UTSA The University of Texas at San Antonio™ HONORS COLLEGE

Honors Thesis Submission Form

Student Information

Name: Joshua Kuehne

myUTSA ID (abc123): ptj732

Preferred Email: kuehnejtk@gmail.com

Title of thesis: The Evaluation of Repetitive Overhead Movements in Heating Ventilation and Air Conditioning Technicians

Term of submission: Fall 2016 Term of graduation: Fall 2016

Degree to which thesis applies: BS N/A

1st Major: Kinesiology 1st Minor: Biology

2nd Major: 2nd Minor:

Thesis Committee Members

Thesis Advisor Signature Print Name: Dr. Sakiko Oyama Date: 12-6-2016

Reader Signature Print Name: Dr. Alberto Cordova Date: 12/7/2016

Reader Signature Print Name: Dr. Catherine Ortega Date: 12/7/2016

Reader Signature Print Name: Date:

Honors College

Associate Dean Signature: n/a Date:

Based on faculty's recommendation, I hereby ☑ Approve ☐ Deny the request.

Dean Signature: Date: 12/15/16

Submission

Save this form and email it to honors@utsa.edu

THE EVALUATION OF REPETITIVE OVERHEAD MOVEMENTS IN HEATING VENTILATION AND AIR CONDITIONING TECHNICIANS

by

JOSHUA T. KUEHNE

THESIS
Presented to the Faculty of the
Honors College
The University of Texas at San Antonio
In Partial Fulfillment
Of the Requirements
For the Degree of

BACHELOR OF SCIENCE IN KINESIOLOGY
WITH HIGHEST HONORS IN THE HONORS COLLEGE

THE UNIVERSITY OF TEXAS AT SAN ANTONIO
College of Education and Human Development
Department of Health and Kinesiology
December 2016

ACKNOWLEDGMENTS

I would like to acknowledge my thesis advisor, Dr. Sakiko Oyama for her endless guidance and support through this entire process. Working as one of her research assistants dramatically aided my undergraduate career. I would also like to thank my readers, Dr. Ortega and Dr. Cordova for taking their time to give me feedback in the writing process. I'd like to thank my peers in the Applied Biomechanics Lab, Hannah, Audrey, and Stefan for their help in learning the biomechanics equipment and support through all the obstacles data collection presented during this study. Lastly, I would like to thank my dear friend Connor Czar, for inspiring me to work for this. If it weren't for him this project would not have happened. Thank you and rest in peace Connor.

December 2016

ABSTRACT

THE EVALUATION OF REPETITIVE OVERHEAD MOVEMENTS IN HEATING VENTILATION AND AIR CONDITIONING TECHNICIANS

Joshua Kuehne, B.S.

The University of Texas at San Antonio, 2016

Supervising Professor: Sakiko Oyama, Ph.D. ATC.

Air conditioning technicians are the most non-fatally injured amongst construction workers due to work-related musculoskeletal disorders (MSD).[1] It has been identified that the shoulder is one of joints most commonly affected in industrial workers. Industrial work is very demanding and requires heavy lifting and monotonous movements all done in awkward postures. The current literature suggests that MSD in the shoulder joint is developed from repetitive overhead movements. While repetitive overhead movements have been evaluated in construction workers, it has not been described in air conditioning technicians. The purpose of this study was to describe repetitive arm movement performed by air conditioning technicians using inertial measurement unit (IMU) system. An IMU is a small portable motion detection monitor that can be placed in multiple places to track multi-axial joint kinematics outside of the laboratory setting. The air conditioning technicians perform work-specific tasks (e.g., mounting ceiling vents, installing and repairing air conditioning units), but also spend time performing non-work-specific tasks. The arm activity was described separately and compared between times when the technicians performed work-specific and non-work specific tasks. It was found that they spent 3.9±1.4 hours (41.6±15.6 %) performing work-specific tasks and 4.9±1.1 hours (53.8±11.9 %) performing non-work-specific tasks. The participants' arm were elevated above 60° for 1.7±0.7 hours (18.5±8.0 %), and above 90° for 0.4±0.2 hours (4.2±2.6 %). These findings were similar to

what has been reported in previous studies on electricians and suggest that HVAC technicians may be at risk for developing shoulder pain. Future studies should take into consideration other factors that may affect the development of shoulder pain in HVAC technicians.

