximum EMG. Finally, the magnitude of muscle activity was expressed in terms of percentage of Maximum Voluntary Contraction (% MVC), which was calculated by the equation, %MVC=(EMG/Maximum EMG) x 100.

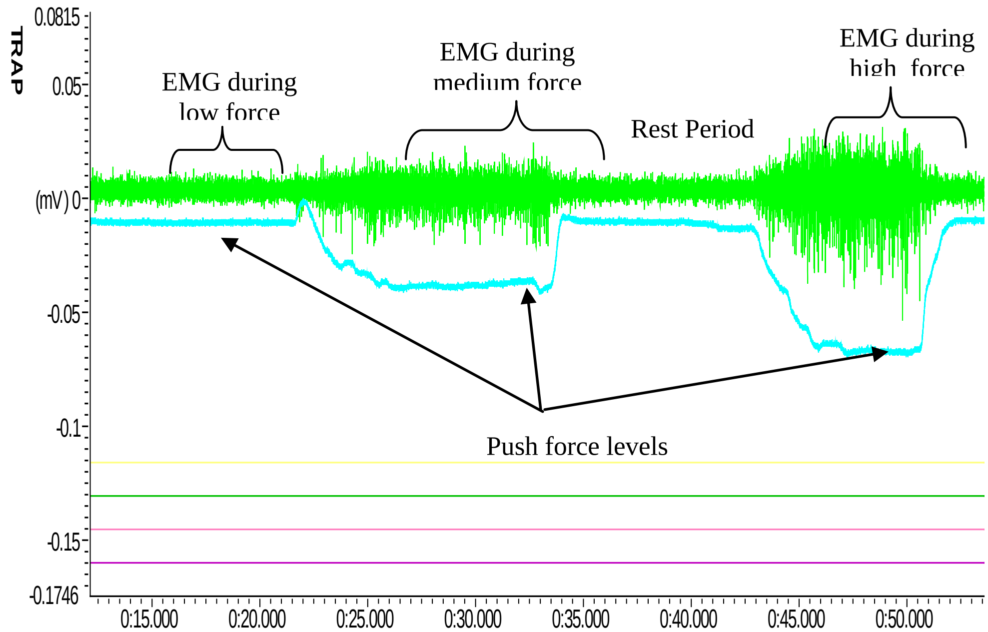

Figure 3.5 Typical EMG activity of trapezius muscle and push force in an experimental trial.

CHAPTER 4

RESULTS AND ANALYSIS

Statistical Analysis was performed using Minitab 15. A repeated measures two factorial analysis of Variance (ANOVA) was used, with the three independent variables being reach, arm rotation angle and downward push force. The details of ANOVA results can be found in Appendix B. Participants were used as blocks to determine the statistical significance effects at a p-value less than 0.05. Appendix C presents the mean muscle EMG's for three levels of force and reach.

4.1 Changes in Muscle Activity with Reach, Angle and Force

EMG Activity levels of all four muscles i.e. supraspinatus, trapezius, pectoralis major and triceps were found significantly different for various reaches and for different forces. Humeral rotation angle did not produce a significant effect in any other muscles, but for triceps. The interaction effects were found significantly different for force and reach for all four muscles.

The trapezius and supraspinatus muscle EMG activity increased as the force level went from medium to high, to low, and mean activity levels are shown in the Figure 4.1. The mean muscle EMG activity for triceps and perctoralis major increased as the force level went from low to medium, to high, and as shown in the Figure 4.1.

Significant effects ($p<0.05$) existed in mean muscle activation between three reaches for all four muscles being tested. The trapezius and supraspinatus muscle activation increased as the reach level went from maximum to extreme and as reach level varied from normal to extreme (Figure 4.2). EMG for the triceps and pectoralis major increased as reach level went from normal to maximum, to extreme, and as shown in the Figure 4.2.

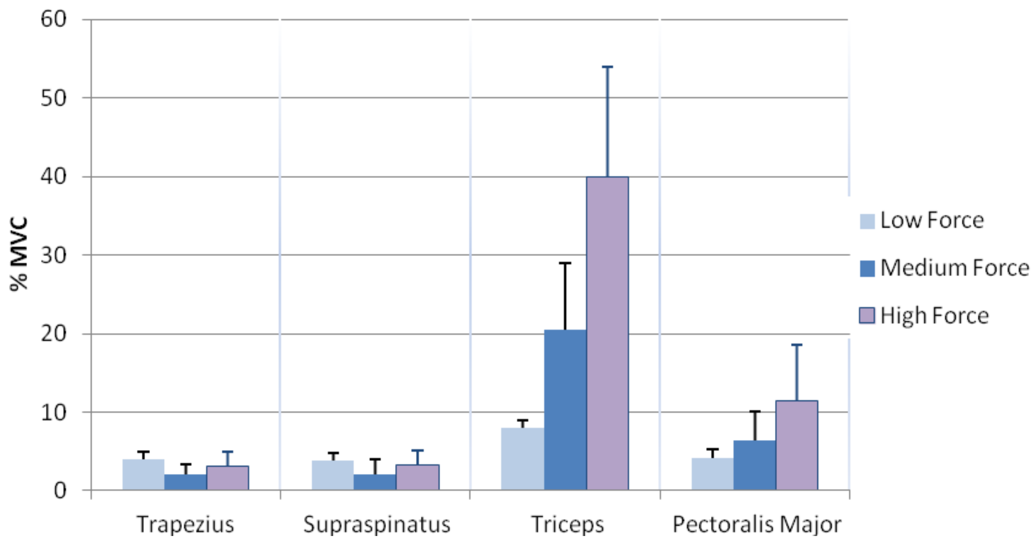

Figure 4.1 % MVC of the four muscles with varying force levels.

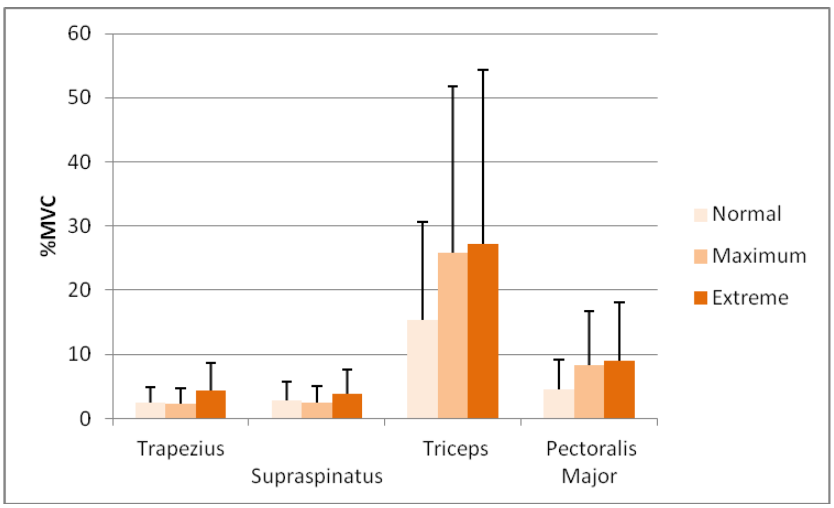

Figure 4.2 % MVC of the four muscles with varying reach levels.

Humeral rotation angle effect was not found statistically significant for any of the muscles except for triceps. External rotation (45^o) caused 2.6% of MVC increase as compared to internal rotation (-45^o) for the triceps EMG.

4.2 Discussion

The purpose of this study was to investigate the effect of arm reach, push force and humeral rotation angle on four muscle activation levels. One would think that with increasing force and the reach, muscle activations will increase proportionately. Similarly the muscle activations were thought to be affected by different humeral rotation angles, but statistically EMG activities with varying angle were not found to be significantly different for any of the shoulder muscles. Since the interaction effects for force and reach were found to be significant, the changes in muscle activity with the changes in force and reach levels are explained below.

