

EFFECT OF OVERHEAD DRILLING SUPPORT ON MUSCULAR ACTIVITY OF SHOULDER

A Thesis

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Dedicated to my beloved parents: Mrs. Satyavani and Mr. Bapiraju

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ABSTRACT

This study examines the effect of an overhead drilling support and position of the arm on muscular activity of the shoulder. Five male participants simulated an overhead drilling task by using a drill in near, middle and far reach positions. Electromyographic measurements were taken from the dominant side anterior deltoid, bicep and trapezius muscles. Root mean square amplitude (RMS) of the EMG activity from these muscles was used to determine the load on the muscular system. The participants used a subjective rating scale to evaluate the overhead support stand and holding position.

The results demonstrate that the overhead support stand was effective in reducing the muscular load. The mean RMS value reduction with overhead support stand, when compared to the without support in bicep muscles during near, middle and far reach positions were 18%, 24 % and 47%, respectively. For anterior deltoid muscles the percentage decrease in mean RMS values for near, middle and far reach positions were 24%, 33% and 49%, respectively; and for trapezius muscles the percentage decrease in mean RMS values during near, middle and far reach positions were 32%, 33% and 42%, respectively.

The middle reach position, in contrast to near and far reach positions resulted in the lowest RMS values. The mean RMS values without support stand for biceps muscles was the lowest in middle position (0.139mv). Similarly the mean RMS values of anterior deltoid (0.231mv) and trapezius (0.066mv) muscles without overhead support stand were least for the middle position. The mean RMS values for the bicep (0.105 mv), anterior deltoid (0.155mv) and trapezius (0.041mv) muscles with overhead support stand were the lowest during the middle position. The subjective rating results also supported the above

conclusions. These findings indicate that workers performing overhead drilling tasks in coronal plane should work in middle position in order to reduce the muscular load.

CHAPTER 1

INTRODUCTION

Hand tools have been in use for a very long time and have developed in an evolutionary manner. It is believed that human beings prospered in 20th century because our ancestors took the time to develop the appropriate tools. These early tools, which were crude in design, helped our ancestors obtain food and protect themselves from predators. In fact, the economic and political stability of various civilizations depend directly on the sophistication of their hand tools (Chaffin *et al.*, 1999).

Specialized hand tools help users perform a wide variety of tasks. Any task can be performed in an efficient manner, if the hand tool decreases the effort of the worker. Over the years, research has been performed to understand the relationship between human capability, performance, and hand tool design. (Greenburg and Chaffin, 1997; Huston *et al.*, 1984; Johnson and Childress, 1988; Mital, 1986; Mital and Chennaveeriah, 1988; Pheasant and O'Neil, 1975; Radwin *et al.*, 1989; Tichauer and Gage, 1977; Ulin *et al.*, 1990). From the previous research it was observed that hand tools significantly affect productivity and the quality of products. At the same time, the use of hand tools may cause excessive biomechanical stresses, which may lead to degradation of performance, muscle fatigue, and musculoskeletal disorders thereby decreasing the efficiency of work (Chaffin *et al.*, 1999).

From the analysis of occupational risk factors like shoulder tendonitis, biceps tendonitis one can easily conclude that many risk factors are directly related to the design of hand tools and methods employed to use them (Armstrong and Silverstein, 1987).

Hence, inadequate tool design and improper use of a tool can increase or generate excessive biomechanical stress.

The introduction of powered hand tools has increased the productivity, but has also increased the risk of injuries due to higher speed, vibrations, and noise, large operating forces, increased weight of the tool, and unsatisfactory tool design. Working with hand tools requires forceful squeezing and turning which further mitigates the requirements to work efficiently. Unfortunately, some of the powered tools are quite heavy, especially when the weight includes the power cords. Heavy hand tools like drills, sanders and buffers weighing 5.1 kg (50N) along with the power cords is a common phenomena. To make matters worse, the effects of this additional weight is aggravated by additional muscle actions necessary to precisely position and stabilize a tool during its operation (Chaffin *et al.*, 1999).

In most of the construction trades, it is often necessary to work with arms in awkward postures such as overhead positions (NIOSH, 1997). Additionally, construction work may require using high forces during drilling tasks such as when sheet metal workers drill into concrete ceilings. There is strong evidence that the combination of two or more risk factors, such as force and awkward posture, increases the risk of work-related musculoskeletal disorders (NIOSH, 1997). When screw driving is performed with an elevated arm, tool weight together with the moment arm lengths will always be a significant factor in influencing the load in the shoulder muscles (Cederqvist and Lindberg, 1993). While much attention in manufacturing has focused on the hand grip force and shape of the tool, very little attention has been given to the role of weight of the

tool. The purpose of this research is to evaluate the effect of change in the weight of the powered hand tool in shoulder muscles during overhead work.

CHAPTER 2

LITERATURE REVIEW

2.1 Hand Tools

The history of hand tools is as old as the history of humankind. In fact, the invention of hand tools by our ancestors marked the beginning of the development of human civilization. Once invented, hand tools grew and evolved along with humans. Hand tools that are in use today can be classified into two general classes of hand tools: human powered (manual) and externally powered (powered). These powered tools may be powered electrically, pneumatically, by internally combustible engine, or by explosive charges (Aghazadeh and Mital, 1987).

Table 1: Hand tool Classification (Fraser, 1980)

Type	Example
Manually driven tools	
Percussive tools	Axe, hammer
Scraping tools	Saws, Files, Chisels, Planes
Drilling and boring tools	Awl, Gimlet, Borer, Drill
Screwdrivers and wrenches	
Holding tools	Tongs, Pliers, Pincers
Cutting tools	Knives, scissors, Shears,
Powered driven tools	
Electrically power tools	Power saws, Power drills, Screwdrivers, Electrical hammers
Compresses air tools	Percussive tools, rotator tools
Internal Combustion tools	Chain saws
Explosive drive tools	Bolt guns, Cutters, Splicers, Riveters

Most of the modern tools are designed primarily for performance, and not much attention is given toward the possible effects of the use of such tools on the user. The

result of ignoring ergonomics leads to substandard production of goods, high injuries and illnesses (Chaffin *et al.*, 1999).

Over the years research has been conducted to understand the relationship between human capability, performance and hand tool design, in order to ensure that hand tools are used more effectively, accurately, comfortably and safely. Attempts have also been made to develop ergonomic guidelines for designing new tools or redesigning the existing ones (Greenburg and Chaffin, 1997; Huston *et al.*, 1984; Johnson and Childress, 1988; Mital, 1986; Mital and Chennaveeriah, 1988; Pheasant and O'Neil, 1975; Radwin *et al.*, 1989; Tichauer and Gage, 1977; Ulin *et al.*, 1990). However, hand tools are still involved in many industrial accidents and injuries, which are costly, severe, and frequent. Due to the tool use the upper extremities are injured more frequently than any other part of the body (Aghazadeh and Mital, 1987).

A report in 2003 by National Safety Council estimated that 4.39% of all the compensatable work related injuries were caused by hand tools. The number and percentages of injury illness cases caused by tools is depicted in Table 2. The total number of cases was 68118 for non-powered hand tools and 18140 for powered hand tools. High number of injuries associated with the use of powered hand tools does not mean that non-powered hand tools are more hazardous to operate than powered hand tools. It is an indication that non-powered tools outnumber the powered hand tools. Even though the powered tools cause fewer injuries compared to that of non-powered hand tools, the severity of injuries caused by powered hand tools is greater.

Work related musculoskeletal disorders (WMSD's) or illness is another problem that results from using improperly designed hand tools.

Table 2: Number and Percentage distribution of cases (Aghazadeh and Mital, 1987)

HAND TOOL TYPE	TOTAL	PERCENT
Non-Powered hand tools		
Axe	517	0.8
Blow torch	187	0.3
Chisel	476	0.7
Crowbar	2047	3
File	143	0.2
Hammer	328	0.5
Hatchet	6838	10
Knife	94	0.1
Pick	373	0.5
Plane	31	0
Pliers, Tongs	676	1
Punch	92	0.1
Rope, Chain	2290	3.4
Saw	940	1.4
Scissors	1645	2.4
Screwdriver	1420	2.1
Shovel	3850	5.7
Hand tool, not powered, NEC	9927	14.6
Total	68118	100
Powered hand tools		
Grinder	1502	8.3
Buffer, etc	377	2.1
Chisel	38	0.2
Drill	3192	17.6
Hammer	1458	8
Ironer	9	0
Knife	272	1.5
Power activated tools	107	0.6
Riveter	178	1
Sandblaster	94	0.5
Screwdriver	248	1.4
Welding tools	763	4.2
Hand tools, powered, NEC	3814	21
Total	18140	100

NIOSH (1997) lists the following risk factors for work related musculoskeletal disorders as repetitive, forceful, or prolonged exertions of the hands; frequent or heavy

lifting, pushing, pulling, or carrying of heavy objects; prolonged awkward postures; and vibration. For the shoulder related musculoskeletal disorders, using epidemiological studies, it was found that the work related causality is due to posture and repetitions (Hammer and Price, 2001).

The human hand is designed in such a manner that it supports a variety of configurations and functions. Repeated manual exertions in daily work life cycle can cause a progressive deterioration of support tissues and muscles, resulting in discomfort, pain, and loss of function called cumulative trauma disorders to the musculoskeletal system (Chaffin *et al.*, 1999).

The literature related to this matter such as Armstrong *et al.*, (1982), Armstrong and Silverstein (1987), Kroemer (1992) and Hagberg *et al.*, (1995) list a variety of occupational risk factors associated with common hand and wrist disorders (Table 3). From observation of all occupational risk factors listed in Table 3, we can conclude that many risk factors are directly related to the design of hand tools and to the methods employed. Hence, improper use of tools, inadequate tools design, and improper selection of a tool can increase or generate excessive biomechanical stresses (Chaffin *et al.*, 1999).

2.2 Ergonomic Guidelines for Hand Tools

Workplace factors such as the worker's rate of production, shape of the tool, and the nature of work produce both external and internal biomechanical and physiological effects on the worker. Work postures are affected by the interaction between the shape of the tool and the location of work. These external risk factors can cause internal reactions within worker's upper limb such as deformation of tissues and nerve entrapment. Biomechanical stress on workers may also depend on their individual factors like body

Table 3: Some of the reported occupational risk factors for cumulative trauma disorders of the upper extremity (Armstrong and Silverstein, 1987 as cited in Chaffin, 1999)

Carpal tunnel syndrome	Hands held in fixed position over prolonged period, repeated exertions with flexed or hyper extended wrist, repetitive exertions or movements with low force, pressure at the base of the palm, vibration.
Ulnar nerve entrapment in Guyon's canal	Repetitive hand hammering, prolonged flexion and hyperextensions of the wrist, heavy lifting with palmer pressure.
Perineural fibrosis of digital nerves	Repeated minor trauma, grasping sharp objects in the hand.
Posterior interosseous nerve syndrome	Repetitive wrist extension.
Ulnar arterial thrombosis (hypothenar hammer syndrome)	Recurrent blunt trauma, vibration, push, twists hand hammering, repeated impact of catching.
Tenosynovitis, tendonitis, DeQuervain's syndrome, peritendinitis	Repetitive motion, especially in combination with ulnar deviation with fixed thumb, over usage during angular movements, repetitive movements of motion of hands and wrists, rapid finger flexion, unaccustomed repetitive work, repetitive work with thumb and finger, grasping and radial deviation.
Trigger finger	Excessive flexion and extension of digits against resistance, overuse of index finger with pistol airtool.
Gamekeeper's thumb	Thumb abduction-extension with force.
Degenerative joint disease	Pattern of usage at the joints with most use.
Cubital tunnel syndrome	Repeated or prolonged elbow flexion with wrist extension, repeated trauma or leaning elbow or workbench trauma, flexion and pressure.
Pronator teres syndrome	Repeated pronation, grasp, tight gripping, turning of tools, forceful pronation with finger flexion, forced pronation with finger flexion, forced pronation with elbow flexion.
Radial tunnel syndrome	Repeated rotatory movements, assembly of heavy fabric, repetitive wrist flexion with pronation or wrist extension with supination, repeated forceful movements.

size, their working capacity, and the way the person interacts with the tool (Chaffin *et al.*, 1999). The following section presents some of the guidelines for specific hand tool design.

1. Tool shape for avoiding Wrist deviation

There should be an alignment between hand and forearm during forceful grip exertions, which can be achieved by bent handle designs. Tichauer (1978) observed that many wiring operations required a worker to grip a plier with the wrist in a deviated posture, and concluded that wrist posture was dictated by both the layout of the work and the shape of the pliers. In his comparative study of two different types of pliers used by 80 employees, over 60% of those using the common straight handle pliers developed wrist related disorders at the end of 12 weeks, while only 10% of those using the new bent handle design experienced wrist related disorders. Figure 1 shows some of the bent handle designs. In a similar study Armstrong *et al.*, (1982) performed biomechanical job evaluations and found that in certain poultry processing work, a straight handled knife was used which required extreme wrist flexion and ulnar deviation. In such type of jobs, the rate of cumulative trauma disorders in the wrist and hand was about 17 out of 100 workers per year. A biomechanical job analysis resulted in the design of a knife with a pistol grip handle as shown in Figure 2. These studies also revealed that this kind of design would reduce the need to continually grip a slippery handle between cuts, since it was a wrap around design as shown in the Figure 2. By relaxing the hand between cuts, muscle fatigue is reduced. Such a handle design also protects hand slippage. For bent hammer design, Knowlton and Gilbert (1983) showed, however, that curve resulted in

less muscle fatigue. Later some studies (Konz, 1986) were done to evaluate the effect of different degrees of bent angle of the handle of the tools.

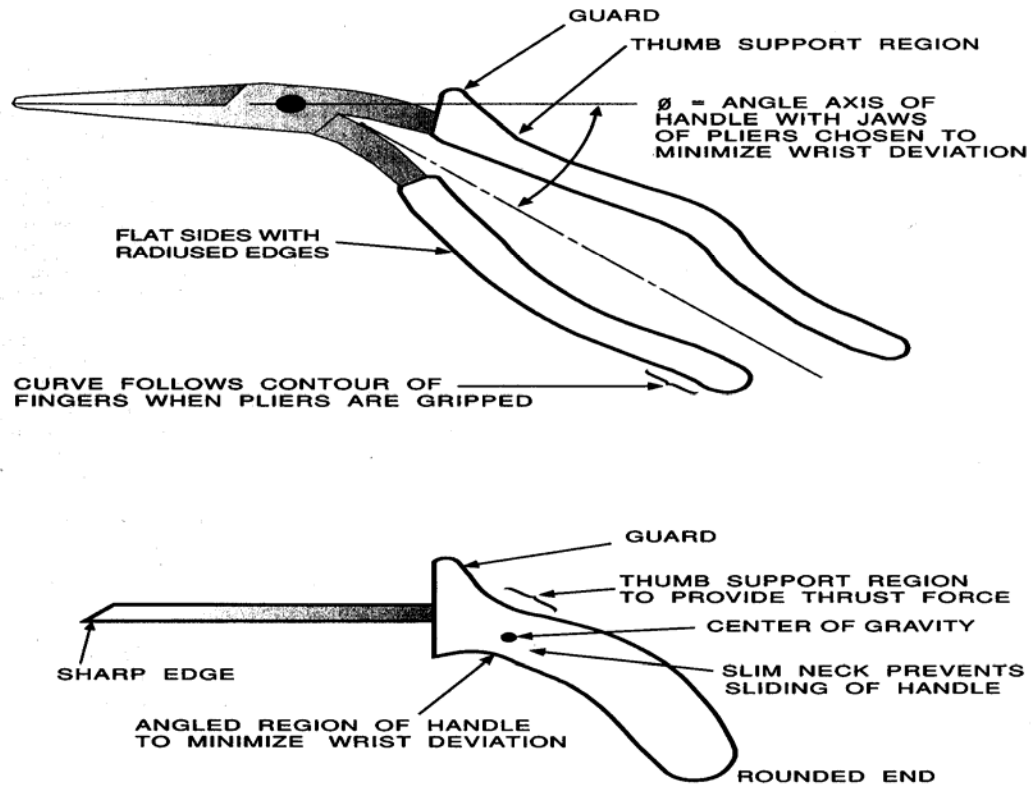


Figure 1: Bent handle designs proposed by Lewis and Narayan (1993), as cited in Chaffin (1999).

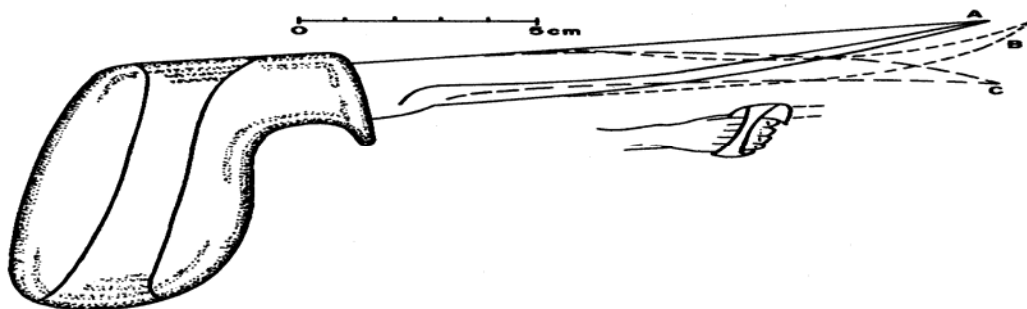


Figure 2: Knife handle with three blades for reducing wrist deviations (Armstrong *et al.*, 1982 as cited in Chaffin 1999).