Table of Contents

ABSTRACT 3
List of Figures 6
List of Tables 7
CHAPTER 1: INTRODUCTION 8
1.1 Musculoskeletal disorders amongst industry workers 8
1.2 Purpose of this Study: 10
Chapter 2: Literature review 11
2.1 Shoulder anatomy 11
2.4 Use of Inertial Magnetic Units for long duration motion capture 16
Chapter 3: Methods and Materials 19
3.1 Study Design 19
3.2 Instrumentation 19
3.3 Participants 20
3.4 Procedure 21
3.5 Data reduction 22
3.6 Data analysis 23
Chapter 4: Results 24
4.1 Results 24
Chapter 5: Discussion and Conclusion 32
5.1 Discussion 32
5.2 Conclusions 35
REFERENCES 36

List of Figures

Figure 1 Compression Press.....11

Figure 2 Inertial Measurement Unit.....17

Figure 3 Percent Time arm in elevation ranges.....29

Figure 4 Cumulative time with arm maintained above 60°.....29

Figure 5 Percent cumulative time with arm maintained above 60°.....30

Figure 6 Cumulative time with arm maintained above 90°.....30

Figure 7 Percent cumulative time with arm maintained above 90°.....31

List of Tables

Table 1 Participants demographics.....20

Table 2 Summary of work and non-work specific tasks 26

Table 3 Summary of non-work specific tasks 27

Table 4 Summary of work specific tasks 28

CHAPTER 1: INTRODUCTION

1.1 Musculoskeletal disorders amongst industry workers

In the United States alone, the construction industry loses 7 billion dollars annually from nonfatal injuries.[1] The cost is primarily associated with missed work days due to work-related musculoskeletal disorders (MSD).[2] While MSD can develop anywhere in the body, due to the work specific tasks, the shoulder has been identified as one of the joints most commonly affected MSD among heating, ventilation and air conditioning (HVAC) technicians.[3] HVAC work involves high repetitions of upper arm elevations, which are associated with development of shoulder complaints.[3-5] HVAC techs spend much of their eight hour workday with their arms elevated overhead using heavy equipment (such as electric saws and battery powered drills) to install air conditioning units.[3] Furthermore, industrial work requires heavy lifting and monotonous movements while in an awkward posture[4]. Work that requires elevating the elbows above shoulder height for more than 10% of an eight hour work day[6] and repetitively performing tasks that require maintaining the arm above 60 degrees of elevation angle for more than five seconds have been linked to shoulder pain.[7] The combination of high repetition/load on the shoulder and exposure to awkward posture increases the risk of developing a chronic shoulder disorder by 80-150%,[7] thus it is not surprising that the HVAC sector experiences work related MSD at rates exceeding the national average for all industries and all construction workers.[8]

The extensive amount of time HVAC technicians, and other types of construction workers spend performing strenuous work using their arms is considered to lead to shoulder dysfunction, fatigue, and pain. It was reported in a study[9] that quantified demand on shoulder muscles during electrical work that approximately 300N of force (i.e. approximately 2.5-3 times the body weight) must be applied to the compression press handles to compress the conductor

and cables together. Considering that the shoulder muscles have a very short moment arm about the shoulder joint, the muscles must produce extremely high forces in order to complete the task. These tasks are performed in high repetitions (up to 100 times or more per day) by the workers,[9] which leads to development of shoulder pain.

In a recent longitudinal study, fifteen electricians were studied to correlate time they kept their shoulder elevated above certain levels, to shoulder pain over a period of 2.5 years. At the start of the study, investigators used an inclinometer on each arm to measure percent and duration of time the electricians spent with their arms elevated above 30°, 60°, and 90° over a full work day. Subsequently, the electricians were asked to rate how much shoulder pain they experienced on two occasions over 2.5 years.[7] The study demonstrated that spending greater amount of time lifting their arm above 60 and 90 degrees, especially when the arm is maintained above the angles for more than five seconds, are associated with shoulder pain amongst young adults. However, since the study only assessed the shoulder elevation angle, there was not delineation about overhead task performed by the electrician leads to pain. In a different study, investigators followed 24 electricians through a full workday and evaluated their shoulder elevation motion using an inclinometer. In this study, work activities were categorized into three tasks, planning, support, and wiredraw. Among the three tasks, wiredrawing required the upper extremity to be elevated for the longest extent of time.