4.2.1 EMG Activity Changes in Trapezius

Mean EMG Activity of the trapezius muscle was highest and at 6.71% of MVC at extreme reach and low force. It was lowest (1.89% of MVC) at medium level of force and maximum reach distance. For extreme reach, the mean level of activation was highest for a low force, for medium force its minimum and there was very small difference between medium and high force levels. For maximum reach, the mean level of activation was highest for high force and lowest for the medium force. For normal reach, the mean level of activation was highest for the medium force level, as shown in the Figure 4.3.

4.2.2 EMG Activity Changes in Supraspinatus

The mean activation of the supraspinatus muscle was highest and at 6.76% of MVC at extreme reach and low force. It was lowest (1.75% of MVC) at medium level of force and extreme reach distance. For extreme reach, the mean level of activation was highest for a low force, and for a medium force was minimum. For maximum reach, the mean level of activation was highest for a high force and lowest for a medium force, although there was very little difference between the mean muscle activation level for low and medium force levels. For normal reach, the mean level of activation had a similar trend as the varying push down force namely high, then low, and then medium, as shown in the Figure 4.4.

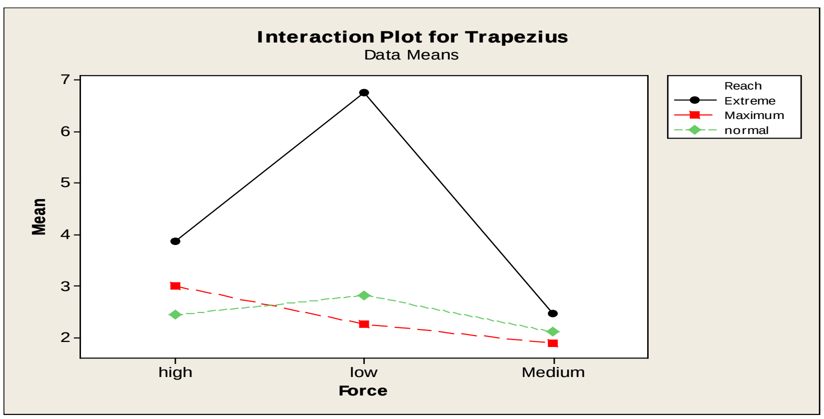

Figure 4.3 Mean muscle activity of trapezius for varying force and reach.

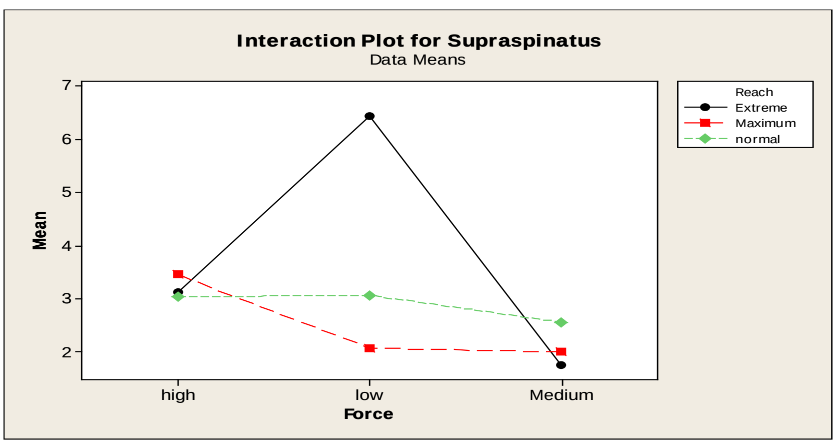

Figure 4.4 Mean muscle activity of supraspinatus for varying reach and force.

4.2.3 EMG Activity Changes in Triceps

The mean activation of the triceps muscles was highest and at 47.33% of MVC at extreme reach and high force level. It was lowest (4.42% of MVC) at low level of force and normal reach distance. For extreme reach, the mean level of activation was highest for a high force, and for a low force was minimum. For maximum reach, the mean level of activation was highest for a high force and lowest for the low force. For normal reach, the mean level of activation was highest for a high force, lower for a medium force and even lower for a low force level.

It should be noted that the low level force was just the weight of the hand and arm. The trend showed that the mean activation of the triceps muscle was also increasing with increasing reach, as shown in the Figure 4.5.

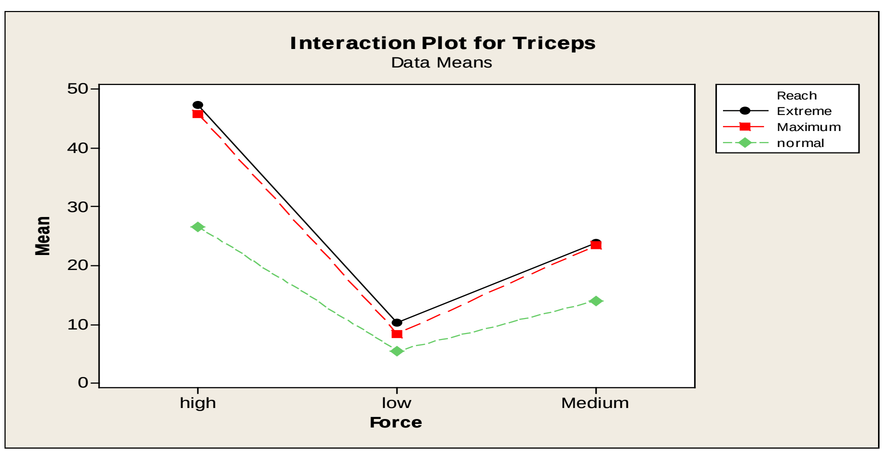

Figure 4.5 Mean muscle activity of triceps for varying reach and force.

4.2.4 EMG Activity Changes in Pectoralis Major

The pectoralis major behaved similarly as triceps muscle. Mean EMG activity of the pectoralis major muscle was highest and at 14.98% of MVC at extreme reach and high force. It was found to be lowest (3.72% of MVC) at a low level of force and a normal reach distance.

For extreme reach, the mean level of activation was highest for high force, and was minimum for a low force. For maximum reach, the mean level of activation was highest for a high force and lowest for the low force, as shown in the Figure 4.6. For normal reach, the mean level of activation behaved similarly as for varying push down force namely highest for high force then reduced for a medium force and reduced further for a low force.

This behavior of the pectoralis major and triceps confirms their function as the main muscles involved in flexing and pushing the arm downward respectively.

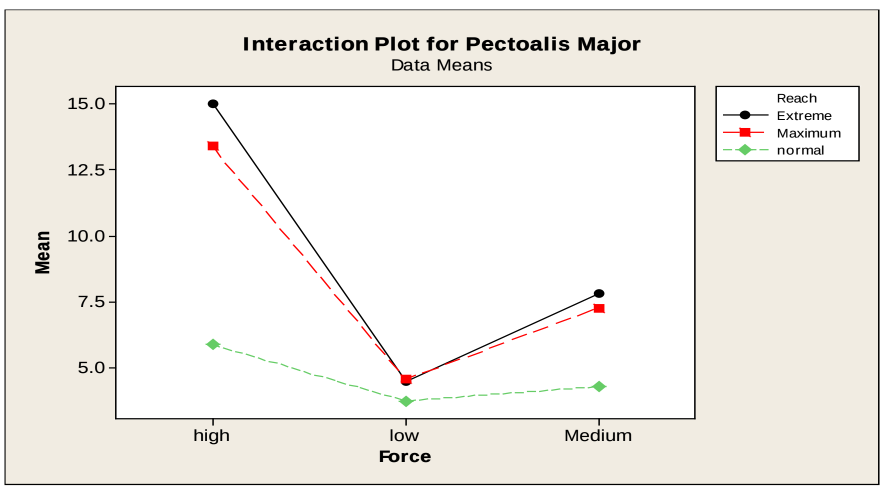

Figure 4.6 Mean muscle activity of pectoralis major for varying force and reach.