2. Tool shape for avoiding Shoulder abduction

While working with any tool that requires an extreme wrist deviation, the worker will raise the arm to reduce the stress on the wrist. There is a trade-off between the stress on wrist and shoulder. Shoulder abduction, greater than 20° from vertical, increases the shoulder moment, especially when the worker is using a hand tool, because the tool and the extremity weight create considerable moment at the end of extremity. It was also observed that, if the shoulder abduction angle was about 30° , the time to reach a considerable fatigue was over three times longer than when the angle was 60° and six times longer than when the shoulder abduction was 90° (Chaffin *et al.*, 1999). Different handle angles were recommended for various job configurations. Figure 3 shows some of these designs.

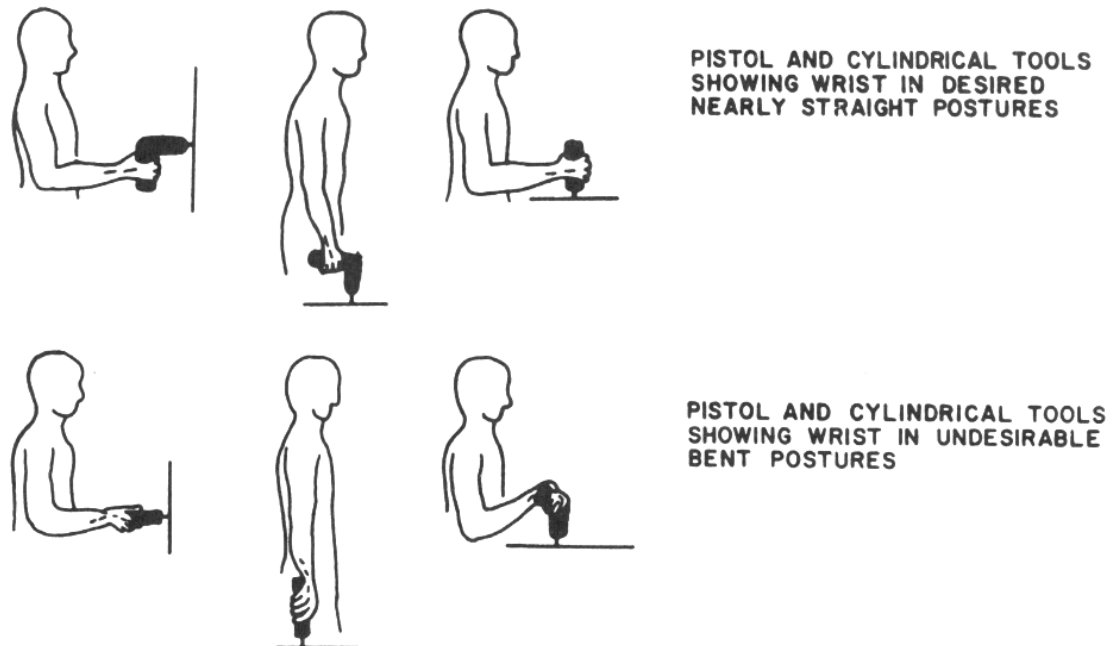


Figure 3: Handles for power drivers, based on the application (Armstrong, 1983 as cited in Chaffin 1999).

According to Eastman Kodak Company (1983), there are five major factors that can affect the health and performance of hand tool users: static loading of the arm and shoulder muscles resulting in fatigue and soreness; awkward hand position; pressure on the palm and fingers; vibration and noise exposure with power tool use; and pinch points with double –handled tools.

Tool weight is one of the primary concerns while selecting or designing a hand tool. The weight of the hand tool will determine the time it can be held (Ergonomic Design for people at work, Eastman Kodak Company, 1983). A tool such as hand drill or grinder that may have to be held away from the body in certain conditions should be counterbalanced in order to reduce the shoulder and arm fatigue. Tool balancers work by counterbalancing the weight of a tool with a long spring suspended over the work and attached to the tool. In general, any tool weighing more than 2.3 kg (5 lb) that requires arm support and has to be held in awkward postures may cause fatigue to the forearm and shoulder muscles. For some jobs, such as drilling concrete, heavier tools may be required to help in absorption of impact vibrations. Table 4 presents weights of some hand drills (Ergonomic Design for people at work, Eastman Kodak Company, 1983).

Table 4: Powered hand drills weights and trigger activation forces (adapted from Eastman Kodak Company, 1983)

Tool type	Weight	Trigger type	Grip	Average force
1/4 –in electric hand drill	2.3 kg (5 lb)	Index finger trigger	Pistol	17-22 N
3/8-in electric hand drill	4.3 kg (9.5lb)	Index finger trigger	Pistol	30 N
½-in electric hand drill	4.5 kg (10lb)	Index finger trigger	Pistol	52 N

2.3 Shoulder and Overhead Work

The shoulder joint is one of the most complex biomechanical structures of the human body. The arrangement of the glenohumeral joint provides a large amount of mobility and while providing such extreme mobility, intrinsic stability is sacrificed (Chaffin *et al.*, 1999). There are three main groups of muscles in the shoulder that help control arm movement. The trapezius, levator scapulae, rhomboid, and serratus anterior arise from the main skeletal and insert onto the scapula, helping to move and stabilize the structure. The rotator cuff muscles including the teres minor, infraspinatus, supraspinatus, and subscapularies arise from the scapula and insert onto the tuberculum, stabilizing the glenohumeral joint. The third group of muscles includes the primary movers of the upper arm: biceps, deltoid and triceps which arise from the clavicle and scapula, and insert onto the humerus (Winkel *et al.*, 1992).

The advancement in industrial technology resulted in the process of simplified work movements, but increased the movement of arms i.e. number of movements required per unit time has increased (Jonsson, 1982; Hagberg, 1981a). Specific risk factors that contribute to shoulder musculoskeletal disorders have been identified by Sommerich *et al.* (1993); they include awkward postures (abduction, arm extensions), static postures, and lack of sufficient rest. Wiker *et al.* (1989) found that hand held weights as light as 0.95kg could induce fatigue while performing a task requiring repetitive arm movement.

In the analysis of occupational health clinic patients for the diagnosis of non-traumatic MSD's, 68.8% of the patients stated that they worked with their hands primarily at or above shoulder level (Bjelle *et al.*, 1979). In construction trades, it is often

necessary to work with arms in awkward postures such as overhead positions. Rosecrance *et al.* (1996) reported that 41% of a sample of construction workers in the pipe trades complained of work related shoulder pain when tasks were performed in different postures including overhead posture. Awkward postures have been defined as shoulder elevation greater than 60°. For a shoulder, a relaxed neutral posture is the one in which the arm hangs straight down by the side of torso. As the arm is flexed, abducted or extended, the angle between the torso and upper arm increases (NIOSH, 1997). There is strong evidence that combination of two or more risk factors, such as force and awkward posture, increases the risk of work related musculoskeletal disorders (NIOSH, 1997). From the studies by Chaffin (1973) and Hagberg (1981a), it is concluded that sustained elevated arm work, especially if the arm is supporting a load, must be minimized to avoid shoulder muscle fatigue and the associated tendonitis problems.

Herberts *et al.* (1984) states that the overhead shoulder angles of equal to or greater than 45° requires substantial supraspinatus muscle activity; and deltoid muscle activity increases when the angle is between 45° and 90°. They also found that the deviation of upper arm from the vertical position increases the load on the upper trapezius muscles and infraspinatus muscle is very sensitive to a small increase in hand held weight when the arm is in an elevated position. Arm abduction in the coronal plane is accomplished by the deltoid muscle, with the assistance from the rotator cuff muscles (Quiring and Warfel, 1967; Perry, 1978). During abduction of the arm, its center of mass moves away from the shoulder joint, thus increasing the load moment arm (Chaffin *et al.*, 1999). Figure 4 shows the relative activity intensity of the deltoid muscle and rotator cuff muscles during abduction.

One essential requirement about arm work is that the hands should not have to reach frequently or be maintained above shoulder height for sustained period (Chaffin *et al.*, 1999). These kinds of jobs which require elevated arm activities have been shown to lead to “degenerative tendinitis” in the biceps muscles (Bjelle *et al.*, 1973). If the arm is held in an elevated posture (e.g., when the worker is welding overhead), shoulder muscle fatigue and biceps tendonitis may develop (Herberts *et al.*, 1980). Hagberg (1981b) observed that the upper part of the trapezius muscle rapidly fatigues when arms are held above 90° (shoulder height).

In a recent study by Cederquist *et al.* (1993), on influence of the overhead screw driving on EMG and maximum contraction force and perceived exertion in the shoulder, it was found that significant myoelectric signs of localized muscle fatigue occurred in the anterior deltoid muscles in the shoulder and the descending parts of trapezius muscles. Table 5 summarizes the epidemiological studies evaluating overhead work and shoulder related musculoskeletal disorders.

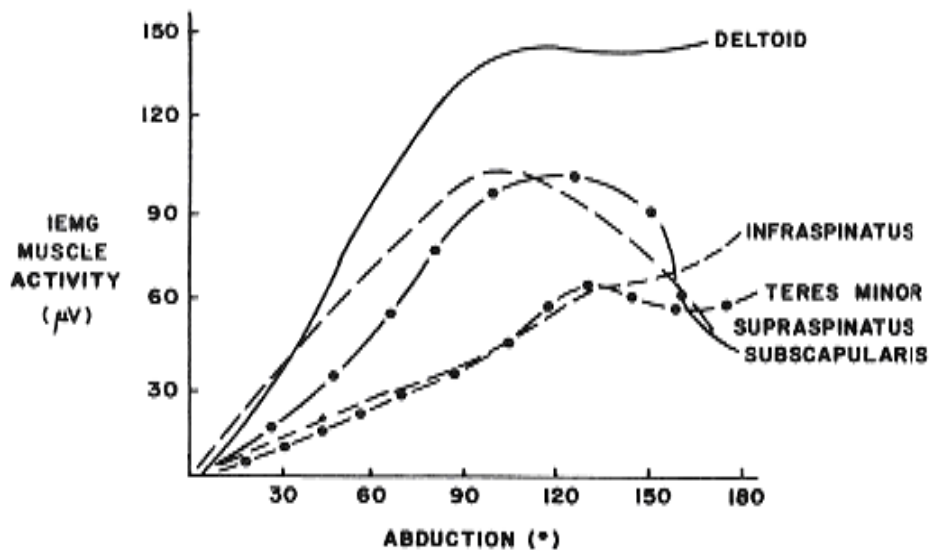


Figure 4: Relative intensity of the deltoid and rotatory cuff muscles during abduction, (Chaffin *et al.*, 1999).

Table 5: Some of the Epidemiological studies evaluating overhead work and shoulder related musculoskeletal disorders

Authors	Results/ Conclusions
Herberts <i>et al.</i> ,1984	The load on upper trapezius muscle increases when deviation is in upper arm from the vertical position. Deltoid muscle activity increases when the angle is between 45°-90°.
Quiring & Warfel,1967	Arm abduction in the coronal plane is accomplished by the deltoid muscle.
Bjelle <i>et al.</i> , 1973	Jobs that require elevated arm activities causes degenerative tendonitis in biceps.
Herberts <i>et al.</i> , 1980	Arms held in an elevated posture may cause shoulder fatigue and biceps tendonitis.
Hagberg, 1981	The upper part of trapezius muscle fatigues when held above 90°.
Huges & Ann, 1996	Arm flexion forward in the saggital plane is accomplished mainly anterior deltoid, biceps brachii.
Cederquist <i>et al.</i> , 1993	Significant fatigue occurs in overhead screw driving in anterior deltoid and trapezius muscle.

A summary of the previous research and Table 5 indicates that there is substantial effect on anterior deltoid, bicep and trapezius muscles while performing overhead works. In this study we consider these three muscles to evaluate a newly designed overhead supporting stand. The anterior deltoid muscle is chosen because it is a prime flexor of the shoulders (Kadefors *et al.*, 1976), and is known to contract synchronously with the supraspinatus during motion (Perry 1988), and biceps brachii is a humeral head stabilizer

during overhead postures and auxiliary shoulder flexor (Perry 1988, Rodosky *et al.*, 1994). According to Cederquist *et al.*, (1993), significant fatigue occurs in overhead screw driving in trapezius muscle.

2.4 Electromyography(EMG)

“Electromyography is an objective measurement technique used in biomechanics research to estimate the muscle fatigue by monitoring changes within muscles before deterioration of mechanical performance can be observed”(Merlette *et al.*, 1991; DeLuca, 1997). EMG signals are obtained as recordings of the sum of several motor unit potentials, or myoelectric signal, emitted from contracting muscles (Chaffin *et al.*, 1999). The readings provide data about number of firing units involved and the rate at which they fire for a particular movement (Sommerich *et al.*, 1993).

According to DeLuca. (1997), there are three main applications in biomechanics that dominate the use of the surface EMG signal: its use as an indicator for the initiation of muscle activation, its relationship to the force produced by a muscle, and its use as an index of the fatigue processes occurring within a muscle. In biomechanical studies the preliminary purpose of recording and processing the myoelectric signals is to predict the muscle tension. As there is increase in tension in muscle, there is an increase in myoelectric activity (Chaffin *et al.*, 1999).

EMG measurement techniques have been used extensively to estimate the relative magnitude and temporal relationships of various muscles during occupational activities as shown in Table 6. Sommerich *et al.*, (1993) cited several studies which used EMG technique to evaluate shoulder pain. Table 6 shows various studies related to shoulder

fatigue, EMG studies of occupational activities, and some EMG application in tool design.

Table 6: Some Examples of EMG studies

Authors	Muscles used, Activity type and Results
Tichauer <i>et al.</i> , 1972	Forearm and biceps muscles during forearm torsion at various elbow angles.
Tichauer, 1966	Hands and muscles during hand tool gripping.
Ortengren <i>et al.</i> , 1975	Shoulder and back muscles in assembly-line working.
Gander and Hutchins., 1985	Power spectral density of the surface myoelectric signal of the biceps brachii as a function of static load.
Hagberg, 1981	Exertion of descending parts of trapezius muscles during tasks involving repetitive shoulder flexion may promote discomfort and complaints referred to the neck.
Hammar skjold <i>et al.</i> , 1992	The upper trapezius and anterior deltoid RMS increased the most among all the subjects for all the tasks involving standardized nailing, sawing and screwing tasks.
Lewis and Narayan., 1993	Confirmed the advantages of using a bent handle design compared to the traditional straight handle design.
Ulin <i>et al.</i> , 1993	Showed that the shape of the hand tool used to drive screwdrivers into horizontal work piece depends on the height of the surface relative to the person's stature.

Many methods are used to reduce the data contained in the electrical signal and present it in the numerical form. The method chosen depends on the purpose of the study. The interpretation of the EMG signal plays an important part in determining the relationship of muscle activity to task performance. The basic information obtained in the myoelectric signal is

1. Whether or not the muscle is active.
2. The relative amount of activity of the muscle.

This information can be combined with an observation of some kind to determine when the muscle is active, when a peak activity occurs and whether muscle fatigue has occurred. Methods that are used to analyze the data are (DeLuca, 1997):

- **Root Mean Square:** The Root Mean Square (RMS) voltage is the effective value of the quantity of an alternating current. The true RMS value of a myoelectric signal measures the electrical power in the signal.
- **Integration:** The total amount of muscle activity occurring during any given interval is represented by the area under the curve during that time interval. The process for determining this area is called integration. Integrated electromyography (IMEG), evaluating the area under the curve, is a continuous evaluation of that area. The IEMG signal therefore increases as long as any myoelectric activity is present and decreases in slope, as there is less myoelectric activity.
- **Frequency analysis:** The myoelectric signal consists of a series of action potentials firing at certain frequencies. Frequency analysis decomposes the myoelectric signal into sinusoidal components of different frequencies.

The frequency analysis gives the energy distribution of the signal as a function of frequency.

- **Zero crossings:** The number of times the raw signal crosses the baseline appears to be related to muscle contraction force. Within limits as the muscle activity increases the frequency increases and this result in more number of zero crossings.
- **Spike countings:** The total number of spikes appearing on the oscilloscope appears to be related to the amount of muscle activity. The number of spikes increases linearly with increasing contraction force to about 70% of MVC and then levels off.
- **Turns:** The number of times the myoelectric signal changes direction also is related to the frequency of the raw signal. A turn is defined as that point where the direction of the signal changes following amplitude difference of more than 100mv. The number of turns increases rapidly as the muscle force at low levels increases but increases very slowly at high levels of muscle force.

The true RMS value of a myoelectric signal measures the electrical power in the signal. Hammerskjold *et al.* (1992) used a variety of performance measures to determine the effect of arm-shoulder fatigue on performance in experienced carpenters. They used the RMS amplitude to evaluate load on trapezius and anterior deltoid. In a similar study done by Dan *et al.* (2001) the effect of overhead drilling position on electromyography was studied using RMS of EMG activity. In this study the root mean square amplitude of

the EMG signal from the anterior deltoid, biceps brachii and trapezius muscles will be used to determine the muscular load.

2.5. Research Rationale

Work-related musculoskeletal disorders of the shoulder are common in the construction and manufacturing trades. The prevalence of disorders such as shoulder tendonitis has been reported to be as high as 30-40% of the work related musculoskeletal disorders (Holmstrom *et al.*, 1992; Olson 1987). Rosecrance *et al.*, (1996) reported that 41% of a sample of construction workers in the pipe trades complained of work related shoulder pain, with the tasks performed in differing postures including directly overhead.