Most field studies evaluating industry worker's shoulder kinematics has been done using a portable inclinometer, which is capable of measuring inclination of body segments relative to the gravitational field. Alternatively, Inertial measurement units (IMUs) have been used to capture elevation angles of the arms and trunk in recent years. An IMU is a small portable instrument that combines information from triaxial accelerometers, gyroscopes, and

magnetometers to track movements. [10] The IMU monitors can be attached to various body landmarks to capture segment angles from vertical.[11]

1.2 Purpose of this Study:

While multiple investigators have assessed industrial worker's shoulder kinematics in a field setting using inclinometers, no study has specifically described arm movement in HVAC technicians. The initial plan of this study was to capture three-dimensional trunk, arm, and scapular kinematics of the HVAC technicians throughout the day using the IMU sensors. However, we realized that the IMU sensors cannot accurately measure their orientations in the horizontal plane, because the input from the magnetometer that informs the direction of magnetic North can be severely affected by the electromagnetic field in the environment. Therefore, the modified purpose of this study was to describe arm elevation angle in HVAC technicians throughout the work shift. Since repetitive arm movements are considered a culprit for musculoskeletal dysfunction at the shoulder, quantifying the patient's arm movements could help clinicians understand the dysfunction more effectively.

Chapter 2: Literature review

2.1 Shoulder anatomy

The underlying anatomy of the shoulder joint is vital in understanding the mechanism of various injuries at the shoulder. The composition of the shoulder joint, which includes multiple bones, tendons, and numerous interconnecting ligaments, is complex. The shoulder girdle consists of the scapula, clavicle, and humerus. Each of these components articulates with each other to form the glenohumeral, sternoclavicular, and the acromioclavicular joints.[12] Additionally, the interface between the scapula and the rib cage, referred to as the scapulothoracic articulation, is an integral component of shoulder movement. Of these joints, many of the chronic shoulder injuries occur around the glenohumeral joint. The glenohumeral joint is a ball and socket joint with six degrees of freedom, providing the upper extremity with an almost unrestricted range of motion.[13] The articular structure of the shoulders permits wide range of motion at a cost of stability. The stability of the joint is minimally provided by the static stabilizers, such as the glenohumeral joint capsule/ligament and coracohumeral ligament, and a few dynamic stabilizers, including the rotator cuff muscles, long head of biceps tendon, and other girdle muscles.[14] Although the large range of motion at the shoulder is important for us to perform overhead tasks, the excessive motion at the joint can compromise the health of the structures around the shoulder.

2.2 Subacromial impingement

Superior to the glenohumeral joint is an area referred to as a subacromial space. This is a space between the superior aspect of the humeral head and coracoacromial arch. This area is traversed by a ligament, and is an osteofibrous roof to the glenohumeral joint that connects acromion and the coracoid process on the scapula.[12,15,16] Located within this space is the long

head of the biceps tendon, supraspinatus, capsule of the shoulder joint, and the subacromial bursa.[13,17] During glenohumeral abduction, the humeral head will narrow the subacromial space and increase contact between the acromion and the anatomical structures within this space.[13] Subacromial impingement syndrome is a term used to describe a condition at the shoulder characterized by pain caused by narrowing of the subacromial space, and compression of the structures within the space. The compression of the structures can cause inflammation of the subacromial bursa, damage both the supraspinatus tendon and long head of the biceps tendon, and/or other shoulder pathologies.[13,18] According to Nordt et al,[19] contact pressure and force at the subacromial space is at its highest in the mid-range glenohumeral abduction. Correspondingly, the pain due to subacromial impingement syndrome worsens when the arm is elevated between 60-120 degrees.

Subacromial impingement syndrome is one of the most common causes of shoulder pain, and can arise from a multitude of mechanisms.[12,13,18] As a result of repetitive overhead movements, dysfunction of scapular stabilization musculature can be a mechanism. A study conducted by Kamkar et al[18] found that continuing to perform repetitive upper extremity elevations with weak or fatigued scapular musculature leads to impingement. When elevating the arm beyond the first 30 degrees of glenohumeral abduction, the range of motion is achieved by the movement at the glenohumeral joint and the scapulothoracic articulation. Specifically, the movement between the glenohumeral joint and scapulothoracic articulation occur at a 2:1 ratio. The upward rotation, external rotation, posterior tilting, and elevation of the scapula help elevate the humerus while decreasing the possibility of the humeral head compressing the subacromial features. Specifically, upper and lower trapezius and serratus anterior function to upwardly rotate, rhomboids and trapezius externally rotate and posteriorly tilt the scapula. Therefore,

fatigue, weakness, or inhibition of these muscles can alter the normal scapular movement, which has been linked to development of subacromial impingement. Ludewig et al demonstrated that the impingement syndrome is associated with anterior tilting of the scapula.[20]