4.2.5 Implications of the results

The mean EMG activity of the trapezius and supraspinatus were highest at low push force and extreme reach. The high levels of muscle activation can be attributed to the higher lift force requirement from the shoulder muscles to support the extended arm

(Figure 1.1a). This is one of the reasons previous studies have suggest using of some kind of support in relieving the shoulder muscle strain (Murphy and Oliver 2011) .Ergonomic guidelines suggest that during sub-maximal hand exertion tasks, the shoulder muscle activation should be limited to 10%-14% of MVC for long lasting intermittent or dynamic work. The EMG activity of the trapezius and supraspinatus muscles for many of the experimental subjects were well above this limit, which may be risk factor for shoulder MSD. The muscle EMG activity for triceps muscles increased with the force increase from low to medium, to high. This result confirms the current understanding of the function of the triceps muscle that it is primarily involved when a downward push force is applied. The pectoralis major muscle increased similarly with increasing force and also contributed in applying a downward force.

The two pairs of muscles i.e. trapezius-supraspinatus and triceps-pectoralis major showed that muscle load shifts from the first pair to the second as the reach was increased and at extreme reach levels the former pair was most active. Ergonomists recommend as low an arm flexion as possible to avoid risky muscle activation levels. The Society of Diagnostic Medical Sonography (SDMS) recommends working under 30^{o} (Hill *et al*. 2007).

Results of this study imply that the arm reach should be kept within the normal reach boundary, or as closer to the body as possible in order to avoid risky levels of muscle activation. The study more specifically indicates that extreme reaches should be avoided where a low push force is required. In this combination of push force and reach distance should an arm support may be most effective.

These results of this study is consistent with those of previous studies. Previous researchers emphasized a straight body posture to avoid injuries. Vanderpool *et al*. (1993) reported that an upright posture correlated negatively with back pain symptoms, since a balanced posture causes the least stress at the spinal discs, joints, muscles, and ligaments. Similarly, Magnavita *et al*. (1999) concluded that the use of a chair and upright body position were apparently protective against neck and back pain (Burnett and Campbell-Kyureghyan 2010). Margaret *et al*. (2006) also suggested that sonographers could reduce stress on their shoulders by positioning themselves as close to clients as possible to reduce reach. They further suggested that reach can be reduced by moving to the other side of the client, rather than reaching across, or by re-positioning the client.

4.3 Limitations

The results of the experiment could have been more specifically related to sonographers if the experimental tasks were performed by actual professional sonographers with the actual set up as found in ultrasound rooms. But due to a limitation of resources this could not be done. Further studies may be performed on actual sonographers in a medical facility setting.

CHAPTER 5

CONCLUSIONS

Interaction effects between force and reach show that the scanning task performed at farthest reach with low push force requires the highest mean trapezius and supraspinatus muscle activity and hence are potentially more likely to cause or enhance injuries in shoulder muscles. The second highest mean EMG activity levels for these two muscles were generated during a maximum reach level and a high push force. This situation is more likely to occur while scanning obese patients. This is consistent with previous research where an increasing numbers of obese patients to be scanned was identified as an organizational risk factor. Scanning obese patients was also stated as one of the possible work-related risk factors that are commonly reported (Brown and Baker. 2004).

For medium force levels, the mean EMG activity was minimum because the hand weight counterbalanced the force required to push. EMG activity started to rise again for these muscles as the push force was increased from medium to high level. The study indicates that extreme reach postures should be avoided as much as possible, especially at low push force requirements, either with engineering, or with administrative controls. For example, the use of arm support may be beneficial for situations where it is likely to scan at higher reach distances and low push force requirements.

APPENDIX A

EMG DATA FOR ALL SUBJECTS

Serial #	Subject	Variables			% MVC			
		Angle	Reach	Force	Trapezius	Supraspinatus	Triceps	Pectoralis
1	1	-45	normal	low	1.7	1.1	2.1	5.1
2	2	-45	normal	low	1	2	0.5	2.1
3	3	-45	normal	low	5	3.5	3.9	4.7
4	4	-45	normal	low	0.6	0.5	5	2.2
5	5	-45	normal	low	5.6	1	6.3	2.5
6	6	-45	normal	low	1	1	11.4	5
7	7	-45	normal	low	3.6	2.5	3.9	5.8
8	8	-45	normal	low	1.3	1.5	11.9	8.6
9	9	-45	normal	low	10.5	14.2	3.2	2.2
10	10	-45	normal	low	0.6	1.1	5.6	3.2
11	1	0	normal	low	1.6	1.2	1.6	4.6
12	2	0	normal	low	1	2.4	0.4	1.7
13	3	0	normal	low	3.8	2.6	4.8	3.1
14	4	0	normal	low	0.9	0.6	4.9	2.2
15	5	0	normal	low	0.7	1.3	6.4	2.2
16	6	0	normal	low	1	0.9	10.6	4.5
17	7	0	normal	low	5	4.5	5	7.1
18	8	0	normal	low	1.8	1.6	12	7.6
19	9	0	normal	low	4.4	5.4	3.7	2.2
20	10	0	normal	low	2.5	2.4	5.2	2.3
21	1	45	normal	low	1.5	1.2	5.2	4.2
22	2	45	normal	low	1.6	5.6	0.9	2.5
23	3	45	normal	low	3.2	3	2.2	4
24	4	45	normal	low	4.8	4.7	5	3.2
25	5	45	normal	low	1.5	2.9	6.4	1.9
26	6	45	normal	low	1	0.9	10.2	3.5
27	7	45	normal	low	3	2.4	4.2	4.3
28	8	45	normal	low	1.6	1.2	11.2	4.9
29	9	45	normal	low	6.9	11	3.3	1.1
30	10	45	normal	low	5.9	7.7	5.6	3.1
31	1	-45	normal	mid	1.7	1.7	15.4	9.6
32	2	-45	normal	mid	1.4	3	9.3	3.5
33	3	-45	normal	mid	4.8	3.4	12.7	5
34	4	-45	normal	mid	1.1	1.3	8	2.1
35	5	-45	normal	mid	4.6	1.3	17.9	2.3

Serial #	Subject	Variables			% MVC			
		Angl	Reach	Force	Trapezi	Supras	Triceps	Pectorali
36	6	-45	normal	mid	1.2	1	23.5	5
37	7	-45	normal	mid	3.2	2	8.5	5.2
38	8	-45	normal	mid	2.5	2.7	20.4	8.5
39	9	-45	normal	mid	6	12	5.9	1.9
40	10	-45	normal	mid	0.7	1.3	10.9	3.1
41	1	0	normal	mid	1.7	1.7	14.2	4.9
42	2	0	normal	mid	1	3.5	9.1	4.3
43	3	0	normal	mid	4	2.7	13.7	3.8
44	4	0	normal	mid	1.5	0.9	8.6	2.3
45	5	0	normal	mid	0.7	1.8	26.1	2.7
46	6	0	normal	mid	1.3	1	23.4	5
47	7	0	normal	mid	3.4	1.2	10.7	6.9
48	8	0	normal	mid	2	1.9	25.1	7.9
49	9	0	normal	mid	2	3.7	9.6	1.7
50	10	0	normal	mid	1.2	1.6	11.1	2.3
51	1	45	normal	mid	1.7	1.4	18.5	6.3
52	2	45	normal	mid	1.2	13.3	3.7	3.7
53	3	45	normal	mid	3.1	2.4	8.7	4.4
54	4	45	normal	mid	1.5	1	8.1	3
55	5	45	normal	mid	1.4	1.1	16.1	2.7
56	6	45	normal	mid	1.5	1.1	22.6	4.7
57	7	45	normal	mid	2.2	1	17.3	5.7
58	8	45	normal	mid	2.1	1.7	22.3	5.2
59	9	45	normal	mid	0.9	1.5	5.8	1
60	10	45	normal	mid	1.6	2.4	11.2	3.1
61	1	-45	normal	high	2.1	2.6	26.2	21.9
62	2	-45	normal	high	1.8	6.4	21.5	4.1
63	3	-45	normal	high	4.8	3.6	21.5	6.5
64	4	-45	normal	high	2.5	4.1	15.8	2.5
65	5	-45	normal	high	2.3	2.1	24.3	3.5
66	6	-45	normal	high	1.9	1.6	36.4	6.4
67	7	-45	normal	high	2.8	3.7	22	6.2
68	8	-45	normal	high	3.7	3.7	35	8.3
69	9	-45	normal	high	1.9	7.5	19.8	2.1
70	10	-45	normal	high	1.1	2.2	19.9	3.5
71	1	0	normal	high	1.9	3	25.2	6.3
72	2	0	normal	high	1.2	4.4	17.2	6.4
73	3	0	normal	high	4.5	3.4	21	7.5
74	4	0	normal	high	2.8	2.1	19.1	2.6