In construction trades, it is often necessary to work with the arms in awkward postures such as overhead positions. Awkward postures have been defined as shoulder elevation greater than 60° (National Institute for Occupational Safety and health [NIOSH], 1997). Additionally, construction workers may be required to use high forces during drilling tasks such as, when sheet metal workers drill into concrete ceilings. There is strong evidence that combination of two or more risk factors, such as force and awkward posture, increase the risk of work-related musculoskeletal disorders (NIOSH, 1997). The working posture with the arm raised above the shoulder is regarded as one of the important causative factors in shoulder pain (Bjelle *et al.*, 1979; Herbert *et al.*, 1981; Herberts and Kadefors 1976; Torner *et al.*, 1991). Working overhead positions causes damage to the shoulder girdle. Mechanical impingement of the bicipital and supraspinatus tendons in the subcromial region may occur, especially if the shoulder elevation is in the 60° to 120° range or at the end range of motion (Flatow *et al.*, 1994).

Laboratory studies have shown that as the angle of the shoulder elevation increases; the load on shoulder becomes higher, and the load on shoulder muscles increases. (Giroux and Lamontagne, 1992; Jonsson and Hagberg, 1974; Sigholm *et al.*, 1984; Sporrang and Styf, 1999). Epidemiological evidence also suggests that work in posture greater than 60° elevations is associated with disorders of the shoulder (Hagberg and Wegman 1987). Bjelle *et al.*, (1981) reported that working with the hands above shoulder level increases workload and could lead to the development of shoulder disorders.

Previous research has shown that the jobs that require elevated arm activities lead to degenerative tendonitis in shoulder and bicep muscles (Bjelle *et al.*, 1973). Also few studies that have examined the effect of overhead positions on shoulder load. Hand tools that are used continuously at work heights with arm flexed or abducted above shoulder must be supported in order to reduce the load on the shoulder muscles. This can be done by counterbalancing the tool weight (Chaffin *et al.*, 1999). The ergonomic implications of the study done by Sighmol *et al.* (1984) revealed that work situations should be designed so that hand tool as well as hand load is minimized to reduce occurrence of musculoskeletal disorders.

Research has been done to determine the effect of overhead work on shoulders. Also few studies that have examined the effect of overhead positions on shoulder load (Dan *et al.*, 2001). But no research has been done to determine the effect of providing a support during overhead tasks. Hence the aim of the study is to evaluate the effect of overhead support stand on shoulder muscle, and determine the optimum position of the arm during overhead work.

2.5.1 Objectives

The objectives of this research were:

- To study the effect of providing a support on the muscular activity of shoulder muscles in overhead work.
- To evaluate which position (low, middle and far) causes less fatigue and stress in the three shoulder muscles.
- To evaluate the newly designed hand tool support, by using a rating system that allowed participants to rate the hand tool support and the arm position subjectively.

CHAPTER 3
METHODS AND PROCEDURES

The objective of this research is to evaluate a newly designed overhead support stand and the determine the best overhead drilling position using the EMG activity of shoulder muscles namely the biceps, anterior deltoid and trapezius muscles. To achieve this objective, Five (5) male participants were recruited to perform the overhead drilling task. The experiment had two sessions: one without overhead support stand and the second being with overhead support stand. Each experimental trial had three sessions each and the EMG activity of the muscles was recorded in order to find the load on the shoulder muscles.

3.1 Subjects

Five (5) young males were asked to participate in this study. The participants did not have any history of medical problems, which would have impaired their ability to perform the tests. Anyone with such a problem was excluded. Height and weight of each participant were measured. Table 7 shows the anthropometric data of the subjects.

The experimental procedure was explained in detail to each participant before the experimental session, and a written consent form was read and signed by each participant.

Table 7: Anthropometric data of subjects

	Mean	Standard Deviation
Age (Years)	24.4	0.5477
Height (Inches)	68.4	1.516
Weight (Lb)	149.8	14.788

3.2 Equipment

A 2.5kgs (approx) portable drill (Black and Decker, USA) was fitted to an adjustable support stand. The support stand could be adjusted to various heights, so that the experiment could be done in three different positions. The support mechanism consists of a belt and a support rod arrangement (Figure 5). Each subject was asked to wear the belt around his waist and an extendable rod was fixed to the belt. The belt is made up of nylon material and has a buckle belt mechanism. The belt has a pivot arrangement to the support the rod so that it can be flexible and move in saggital and coronal planes. The support rod has two rods: one thick (9.5 cm), thin (6 cm) as shown in Figure 5. The thinner rod can slide through the thicker rod so that it can move up and down. The joint between the thinner rod and thicker rod has a lock mechanism so that the rod can be fixed at desired heights. This arrangement allows the user to perform the task in various heights and planes. The support mechanism can move from 75 cm to 150 cm above the waist level. The drill was attached to other end of the rod. Ariel Performance Analysis System (APAS) was used for EMG data recording and analysis (manufactured by ARIEL dynamics, Inc., Watertown, MA).

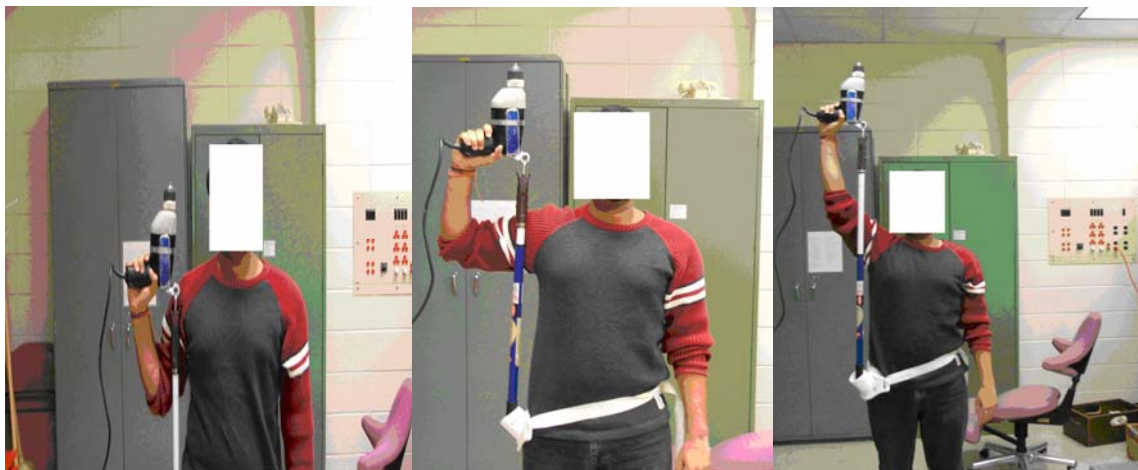


Figure 5: Drilling positions in the experiment

The APAS system includes ARIEL ANALOG and EMG modules, which were used for collection, extraction and analysis of EMG data. The ARIEL ANALOG module software is used as a general-purpose laboratory data measurement and analysis system. The ARIEL EMG software is Windows based program for calculating the integral and normalizing the EMG signal in both time and amplitude. EMG data samples can be analyzed using a number of sophisticated techniques including spike analysis, signal rectification and integration, envelope processing and spectral analysis. In this study we used RMS analysis technique.

3.3 Experimental Design

The experiment was conducted in three-reach positions namely near (N), middle (M) and far (F). In the near reach position, subjects held the drill with the shoulder adducted in coronal plane with elbow closer to the body (Figure 5). In the middle reach position, participants held the drill with the shoulder abducted with an angle of 90° in coronal plane and with an angle of 90° between shoulder and elbow (Figure 5). In the far reach position, participants held the drill with the shoulder abducted at an angle of 180° in the coronal plane with 180° angle between elbow and shoulders (Figure 5).

Each of the participants was asked to perform two experimental trials. Figure 6 shows the two experimental trials in the experiment. In the first trial, the participants assumed the near, middle and far reach positions. The participant held the drill in place without any support for 3 minutes with a rest period of 24 hrs between each position. In the second trial, the participant again assumed the three positions in the same order using the support stand. The support mechanism consisted of a belt and a support rod arrangement. Each participant was asked to wear the belt around his waist. An extendable

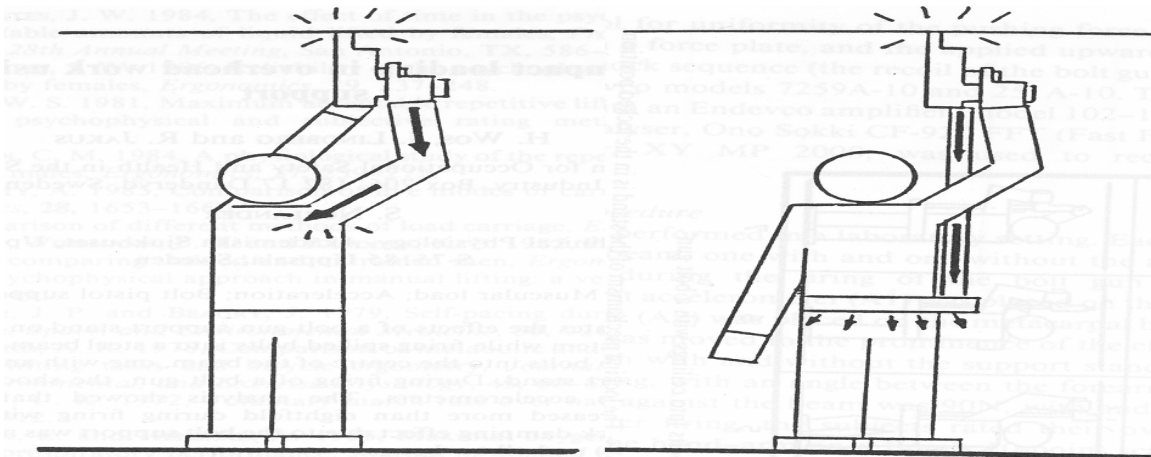


Figure 6: Traditional drill and Supported Drill

rod was fixed to belt. The drill was attached to the other end of the rod. During all experimental trials and all the positions, EMG activity of anterior deltoid, bicep, and trapezius muscles was recorded with the task parameters set as: Rate/Channel at 200, Trigger Level at 0.2 and Preset Trigger percentage at 10. The electrodes were placed parallel to the muscle fibers and placed 2cms apart from each other. Figure 7 shows the diagrammatic representation of deltoid, biceps and trapezius muscles.

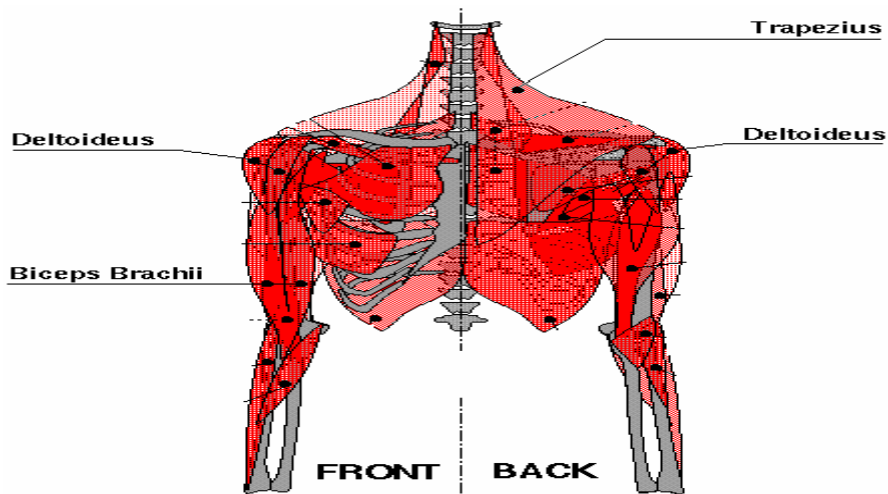


Figure 7: Diagrammatic representation of Deltoid, Biceps brachii and trapezius (extracted from ligwww.epfl.ch/~maurel/CHARM/WP3/Anatomy.html)

In order to evaluate the load on the hip and waist muscles, we used a subjective rating scale from 0 to 4 (Appendix A). The subjective rating consisted of a body map as

shown in Figure 8. The participants were asked to rate the extent of pain or discomfort in the body segments having load according to the scale provided. Participants were instructed to rate body segments of upper chest (labeled 1), shoulder (labeled 2), the upper arm (labeled 4), and the waist region (labeled 9). The subjective rating scale was also used to evaluate the overhead support stand, and to find the best position with and without overhead support stand.

3.4 Statistical Analysis

The aim of this study was to evaluate a new type of overhead supporting stand and to determine whether the overhead supporting stand will reduce the load on shoulder muscles.

3.4.1 Dependant Variables

The EMG of the muscle activity and subjective rating.

3.4.2 Independent Variables

Arm position and support: The three different arm positions with and without overhead supporting stand were the independent variables.

3.5 Research Hypothesis

Hypothesis 1:

Ha: The overhead support stand will not reduce the load on shoulder muscles.

H1: The overhead support stand reduces the load on shoulder muscles.

Hypothesis 2:

Ha: The arm position closest to the body will not causes less load on shoulder muscles.

H1: The arm position closest to the body causes less load on shoulder muscles.

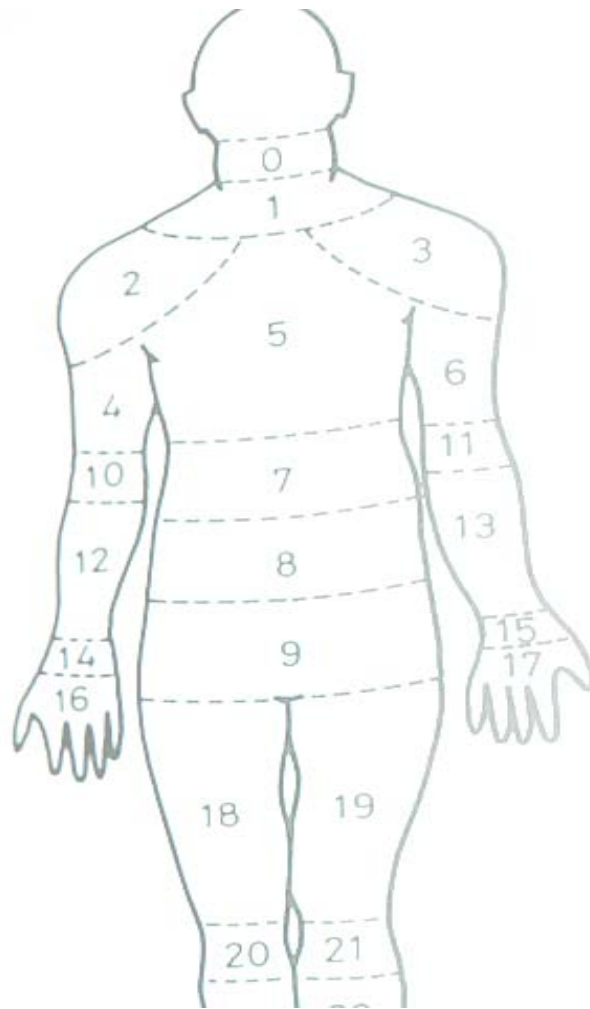


Figure 8: The body map for evaluating body part discomfort, by rating (Wilson J.R., and Corlett E.N., 1995)

CHAPTER 4

RESULTS

The objective of this study was to evaluate the effect of providing support on the muscular activity of the shoulder using an overhead support stand, to determine the best position to hold the drill. Five young males participated in the study, and the myoelectric activity was recorded from the bicep, anterior deltoid and trapezius muscles for 180 seconds at the rate of 200 readings per second. The analysis of raw EMG that was collected during the experimentation process was done by Root Mean Square technique (RMS). The mean RMS values for all the subjects for with and without support for different muscles in three positions were used to perform statistical analysis and to compare the mean difference of the RMS values. The following sections discuss the effectiveness of the overhead support stand on the shoulder muscular activity, determination of the best position using the comparison of mean difference, set of pair T-tests, and subjective rating. The following section evaluates the overhead support stand and the best drill position.

4.1 Evaluation of Overhead Support Stand

The average RMS values of EMG for each of the muscles in the three positions namely near, middle and far reach position were calculated from the raw EMG data. The RMS values were divided into intervals of one second, and the average RMS values for each second were calculated. Table 8 shows the average RMS values and the difference in RMS values for all the muscles in three positions holding the drill with and without support. It can be observed from RMS values in the Table 8 that the overhead support

stand was effective in reducing the load on the muscles in all the positions. The RMS values of without support are greater than those with support. Figure 9, 10& 11 show the graphs that compare the RMS values with support and without support for three muscles namely bicep, anterior deltoid and the trapezius muscle.

As shown in Table 8, for near position for bicep muscles, the mean RMS value with support was less in contrast to without support (0.029mv). This value is 18% lower than the value of without support. Examining the mean RMS values for anterior deltoid (0.064mv) and trapezius muscles (0.028mv) during near reach position, show that the mean RMS values with support were lower than the mean RMS value without support, with a percentage difference of 24 and 32, respectively. For middle reach position for bicep muscles, the mean RMS value with support was less in contrast to without support (0.033mv). This value is 24% lower in value in contrast to the without support. On examining the RMS values for anterior deltoid (0.075mv), and trapezius muscles (0.024mv) during middle reach position, the mean RMS value with support resulted in lowest RMS values with a percentage difference of 33 and 37, respectively. In far reach position the mean RMS value for bicep muscles with support was less when compared to without support (0.155mv). This value is 47% lower in contrast to the without support. The mean RMS value for anterior deltoid was 0.264 and for trapezius muscle was 0.0529 during far reach position. The mean RMS values of anterior deltoid and trapezius muscles with support decreased by 49% and 42%, respectively as compared to without support. The following section explains the statistical analysis for with and without overhead support stand. The statistical analysis involves a set of paired T-tests using in MINITAB statistical software. The mean RMS values for with and without support that are

statistically significant are marked with “SD” next to the percentage decrease in RMS values in Table 8. The statistical analysis shows that the RMS values with and without overhead support stand were statistically different, which supports the above discussion that overhead support stand was effective in reducing the load on shoulder muscles.