Tightness of the posterior, anterior, and inferior portions of the glenohumeral articular capsule is another mechanism of subacromial impingement.[21] The posterior capsular structures have been shown to play a significant role in allowing and controlling normal arthrokinematics between the humeral head and the glenoid.[22] Tightness can occur from increased tensile loading on the posterior capsule, which creates greater than normal mechanical input to the tissue, which responds by becoming stiffer. This stiffness is the result of connective tissue proliferation consistent with Wolff's law, that connective tissue will adapt to the loads under which it is placed.[23] A tight capsule causes humeral head translation in the opposite direction of the tightened area (posterior capsule). This opposite translation increases anterior and superior migration of the humeral head during elevation causes subacromial compression at a lower elevation angle. Lastly, the shape of the acromion process can predispose the subacromial features to impingement. There are three types of acromion shape; flat, curved, and hooked. Individuals with the hooked shaped acromion yield the highest prevalence of impingement.[13] This hook at the end of the acromion shortens the distance between the humeral head and the coracoacromial ligament, thus leading to compression of the subacromial features at an earlier degree of arm elevation.

2.3 Biomechanical studies on electrical work-related tasks

The extensive amount of time electricians spend performing strenuous work using their arms can lead to degeneration of the subacromial features. Furthermore, work-related activities such as overhead wiring, crimping, and wire cutting[9] can be strenuous on the rotator cuff

muscles leading to fatigue. Further, this fatigue compromises the muscles' ability to stabilize the glenohumeral joint, leading to further compression of the subacromial features.[18] Lastly capsular tightness can also occur if an electrician avoids upper extremity elevation, which compromises glenohumeral elevation kinematics, to further compress on subacromial features.

The underlying mechanisms of shoulder injuries in electricians are only partially understood. A few studies have quantified demand on shoulder muscles during electrical work. In one investigation, researchers studied the force needed to complete the task of crimping compression connectors, which is performed frequently by electricians. The task involves tightly connecting two wires with a conductor, and compressing them together with a compression press.

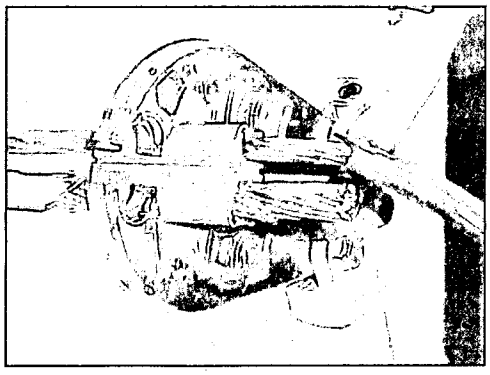


Figure 1: A compression press crimping together two wires with a conductor

The force measured was the peak force needed to compress a conductor to two wires. Investigators simulated a common crimping posture to measure the force required to crimp a common overhead connector and determined that approximately 300N of force needs to be applied to the compression press handles to compress the conductor and cables together. The study estimated that this magnitude of force is applied through the hand .41m away from the shoulder joint. Considering that the shoulder muscles have very short moment arm about the

shoulder joint, the muscles are at significant mechanical disadvantage. This would necessitate the muscles to produce extremely high forces in order to complete the crimping task. An electrician may connect wires up to 100 times or more per day.[9] This high demand placed on the electricians' shoulders leads to development of shoulder pain.

Researchers have attempted to improve the working condition to help minimize physical demand placed on electricians' shoulders by optimizing the position, in which an electrician works in the field. One study attempted to minimize the risk of developing a muscular skeletal disorder by elevating an electrician with a Mobile Elevated Working Platform (MEWP) instead of using a traditional ladder. This study compared discomfort and time to completion of the tasks such as drilling, cabling, wiring, and assembly on a ladder versus a MEWP. It was hypothesized that overhead working posture on a ladder would result in greater muscle loading demands, increased levels of discomfort, and reduced performance due to the restricted posture. However, time to completion of the tasks on a MEWP was twice as long as on a ladder, and therefore platform type did not significantly reduce the discomfort level. This experimental design could not reduce the risk because posture on a MEWP continued to put the shoulder in a compromised position.[24]