Serial #	Subject	Variables			% MVC			
		Angl	Reach	Force	Trapezi	Supras	Triceps	Pectorali
75	5	0	normal	high	0.7	1.6	37.6	3.9
76	6	0	normal	high	2.3	1.6	35.5	6
77	7	0	normal	high	3.3	2.3	32.7	7.6
78	8	0	normal	high	3.1	2.8	41.8	8.2
79	9	0	normal	high	2.7	6.4	33.8	2.1
80	10	0	normal	high	1	1.8	25.5	2.5
81	1	45	normal	high	2	1.7	29.4	13
82	2	45	normal	high	1.2	3.4	17.2	4.1
83	3	45	normal	high	3.7	2.6	11.2	9.7
84	4	45	normal	high	2.9	2.1	17.8	3
85	5	45	normal	high	2	1.1	23.2	3.7
86	6	45	normal	high	2.3	1.6	33.6	5.3
87	7	45	normal	high	2.6	2.9	47	6.5
88	8	45	normal	high	5.1	3.2	39.4	6.8
89	9	45	normal	high	1.9	4.2	23.1	2.2
90	10	45	normal	high	1	1.3	24.4	3.1
91	1	-45	max	low	1.7	1.2	13.4	5.4
92	2	-45	max	low	1.1	2.5	3.9	2.7
93	3	-45	max	low	4	2.7	6.4	5.7
94	4	-45	max	low	0.7	0.6	5.3	5
95	5	-45	max	low	1.3	1	6.7	9.2
96	6	-45	max	low	1.1	1	20.3	5.6
97	7	-45	max	low	2.5	1.1	4.7	11.9
98	8	-45	max	low	1.7	1.4	11.4	9.5
99	9	-45	max	low	0.8	1.3	7.1	3.5
100	10	-45	max	low	0.7	1.3	6.1	3.4
101	1	0	max	low	1.7	1.2	7.2	4.4
102	2	0	max	low	1.1	3.4	5.6	2.1
103	3	0	max	low	5	3.2	4.1	3.4
104	4	0	max	low	0.7	0.6	6	2.8
105	5	0	max	low	1.4	1.2	7.2	2.2
106	6	0	max	low	1	0.9	15.9	4.7
107	7	0	max	low	3.8	1.7	4.8	5.8
108	8	0	max	low	1.5	1.5	11.9	8.9
109	9	0	max	low	9.6	6.5	5.1	2.2
110	10	0	max	low	0.6	1	6.8	2.8
111	1	45	max	low	1.6	1.2	14.1	4.2
112	2	45	max	low	1	4.5	4.6	2
113	3	45	max	low	2.7	2.2	4.9	4

Serial #	Subject	Variables			% MVC			
		Angl	Reach	Force	Trapezi	Supras	Triceps	Pectorali
114	4	45	max	low	0.7	0.5	5.6	2.5
115	5	45	max	low	1.7	1.6	6.7	2.4
116	6	45	max	low	1	1	22.3	4.5
117	7	45	max	low	2.6	0.9	4.2	4.8
118	8	45	max	low	4.3	4.2	13.4	5.7
119	9	45	max	low	4.8	4.2	7.7	1.5
120	10	45	max	low	5.3	6.4	7.2	3.2
121	1	-45	max	mid	2	1.5	21	11.9
122	2	-45	max	mid	1.2	5.5	21.2	16.8
123	3	-45	max	mid	4.2	3	24.6	13.2
124	4	-45	max	mid	1.5	0.8	18.9	4.5
125	5	-45	max	mid	1.6	1.1	33.2	6.3
126	6	-45	max	mid	1.9	1.3	41.2	6.9
127	7	-45	max	mid	2.5	1.2	22.2	7.5
128	8	-45	max	mid	1.9	1.8	24.6	9.6
129	9	-45	max	mid	0.9	1.8	15.1	2.2
130	10	-45	max	mid	0.8	1.2	11.1	4.8
131	1	0	max	mid	2	1.8	21.9	13.7
132	2	0	max	mid	1.1	3.9	21.8	7.2
133	3	0	max	mid	5.2	3.3	22	8.2
134	4	0	max	mid	1.4	1.8	32.2	3.6
135	5	0	max	mid	1.4	1.2	25	4.7
136	6	0	max	mid	1.4	1	30.9	7.1
137	7	0	max	mid	2.9	0.8	23	6.8
138	8	0	max	mid	2.4	1.7	23.6	10.2
139	9	0	max	mid	1.5	2.4	17.1	2
140	10	0	max	mid	0.8	1.1	13.1	4.6
141	1	45	max	mid	2.2	1.7	26.2	11.7
142	2	45	max	mid	1.1	8.3	24.2	7.4
143	3	45	max	mid	3	2.4	23.4	10.7
144	4	45	max	mid	1.7	1	28.2	4
145	5	45	max	mid	1.4	1	22.4	3.6
146	6	45	max	mid	1.9	1.2	33.1	5.6
147	7	45	max	mid	2.5	1.4	22.5	7.5
148	8	45	max	mid	2.3	1.5	29.2	7.4
149	9	45	max	mid	1.1	1.9	16.3	2.2
150	10	45	max	mid	0.9	1.3	13.9	5.6
151	1	-45	max	high	2.7	2.4	30.2	21.7
152	2	-45	max	high	1.6	10.8	45.2	33.8