Table 8: Mean differences and Percentage decrease in RMS values for with and without support

Position	Muscles	Without support RMS(mv)	With support RMS(mv)	Difference in means RMS(mv)	Percentage decrease in RMS
Near(N)	Biceps	0.170	0.140	0.029	18(SD)
	Anterior deltoid	0.268	0.204	0.064	24(SD)
	Trapezius	0.089	0.061	0.028	32(SD)
Middle(M)	Biceps	0.139	0.105	0.033	24(SD)
	Anterior deltoid	0.231	0.155	0.075	33(SD)
	Trapezius	0.066	0.041	0.024	37(SD)
Far(F)	Biceps	0.332	0.176	0.155	47(SD)
	Anterior deltoid	0.545	0.280	0.264	49(SD)
	Trapezius	0.125	0.073	0.0529	42(SD)

4.1.1 Paired T-test Results to Evaluate Overhead Support Stand

A set of paired T-tests was performed to compare the mean RMS values of each muscle during the three positions with and without the overhead support stand for the subjects with an alpha value 0.05. Table 9, 10 & 11 show that the T-test results of the average RMS values of all the subjects for supported and non-supported conditions

during near, middle and far positions for three muscle groups were significantly different.

The individual paired T-test results can be viewed in appendix C.

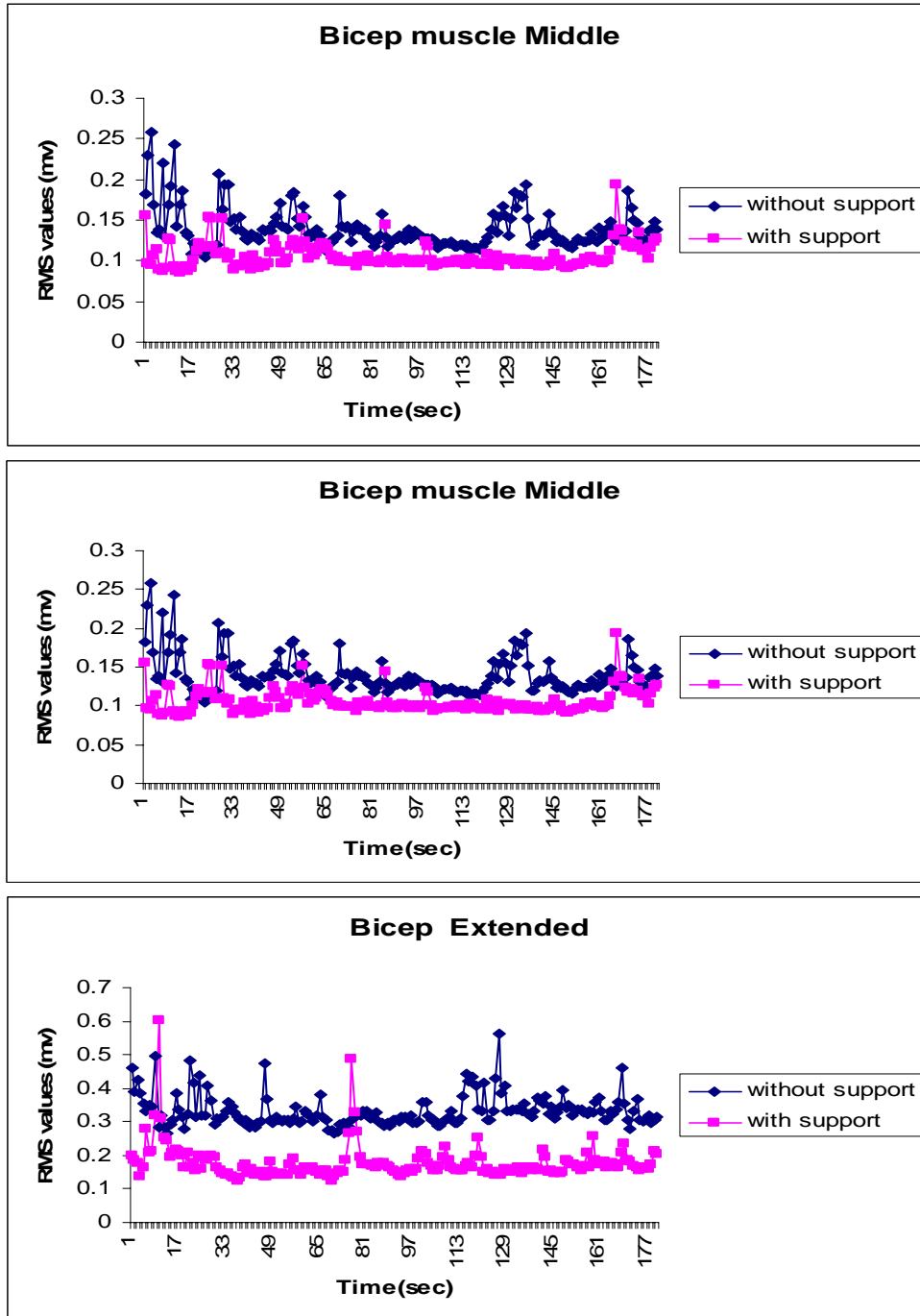


Figure 9: RMS values for bicep muscle for three positions

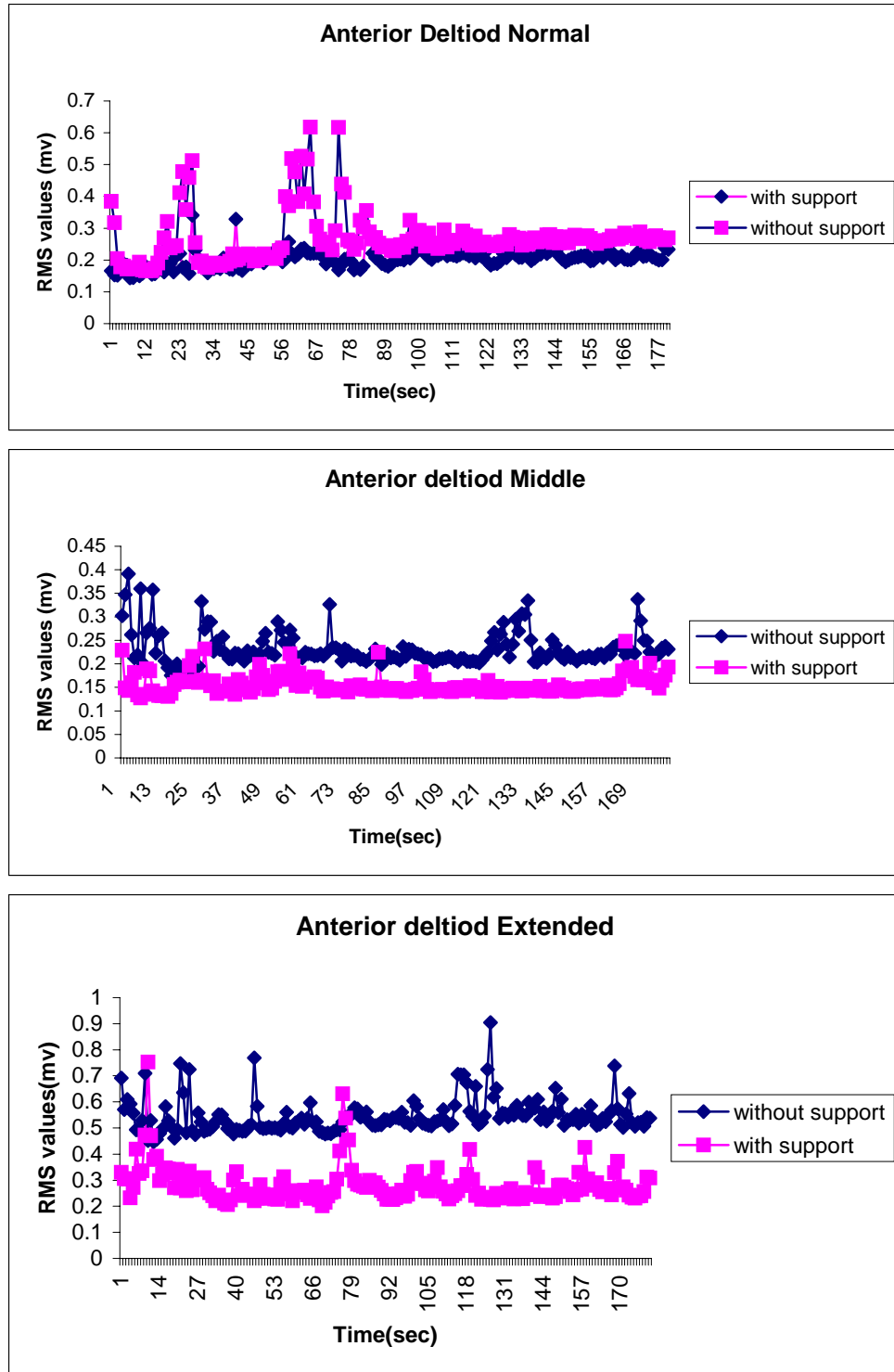


Figure 10: RMS values for anterior deltoid muscle for three positions

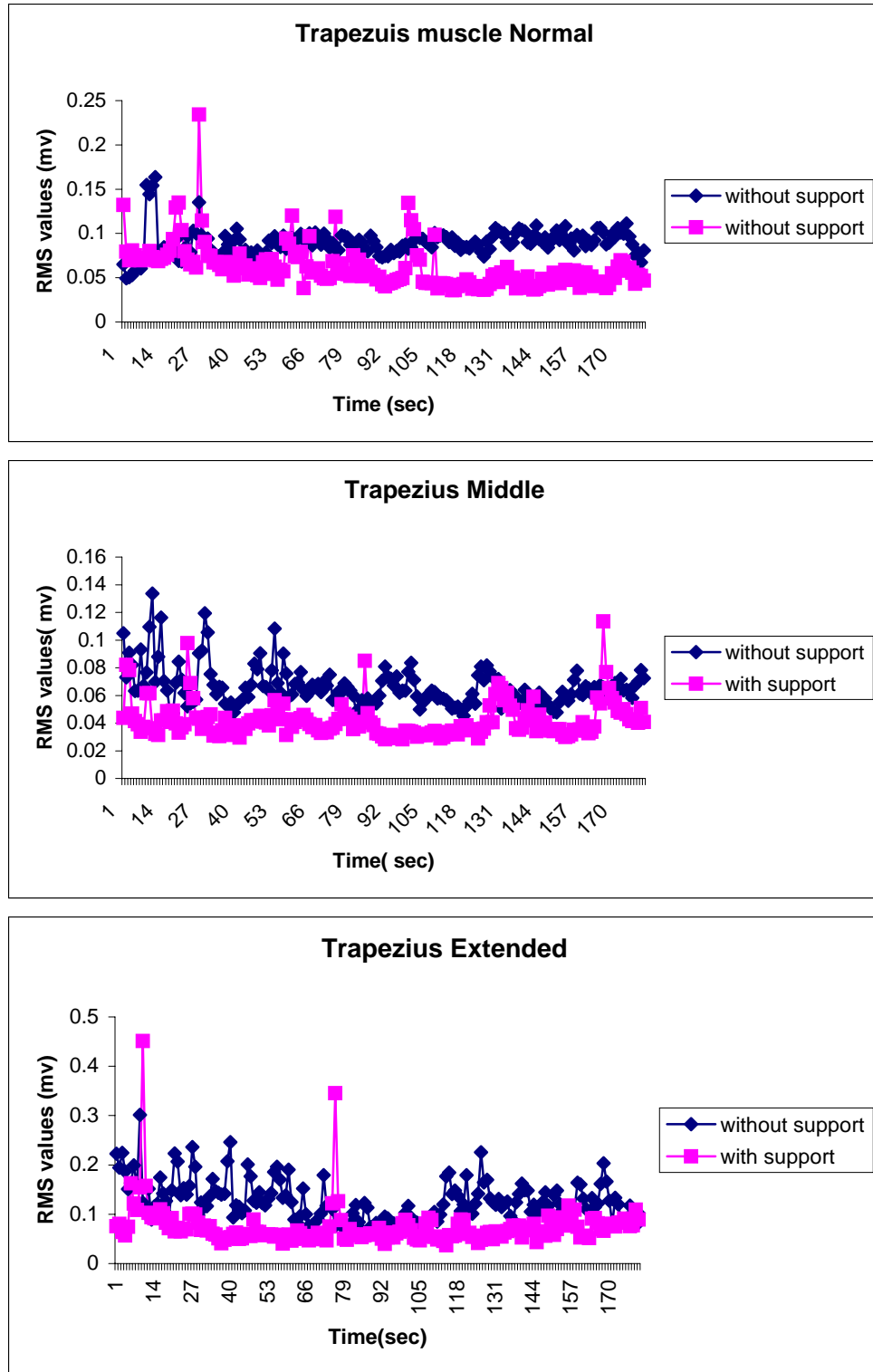


Figure 11: RMS values for trapezius muscle for three positions

Table 9: T-test results of RMS values for all muscles during near position

Type of Muscle	N	Mean		Standard Deviation		Confidence interval		T	P
		Without	With	Without	With	5%	95%		
Bicep	5	0.170	0.140	0.048	0.044	0.002	0.057	3.01	0.039
Anterior Deltoid	5	0.268	0.204	0.086	0.073	0.006	0.121	3.08	0.037
Trapezius	5	0.089	0.061	0.030	0.016	0.009	0.047	4.13	0.014

Table 10: T-test results of RMS values for all muscles during middle position

Type of Muscle	N	Mean		Standard Deviation		Confidence interval		T	P
		Without	With	Without	With	5%	95%		
Bicep	5	0.139	0.105	0.025	0.036	0.008	0.059	3.66	0.022
Anterior Deltoid	5	0.231	0.155	0.062	0.050	0.015	0.135	3.51	0.025
Trapezius	5	0.066	0.041	0.018	0.018	0.015	0.032	7.99	0.001

Table 11: T-test results of RMS values for all muscles during far position

Type of Muscle	N	Mean		Standard Deviation		Confidence interval		T	P
		Without	With	Without	With	5%	95%		
Bicep	5	0.332	0.176	0.102	0.065	0.015	0.294	3.09	0.037
Anterior Deltoid	5	0.545	0.280	0.188	0.139	0.030	0.498	3.14	0.035
Trapezius	5	0.125	0.065	0.048	0.009	0.000	0.120	2.79	0.049

4.2 Evaluation of Drill Position

4.2.1 Evaluation of Drill Position Without Overhead Support Stand

An experiment was performed in three different positions namely near, middle and far with and without overhead support stand. The average RMS values, calculated per second, were used in the analysis. Table 12 shows the mean differences and percentage difference in RMS values for the three muscles in different positions without overhead support stand.

Data in Table 12 indicates that the RMS values for biceps muscles are the lowest in middle position (0.139mv). This value is 18% lower than the value for the near position and 32% lower than the value for the far position. The mean RMS value of anterior deltoid muscle in middle position (0.231mv) is lower than the mean RMS value in near position (0.268 mv) by 14 % and lower than mean RMS value in far position (0.545 mv) by 55%. Examining values for the trapezius muscle shows that the minimum RMS value occurred in middle position (0.066mv), which was 26% less than the near position (0.089 mv) and 47% less than the far position (0.125 mv). Also, we can see that the anterior deltoid worked the most among the three muscles.

The following section explains the statistical analysis for three muscles in the three positions without overhead support stand. Table 12 also indicates whether the mean RMS values for muscles in different positions were statistically different by marking them as “SD” indicating as statistically different, and “NSD” indicating as not being statistically different. This statistical analysis shows that the RMS values of the middle position are statistically different from far reach position in biceps and anterior deltoid muscles without overhead support stand.

Table 12: Mean differences and percentage decrease in RMS values in all positions without support (Near -N; Middle-M; Far-F)

Muscles	Positions	RMS(mv)		Difference in means RMS(mv)	% difference in RMS
Bicep	N vs. M	0.170 (N)	0.139 (M)	0.030	18(NSD)
	F vs. N	0.332 (F)	0.170 (N)	0.162	49(NSD)
	F vs. M	0.332 (F)	0.139 (M)	0.193	58(SD)
Anterior deltoid	N vs. M	0.268 (N)	0.231 (M)	0.037	14(NSD)
	F vs. N	0.545 (F)	0.268 (N)	0.27	51(NSD)
	F vs. M	0.545 (F)	0.231 (M)	0.314	55(SD)
Trapezius	N vs. M	0.089 (N)	0.066 (M)	0.023	26(NSD)
	F vs. N	0.125 (F)	0.089 (N)	0.036	29(NSD)
	F vs. M	0.125 (F)	0.066 (M)	0.059	47(NSD)

Paired T-test results to Evaluate Drill Position Without Overhead Support Stand

A set of paired T-tests were performed to compare the RMS values for each muscle during different positions with an alpha value 0.05. An examination of Tables 13, 14 & 15 indicates that all RMS values were significantly different at 95% confidence interval. The individual T-test for evaluation of drill position without is in appendix D.