In a recent longitudinal study, fifteen electricians were studied to correlate time they kept their shoulder elevation above certain levels, to shoulder pain over a period of 2.5 years. At the start of the study, investigators used an inclinometer on each arm to measure percent and duration of time the electricians spent with their arms elevated above 30°, 60°, and 90° over a full work day. In addition, the electricians were asked to rate how much shoulder pain they experience on two occasions over the subsequent 2.5 years.[7] The study demonstrated that daily, repetitive arm elevation above 60 degrees, prolonged for more than five seconds alone, is

correlated to shoulder pain amongst young adults. However, since the study only looked at the shoulder elevation angle, it did delineate what overhead task performed by the electrician leads to pain.

In a different study, investigators followed 12 Brazilian electricians and 12 Norwegian electricians through a full workday and evaluated their shoulder elevation motion using an inclinometer. In this study, work activities were categorized into three tasks, planning, support, and wiredraw. Planning tasks consisted of checking blueprints, making and receiving phone calls, communicating and driving; support tasks consisted of moving furniture, cleaning, and organizing equipment; wiredraw tasks consisted of dragging/pulling cables, boring/drilling/screwing and installation of fittings. Among the three tasks, wiredrawing required the upper extremity to be elevated for the longest extent of time. Although, the Brazilian electricians had a break that was twice as long in work day, they still presented awkward postures that were quantified by excessive extension of the head, upper back and neck, as well as highly elevated upper arms.[25] Therefore, these studies provided kinematic data further proved the need to evaluate electricians' shoulder movement to help improve their working conditions.

2.4 Use of Inertial Magnetic Units for long duration motion capture

Most field studies evaluating electrician's shoulder kinematics has been done using a portable inclinometer, which is capable of measuring inclination of body segments relative to the gravitational field. Inclinometers can be very precise and accurate when measuring a single joint. However, they are limited regarding kinematic information such that they cannot capture body kinematic data continuously in three-dimensions.[26] During arm movement, the shoulder not only elevates, but also abducts and adducts along the transverse plane, and rotates internally and externally about the long axis of the humerus. Furthermore, movement of the scapula on the

ribcage, which is an integral part of shoulder movement, cannot be measured with an inclinometer. Regardless of what axis the movements occur, researchers can use optical motion capture systems (OMC) in a lab setting and simulate electrical work to evaluate shoulder kinematics as well. OMC are the gold standard, relying on measurements of reflected light caught by high speed cameras that record positions. Algorithms are then used to calculate direction of the body segments.[27] Nevertheless, OMC present a significant limitation: the data must be collected in a lab setting.[28] Thus, data collected won't be as genuine as it would be in a field study.

An inertial measurement unit (IMU) is a small portable instrument that combines information from triaxial accelerometers, gyroscopes, and magnetometers to track rotational and translational movements. [10] Each of the sensors plays an important role measuring movement. While three accelerometers and three gyroscopes measure acceleration in and angular displacement or angular rate of turn/angular velocity in three dimensions, respectively; the three-axis magnetometer theoretically allows the IMU to provide a measurement of orientation relative to both direction of gravity and the earth's magnetic field. The system then maintains time-synchronization between monitors and can store on board information for up to 16 hours. The large memory, small size, and capability of story data allow IMU monitors to record participant's continuous, multi-axial movements in a long duration field study. [26,29-32] However, we observed that the IMU cannot be used to capture its orientation because the electromagnetic field in the environment can distort the magnetometer input. The IMU, therefore, was used to measure orientation of the monitors relative to gravity, in this study

Various studies have demonstrated the reliability of IMU systems in field studies. A study by Schall et al.[32] compared the measurement of trunk angular displacement and upper arm

elevation in an IMU system against the gold standard, OMC system. The IMU system displayed as little as 2.5 degrees of change over an eight-hour sample. In measuring the effect of velocity, Lebel et al. found at 90 degrees, IMU monitors remain relatively stable regardless of direction of motion.[31] These results suggest that IMU systems are a good candidate to be used for long-term real-life movement evaluation, and that they can serve as an acceptable instrument to provide accurate kinematic data of occupational work in a field setting.

Chapter 3: Methods and Materials

3.1 Study Design

This descriptive study evaluated shoulder elevation angle in service and construction air conditioning technicians (AC). The upper body movement of the participant AC technicians were monitored using inertial magnetic unit (IMU) motion recording systems throughout a full workday. The specific activities performed by the AC tech were observed and reported by an investigator.