Serial #	Subject	Variables			% MVC			
		Angl	Reach	Force	Trapezi	Supras	Triceps	Pectorali
153	3	-45	max	high	5.2	3.5	50.5	18.9
154	4	-45	max	high	3.2	3.6	49.1	7.2
155	5	-45	max	high	2.9	2.1	46.1	7.3
156	6	-45	max	high	3.2	2.1	53.2	10.7
157	7	-45	max	high	3.1	3.5	58.9	10.5
158	8	-45	max	high	5.8	4.9	40.9	17.7
159	9	-45	max	high	1.9	5	41.3	4.4
160	10	-45	max	high	1.5	2.1	24.9	15.7
161	1	0	max	high	3	2.8	38.4	24.1
162	2	0	max	high	1.6	7.4	39.6	22.4
163	3	0	max	high	5.5	4.3	47.1	20.1
164	4	0	max	high	3.2	3.6	41.8	7.8
165	5	0	max	high	2.5	1.6	56	12.5
166	6	0	max	high	2.6	1.7	50.7	12.2
167	7	0	max	high	3.2	2.6	46.3	8.8
168	8	0	max	high	4.1	2.8	46.1	14.3
169	9	0	max	high	1.9	4.2	42.5	4.7
170	10	0	max	high	1.5	1.7	29.3	9.8
171	1	45	max	high	4.1	2.7	51.4	19
172	2	45	max	high	1.6	8	53.8	17.3
173	3	45	max	high	3.7	2.8	41.7	21
174	4	45	max	high	2.9	2.3	43.4	6.7
175	5	45	max	high	1.9	1	56.5	5.4
176	6	45	max	high	3.1	1.5	56.5	9.4
177	7	45	max	high	3	3	67.6	9.3
178	8	45	max	high	6.4	4.3	56.9	15.9
179	9	45	max	high	1.9	3.8	39.3	4.8
180	10	45	max	high	1.3	1.4	29	8
181	1	-45	Ext	low	1.8	1.2	13.4	5.8
182	2	-45	Ext	low	1.2	2	6.8	2.3
183	3	-45	Ext	low	4	2.7	9.3	6.5
184	4	-45	Ext	low	9.3	6.9	5.4	2.2
185	5	-45	Ext	low	1.7	1.2	8.9	4.6
186	6	-45	Ext	low	1.3	1.1	20.6	6.4
187	7	-45	Ext	low	6.8	4.6	4.7	9.6
188	8	-45	Ext	low	4.5	4.3	11.2	7.2
189	9	-45	Ext	low	15.5	14.1	5.7	2.4
190	10	-45	Ext	low	1.3	1.4	8.9	3.9
191	1	0	Ext	low	1.6	1.2	10.8	4.9

Serial #	Subject	Variables			% MVC			
		Angl	Reach	Force	Trapezi	Supras	Triceps	Pectorali
192	2	0	Ext	low	3.3	4.1	4.6	2.1
193	3	0	Ext	low	3.8	2.9	13.1	6.3
194	4	0	Ext	low	7.8	7.9	5.6	2.2
195	5	0	Ext	low	9.9	3	10.1	2.4
196	6	0	Ext	low	1.3	1.2	19.7	5
197	7	0	Ext	low	21.8	18.9	5.9	6.7
198	8	0	Ext	low	10.7	11.2	11.6	8.2
199	9	0	Ext	low	11.3	12.2	6.5	1.7
200	10	0	Ext	low	0.8	1.1	9.4	3.3
201	1	45	Ext	low	1.5	1.2	17	5.8
202	2	45	Ext	low	7.6	5.5	5.7	2.3
203	3	45	Ext	low	3.6	2.6	16.4	5.7
204	4	45	Ext	low	12.8	19.7	5.2	2.3
205	5	45	Ext	low	9.5	7.7	11.4	1.9
206	6	45	Ext	low	1.2	1.1	24.5	4.1
207	7	45	Ext	low	9.6	10.8	4.3	6.9
208	8	45	Ext	low	8.7	8	14.2	5.7
209	9	45	Ext	low	13.8	18	8	1.5
210	10	45	Ext	low	14.8	15.1	9.8	3.6
211	1	-45	Ext	mid	2.1	1.7	24.5	9.9
212	2	-45	Ext	mid	1.4	2.8	19.7	14.2
213	3	-45	Ext	mid	5	3.1	23.3	11.3
214	4	-45	Ext	mid	2.3	0.8	14.1	3.4
215	5	-45	Ext	mid	3.6	1.2	27.1	5.1
216	6	-45	Ext	mid	2.1	1.3	27.1	6.5
217	7	-45	Ext	mid	2.9	0.9	20	8
218	8	-45	Ext	mid	3.1	1.5	9.9	9.7
219	9	-45	Ext	mid	1.4	1.8	12.6	1.9
220	10	-45	Ext	mid	1.7	1.5	16.2	5.8
221	1	0	Ext	mid	2	1.7	26.6	10.7
222	2	0	Ext	mid	1.2	2.6	18	7
223	3	0	Ext	mid	4.6	3.4	31.1	9.7
224	4	0	Ext	mid	2.5	0.9	20.3	3.5
225	5	0	Ext	mid	3.1	2	36.8	7.3
226	6	0	Ext	mid	1.8	1.2	24.3	5.6
227	7	0	Ext	mid	3.5	1.4	29.5	16.2
228	8	0	Ext	mid	3.6	1.7	34.4	9.1
229	9	0	Ext	mid	1.4	2.3	16.3	2.3
230	10	0	Ext	mid	0.9	1.1	21.5	5.2

Serial #	Subject	Variables			% MVC			
		Angl	Reach	Force	Trapezi	Supras	Triceps	Pectorali
231	1	45	Ext	mid	1.8	1.8	35.8	10.7
232	2	45	Ext	mid	1.1	3.3	16.6	13.8
233	3	45	Ext	mid	4.5	3.1	31.8	12.6
234	4	45	Ext	mid	1.6	0.7	10.8	4.7
235	5	45	Ext	mid	3.6	1.4	37	6.2
236	6	45	Ext	mid	2.2	1.2	38.7	5.8
237	7	45	Ext	mid	3.3	0.9	19.5	9.4
238	8	45	Ext	mid	3.7	2.3	39.3	11.2
239	9	45	Ext	mid	1.3	1.7	12.4	1.5
240	10	45	Ext	mid	0.9	1.3	21.8	6.1
241	1	-45	Ext	high	2.6	2.2	40.6	14.4
242	2	-45	Ext	high	1.9	7	48.5	22.7
243	3	-45	Ext	high	6.9	3.9	39.9	19.5
244	4	-45	Ext	high	3.3	2.8	52.2	6.6
245	5	-45	Ext	high	5.1	1.9	51.9	13.8
246	6	-45	Ext	high	3.9	2.2	36.8	8.6
247	7	-45	Ext	high	4.9	2.3	43.4	11.5
248	8	-45	Ext	high	6.1	4.4	59.2	16.3
249	9	-45	Ext	high	2.4	3.1	30.3	5.5
250	10	-45	Ext	high	2.3	1.6	35.7	9.8
251	1	0	Ext	high	2.2	2.1	42.7	14.7
252	2	0	Ext	high	1.7	4.7	46.4	23.6
253	3	0	Ext	high	6.1	4.1	54.8	18.5
254	4	0	Ext	high	2.9	1.7	55.4	6.8
255	5	0	Ext	high	4.5	2	63.8	23.6
256	6	0	Ext	high	3.4	1.9	34	9.4
257	7	0	Ext	high	3.7	2	60.1	29.3
258	8	0	Ext	high	7.1	4	65.6	13.7
259	9	0	Ext	high	2.4	4.2	35.5	11.1
260	10	0	Ext	high	1.5	1.4	34.1	10.1
261	1	45	Ext	high	2.5	3	46.1	12.9
262	2	45	Ext	high	1.7	7.7	47.6	28.1
263	3	45	Ext	high	5.5	3.4	40.2	20.4
264	4	45	Ext	high	2.4	1.1	36.1	11.4
265	5	45	Ext	high	3.7	1.5	56.9	19
266	6	45	Ext	high	4.2	2.8	57.1	17.3
267	7	45	Ext	high	3.5	1.9	69.6	19.1
268	8	45	Ext	high	13.9	8.9	73.9	17.4
269	9	45	Ext	high	2.5	2.7	29.4	5.8

Serial #	Subject	Variables			% MVC			
		Angl	Reach	Force	Trapezi	Supras	Triceps	Pectorali
270	10	45	Ext	high	1.2	1.4	32	8.6

APPENDIX B

MINITAB OUTPUT

General Linear Model: Supraspinatu, Trapezius, ... versus Subject, Angle, ...