Table 13: T-test results for bicep muscle RMS values for without support for all three positions (Near -N; Middle-M; Far-F)

Type of Comparison	N	Mean		Standard Deviation		Confidence Interval		T	P
						5%	95%		
N vs. M	5	0.170 (N)	0.139 (M)	0.048 (N)	0.025 (M)	-0.045	0.107	1.12	0.326
N vs. F	5	0.170 (N)	0.332 (F)	0.048 (N)	0.102 (F)	-0.341	0.017	-2.51	0.066
M vs. F	5	0.139 (M)	0.332 (F)	0.025 (M)	0.102 (F)	-0.320	-0.065	-4.20	0.014

Table 14: T-test results for anterior deltoid muscle RMS values for without support for all three positions (Near -N; Middle-M; Far-F)

Type of Comparison	N	Mean		Standard Deviation		Confidence Interval		T	P
						5%	95%		
N vs. M	5	0.268 (N)	0.231 (M)	0.086 (N)	0.062 (M)	- 0.069	0.143	0.97	0.387
N vs. F	5	0.268 (N)	0.545 (F)	0.086 (N)	0.188 (M)	- 0.606	0.052	- 2.34	0.080
M vs. F	5	0.231 (M)	0.545 (F)	0.062 (M)	0.188 (F)	- 0.566	- 0.062	- 3.46	0.026

Table 15: T-test results for trapezius muscle RMS values for without support for all three positions (Near -N; Middle-M; Far-F)

Type of Comparison	N	Mean		Standard Deviation		Confidence Interval		T	P
						5%	95%		
N vs. M	5	0.089 (N)	0.066 (M)	0.030 (N)	0.0181 (M)	- 0.032	0.080	1.17	0.307
N vs. F	5	0.089 (N)	0.125 (F)	0.030 (N)	0.048 (F)	- 0.095	0.023	- 1.69	0.166
M vs. F	5	0.066 (M)	0.125 (F)	0.018 (M)	0.048 (F)	- 0.134	0.014	- 2.23	0.090

4.2.2 Evaluation of Drill Position With Overhead Support Stand

An experiment was performed in three different positions namely near, middle and far with and without overhead support stand. The average RMS values calculated per second were used in the analysis. Table 16 shows the mean differences and percentage difference in RMS values for the three muscles in different positions with overhead support stand.

Data in Table 16 indicates that the RMS values for biceps muscles are the lowest in the middle position (0.105mv). This value is 25% lower than the value for near position and 45% lower than the value for the far position. The mean RMS value of anterior deltoid muscle in middle position (0.155mv) is lower than the mean RMS value in near position by 22% and lower than mean RMS value in far position by 45%.

Examining values for the trapezius muscle shows that the minimum RMS value occurred in the middle position (0.041mv) which was 32% less compared to near position and 43% compared to far position.

The following section explains the statistical analysis for three muscles in the three positions without overhead support stand. Table 16 also indicates whether the mean RMS values for muscles in different positions were statistically different by marking them as “SD” indicating as statistically different, and “NSD” indicating as not statistically different. This statistical analysis shows that the RMS values of the middle position were not statistically different from near and far reach position with overhead support stand.

Table 16: Mean differences and percentage decrease in RMS values in all positions with support (Near -N; Middle-M; Far-F)

Muscles	Positions	RMS(mv)		Difference in means RMS(mv)	% difference in RMS
Bicep	N vs. M	0.140 (N)	0.105 (M)	0.034	25(NSD)
	F vs. N	0.176 (F)	0.140 (N)	0.036	21(NSD)
	F vs. M	0.176 (F)	0.105 (M)	0.071	40(NSD)
Anterior deltoid	N vs. M	0.204 (N)	0.155 (M)	0.048	22(NSD)
	F vs. N	0.280 (F)	0.204 (N)	0.076	27(NSD)
	F vs. M	0.280 (F)	0.155 (M)	0.125	45(NSD)
Trapezius	N vs. M	0.061 (N)	0.041 (M)	0.019	32(NSD)
	F vs. N	0.073 (F)	0.061 (N)	0.012	17(NSD)
	F vs. M	0.073 (F)	0.041 (M)	0.031	43(NSD)

Paired T-test results to Evaluate Drill Position Using Overhead Support Stand

A paired T-test was performed to compare the RMS values for each muscle during different positions with an alpha value 0.05. An examination of Tables 17, 18 & 19 indicates that all RMS values were significantly different at 95% confidence interval.

The individual T-test for evaluation of drill position without is in appendix D.

Table 17: T-test results for bicep muscle RMS values with support for all three positions (Near -N; Middle-M; Far-F)

Type of Comparison	N	Mean		Standard Deviation		Confidence Interval		T	P
						5%	95%		
N vs. M	180	0.140 (N)	0.105 (M)	0.044 (N)	0.036 (M)	- 0.046	0.115	1.20	0.297
N vs. M	180	0.140 (N)	0.176 (F)	0.044 (N)	0.065 (F)	- 0.144	0.071	- 0.94	0.399
M vs. F	180	0.105 (M)	0.176 (F)	0.036 (M)	0.065 (F)	- 0.120	- 0.022	- 4.05	0.015

Table 18: T-test results for anterior deltoid muscle RMS values with support for all three positions (Near -N; Middle-M; Far-F)

Type of Comparison	N	Mean		Standard Deviation		Confidence Interval		T	P
						5%	95%		
N vs. M	180	0.204 (N)	0.155 (M)	0.073 (N)	0.050 (M)	- 0.077	0.174	1.08	0.342
N vs. M	180	0.204 (N)	0.280 (F)	0.073 (N)	0.139 (F)	- 0.296	0.143	- 0.97	0.388
M vs. F	180	0.155 (M)	0.280 (F)	0.050 (M)	0.139 (F)	- 0.257	0.007	- 2.63	0.058

Table 19: T-test results for trapezius muscle RMS values with support for all three positions (Near -N; Middle-M; Far-F)

Type of Comparison	N	Mean		Standard Deviation		Confidence Interval		T	P
						5%	95%		
N vs. M	180	0.061 (N)	0.041 (M)	0.024 (N)	0.012 (M)	0.015	0.023	9.62	0.000
N vs. M	180	0.061 (N)	0.073 (F)	0.024 (N)	0.040 (F)	-0.019	-0.006	- 3.84	0.000
M vs. F	180	0.041 (M)	0.073 (F)	0.012 (M)	0.040 (F)	-0.037	-0.025	- 10.5	0.000

4.3 Subjective Rating for Evaluation of Overhead Support Stand and Best Position

After each trial of the experiment participants were asked to fill a subjective rating form to indicate in what segment of the body they felt stiffness, ache, pain or discomfort. At the end of the six trials the participants were instructed to evaluate the overhead support stand and choose the best position. The subjective rating form consisted of a body map as shown in Figure 8. The participants were asked to rate the extent of pain or discomfort in the body segments according to the scale provided which is rated from 0 – 4 (Appendix A). The pain or amount of discomfort was rated from 0 to 4 (0 being the least and 4 being the highest).

Participants felt that use of the overhead support stand was better than no support. They also felt the least discomfort in the middle position. All participants rated the body segments of upper chest (labeled 1), shoulder (labeled 2), and upper arm (labeled 4) for the level of pain or discomfort. The subjects rated the amount of discomfort in the waist region zero which suggests that they did not experience any load in that part of the body with overhead support stand testing. From Figure 12, which is the plot for average discomfort rate versus the body segment for no support, it is observed that for the body segment “upper chest,” the middle position resulted the least average subjective rating (2.4). For the body segment “shoulders,” the least subjective rating was for middle position (2). For the body segment “upper arm,” the subjective rating was the same for middle, near and far reaches position (2). The graph (Figure 12) and above discussions indicate that during middle position the least subjective rating was recorded in the body segments 1, 2 and 4 (2.4, 2, and 2). Thus, we can conclude that the middle position was better than the near and far reach positions without using overhead support stand.



Figure 12: Subjective Rating during No Support versus Body segment

Table 20: Subjective rating results without support

Position	Upper chest	Shoulder	Upper arm	Standard deviation(Upper chest, Shoulder, Upper arm)	Waist
Near	2.8	2.6	2	0.416	0
Middle	2.4	2	2	0.230	0
Far	3	3	3.2	0.115	0

From the Figure 13, which is the plot for average discomfort rate versus the body segment for with support, it is observed that for body segment labeled 1, middle positions recorded the least average subjective rating (1.2). For body segment labeled as 2, the three positions recorded the same rating (1.2). For the body segment labeled as 4, the least subjective rating was during middle. The graph (Figure 13) shows that during middle position the least subjective rating was recorded in body segments 1, 2 and 4(1.2, 1.2, and 1.2). Thus, we conclude that middle position was better than the near and far reach positions with overhead support stand.

From the subjective rating results we can conclude that the middle position is better than the near and far reach positions, and there was no pain or discomfort in the waist region using the overhead support stand.

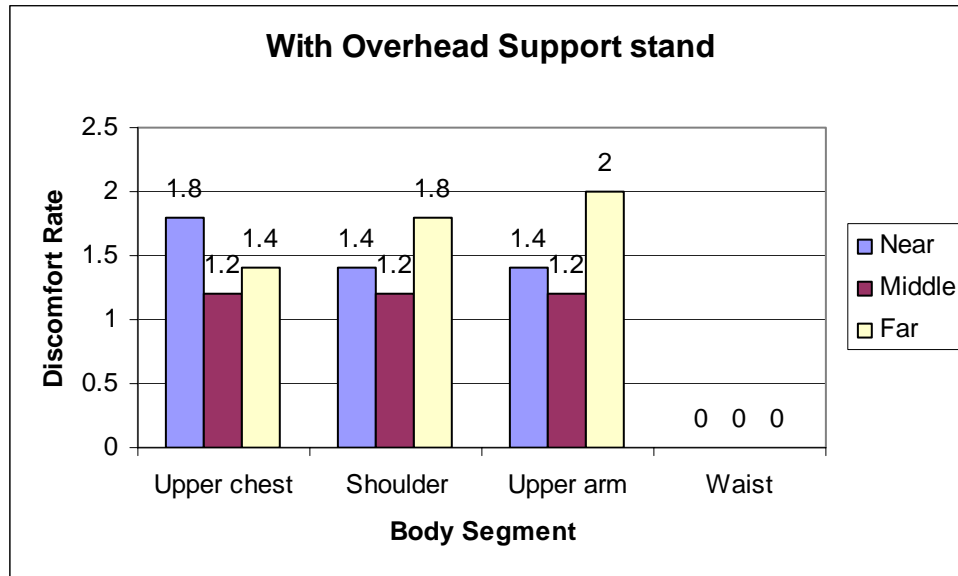


Figure 13: Subjective Rating with overhead Support versus Body segment

Table 21: Subjective rating results with support

Position	Upper chest	Shoulder	Upper arm	Standard deviation(Upper chest, Shoulder, Upper arm)	Waist
Near	1.8	1.4	1.4	0.230	0
Middle	1.2	1.2	1.2	0	0
Far	1.4	1.8	2	0.3055	0

From the above-discussed tables, we can say that the middle position is better in comparison to near and far reach positions considering the EMG activities of the muscles while working with and without overhead support stand. According to Dan *et al.*, (2001) it is more advantageous to perform overhead work in the near position. But the results of the present study suggest that the middle position is more advantageous than near or far

positions for performing overhead work. According to Karlsson's model (Karlsson, 1992), when arms are lowered, higher forces in the biceps muscles were observed than when they were raised. The results of this study support the Karlsson's model that higher forces were recorded in the biceps muscles in the lower arm position than when the arms were raised. Hence the middle position is preferred over the near position when considering the bicep muscle activity. The individual subjective rating results are attached in appendix B.

The study done by Dan *et al.*, (2001) considered biceps, triceps and anterior deltoid muscles, and they performed the experiment in saggital plane. But in this study we performed the experiment using biceps, anterior deltoid, and trapezius muscles, in the coronal plane. Hence it might be concluded that the load on individual muscle may vary according to the plane in which they are working. This may be the reason for the difference in results.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research was to study the effect of providing a support in overhead work on the muscular activity of the shoulder muscles and to evaluate which positions of the arm causes less fatigue. Five males participated in this study. Anthropometric measurements (height and weight) of subjects were recorded. The experiment was conducted in three arm reach positions namely near, middle and far reach. The experiment had six sessions, three with overhead support stand and three without the overhead support stand.

5.1 Conclusions

5.1.1 Overhead Support Stand

The reductions in biceps mean RMS value with overhead support stand when compared to without support during near, middle and far reach positions were 18%, 24% and 46%, respectively. We can conclude that overhead support stand was effective in reducing the load on the bicep muscle. Similarly for the anterior deltoid muscle the percentage decrease in mean RMS values with and without overhead support stand during near, middle and far reach positions were 24%, 33% and 49%, respectively. For trapezius muscle, the total percentage decrease in mean RMS values with and without overhead support stand during near, middle and far reach positions were 32%, 37% and 42%, respectively. During experimental trials with and without support, the deltoid muscle recorded the maximum mean RMS value during the three positions indicating that deltoid muscles worked the most compared to biceps and trapezius muscles. Furthermore,

the T-test values indicate that the mean RMS values during with and without overhead support stand were statistically different. The subjects rated the amount of discomfort in the waist region zero which suggests that they did not experience any load in that part of the body while wearing the overhead support stand. All the subjects felt that overhead support stand was better compared to that of without support and felt that it was effective in reducing the load on the muscles. Hence, it can be concluded from the above findings that overhead support stand was effective in reducing the load on the shoulder muscles.

5.1.2 Analysis of Drill Position

The mean RMS value without overhead support stand for bicep muscles was the lowest in the middle position (0.139mv). This value is 18% lower than the value for near position, and 32% lower than the value for far position. Similarly the mean RMS value of anterior deltoid muscles without the overhead support stand during middle position (0.231mv) is lower than the RMS value for near position by 14%, and lower than RMS value for far position by 55%. Examining values for the trapezius muscle shows that the least average RMS value occurred in the middle position (0.066mv), which was 26% less compared to the near position, and 47% compared to the far position. The T-test results indicated that the mean RMS value for far versus middle positions in biceps and anterior deltoid muscles were statistically significant. From the mean RMS values during three positions, it can be concluded that middle position is better than near and far positions in overhead work without overhead support stand.

The mean RMS value for bicep muscles with overhead support stand was the lowest during middle position (0.105mv). This value is 25% lower than the value for near position and 45% lower than the value for far position. The mean RMS value of anterior

deltoid muscle with overhead support stand during middle position (0.155mv) is lower than the mean RMS value in near position by 22% and lower than mean RMS value in far position by 45%. Examining values for the trapezius muscle shows that the minimum RMS value occurred in the middle position (0.041mv) which was 32% less compared to the near position, and 43% compared to far position. The T-test results indicated that mean difference in mean RMS values during three positions for the muscles were not statistically significant. The results of the subjective rating showed that all participants experienced the least pain in all the three muscles in the middle position and the highest pain during the extended position during both with and without overhead support stand experimental condition. During middle position, the least subjective rating was for body segments of 1, 2 and 4 for both with and without overhead support stand.

Thus from the mean RMS values and subjective rating results, it can be concluded that middle reach position is better than near and far reach positions in overhead work with overhead support stand.

5.2 Recommendations for Future Work

- Female subjects may be used in future studies.
- In this experiment, there was no drilling task. In future studies the participant may be asked to perform drilling task so that the exact load on the muscle may be measured. This can be done by using subjective rating and by calculating the forces on the shoulder joints.
- Force on the end of the support stand can be calculated so that the load on the waist muscles can be evaluated.

- Experiment may be performed in saggital plane and hence the difference between working in saggital and coronal planes can be determined.
- Similar studies can be performed on older population.
- This study used the RMS values of the raw EMG. RMS technique is used to quantify the muscle load. For analysis of fatigue, median frequency technique is used. Future studies may consider the fatigue factor by using median frequency analysis, and hence determine whether the overhead support stand can help in reducing the load, and whether the middle position is the least stressful position.

REFERENCES

AGHAZADEH, F., and MITAL, A., 1987, Injuries due to hand tools, *Applied Ergonomics*, **18(4)**, pp273-278.

ANTON DAN., NATHAN B., HESS J., THOMAS. M., and ROSECRANCE. 2001, The effect of overhead drilling position on shoulder moment and electromyography, *Ergonomics*, **44(5)**, 489 -501.

ARMSTRONG, T.J., FOULKE, J.A., JOSEPH, B.S., and GOLDSTEIN S.A., 1982, Investigation of cumulative trauma disorders in a poultry processing plant, *American Industrial Hygiene Association Journal*, **43(2)**, 103-116.

ARMSTRONG, T.J., and SILVERSTEIN B, J., 1987., Upper extremity pain in the workplace—Role of Usage in Causality, in N. Handler, Ed., *Clinical Concepts in regional musculoskeletal ill-ness*, Grune and Stratton, Inc., pp 333-354.

BJELLE, A., HAGBERG, M., and MICHAELSSON, G., 1973, Occupational and individual factors in acute shoulder-neck disorders among industrial workers, *British Journal of Industrial medicine*, **15(4)**, 346-354.

BJELLE, A., HAGBERG, M., and MICHAELSSON, G., 1979, Clinical and ergonomic factors in prolonged shoulder pain among industrial workers, *Scandinavian Journal of Work, Environment and Health*, **5**, 205-210.

BJELLE, A., HAGBERG, M AND MICHEALSON, G.1981, Occupational and individual factors in acute shoulder-neck disorders among industrial workers, *British Journal of Industrial Medicine*, **38**, 356-363.

CEDERQVIST, T., and LINDBERG M., 1993, Screwdrivers and their use from a Swedish construction industry perspective, *Applied Ergonomics*, **23(4)**, pp 148-157.

CHAFFIN, D.B., ANDERSSON, G.B.J., MARTIN, B.J, Occupational biomechanics, 3rd edition, A Wiley-Interscience Publication, 1999.

DELUCA, C.J., 1997, The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, **13**, 135-163.

EASTMAN KODAK COMPANY, Ergonomic Design for People at Work, Volume 1, Van Nostrand Reinhold Publication, 2000.

FLATOW, E., SOSLOWSKY, L. and TICKER, J.E.A. 1994, Excursion of the rotator cuff under the acromion: patterns of subacromial contact, *American Journal of Sports Medicine*, **22**, 779-788.