3.2 Instrumentation

The inertial magnetic unit (IMU; Model: Opal, APDM Inc., Portland, OR) with 5 time-synchronized monitors (Dimension: 48.4 mm x 36.1mm x 13.4mm) was used in this study. The monitor weighs just less than 22 grams with its battery, holds up to 8 Gb memory (~720h storage), and has a battery life of up to 12 hours of synchronous logging.[33] The orientation estimates for static accuracy (roll/pitch), static accuracy (heading), and dynamic accuracy is 1.15 degrees, 1.50 degrees, and 2.80 degrees, respectively. The four monitors were attached to the participants', trunk, scapula, arm, and forearm segments to collect kinematic data. The fifth monitor was used as an external trigger to mark events in the data stream. The IMU data were sampled at 20Hz per second. The data collected were imported into Motion Studio software (APDM Inc., Portland, OR).

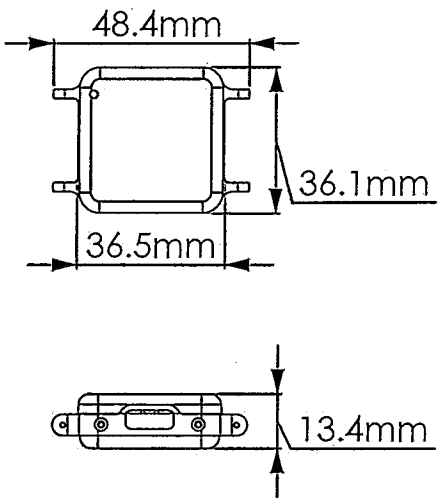


Figure 2: A schematic representation of an IMU with corresponding dimensions.

3.3 Participants

A total of 7 HVAC technicians participated in this study. However, data from 1 participant were not analyzed because the IMU monitors frequently fell off throughout the data collection due to excessive perspiration.. The demographics of the participants are presented in Table 1. Two service technicians, one supervisor HVAC technicians, and four HVAC laborers were recruited from the HVAC service company. Service technicians provide technical help in response to service calls throughout their workday. Service calls included request for full repairs, full installations, and minor adjustments of the HVAC unit. Supervising technicians primarily work on installing new air conditioning units into housing under construction. Lastly, the laborers generally do the same labor as the supervisors and service technicians under supervision. The licensed HVAC technician was not included in this study, because they no longer perform as much strenuous work as the service technicians, HVAC technicians, and the laborers. All participants were free from shoulder pain that limited the use of their working arm (testing arm).

Table 1: Participant demographics

Variables	Average	Standard deviation	Median	Minimum	Maximum
Age (Years)	30.7	8.8	31	22	46
Body mass (kg)	85.0	27.4	72.6	61.2	129.3
Height (m)	1.75	0.09	1.73	1.68	1.93
Body mass index	27.2	6.5	23.9	21.8	36.3
DASH - score	8.9	7.2	7.1	0	17.5
DASH - work module score	12.5	20.9	0	0	50

* DASH: Disability of arm, shoulder, and hand

3.4 Procedure

Each participant reported to TexAir's office thirty minutes prior to their work shift, on the scheduled data collection day. Each signed an informed consent form and filled out the Disability of Arm, shoulder, and hand (DASH) questionnaire. Four IMU monitors were secured on their skin with double-sided adhesive tape. IMU monitors were placed 2cm below the spinous process of the 7th cervical vertebrae (C7), the flat broad portion of the acromion process on the dominant arm, the posterior aspect of the dominant arm just superior of the elbow, and on the dorsal aspect of the dominant-side wrist.

Once the IMU monitors were secured, the investigator then accompanied the participant to their work place to capture data. Once the participants arrived at work, they went about their normal routine for that workday. The IMU monitors recorded trunk and upper extremity movement of the AC technician through the workday. Throughout the day, the investigator clicked the trigger to note the start and end of specific work tasks, and the start and end of the workday. Once the participant's work shift had finished, the IMU monitors were removed.