Factor	Type	Levels	Values
Subject	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Angle	fixed	3	-45, 0, 45
Reach	fixed	3	Extreme, Maximum, normal
Force	fixed	3	high, low, Medium

Analysis of Variance for Supraspinatus, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject	9	502.773	502.773	55.864	9.79	0.000
Angle	2	23.863	23.863	11.931	2.09	0.126
Reach	2	76.085	76.085	38.042	6.66	0.002
Force	2	141.261	141.261	70.630	12.37	0.000
Angle*Reach	4	36.917	36.917	9.229	1.62	0.171
Angle*Force	4	82.746	82.746	20.687	3.62	0.007
Reach*Force	4	250.525	250.525	62.631	10.97	0.000
Angle*Reach*Force	8	28.322	28.322	3.540	0.62	0.761
Error	234	1335.862	1335.862	5.709		
Total	269	2478.353				

S = 2.38931   R-Sq = 46.10%   R-Sq(adj) = 38.04%

Unusual Observations for Supraspinatus

Obs	Supraspinatus	Fit	SE Fit	Residual	St Resid	
21	1.2000	7.7022	0.8725	-6.5022	-2.92	R
35	10.8000	6.0581	0.8725	4.7419	2.13	R
48	5.5000	11.0281	0.8725	-5.5281	-2.49	R
49	13.3000	4.7481	0.8725	8.5519	3.84	R
75	2.6000	9.0207	0.8725	-6.4207	-2.89	R
102	19.7000	8.6800	0.8725	11.0200	4.95	R
156	1.1000	7.2652	0.8725	-6.1652	-2.77	R
174	18.9000	6.3689	0.8725	12.5311	5.63	R
201	11.2000	6.6763	0.8725	4.5237	2.03	R
216	8.9000	3.7463	0.8725	5.1537	2.32	R
217	14.2000	5.6056	0.8725	8.5944	3.86	R
219	14.1000	6.7156	0.8725	7.3844	3.32	R
220	12.0000	5.7356	0.8725	6.2644	2.82	R
235	18.0000	11.7356	0.8725	6.2644	2.82	R
255	1.1000	5.7319	0.8725	-4.6319	-2.08	R
264	15.1000	8.3319	0.8725	6.7681	3.04	R

R denotes an observation with a large standardized residual.

Analysis of Variance for Trapezius, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P

Subject	9	312.112	312.112	34.679	7.24	0.000
Angle	2	6.662	6.662	3.331	0.70	0.500
Reach	2	227.858	227.858	113.929	23.79	0.000
Force	2	144.162	144.162	72.081	15.05	0.000
Angle*Reach	4	22.269	22.269	5.567	1.16	0.328
Angle*Force	4	32.619	32.619	8.155	1.70	0.150
Reach*Force	4	169.682	169.682	42.420	8.86	0.000
Angle*Reach*Force	8	25.423	25.423	3.178	0.66	0.723
Error	234	1120.520	1120.520	4.789		
Total	269	2061.306				

S = 2.18827   R-Sq = 45.64%   R-Sq(adj) = 37.51%

Unusual Observations for Trapezius

Obs	Trapezius	Fit	SE Fit	Residual	St Resid	
12	1.6000	6.1989	0.7990	-4.5989	-2.26	R
21	1.5000	7.2789	0.7990	-5.7789	-2.84	R
66	3.8000	8.5841	0.7990	-4.7841	-2.35	R
75	3.6000	9.6641	0.7990	-6.0641	-2.98	R
84	9.3000	4.6163	0.7990	4.6837	2.30	R
102	12.8000	8.1863	0.7990	4.6137	2.26	R
147	1.3000	6.0915	0.7990	-4.7915	-2.35	R
156	1.2000	7.1715	0.7990	-5.9715	-2.93	R
174	21.8000	8.4285	0.7990	13.3715	6.56	R
216	13.9000	5.3011	0.7990	8.5989	4.22	R
217	10.5000	4.2293	0.7990	6.2707	3.08	R
219	15.5000	5.8793	0.7990	9.6207	4.72	R
227	9.6000	3.7793	0.7990	5.8207	2.86	R
235	13.8000	9.4493	0.7990	4.3507	2.14	R
255	0.8000	6.1767	0.7990	-5.3767	-2.64	R
264	14.8000	7.2567	0.7990	7.5433	3.70	R

R denotes an observation with a large standardized residual.

Analysis of Variance for Triceps, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject	9	5878.2	5878.2	653.1	16.85	0.000
Angle	2	328.2	328.2	164.1	4.23	0.016
Reach	2	7597.3	7597.3	3798.6	98.01	0.000
Force	2	46518.4	46518.4	23259.2	600.13	0.000
Angle*Reach	4	265.7	265.7	66.4	1.71	0.148
Angle*Force	4	140.4	140.4	35.1	0.91	0.461
Reach*Force	4	2662.2	2662.2	665.6	17.17	0.000
Angle*Reach*Force	8	141.5	141.5	17.7	0.46	0.886
Error	234	9069.1	9069.1	38.8		
Total	269	72601.0				

S = 6.22551   R-Sq = 87.51%   R-Sq(adj) = 85.64%

Unusual Observations for Triceps

Obs	Triceps	Fit	SE Fit	Residual	St Resid	
8	30.2000	44.1726	2.2732	-13.9726	-2.41	R
79	11.2000	25.4837	2.2732	-14.2837	-2.46	R
95	32.2000	19.8248	2.2732	12.3752	2.14	R
105	10.8000	23.1348	2.2732	-12.3348	-2.13	R

144	36.8000	51.2148	2.2732	-14.4148	-2.49 R
153	34.0000	56.6048	2.2732	-22.6048	-3.90 R
170	58.9000	45.7800	2.2732	13.1200	2.26 R
187	47.0000	28.3800	2.2732	18.6200	3.21 R
188	67.6000	51.3600	2.2732	16.2400	2.80 R
189	69.6000	50.6400	2.2732	18.9600	3.27 R
195	9.9000	26.1593	2.2732	-16.2593	-2.81 R
216	73.9000	55.5993	2.2732	18.3007	3.16 R
243	29.4000	43.0067	2.2732	-13.6067	-2.35 R
251	24.9000	37.9170	2.2732	-13.0170	-2.25 R
269	29.0000	43.4970	2.2732	-14.4970	-2.50 R

R denotes an observation with a large standardized residual.

Analysis of Variance for Pectoalis Major, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject	9	1807.73	1807.73	200.86	19.05	0.000
Angle	2	29.74	29.74	14.87	1.41	0.246
Reach	2	1042.64	1042.64	521.32	49.45	0.000
Force	2	2427.39	2427.39	1213.69	115.12	0.000
Angle*Reach	4	94.80	94.80	23.70	2.25	0.065
Angle*Force	4	21.96	21.96	5.49	0.52	0.721
Reach*Force	4	615.10	615.10	153.78	14.59	0.000
Angle*Reach*Force	8	53.49	53.49	6.69	0.63	0.749
Error	234	2467.08	2467.08	10.54		
Total	269	8559.95				

S = 3.24701   R-Sq = 71.18%   R-Sq(adj) = 66.87%

Unusual Observations for Pectoalis Major

Obs	Pectoalis Major	Fit	SE Fit	Residual	St Resid
7	21.9000	9.5770	1.1856	12.3230	4.08 R
17	24.1000	16.7470	1.1856	7.3530	2.43 R
27	12.9000	19.0770	1.1856	-6.1770	-2.04 R
32	16.8000	10.6470	1.1856	6.1530	2.04 R
35	33.8000	17.0670	1.1856	16.7330	5.54 R
36	22.7000	15.1470	1.1856	7.5530	2.50 R
44	22.4000	15.9470	1.1856	6.4530	2.13 R
54	28.1000	18.2770	1.1856	9.8230	3.25 R
80	21.0000	14.1126	1.1856	6.8874	2.28 R
116	7.3000	13.4633	1.1856	-6.1633	-2.04 R
126	23.6000	14.7533	1.1856	8.8467	2.93 R
177	16.2000	9.3704	1.1856	6.8296	2.26 R
179	8.8000	15.3804	1.1856	-6.5804	-2.18 R
180	29.3000	17.7904	1.1856	11.5096	3.81 R