FRASER, T.M., 1980, Ergonomics principles in the design of hand tools. Occupational Safety and Health series, No 44, Geneva, Switzerland International Labor Office.

GIROUX, B. and LAMONTAGNE, M. 1992, Net shoulder joint moment and muscular activity during light weight handling at different displacements and frequencies, *Ergonomics*, 35, 385 - 403.

GREENBURG, L., and CHAFFIN, D.B., 1997, Workers and their tools: a guide to the ergonomic design of hand tools and small presses, Pental Publications Company, Midland, MI.

HAMMER, W., and PRICE, D., 2001, Occupational Safety Management and Engineering, 5th edition, Prentice Hall, New Jersey.

HAGBERG, M., KADEFORS, R., and BROMAN, H., 1980, "Arm positioning in manual tasks-an electromyography study of localized muscle fatigue", *Ergonomics*, **23(7)**, 655-665.

HAGBERG, M., SILVERSTEIN, R., WELLS, M.J., HENDRICK, H.W., CARAYON, P., and PERUSSE, I and FORCIER, L Eds., Work related musculoskeletal disorders (WMSD's): A reference book for prevention, Taylor and Francis, London,1995.

HAGBERG, M., 1981a, "Muscular endurance and surface electromyography in Isometric and dynamic Exercise", *Journal of Applied Physiological: Respiratory, Environmental and exercise physiological*, **51**, 1-7.

HAGBERG, M., 1981b, Work load and fatigue in repetitive arm elevations, *Ergonomics*, **24(7)**, 543-555.

HAGBERG, M. and WEGMAN, D. 1987, Prevalence rates and odds ratios of shoulder-neck diseases in different occupational groups, *British Journal of Industrial Medicine*, 44,602 - 610.

HERBERTS, P. AND KADEFORS, R. 1976, A study of painful shoulder in welders, *Acta Orthopaedica Scandinavica*, 47, 381-387.

HERBERTS, P., KADEFORS, R., ANDERSSON, G. AND PETERSEN, I. 1980, Shoulder pain in industry: an epidemiological study on welders, *Acta Orthopaedica Scandinavica*, 52, 299-306.

HERBERTS, P., KADEFORS, R., HOGFORS, C., SIGHOLM, G., 1984, Shoulder pain and heavy manual labor, *Clinical Orthopaedics and Related Research*, **191**,166-178.

HOLMSTROM, E., LINDELL, J. AND MORITZ, U. 1992, Low back and neck/shoulder

Pain in construction workers: occupational workload and psychosocial risk factors, *Spine*, **17**, 672-677.

HUGHES, R.E. and AN, K.N. 1996, Force analysis of rotatory cuff muscles, *Clinical Orthopaedics*, **330**,75-83.

HUSTON, T., SANGHAVI, N., and MITAL, A., 1984, Human torque exertion capabilities on a fastener device with wrenches and screwdrivers' in *Trends in Ergonomics/human factors I*, North Holland, Amsterdam, pp 51-58.

JOHNSON, S.L., and CHILDRESS, L.J., 1988, Powered screwdriver design and use; tool, task and operator effects, *International Journal of Industrial Ergonomics*, **2**, pp 183-191.

JONSSON, B. and HAGBERG, M. 1974, The effect of different working heights on the deltoid muscle, *Scandinavian Journal of Rehabilitation Medicine, Suppl.*, **3**, 26 - 32.

JONSSON, B., 1982, Measurement and evaluation of local muscular strain in the shoulder during constrained work, *Journal of human ergology*, **11**, 73-88.

KADEFORS, R., PETERSEN, I., and HERBERTS, P., 1976, Muscular reaction to welding works: an electromyographic investigation, *Ergonomics*, **19**, 543-558.

KARLSSON, D., 1992, Force distributions in the Human Shoulders, Chalmers University of Technology, Goteborg, Sweden, 1992.

KNOWLTON, R.G., and GILBERT, J.C., 1983, Ulnar deviation and the short-term strength reductions as affected by a cure-handled ripping hammer and conventional claw hammer, *Ergonomics*, **26(2)**, 173-179.

KNOZ, S., 1986, Bent hammer handles, *Human factors*, **28(3)**, 317-323.

KROEMER, K.H.E, 1992, Avoiding cumulative trauma disorders in shops and offices, *American Industrial Hygiene Association Journal*, **53**, 596-604.

LOHR, J. AND UHTHOFF, H. 1990, The microvascular pattern of the supraspinatus tendon, *Clinical Orthopaedics and Related Research*, **254**, 35-38.

MITAL, A., 1986, Effect on body posture and common hand tools on peak torque for wrenches and screwdrivers, *Applied Ergonomics*, **17**, pp 87-96.

MITAL, A. and AGHAZADEH, F. 1985, A review of handtools injuries, In I.D.Brown, R. Goldsmith. COOMBES AND M.A.Sinclair(eds), *Ergonomics International* **85**(London: Taylor &Francis), 85-87.

MITAL, A., and CHANNAVEERAIHAH, C. 1988, Peak volitional torques for wrenches and screwdrivers, *International Journal of Industrial Engineers*, **3**, 41-64.

MERLETTI, R., LO CONTER, L.R., and ORIZIO, C. 1991, Indices of muscle fatigue. *Journal of Electromyography and Kinesiology*, **1(1)**, 20-33.

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH). 1997, Musculoskeletal disorders and workplace factors: A critical review of epidemiological evidence for work related musculoskeletal disorders of the neck, upper extremity, and lower back. (DHHA publication No.97-141). Cincinnati, OH: US. Department of Health and Human Services, Centre for Disease Control and Prevention.

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH). 1997, Work related musculoskeletal disorders, NIOSH facts, NIOSH publications office. NATIONAL SAFETY COUNCIL (NSC)., 2003, Injury Facts, Itasca, IL: Author.

ORTENGREN, R., ANDERSSON, H., BROMAN, R., MAGNUSSON, PETERSON, I., 1975, Vocational electromyography: Studies of localized muscle fatigue at the assembly line", *Ergonomics*, **18**, 157-174.

OLSON, P.1987, Working postures related to musculoskeletal disorders, abstract and poster presented at The XXII International Congress on Occupational Health, Sydney, Australia, September 1987.

PERRY, T., 1978, Normal upper extremity Kinesiology, *Physical Therapy*, **58**,267-278.

PERRY,J. 1988, Muscle control of the shoulder, in C.R. Rowe (ed.), *The shoulder*(New york: Churchill Livingstone) , 17-34.

PHEASANT, S., and O'NEIL, O., 1975, Performance in gripping and turning: A study in hand/handle effectiveness, *Applied Ergonomics*, **6(4)**, pp 205-209.

QUIRING, D.P., and WARFEL, J.H., 1967, The Extremities, Lea and Febiger, Philadelphia.

RADWIN, R.G., VANBERGEIJK, R., and ARMSTRONG, T.J., 1989, Muscle response pneumatic hand tool torque reaction forces, *Ergonomics*, **32(6)**, 665-673.

RODOSKY, M.W., HARNER, C.D. and FU.F.H. 1994, The role of the long head of the biceps muscle and superior glenoid labrum in the anterior stability of the shoulder, *American Journal of Sports Medicine*, **22(1)**, 121-130.

ROSECRANCE, J., COOK, T. and ZIMMERMANN, C. 1996, Work-related Musculoskeletal disorders among construction workers in the pipe trades, *Work*, **7**, 13-20.

SAKAKIBARA, H., MIYAO, M., KONDO, T., and YAMADA, S. 1995, Overhead work and shoulder-neck pain in orchard farmers harvesting pears and apples, *Ergonomics*, 38(4), 700-706.

SIGHOLM, G., HERBERTS, P., ALMSTROÈ M, C. and KADEFORS, R. 1984, Electromyographic analysis of shoulder muscle load, *Journal of Orthopedic Research*, 1, 379 - 386.

SOMMERICH, C.M., McGLOTHING, J.D., and MARRAS, W.S., 1993, Occupational risk factors associated with soft tissues disorders and shoulder: a review of recent investigation in the literature, *Ergonomics*, **36(6)**, 697-717.

SPORRONG, H. and STYF, J. 1999, Effects of isokinetic muscle activity on pressure in the supraspinatus muscle and shoulder torque, *Journal of Orthopaedic Research*, 17, 546-553.

SWIONTKOWSKI, M., IANOTTI, J. and BOULAS, H. 1990, Intraoperative assessment of rotator cuff vascularity using laser Doppler flowmetry, in M. Post, B. Morrey and R. Hawkins (eds), *Surgery of the Shoulder* (St. Louis, MO: Mosby Year Book), 208 - 212.

TORNER, M., ZETTERBER, C., HANSSON, T. and LINDELL V. 1991, Work-load and musculoskeletal problems: a comparison between welders and office clerks (with reference also fisherman), *Ergonomics*, 34, 1179-1196.

TICHAUER, E. R., 1966, Some aspects of stress on forearm and hand industry, *Journal of Occupational Medicine*, **8(2)**, 63-71.

TICHAUER, E. R., GAGE H., Harrison, L.B., 1972, The use of biomechanical profiles in objective work measurement, *Journal of Industrial Engineering*, **4**, 20-27.

TICHAUER, E. R., and GAGE H, 1977, Ergonomic principles basic to hand tool design, *American Industrial Hygiene Association Journal*, **38(38)**, pp 662-634.

TICHAUER, E.R., 1978, *The Biomechanical basis of Ergonomics*, Wiley Interscience, New York, 41-43.

ULIN, S.S., WAYS, C.M., ARMSTRONG, T.J., and SNOOK, S.H., 1990, Perceived exertion and discomfort versus work height with pistol-shaped screwdriver, *American Industrial Hygiene Association Journal*, **51**, pp 588-594.

U.S. Department of Labor, Occupational Safety and Health Administration, Remarks of Joseph, A.D., Before the American physiological association conference "Work, Stress, & Health '95", sep 14th 1995.

WIKER, S., CHAFFIN, D.B., LANGOLF, G.D., 1989, Shoulder posture and localized muscle fatigue and discomfort, *Ergonomics*, **32**, 211-237.

WILSON, J.R., and CORLETT E.N., 1995, Evaluation of Human Work, second edition, Taylor and Francis Ltd, London.

WINKEL, J., and WEGTGAARD, R., 1992, Occupational and individual risks factors for shoulder-neck complaints, Part-II: The scientific basis (literature review) for the guide, *International Journal of Industrial Ergonomics*, **10**, 85-104.

APPENDIX A
SUBJECTIVE RATING

Please mark your answer for each question by putting an X in the space provided. It is important that you answer all questions to the best of your ability.

Choose the best one:

Overhead Support System

Without Support

Which position is comfortable?

Overhead Support system

Far
 Middle
 Near

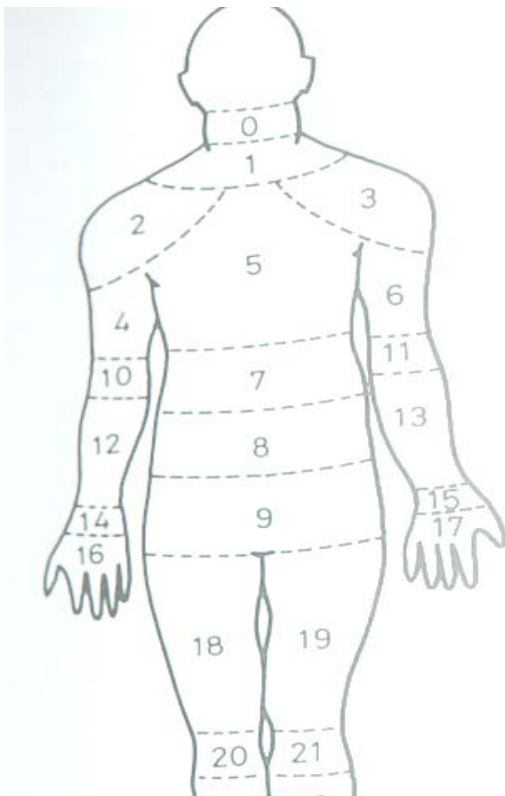
Without support

Far
 Middle
 Near

In this following table, you can see the different body parts involved with and without overhead support system. Please state the areas you have had stiffness, ache, pain or discomfort at any time based on the scale provided.

Extent	
<input type="checkbox"/> None	0
<input type="checkbox"/> Slight	1
<input type="checkbox"/> Moderate	2
<input type="checkbox"/> Severe	3
<input type="checkbox"/> Extreme	4

Figure: The body map for evaluating body part discomfort, by rating.



Body segment affected	Level of pain or discomfort
1	
2	
4	
9	

APPENDIX B
INSTITUTIONAL REVIEW BOARD CERTIFICATE



*Institutional Review Board
203 B-1 David Boyd Hall
Louisiana State University and A&M College
Baton Rouge LA 70803*

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irb@lsu.edu

INSTITUTIONAL REVIEW BOARD

ACTION ON PROTOCOL APPROVAL REQUEST

TO: Fereydoun Aghazadeh
Industrial Engineering

FROM: Robert C. Mathews
Chair, Institutional Review Board for Research with Human Subjects

DATE: September 20, 2005

RE: IRB# 2553

TITLE: "Effect of Overhead Drilling Supported on Muscular Activity of Shoulder"

New Protocol/Modification/Continuation : N

Review type: Full Expedited Review date: 09/16/2005


Risk Factor: Minimal Uncertain Greater Than Minimal

Approved Disapproved

Approval Date: 09/20/2005 Approval Expiration Date: 09/20/2006

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 5

By: Robert C. Mathews, Chairman 

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING -- Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at <http://www.fas.lsu.edu/osp/irb>*

APPENDIX C
PARTICIPANT SUBJECTIVE RATING

Subjective rating for individual subjects without support

Body Segment	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Upper chest(1)	3	4	4	3	2
Shoulder (2)	3	3	2	3	2
Upper arms(4)	2	2	2	2	2
Waist (9)	0	0	0	0	0

Subjective rating for individual subjects with support

Body Segment	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Upper chest(1)	2	3	1	1	2
Shoulder (2)	1	2	1	2	1
Upper arms(4)	1	2	2	1	1
Waist (9)	0	0	0	0	0

APPENDIX D

PAIRED T-TEST RESULTS FOR WITH AND WITHOUT SUPPORT

Participant 1

NORMAL

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.101641	0.016714	0.001246
C6	180	0.097767	0.009361	0.000698
Difference	180	0.003875	0.020877	0.001556

95% CI for mean difference: (0.000804, 0.006946)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.49 P-Value = 0.014

Anterior Deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.158507	0.006336	0.000472
C7	180	0.130960	0.009101	0.000678
Difference	180	0.027547	0.012301	0.000917

95% CI for mean difference: (0.025738, 0.029356)
T-Test of mean difference = 0 (vs not = 0): T-Value = 30.05 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C8

	N	Mean	StDev	SE Mean
C3	180	0.064573	0.013388	0.000998
C8	180	0.044776	0.029364	0.002189
Difference	180	0.019797	0.032315	0.002409

95% CI for mean difference: (0.015044, 0.024550)
T-Test of mean difference = 0 (vs not = 0): T-Value = 8.22 P-Value = 0.000

Middle

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.170952	0.058488	0.004359
C6	180	0.150161	0.009031	0.000673
Difference	180	0.020791	0.059608	0.004443

95% CI for mean difference: (0.012024, 0.029558)
T-Test of mean difference = 0 (vs not = 0): T-Value = 4.68 P-Value = 0.000

Anterior deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.273009	0.092542	0.006898
C7	180	0.208254	0.011926	0.000889
Difference	180	0.064755	0.094188	0.007020

95% CI for mean difference: (0.050902, 0.078608)
T-Test of mean difference = 0 (vs not = 0): T-Value = 9.22 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C8

	N	Mean	StDev	SE Mean
C3	180	0.092067	0.009879	0.000736
C8	180	0.068894	0.030553	0.002277
Difference	180	0.023173	0.032051	0.002389

95% CI for mean difference: (0.018459, 0.027887)
T-Test of mean difference = 0 (vs not = 0): T-Value = 9.70 P-Value = 0.000

Extended

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.443247	0.073977	0.005514
C6	180	0.280973	0.027792	0.002071
Difference	180	0.162274	0.079868	0.005953

95% CI for mean difference: (0.150527, 0.174021)
T-Test of mean difference = 0 (vs not = 0): T-Value = 27.26 P-Value = 0.000

Anterior deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.788638	0.107598	0.008020
C7	180	0.505129	0.030535	0.002276
Difference	180	0.283509	0.115554	0.008613

95% CI for mean difference: (0.266513, 0.300505)
T-Test of mean difference = 0 (vs not = 0): T-Value = 32.92 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C8

	N	Mean	StDev	SE Mean
C3	180	0.097863	0.068015	0.005070
C8	180	0.056858	0.031994	0.002385
Difference	180	0.041005	0.074143	0.005526

95% CI for mean difference: (0.030100, 0.051910)
T-Test of mean difference = 0 (vs not = 0): T-Value = 7.42 P-Value = 0.000

Participant 2

Normal

Bicep

Paired T-Test and CI: C1, C7

	N	Mean	StDev	SE Mean
C1	180	0.192995	0.046240	0.003447
C7	180	0.184889	0.014387	0.001072
Difference	180	0.008106	0.048001	0.003578

95% CI for mean difference: (0.001046, 0.015166)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.27 P-Value = 0.025

Anterior Deltoid

Paired T-Test and CI: C2, C8

	N	Mean	StDev	SE Mean
C2	180	0.285524	0.023586	0.001758
C8	180	0.254100	0.077612	0.005785
Difference	180	0.031424	0.073958	0.005512