3.5 Data reduction

The elevation angle of the participants' dominant limb was calculated from the accelerometer and gyroscope data from the IMU sensors. As stated earlier, the original plan was to calculate three-dimensional orientation of the monitors/body segment (arm, trunk, and scapula) using all three inputs from the IMU. However, the input from the magnetometer was affected by the electromagnetic field in the environment, and thus was deemed unusable. The elevation angle of the participant's limb was calculated using the complementary weighing algorithm-based estimates. The acceleration-based arm elevation was first calculated. Then, the angles were adjusted using the angular velocity data from the gyroscope using a weighing coefficient of 0.06.

Based on the continuous arm elevation angle, percent of work-shift time the arm was positioned below 30°, 30-60°, 60-90°, and above 90° were calculated. Additionally, the cumulative time the arm was maintained above 60 degrees for longer than 5 seconds, 10 seconds, and 20 seconds, and cumulative time the arm was maintained above 90 degrees for longer than 5 seconds, 10 seconds, and 20 seconds were calculated.

The tasks logged by the investigator were divided into ones that are specific to the HVAC technicians, and tasks that are not specific to the HVAC technicians. The work-specific tasks included loading/unloading equipment at each work site, mounting ceiling vents, installing and repairing air conditioning units. The non-work-specific tasks included listening to directions, driving/riding in a vehicle, walking between work sites, and eating lunch. Based on this task categorization, and the timestamp indicating the start and end of the tasks, the variables described above were calculated separately for the times participants spent performing work-

specific and non-work-specific tasks. All data processing was be conducted using Matlab (Version R2015b, MathWorks Inc. Natick, MA).

3.6 Data analysis

Descriptive statistics were used to describe arm elevation angle throughout the participant's work shift. Specifically, percent of work-shift time the arm was positioned below 30°, 30-60°, 60-90°, and above 90° were calculated. Additionally, the cumulative time the arm was maintained above 60 degrees for longer than 5 seconds, 10 seconds, and 20 seconds, and cumulative time the arm was maintained above 90 degrees for longer than 5 seconds, 10 seconds, and 20 seconds were calculated. Wilcoxon signed rank tests were used to compare the variables between times spent performing work-specific tasks and non-work specific tasks. The analyses were conducted using IBM SPSS statistical analysis software (Version 22). An a-priori Alpha level of 0.05 was used for all analysis.

Chapter 4: Results

4.1 Results

The summary of arm movement over an entire workday is presented in Table 2. Additionally, the summary of arm movement over a time, in which the participants performed non-work-specific tasks and work-specific tasks are presented in Tables 3 and 4 respectively. The summaries of arm movements are also presented in Figures 3, 4, 5, 6, and 7. The work-specific-tasks consisted of loading/unloading equipment at each work site, mounting ceiling vents, installing and repairing air conditioning units. The non-work-specific activities consisted of listening to directions, driving/riding in a vehicle, walking between work sites, and eating lunch. Installing air conditioning units required installing air handlers, air condensers, and thermostats. Installation required the HVAC technicians to use a drill to open up each, measuring out space for air handlers and air condensers, wiring to connect the thermostat to both the condenser and handler, bending copper and PVC pipes, soldering copper pipes to both the handler and condenser, cutting and placing duct board to insulate the air handler, connecting thermaflex duct vents to air handlers, and sometimes sawing open area to place the air handler. Repairing air handlers, condensers, and thermostats required opening up each, checking voltage to air handlers, checking air pressure at air condensers, drilling, and wiring.

The data were collected over 9.1±1.1 hours. Of the entire workday, the participants spent 3.9±1.4 hours (41.6±15.6 %) performing work-specific tasks and 4.9±1.1 hours (53.8±11.9 %) performing non-work-specific tasks. The participants' arm was elevated above 60° for 1.7±0.7 hours (18.5±8.0 %), and above 90° for 0.4±0.2 hours (4.2±2.6 %) (Table 2 & Figure 3). The percent of time that participants had their arm below 30° and above 90° were greater while performing work-specific tasks than non-work-specific tasks ($p<0.05$) (below 30°: 48.7 % vs.

28.3%, above 90°: 6.8% vs. 2.8%). However, the percent of time that participants had their arm between 60-90° was greater while performing non-work-specific tasks (53.6%) than non-work-specific tasks (34.1%).

The cumulative time, in which the participants kept their arm above 60° for more than 5 seconds, 10 seconds, and 20 seconds were 1.2±0.5 hours (13.0±4.1 %), 0.94±0.5 hours (10.1±4.1 %), and 0.7±0.5 hours (7.4±4.2 %), respectively (Table 2 & Figure 4, 5). The cumulative time, in which the participants kept their arm above 90° for more than 5 seconds, 10 seconds, and 20 seconds were 0.23±0.15 hours (2.6±1.7 %), 0.16±0.1 hours (1.8±1.2 %), and 0.1±0.1 hours (0.9±0.8 %), respectively (Table 2 & Figure 6,7). These cumulative times were not significantly different between times spent performing work-specific tasks and non-work-specific tasks.