R denotes an observation with a large standardized residual.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Supraspinatus
All Pairwise Comparisons among Levels of Angle
Angle = -45 subtracted from:

```
Angle    Lower    Center   Upper   --+---------+---------+---------+----
  0    -0.8534  -0.01222  0.8290   (-----------*-----------)
 45    -0.2168   0.62444  1.4656            (-----------*-----------)
```

```
                                 --+---------+---------+---------+----
                                 -0.70      0.00      0.70      1.40


Angle =   0  subtracted from:

Angle    Lower  Center  Upper   --+---------+---------+---------+----
 45    -0.2045  0.6367  1.478            (-----------*-----------)
                                --+---------+---------+---------+----
                               -0.70      0.00      0.70      1.40


Tukey Simultaneous Tests
Response Variable Supraspinatus
All Pairwise Comparisons among Levels of Angle
Angle = -45  subtracted from:

       Difference       SE of            Adjusted
Angle    of Means  Difference   T-Value   P-Value
  0      -0.01222      0.3562  -0.03431    0.9994
 45       0.62444      0.3562   1.75318    0.1879


Angle =   0  subtracted from:

       Difference       SE of           Adjusted
Angle    of Means  Difference  T-Value   P-Value
 45        0.6367      0.3562    1.787    0.1760


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Supraspinatus
All Pairwise Comparisons among Levels of Reach
Reach = Extreme  subtracted from:

Reach      Lower  Center    Upper    -+---------+---------+---------+-----
Maximum  -2.108  -1.267  -0.4255    (-------*--------)
normal   -1.729  -0.888  -0.0466        (-------*--------)
                                     -+---------+---------+---------+-----
                                   -2.0      -1.0       0.0       1.0


Reach = Maximum  subtracted from:

Reach      Lower  Center  Upper    -+---------+---------+---------+-----
normal  -0.4623  0.3789  1.220                   (--------*-------)
                                   -+---------+---------+---------+-----
                                 -2.0      -1.0       0.0       1.0


Tukey Simultaneous Tests
Response Variable Supraspinatus
All Pairwise Comparisons among Levels of Reach
Reach = Extreme  subtracted from:

         Difference       SE of            Adjusted
Reach      of Means  Difference  T-Value   P-Value
Maximum      -1.267      0.3562   -3.556    0.0013
normal       -0.888      0.3562   -2.493    0.0356


Reach = Maximum  subtracted from:
```

```
        Difference       SE of            Adjusted
Reach     of Means  Difference  T-Value   P-Value
normal      0.3789      0.3562    1.064    0.5375


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Supraspinatus
All Pairwise Comparisons among Levels of Force
Force = high  subtracted from:

Force    Lower  Center    Upper   --+---------+---------+---------+----
low     -0.192   0.649   1.4901                        (------*------)
Medium  -1.945  -1.103  -0.2621         (------*------)
                                  --+---------+---------+---------+----
                                 -2.4      -1.2       0.0       1.2


Force = low  subtracted from:

Force    Lower  Center    Upper   --+---------+---------+---------+----
Medium  -2.593  -1.752  -0.9110   (------*------)
                                  --+---------+---------+---------+----
                                 -2.4      -1.2       0.0       1.2


Tukey Simultaneous Tests
Response Variable Supraspinatus
All Pairwise Comparisons among Levels of Force
Force = high  subtracted from:

        Difference       SE of            Adjusted
Force     of Means  Difference  T-Value   P-Value
low          0.649      0.3562    1.822    0.1647
Medium      -1.103      0.3562   -3.098    0.0062


Force = low  subtracted from:

        Difference       SE of            Adjusted
Force     of Means  Difference  T-Value   P-Value
Medium      -1.752      0.3562   -4.920    0.0000


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Trapezius
All Pairwise Comparisons among Levels of Angle
Angle = -45  subtracted from:

Angle    Lower  Center   Upper  ---+---------+---------+---------+---
  0    -0.6326  0.1378  0.9082  (---------------*--------------)
 45    -0.3904  0.3800  1.1504       (---------------*--------------)
                                ---+---------+---------+---------+---
                                -0.50      0.00      0.50      1.00


Angle =   0  subtracted from:

Angle    Lower  Center  Upper  ---+---------+---------+---------+---
 45    -0.5282  0.2422  1.013    (---------------*--------------)
                               ---+---------+---------+---------+---
                               -0.50      0.00      0.50      1.00
```

```
Tukey Simultaneous Tests
Response Variable Trapezius
All Pairwise Comparisons among Levels of Angle
Angle = -45  subtracted from:

       Difference       SE of           Adjusted
Angle    of Means  Difference  T-Value   P-Value
  0        0.1378      0.3262   0.4224    0.9064
 45        0.3800      0.3262   1.1649    0.4754


Angle =   0  subtracted from:

       Difference       SE of           Adjusted
Angle    of Means  Difference  T-Value   P-Value
 45        0.2422      0.3262   0.7425    0.7384


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Trapezius
All Pairwise Comparisons among Levels of Reach
Reach = Extreme  subtracted from:

Reach      Lower  Center   Upper  --------+---------+---------+--------
Maximum  -2.754  -1.983  -1.213  (-------*-------)
normal   -2.683  -1.912  -1.142   (-------*-------)
                                  --------+---------+---------+--------
                                       -2.0      -1.0       0.0


Reach = Maximum  subtracted from:

Reach      Lower   Center   Upper  --------+---------+---------+--------
normal  -0.6993  0.07111  0.8415                      (-------*------)
                                   --------+---------+---------+--------
                                        -2.0      -1.0       0.0


Tukey Simultaneous Tests
Response Variable Trapezius
All Pairwise Comparisons among Levels of Reach
Reach = Extreme  subtracted from:

         Difference       SE of           Adjusted
Reach      of Means  Difference  T-Value   P-Value
Maximum      -1.983      0.3262   -6.080    0.0000
normal       -1.912      0.3262   -5.862    0.0000


Reach = Maximum  subtracted from:

        Difference       SE of           Adjusted
Reach     of Means  Difference  T-Value   P-Value
normal     0.07111      0.3262   0.2180    0.9741


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Trapezius
All Pairwise Comparisons among Levels of Force
Force = high  subtracted from:

Force     Lower   Center    Upper    -+---------+---------+---------+-----
low      0.073   0.8433   1.6138                           (-----*-----)
```

```
Medium  -1.716  -0.9456  -0.1751           (-----*------)
                                    -+---------+---------+---------+-----
                                  -2.4      -1.2       0.0       1.2


Force = low  subtracted from:

Force    Lower  Center   Upper    -+---------+---------+---------+-----
Medium  -2.559  -1.789  -1.018    (-----*------)
                                  -+---------+---------+---------+-----
                                -2.4      -1.2       0.0       1.2


Tukey Simultaneous Tests
Response Variable Trapezius
All Pairwise Comparisons among Levels of Force
Force = high  subtracted from:

        Difference       SE of            Adjusted
Force     of Means  Difference  T-Value   P-Value
low         0.8433      0.3262    2.585    0.0278
Medium     -0.9456      0.3262   -2.899    0.0114


Force = low  subtracted from:

        Difference       SE of            Adjusted
Force     of Means  Difference  T-Value   P-Value
Medium      -1.789      0.3262   -5.484    0.0000


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Triceps
All Pairwise Comparisons among Levels of Angle
Angle = -45  subtracted from:

Angle    Lower  Center  Upper  -------+---------+---------+---------
  0    -0.2829   1.909  4.101        (----------*----------)
 45     0.4171   2.609  4.801           (----------*----------)
                               -------+---------+---------+---------
                                    0.0       2.0       4.0


Angle =   0  subtracted from:

Angle   Lower  Center  Upper  -------+---------+---------+---------
 45    -1.492  0.7000  2.892  (----------*---------)
                              -------+---------+---------+---------
                                   0.0       2.0       4.0

Tukey Simultaneous Tests
Response Variable Triceps
All Pairwise Comparisons among Levels of Angle
Angle = -45  subtracted from:

       Difference       SE of            Adjusted
Angle    of Means  Difference  T-Value   P-Value
  0         1.909      0.9280    2.057    0.1012
 45         2.609      0.9280    2.811    0.0148

Angle =   0  subtracted from:

       Difference       SE of            Adjusted
```

```
Angle    of Means  Difference  T-Value   P-Value
 45        0.7000      0.9280   0.7543    0.7313
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Triceps
All Pairwise Comparisons among Levels of Reach
Reach = Extreme  subtracted from:

Reach     Lower  Center   Upper  --------+---------+---------+--------
Maximum   -3.50   -1.31   0.885                     (---*----)
normal   -14.04  -11.85  -9.657  (---*----)
                                 --------+---------+---------+--------
                                     -10.0      -5.0       0.0
Reach = Maximum  subtracted from:

Reach    Lower  Center   Upper  --------+---------+---------+--------
normal  -12.73  -10.54  -8.350     (---*---)
                                --------+---------+---------+--------
                                    -10.0      -5.0       0.0

Tukey Simultaneous Tests
Response Variable Triceps
All Pairwise Comparisons among Levels of Reach
Reach = Extreme  subtracted from:

         Difference       SE of           Adjusted
Reach      of Means  Difference  T-Value   P-Value
Maximum       -1.31      0.9280    -1.41    0.3384
normal       -11.85      0.9280   -12.77    0.0000


Reach = Maximum  subtracted from:

        Difference       SE of           Adjusted
Reach     of Means  Difference  T-Value   P-Value
normal      -10.54      0.9280   -11.36    0.0000


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Triceps
All Pairwise Comparisons among Levels of Force
Force = high  subtracted from:

Force    Lower  Center   Upper  ---+---------+---------+---------+---
low     -34.08  -31.89  -29.70  (-*)
Medium  -21.68  -19.48  -17.29           (*)
                                ---+---------+---------+---------+---
                                 -30       -15         0        15


Force = low  subtracted from:

Force   Lower  Center  Upper  ---+---------+---------+---------+---
Medium  10.21   12.41  14.60                                (*-)
                              ---+---------+---------+---------+---
                               -30       -15         0        15


Tukey Simultaneous Tests
Response Variable Triceps
All Pairwise Comparisons among Levels of Force
Force = high  subtracted from:

        Difference       SE of           Adjusted
```