95% CI for mean difference: (0.020546, 0.042302)
T-Test of mean difference = 0 (vs not = 0): T-Value = 5.70 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C9

	N	Mean	StDev	SE Mean
C3	180	0.125536	0.030825	0.002298
C9	180	0.084253	0.027528	0.002052
Difference	180	0.041283	0.045003	0.003354

95% CI for mean difference: (0.034664, 0.047902)
T-Test of mean difference = 0 (vs not = 0): T-Value = 12.31 P-Value = 0.000

Middle

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.118921	0.012001	0.000895
C6	180	0.104564	0.032115	0.002394
Difference	180	0.014357	0.035088	0.002615

95% CI for mean difference: (0.009196, 0.019518)
T-Test of mean difference = 0 (vs not = 0): T-Value = 5.49 P-Value = 0.000

Anterior Deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.194068	0.015376	0.001146
C7	180	0.151221	0.046758	0.003485
Difference	180	0.042847	0.050032	0.003729

95% CI for mean difference: (0.035489, 0.050206)
T-Test of mean difference = 0 (vs not = 0): T-Value = 11.49 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C8

Paired T for C3 - C8

	N	Mean	StDev	SE Mean
C3	180	0.057907	0.021659	0.001614
C8	180	0.043773	0.010315	0.000769
Difference	180	0.014133	0.024550	0.001830

95% CI for mean difference: (0.010523, 0.017744)
T-Test of mean difference = 0 (vs not = 0): T-Value = 7.72 P-Value = 0.000

EXTENDED

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.215508	0.058673	0.004373
C6	180	0.191687	0.051154	0.003813
Difference	180	0.023821	0.073461	0.005475

95% CI for mean difference: (0.013016, 0.034626)

T-Test of mean difference = 0 (vs not = 0): T-Value = 4.35 P-Value = 0.000

Anterior Deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.334800	0.090871	0.006773
C7	180	0.306070	0.092728	0.006912
Difference	180	0.028730	0.123433	0.009200

95% CI for mean difference: (0.010575, 0.046885)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.12 P-Value = 0.002

Trapezius

Paired T-Test and CI: C3, C8

	N	Mean	StDev	SE Mean
C3	180	0.084765	0.033560	0.002501
C8	180	0.077304	0.033272	0.002480
Difference	180	0.007460	0.046257	0.003448

95% CI for mean difference: (0.000657, 0.014264)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.16 P-Value = 0.032

Participant 3

NORMAL

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.141760	0.171853	0.012809
C6	180	0.090711	0.065715	0.004898
Difference	180	0.051048	0.183820	0.013701

95% CI for mean difference: (0.024012, 0.078085)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.73 P-Value = 0.000

Anterior Deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.240602	0.333542	0.024861
C7	180	0.123029	0.075292	0.005612
Difference	180	0.117573	0.342137	0.025501

95% CI for mean difference: (0.067251, 0.167895)
T-Test of mean difference = 0 (vs not = 0): T-Value = 4.61 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C8

	N	Mean	StDev	SE Mean
C3	180	0.066247	0.061939	0.004617
C8	180	0.053300	0.057428	0.004280
Difference	180	0.012947	0.086351	0.006436

95% CI for mean difference: (0.000247, 0.025648)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.01 P-Value = 0.046

Middle

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.129498	0.084258	0.006280
C6	180	0.104905	0.051941	0.003871
Difference	180	0.024593	0.101269	0.007548

95% CI for mean difference: (0.009698, 0.039488)

T-Test of mean difference = 0 (vs not = 0): T-Value = 3.26 P-Value = 0.001

Anterior Deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.186288	0.130028	0.009692
C7	180	0.163751	0.062317	0.004645
Difference	180	0.022537	0.146951	0.010953

95% CI for mean difference: (0.000923, 0.044151)

T-Test of mean difference = 0 (vs not = 0): T-Value = 2.06 P-Value = 0.041

Trapezius

Paired T-Test and CI: C3, C8

	N	Mean	StDev	SE Mean
C3	180	0.077075	0.051050	0.003805
C8	180	0.046059	0.047265	0.003523
Difference	180	0.031016	0.071872	0.005357

95% CI for mean difference: (0.020445, 0.041587)

T-Test of mean difference = 0 (vs not = 0): T-Value = 5.79 P-Value = 0.000

EXTENDED

Bicep

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.377039	0.066520	0.004958
C6	180	0.132701	0.165642	0.012346
Difference	180	0.244338	0.176287	0.013140

95% CI for mean difference: (0.218410, 0.270267)

T-Test of mean difference = 0 (vs not = 0): T-Value = 18.60 P-Value = 0.000

Anterior Deltoid

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.629695	0.061531	0.004586
C7	180	0.188441	0.216563	0.016142
Difference	180	0.441254	0.219628	0.016370

95% CI for mean difference: (0.408951, 0.473558)

T-Test of mean difference = 0 (vs not = 0): T-Value = 26.95 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C8

	N	Mean	StDev	SE Mean
C3	180	0.124384	0.089458	0.006668
C8	180	0.077073	0.127025	0.009468
Difference	180	0.047311	0.155660	0.011602

95% CI for mean difference: (0.024416, 0.070206)

T-Test of mean difference = 0 (vs not = 0): T-Value = 4.08 P-Value = 0.000

Participant 4

NORMAL

Bicep

Paired T-Test and CI: C1, C8

	N	Mean	StDev	SE Mean
C1	180	0.189403	0.105224	0.007843
C8	180	0.149082	0.075782	0.005648

Difference 180 0.040321 0.099621 0.007425
 95% CI for mean difference: (0.025668, 0.054973)
 T-Test of mean difference = 0 (vs not = 0): T-Value = 5.43 P-Value = 0.000

Anterior Deltoid

Paired T-Test and CI: C2, C9

	N	Mean	StDev	SE Mean
C2	180	0.259951	0.194213	0.014476
C9	180	0.228484	0.099718	0.007433
Difference	180	0.031468	0.193062	0.014390

95% CI for mean difference: (0.003072, 0.059863)
 T-Test of mean difference = 0 (vs not = 0): T-Value = 2.19 P-Value = 0.030

Trapezius

Paired T-Test and CI: C3, C10

	N	Mean	StDev	SE Mean
C3	180	0.120318	0.032981	0.002458
C10	180	0.071339	0.071082	0.005298
Difference	180	0.048980	0.062332	0.004646

95% CI for mean difference: (0.039812, 0.058148)
 T-Test of mean difference = 0 (vs not = 0): T-Value = 10.54 P-Value = 0.000

MIDDLE

Bicep

Paired T-Test and CI: C1, C8

	N	Mean	StDev	SE Mean
C1	180	0.113998	0.091809	0.006843
C8	180	0.049192	0.034236	0.002552
Difference	180	0.064806	0.086059	0.006414

95% CI for mean difference: (0.052149, 0.077464)
 T-Test of mean difference = 0 (vs not = 0): T-Value = 10.10 P-Value = 0.000

Anterior Deltoid

Paired T-Test and CI: C2, C9

	N	Mean	StDev	SE Mean
C2	180	0.180727	0.129853	0.009679
C9	180	0.074339	0.050261	0.003746
Difference	180	0.106388	0.125719	0.009371

95% CI for mean difference: (0.087897, 0.124879)
 T-Test of mean difference = 0 (vs not = 0): T-Value = 11.35 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C10

	N	Mean	StDev	SE Mean
C3	180	0.047281	0.056841	0.004237
C10	180	0.024064	0.021771	0.001623
Difference	180	0.023217	0.050858	0.003791

95% CI for mean difference: (0.015737, 0.030697)
 T-Test of mean difference = 0 (vs not = 0): T-Value = 6.12 P-Value = 0.000

EXTENDED

Bicep

Paired T-Test and CI: C1, C8

	N	Mean	StDev	SE Mean
C1	180	0.395022	0.222622	0.016593
C8	180	0.111057	0.142404	0.010614
Difference	180	0.283965	0.248619	0.018531

95% CI for mean difference: (0.247398, 0.320532)
T-Test of mean difference = 0 (vs not = 0): T-Value = 15.32 P-Value = 0.000

Anterior Deltoid

Paired T-Test and CI: C2, C9

	N	Mean	StDev	SE Mean
C2	180	0.597260	0.303213	0.022600
C9	180	0.147867	0.173419	0.012926
Difference	180	0.449393	0.333056	0.024825

95% CI for mean difference: (0.400407, 0.498379)

T-Test of mean difference = 0 (vs not = 0): T-Value = 18.10 P-Value = 0.000

Trapezius

Paired T-Test and CI: C3, C10

	N	Mean	StDev	SE Mean
C3	180	0.208622	0.159943	0.011921
C10	180	0.074248	0.116776	0.008704
Difference	180	0.134374	0.185812	0.013850

95% CI for mean difference: (0.107044, 0.161703)

T-Test of mean difference = 0 (vs not = 0): T-Value = 9.70 P-Value = 0.000

APPENDIX E

PAIRED T-TEST RESULTS FOR BEST POSITION

Participant 1 without support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C6

	N	Mean	StDev	SE Mean
C1	180	0.101641	0.016714	0.001246
C6	180	0.170952	0.058488	0.004359
Difference	180	-0.069310	0.062354	0.004648

95% CI for mean difference: (-0.078481, -0.060139)
T-Test of mean difference = 0 (vs not = 0): T-Value = -14.91 P-Value = 0.000

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C10

	N	Mean	StDev	SE Mean
C1	180	0.101641	0.016714	0.001246
C10	180	0.443247	0.073977	0.005514
Difference	180	-0.341606	0.081634	0.006085

95% CI for mean difference: (-0.353613, -0.329599)
T-Test of mean difference = 0 (vs not = 0): T-Value = -56.14 P-Value = 0.000

Near Vs Middle (Anterior Deltoid)

Paired T-Test and CI: C2, C7

	N	Mean	StDev	SE Mean
C2	180	0.158507	0.006336	0.000472
C7	180	0.273009	0.092542	0.006898
Difference	180	-0.114502	0.093089	0.006938

95% CI for mean difference: (-0.128194, -0.100810)
T-Test of mean difference = 0 (vs not = 0): T-Value = -16.50 P-Value = 0.000

Near Vs Far (Anterior Deltoid)

Paired T for C2 - C11

	N	Mean	StDev	SE Mean
C2	180	0.158507	0.006336	0.000472
C11	180	0.788638	0.107598	0.008020
Difference	180	-0.630131	0.110075	0.008205

95% CI for mean difference: (-0.646321, -0.613941)
T-Test of mean difference = 0 (vs not = 0): T-Value = -76.80 P-Value = 0.000

Near Vs Far (Trapezius)

Paired T for C3 - C12

	N	Mean	StDev	SE Mean
C3	180	0.064573	0.013388	0.000998
C12	180	0.097863	0.068015	0.005070
Difference	180	-0.033290	0.071145	0.005303

95% CI for mean difference: (-0.043754, -0.022826)
T-Test of mean difference = 0 (vs not = 0): T-Value = -6.28 P-Value = 0.000

Near Vs Middle (Trapezius)

Paired T for C3 - C8

	N	Mean	StDev	SE Mean
C3	180	0.064573	0.013388	0.000998
C8	180	0.092067	0.009879	0.000736
Difference	180	-0.027494	0.016191	0.001207

95% CI for mean difference: (-0.029875, -0.025113)

T-Test of mean difference = 0 (vs not = 0): T-Value = -22.78 P-Value = 0.000

Participant 1 with support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C5

	N	Mean	StDev	SE Mean
C1	180	0.097767	0.009361	0.000698
C5	180	0.150161	0.009031	0.000673
Difference	180	-0.052394	0.011462	0.000854

95% CI for mean difference: (-0.054080, -0.050708)
T-Test of mean difference = 0 (vs not = 0): T-Value = -61.33 P-Value = 0.000

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C9

	N	Mean	StDev	SE Mean
C1	180	0.097767	0.009361	0.000698
C9	180	0.280973	0.027792	0.002071
Difference	180	-0.183206	0.030242	0.002254

95% CI for mean difference: (-0.187654, -0.178758)
T-Test of mean difference = 0 (vs not = 0): T-Value = -81.28 P-Value = 0.000

Middle Vs Far (Bicep)

Paired T-Test and CI: C5, C9

	N	Mean	StDev	SE Mean
C5	180	0.150161	0.009031	0.000673
C9	180	0.280973	0.027792	0.002071
Difference	180	-0.130813	0.029679	0.002212

95% CI for mean difference: (-0.135178, -0.126447)
T-Test of mean difference = 0 (vs not = 0): T-Value = -59.13 P-Value = 0.000

Near Vs Middle (Anterior Deltoid)

Paired T-Test and CI: C2, C6

	N	Mean	StDev	SE Mean
C2	180	0.130960	0.009101	0.000678
C6	180	0.208254	0.011926	0.000889
Difference	180	-0.077294	0.012921	0.000963

95% CI for mean difference: (-0.079194, -0.075394)
T-Test of mean difference = 0 (vs not = 0): T-Value = -80.26 P-Value = 0.000

Near Vs Far (Anterior Deltoid)

Paired T-Test and CI: C2, C10

	N	Mean	StDev	SE Mean
C2	180	0.130960	0.009101	0.000678
C10	180	0.505129	0.030535	0.002276
Difference	180	-0.374169	0.032745	0.002441

95% CI for mean difference: (-0.378985, -0.369353)
T-Test of mean difference = 0 (vs not = 0): T-Value = -153.30 P-Value = 0.000

Middle Vs Far (Bicep)

Paired T-Test and CI: C6, C10

	N	Mean	StDev	SE Mean
C6	180	0.208254	0.011926	0.000889
C10	180	0.505129	0.030535	0.002276
Difference	180	-0.296875	0.033729	0.002514

95% CI for mean difference: (-0.301836, -0.291914)
T-Test of mean difference = 0 (vs not = 0): T-Value = -118.09 P-Value = 0.000

Near Vs Middle (Trapezius)

Paired T-Test and CI: C3, C7

	N	Mean	StDev	SE Mean
C3	180	0.044776	0.029364	0.002189
C7	180	0.068894	0.030553	0.002277
Difference	180	-0.024118	0.046646	0.003477

95% CI for mean difference: (-0.030979, -0.017257)
T-Test of mean difference = 0 (vs not = 0): T-Value = -6.94 P-Value = 0.000

Near Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.044776	0.029364	0.002189
C11	180	0.056858	0.031994	0.002385
Difference	180	-0.012082	0.048018	0.003579

95% CI for mean difference: (-0.019145, -0.005020)
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.38 P-Value = 0.001

Middle Vs Far (Trapezius)

Paired T-Test and CI: C7, C11

	N	Mean	StDev	SE Mean
C7	180	0.068894	0.030553	0.002277
C11	180	0.056858	0.031994	0.002385
Difference	180	0.012036	0.041699	0.003108

95% CI for mean difference: (0.005903, 0.018169)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.87 P-Value = 0.000

Participant 2 without support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C5

	N	Mean	StDev	SE Mean
C1	180	0.192995	0.046240	0.003447
C5	180	0.118921	0.012001	0.000895
Difference	180	0.074074	0.048315	0.003601

95% CI for mean difference: (0.066968, 0.081180)
T-Test of mean difference = 0 (vs not = 0): T-Value = 20.57 P-Value = 0.000

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C9

	N	Mean	StDev	SE Mean
C1	180	0.192995	0.046240	0.003447
C9	180	0.215508	0.058673	0.004373
Difference	180	-0.022513	0.078899	0.005881

95% CI for mean difference: (-0.034118, -0.010909)
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.83 P-Value = 0.000

Middle Vs Far (Bicep)

Paired T-Test and CI: C5, C9

	N	Mean	StDev	SE Mean
C5	180	0.118921	0.012001	0.000895
C9	180	0.215508	0.058673	0.004373
Difference	180	-0.096587	0.058907	0.004391

95% CI for mean difference: (-0.105251, -0.087923)
T-Test of mean difference = 0 (vs not = 0): T-Value = -22.00 P-Value = 0.000

Near Vs Middle (Anterior Deltoid)

Paired T-Test and CI: C2, C6

	N	Mean	StDev	SE Mean
C2	180	0.285524	0.023586	0.001758
C6	180	0.194068	0.015376	0.001146
Difference	180	0.091456	0.020952	0.001562

95% CI for mean difference: (0.088374, 0.094538)
T-Test of mean difference = 0 (vs not = 0): T-Value = 58.56 P-Value = 0.000

Near Vs Far (Anterior Deltoid)

Paired T-Test and CI: C2, C10

	N	Mean	StDev	SE Mean
C2	180	0.285524	0.023586	0.001758
C10	180	0.334800	0.090871	0.006773
Difference	180	-0.049276	0.097417	0.007261

95% CI for mean difference: (-0.063604, -0.034947)
T-Test of mean difference = 0 (vs not = 0): T-Value = -6.79 P-Value = 0.000

Middle Vs Far (Anterior Deltoid)

Paired T-Test and CI: C6, C10

	N	Mean	StDev	SE Mean
C6	180	0.194068	0.015376	0.001146
C10	180	0.334800	0.090871	0.006773
Difference	180	-0.140732	0.094481	0.007042

95% CI for mean difference: (-0.154628, -0.126835)
T-Test of mean difference = 0 (vs not = 0): T-Value = -19.98 P-Value = 0.000

Near Vs Middle (Trapezius)

Paired T-Test and CI: C3, C7

	N	Mean	StDev	SE Mean
C3	180	0.125536	0.030825	0.002298
C7	180	0.057907	0.021659	0.001614
Difference	180	0.067629	0.041193	0.003070

95% CI for mean difference: (0.061571, 0.073688)
T-Test of mean difference = 0 (vs not = 0): T-Value = 22.03 P-Value = 0.000