Force	of Means	Difference	T-Value	P-Value
low	-31.89	0.9280	-34.36	0.0000
Medium	-19.48	0.9280	-21.00	0.0000

Force = low subtracted from:

Force	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
Medium	12.41	0.9280	13.37	0.0000

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Pectoalis Major
All Pairwise Comparisons among Levels of Angle
Angle = -45 subtracted from:

```
Angle   Lower   Center   Upper  ----+---------+---------+---------+--
  0    -1.641  -0.4978  0.6454     (--------------*-------------)
 45    -1.949  -0.8056  0.3376  (-------------*-------------)
                                ----+---------+---------+---------+--
                                  -1.60     -0.80     -0.00      0.80
```

Angle =   0 subtracted from:

```
Angle   Lower   Center   Upper  ----+---------+---------+---------+--
 45    -1.451  -0.3078  0.8354        (-------------*-------------)
                                ----+---------+---------+---------+--
                                  -1.60     -0.80     -0.00      0.80
```

Tukey Simultaneous Tests
Response Variable Pectoalis Major
All Pairwise Comparisons among Levels of Angle
Angle = -45 subtracted from:

Angle	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
0	-0.4978	0.4840	-1.028	0.5597
45	-0.8056	0.4840	-1.664	0.2212

Angle =   0 subtracted from:

Angle	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
45	-0.3078	0.4840	-0.6359	0.8005

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Pectoalis Major
All Pairwise Comparisons among Levels of Reach
Reach = Extreme subtracted from:

```
Reach      Lower  Center   Upper  --------+---------+---------+--------
Maximum  -1.838  -0.694   0.449                      (-----*----)
normal   -5.615  -4.472  -3.329  (-----*----)
                                  --------+---------+---------+--------
                                       -4.0      -2.0       0.0
```

Reach = Maximum subtracted from:

```
Reach    Lower  Center   Upper  --------+---------+---------+--------
normal  -4.921  -3.778  -2.635     (-----*-----)
                                --------+---------+---------+--------
                                     -4.0      -2.0       0.0
```

Tukey Simultaneous Tests
Response Variable Pectoalis Major
All Pairwise Comparisons among Levels of Reach
Reach = Extreme subtracted from:

Reach	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
Maximum	-0.694	0.4840	-1.435	0.3248
normal	-4.472	0.4840	-9.239	0.0000

Reach = Maximum subtracted from:

Reach	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
normal	-3.778	0.4840	-7.805	0.0000

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Pectoalis Major
All Pairwise Comparisons among Levels of Force
Force = high subtracted from:

```
Force    Lower  Center   Upper  ----+---------+---------+---------+--
low     -8.313  -7.170  -6.027  (---*--)
Medium  -6.106  -4.963  -3.820         (--*--)
                                ----+---------+---------+---------+--
                                 -7.0      -3.5       0.0       3.5
```

Force = low subtracted from:

```
Force   Lower  Center  Upper  ----+---------+---------+---------+--
Medium  1.064   2.207  3.350                           (--*---)
                              ----+---------+---------+---------+--
                               -7.0      -3.5       0.0       3.5
```

Tukey Simultaneous Tests
Response Variable Pectoalis Major
All Pairwise Comparisons among Levels of Force
Force = high subtracted from:

Force	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
low	-7.170	0.4840	-14.81	0.0000
Medium	-4.963	0.4840	-10.25	0.0000

Force = low subtracted from:

Force	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
Medium	2.207	0.4840	4.559	0.0000

APPENDIX C

DESCRIPTIVE STATISTICS FOR MUSCLE EMG (%MVC)

Results for Force = high

Variable	Reach	Mean	StDev
Trapezius	Extreme	3.867	2.496
	Maximum	3.003	1.342
	normal	2.437	1.114
Supraspinatus	Extreme	3.130	1.902
	Maximum	3.450	2.127
	normal	3.033	1.565
Triceps	Extreme	47.33	12.27
	Maximum	45.81	9.78
	normal	26.60	8.75
Pectoalis Major	Extreme	14.98	6.48
	Maximum	13.38	7.07
	normal	5.850	3.981

Results for Force = low

Variable	Reach	Mean	StDev
Trapezius	Extreme	6.760	5.451
	Maximum	2.257	1.986
	normal	2.820	2.332
Supraspinatus	Extreme	6.43	5.92
	Maximum	2.067	1.634
	normal	3.063	3.133
Triceps	Extreme	10.290	5.208
	Maximum	8.353	4.809
	normal	5.420	3.386
Pectoalis Major	Extreme	4.450	2.206
	Maximum	4.533	2.509
	normal	3.720	1.832

Results for Force = Medium

Variable	Reach	Mean	StDev
Trapezius	Extreme	2.473	1.163
	Maximum	1.890	0.981
	normal	2.107	1.311
Supraspinatus	Extreme	1.753	0.778
	Maximum	1.997	1.563
	normal	2.553	2.864
Triceps	Extreme	23.90	8.76
	Maximum	23.44	6.59
	normal	13.95	6.39
Pectoalis Major	Extreme	7.813	3.779
	Maximum	7.250	3.650
	normal	4.260	2.086

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