Near Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.125536	0.030825	0.002298
C11	180	0.084765	0.033560	0.002501
Difference	180	0.040772	0.053137	0.003961

95% CI for mean difference: (0.032956, 0.048587)
T-Test of mean difference = 0 (vs not = 0): T-Value = 10.29 P-Value = 0.000

Middle Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.125536	0.030825	0.002298
C11	180	0.084765	0.033560	0.002501
Difference	180	0.040772	0.053137	0.003961

95% CI for mean difference: (0.032956, 0.048587)
T-Test of mean difference = 0 (vs not = 0): T-Value = 10.29 P-Value = 0.000

Participant 2 with support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C5

	N	Mean	StDev	SE Mean
C1	180	0.184889	0.014387	0.001072
C5	180	0.104564	0.032115	0.002394
Difference	180	0.080325	0.032381	0.002414

95% CI for mean difference: (0.075562, 0.085088)
T-Test of mean difference = 0 (vs not = 0): T-Value = 33.28 P-Value = 0.000

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C9

	N	Mean	StDev	SE Mean
C1	180	0.184889	0.014387	0.001072
C9	180	0.191687	0.051154	0.003813
Difference	180	-0.006798	0.054270	0.004045

95% CI for mean difference: (-0.014780, 0.001184)
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.68 P-Value = 0.095

Middle Vs Far (Bicep)

Paired T-Test and CI: C5, C9

	N	Mean	StDev	SE Mean
C5	180	0.104564	0.032115	0.002394
C9	180	0.191687	0.051154	0.003813
Difference	180	-0.087123	0.058908	0.004391

95% CI for mean difference: (-0.095787, -0.078459)
T-Test of mean difference = 0 (vs not = 0): T-Value = -19.84 P-Value = 0.000

Near Vs Middle (Anterior Deltoid)

Paired T-Test and CI: C2, C6

	N	Mean	StDev	SE Mean
C2	180	0.254100	0.077612	0.005785
C6	180	0.151221	0.046758	0.003485
Difference	180	0.102879	0.089512	0.006672

95% CI for mean difference: (0.089714, 0.116045)
T-Test of mean difference = 0 (vs not = 0): T-Value = 15.42 P-Value = 0.000

Near Vs Far (Anterior Deltoid)

Paired T-Test and CI: C2, C10

	N	Mean	StDev	SE Mean
C2	180	0.254100	0.077612	0.005785
C10	180	0.306070	0.092728	0.006912
Difference	180	-0.051970	0.117188	0.008735

95% CI for mean difference: (-0.069206, -0.034733)
T-Test of mean difference = 0 (vs not = 0): T-Value = -5.95 P-Value = 0.000

Middle Vs Far (Anterior Deltoid)

Paired T-Test and CI: C6, C10

	N	Mean	StDev	SE Mean
C6	180	0.151221	0.046758	0.003485
C10	180	0.306070	0.092728	0.006912
Difference	180	-0.154849	0.104263	0.007771

95% CI for mean difference: (-0.170184, -0.139514)
T-Test of mean difference = 0 (vs not = 0): T-Value = -19.93 P-Value = 0.000

Near Vs Middle (Trapezius)

Paired T-Test and CI: C3, C7

	N	Mean	StDev	SE Mean
C3	180	0.084253	0.027528	0.002052
C7	180	0.043773	0.010315	0.000769
Difference	180	0.040480	0.029324	0.002186

95% CI for mean difference: (0.036167, 0.044793)
T-Test of mean difference = 0 (vs not = 0): T-Value = 18.52 P-Value = 0.000

Near Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.084253	0.027528	0.002052
C11	180	0.077304	0.033272	0.002480
Difference	180	0.006949	0.035911	0.002677

95% CI for mean difference: (0.001667, 0.012231)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.60 P-Value = 0.010

Middle Vs Far (Trapezius)

Paired T-Test and CI: C7, C11

	N	Mean	StDev	SE Mean
C7	180	0.043773	0.010315	0.000769
C11	180	0.077304	0.033272	0.002480
Difference	180	-0.033531	0.036351	0.002709

95% CI for mean difference: (-0.038877, -0.028184)
T-Test of mean difference = 0 (vs not = 0): T-Value = -12.38 P-Value = 0.000

Participant 3 without support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C5

	N	Mean	StDev	SE Mean
C1	180	0.141760	0.171853	0.012809
C5	180	0.129498	0.084258	0.006280
Difference	180	0.012261	0.196505	0.014647

95% CI for mean difference: (-0.016641, 0.041164)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.84 P-Value = 0.404

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C9

	N	Mean	StDev	SE Mean
C1	180	0.141760	0.171853	0.012809
C9	180	0.132701	0.165642	0.012346
Difference	180	0.009059	0.223535	0.016661

95% CI for mean difference: (-0.023819, 0.041936)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.54 P-Value = 0.587

Middle Vs Far (Bicep)

Paired T-Test and CI: C5, C9

	N	Mean	StDev	SE Mean
C5	180	0.129498	0.084258	0.006280
C9	180	0.132701	0.165642	0.012346
Difference	180	-0.003203	0.195177	0.014548

95% CI for mean difference: (-0.031910, 0.025504)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.22 P-Value = 0.826

Near Vs Middle (Anterior deltoid)

Paired T-Test and CI: C2, C6

	N	Mean	StDev	SE Mean
C2	180	0.240602	0.333542	0.024861
C6	180	0.186288	0.130028	0.009692
Difference	180	0.054314	0.358920	0.026752

95% CI for mean difference: (0.001524, 0.107105)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.03 P-Value = 0.044

Near Vs Far (Anterior deltoid)

Paired T-Test and CI: C2, C10

	N	Mean	StDev	SE Mean
C2	180	0.240602	0.333542	0.024861
C10	180	0.188441	0.216563	0.016142
Difference	180	0.052161	0.372823	0.027789

95% CI for mean difference: (-0.002674, 0.106997)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.88 P-Value = 0.062

Middle Vs Far (Anterior deltoid)

Paired T-Test and CI: C6, C10

	N	Mean	StDev	SE Mean
C6	180	0.186288	0.130028	0.009692
C10	180	0.188441	0.216563	0.016142
Difference	180	-0.002153	0.266803	0.019886

95% CI for mean difference: (-0.041394, 0.037089)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.11 P-Value = 0.914

Near Vs Middle (Trapezius)

Paired T-Test and CI: C3, C7

	N	Mean	StDev	SE Mean
C3	180	0.066247	0.061939	0.004617
C7	180	0.077075	0.051050	0.003805
Difference	180	-0.010828	0.083654	0.006235

95% CI for mean difference: (-0.023132, 0.001476)
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.74 P-Value = 0.084

Near Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.066247	0.061939	0.004617
C11	180	0.077073	0.127025	0.009468
Difference	180	-0.010826	0.132241	0.009857

95% CI for mean difference: (-0.030276, 0.008624)
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.10 P-Value = 0.274

Middle Vs Far (Trapezius)

Paired T-Test and CI: C7, C11

	N	Mean	StDev	SE Mean
C7	180	0.077075	0.051050	0.003805
C11	180	0.077073	0.127025	0.009468
Difference	180	0.000002	0.141997	0.010584

95% CI for mean difference: (-0.020883, 0.020887)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.00 P-Value = 1.000

Participant 3 with support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C5

	N	Mean	StDev	SE Mean
C1	180	0.090711	0.065715	0.004898
C5	180	0.129498	0.084258	0.006280
Difference	180	-0.038787	0.111161	0.008285

95% CI for mean difference: (-0.055136, -0.022437)
T-Test of mean difference = 0 (vs not = 0): T-Value = -4.68 P-Value = 0.000

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C9

	N	Mean	StDev	SE Mean
C1	180	0.090711	0.065715	0.004898
C9	180	0.132701	0.165642	0.012346
Difference	180	-0.041990	0.182083	0.013572

95% CI for mean difference: (-0.068771, -0.015209)
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.09 P-Value = 0.002

Middle Vs Far (Bicep)

Paired T-Test and CI: C5, C9

	N	Mean	StDev	SE Mean
C5	180	0.129498	0.084258	0.006280
C9	180	0.132701	0.165642	0.012346
Difference	180	-0.003203	0.195177	0.014548

95% CI for mean difference: (-0.031910, 0.025504)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.22 P-Value = 0.826

Near Vs Middle (Anterior Deltoid)

Paired T-Test and CI: C2, C6

	N	Mean	StDev	SE Mean
C2	180	0.123029	0.075292	0.005612
C6	180	0.186288	0.130028	0.009692
Difference	180	-0.063259	0.154183	0.011492

95% CI for mean difference: (-0.085936, -0.040582)
T-Test of mean difference = 0 (vs not = 0): T-Value = -5.50 P-Value = 0.000

Near Vs Far (Anterior Deltoid)

Paired T-Test and CI: C2, C10

	N	Mean	StDev	SE Mean
C2	180	0.123029	0.075292	0.005612
C10	180	0.188441	0.216563	0.016142
Difference	180	-0.065412	0.234652	0.017490

95% CI for mean difference: (-0.099925, -0.030899)
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.74 P-Value = 0.000

Middle Vs Far (Anterior Deltoid)

Paired T-Test and CI: C6, C10

	N	Mean	StDev	SE Mean
C6	180	0.186288	0.130028	0.009692
C10	180	0.188441	0.216563	0.016142
Difference	180	-0.002153	0.266803	0.019886

95% CI for mean difference: (-0.041394, 0.037089)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.11 P-Value = 0.914

Near Vs Middle (Trapezius)

Paired T-Test and CI: C3, C7

	N	Mean	StDev	SE Mean
C3	180	0.053300	0.057428	0.004280
C7	180	0.077075	0.051050	0.003805
Difference	180	-0.023775	0.077246	0.005758

95% CI for mean difference: (-0.035137, -0.012414)
T-Test of mean difference = 0 (vs not = 0): T-Value = -4.13 P-Value = 0.000

Near Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.053300	0.057428	0.004280
C11	180	0.077073	0.127025	0.009468
Difference	180	-0.023773	0.134710	0.010041

95% CI for mean difference: (-0.043587, -0.003960)
T-Test of mean difference = 0 (vs not = 0): T-Value = -2.37 P-Value = 0.019

Middle Vs Far (Trapezius)

Paired T-Test and CI: C7, C11

	N	Mean	StDev	SE Mean
C7	180	0.077075	0.051050	0.003805
C11	180	0.077073	0.127025	0.009468
Difference	180	0.000002	0.141997	0.010584

95% CI for mean difference: (-0.020883, 0.020887)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.00 P-Value = 1.000

Participant 4 without support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C5

	N	Mean	StDev	SE Mean
C1	180	0.189403	0.105224	0.007843
C5	180	0.113998	0.091809	0.006843
Difference	180	0.075405	0.145471	0.010843

95% CI for mean difference: (0.054009, 0.096801)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.95 P-Value = 0.000

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C9

	N	Mean	StDev	SE Mean
C1	180	0.189403	0.105224	0.007843
C9	180	0.111057	0.142404	0.010614
Difference	180	0.078346	0.169176	0.012610

95% CI for mean difference: (0.053463, 0.103229)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.21 P-Value = 0.000

Middle Vs Far (Bicep)

Paired T-Test and CI: C5, C9

	N	Mean	StDev	SE Mean
C5	180	0.113998	0.091809	0.006843
C9	180	0.111057	0.142404	0.010614
Difference	180	0.002941	0.119331	0.008894

95% CI for mean difference: (-0.014611, 0.020492)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.33 P-Value = 0.741

Near Vs Middle (Anterior Deltoid)

Paired T-Test and CI: C2, C6

	N	Mean	StDev	SE Mean
C2	180	0.259951	0.194213	0.014476
C6	180	0.180727	0.129853	0.009679
Difference	180	0.079224	0.238888	0.017806

95% CI for mean difference: (0.044088, 0.114360)
T-Test of mean difference = 0 (vs not = 0): T-Value = 4.45 P-Value = 0.000

Near Vs Far (Anterior Deltoid)

Paired T-Test and CI: C2, C10

	N	Mean	StDev	SE Mean
C2	180	0.259951	0.194213	0.014476
C10	180	0.147867	0.173419	0.012926
Difference	180	0.112084	0.239669	0.017864

95% CI for mean difference: (0.076833, 0.147335)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.27 P-Value = 0.000

Middle Vs Far (Anterior Deltoid)

Paired T-Test and CI: C6, C10

	N	Mean	StDev	SE Mean
C6	180	0.180727	0.129853	0.009679
C10	180	0.147867	0.173419	0.012926
Difference	180	0.032860	0.152680	0.011380

95% CI for mean difference: (0.010404, 0.055316)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.89 P-Value = 0.004

Near Vs Middle (Trapezius)

Paired T-Test and CI: C3, C7

	N	Mean	StDev	SE Mean
C3	180	0.120318	0.032981	0.002458
C7	180	0.047281	0.056841	0.004237
Difference	180	0.073037	0.071452	0.005326

95% CI for mean difference: (0.062528, 0.083547)
T-Test of mean difference = 0 (vs not = 0): T-Value = 13.71 P-Value = 0.000

Near Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.120318	0.032981	0.002458
C11	180	0.074248	0.116776	0.008704
Difference	180	0.046070	0.123985	0.009241

95% CI for mean difference: (0.027834, 0.064306)
T-Test of mean difference = 0 (vs not = 0): T-Value = 4.99 P-Value = 0.000

Middle Vs Far (Trapezius)

Paired T-Test and CI: C7, C11

	N	Mean	StDev	SE Mean
C7	180	0.047281	0.056841	0.004237
C11	180	0.074248	0.116776	0.008704
Difference	180	-0.026967	0.096499	0.007193

95% CI for mean difference: (-0.041161, -0.012774)
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.75 P-Value = 0.000

Participant 4 with support

Near Vs Middle (Bicep)

Paired T-Test and CI: C1, C5

	N	Mean	StDev	SE Mean
C1	180	0.149082	0.075782	0.005648
C5	180	0.049192	0.034236	0.002552
Difference	180	0.099891	0.076170	0.005677

95% CI for mean difference: (0.088688, 0.111094)
T-Test of mean difference = 0 (vs not = 0): T-Value = 17.59 P-Value = 0.000

Near Vs Far (Bicep)

Paired T-Test and CI: C1, C9

	N	Mean	StDev	SE Mean
C1	180	0.149082	0.075782	0.005648
C9	180	0.395022	0.222622	0.016593
Difference	180	-0.245940	0.234655	0.017490

95% CI for mean difference: (-0.280453, -0.211426)
T-Test of mean difference = 0 (vs not = 0): T-Value = -14.06 P-Value = 0.000

Middle Vs Far (Bicep)

Paired T-Test and CI: C5, C9

	N	Mean	StDev	SE Mean
C5	180	0.049192	0.034236	0.002552
C9	180	0.395022	0.222622	0.016593
Difference	180	-0.345831	0.216917	0.016168

95% CI for mean difference: (-0.377735, -0.313926)
T-Test of mean difference = 0 (vs not = 0): T-Value = -21.39 P-Value = 0.000

Near Vs Middle (Anterior Deltoid)

Paired T-Test and CI: C2, C6

	N	Mean	StDev	SE Mean
C2	180	0.228484	0.099718	0.007433
C6	180	0.074339	0.050261	0.003746
Difference	180	0.154145	0.101928	0.007597

95% CI for mean difference: (0.139153, 0.169137)
T-Test of mean difference = 0 (vs not = 0): T-Value = 20.29 P-Value = 0.000

Near Vs Far (Anterior Deltoid)

Paired T-Test and CI: C2, C10

	N	Mean	StDev	SE Mean
C2	180	0.228484	0.099718	0.007433
C10	180	0.597260	0.303213	0.022600
Difference	180	-0.368776	0.325353	0.024250

95% CI for mean difference: (-0.416630, -0.320923)
T-Test of mean difference = 0 (vs not = 0): T-Value = -15.21 P-Value = 0.000

Middle Vs Far (Anterior Deltoid)

Paired T-Test and CI: C6, C10

	N	Mean	StDev	SE Mean
C6	180	0.074339	0.050261	0.003746
C10	180	0.597260	0.303213	0.022600
Difference	180	-0.522921	0.297118	0.022146

95% CI for mean difference: (-0.566622, -0.479220)
T-Test of mean difference = 0 (vs not = 0): T-Value = -23.61 P-Value = 0.000

Near Vs Middle (Trapezius)

Paired T-Test and CI: C3, C7

	N	Mean	StDev	SE Mean
C3	180	0.071339	0.071082	0.005298
C7	180	0.024064	0.021771	0.001623
Difference	180	0.047274	0.070769	0.005275

95% CI for mean difference: (0.036865, 0.057683)
T-Test of mean difference = 0 (vs not = 0): T-Value = 8.96 P-Value = 0.000

Near Vs Far (Trapezius)

Paired T-Test and CI: C3, C11

	N	Mean	StDev	SE Mean
C3	180	0.071339	0.071082	0.005298
C11	180	0.208622	0.159943	0.011921
Difference	180	-0.137284	0.166638	0.012420

95% CI for mean difference: (-0.161793, -0.112774)
T-Test of mean difference = 0 (vs not = 0): T-Value = -11.05 P-Value = 0.000

Middle Vs Far (Trapezius)

Paired T-Test and CI: C7, C11

	N	Mean	StDev	SE Mean
C7	180	0.024064	0.021771	0.001623
C11	180	0.208622	0.159943	0.011921
Difference	180	-0.184558	0.155168	0.011566

95% CI for mean difference: (-0.207380, -0.161736)
T-Test of mean difference = 0 (vs not = 0): T-Value = -15.96 P-Value = 0.000

VITA

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