Table 2: Summary of arm elevation angles during time spent performing both work-specific tasks and non-work-specific tasks

Variables	Average	Standard Deviation	Median	Range
Percent time spent in elevation angle ranges				
Below 30° (%Time)	35.0	11.6	35.2	19.7 – 53.0
30°-60° (%Time)	46.5	12.2	45.9	27.6 – 65.8
60°-90° (%Time)	14.3	5.4	12.7	9.0 – 22.7
Above 90° (%Time)	4.2	2.6	3.8	1.8 – 8.4
Cumulative time of elevation maintained above 60°				
Longer than 5s (min)	72.0 (13.0%)	29.2 (4.1%)	71.8 (13.0%)	38.9 – 120.4 (7.1 – 18.5%)
Longer than 10s (min)	56.4 (10.14)	27.5 (4.1)	52.3 (9.5%)	23.9 – 100.8 (4.3 – 15.5%)
Longer than 20s (min)	41.7 (7.4%)	27.5 (4.2%)	33.4 (6.0%)	12.2 – 87.1 (2.2 – 13.4%)
Cumulative time of elevation maintained above 90°				
Longer than 5s (min)	13.9 (2.6%)	8.9 (1.7%)	13.0 (2.2%)	5.0 – 26.8 (1.0 – 4.9%)
Longer than 10s (min)	9.4 (1.8%)	5.9 (1.2%)	9.9 (1.7%)	2.8 – 15.3 (0.5 – 3.4%)
Longer than 20s (min)	4.8 (0.9%)	3.9 (0.8%)	3.3 (0.6%)	1.1 – 9.8 (0.2 – 2.1%)

* Values in parentheses are % time of a total time spent non-work-specific duties

Table 3: Summary of arm elevation angles during time spent performing non-work-specific tasks

Variables	Average	Standard Deviation	Median	Range
Percent time spent in elevation angle ranges				
Below 30° (%Time)	28.3	12.3	28.005	15.5 – 48.2
30°-60° (%Time)	53.6	14.2	53.31	31.4 – 75.5
60°-90° (%Time)	15.2	7.2	11.97	7.5 – 24.5
Above 90° (%Time)	2.8	2.8	1.46	1.04 – 8.31
Cumulative time of elevation maintained above 60°				
Longer than 5s (min)	35.9 (11.3%)	29.4 (7.14%)	17.45 (7.44%)	16 – 76.8 (4.9 – 21.8%)
Longer than 10s (min)	30.4 (9.4%)	27.4 (6.8%)	13.53 (5.8%)	11.3 – 69.9 (4.07 – 19.8%)
Longer than 20s (min)	24.4 (7.4%)	25.0 (6.4%)	10.34 (4.5%)	4.74 – 60.24 (1.92 – 17.1%)
Cumulative time of elevation maintained above 90°				
Longer than 5s (min)	4.1 (1.4%)	3.35 (1.2%)	4.13 (1.3%)	8.48 (0.2 – 2.8%)
Longer than 10s (min)	2.1 (0.7%)	1.79 (0.5%)	1.84 (0.8%)	4.69 (.06 – 1.5%)
Longer than 20s (min)	0.7 (0.2%)	1.05 (0.4%)	0 (0%)	2.15 (0 – 0.8%)

* Values in parentheses are % time of a total time spent non-work-specific duties

Table 4: Summary of arm elevation angles during time spent performing work-specific tasks

Variables	Average	Standard Deviation	Median	Range
Percent time spent in elevation angle ranges				
Below 30° (%Time)	48.7	12.4	52.3	30.3 – 60.7
30°-60° (%Time)	34.1	6.9	34.4	24.9 – 41.3
60°-90° (%Time)	10.4	3.3	9.8	6.8 – 15.8
Above 90° (%Time)	6.8	4.9	5.2	2.5 – 15.7
Cumulative time of elevation maintained above 60°				
Longer than 5s (min)	20.9 (9.4%)	13.6 (6.5%)	19.6 (8.1%)	3.7 – 39.5 (2.3 – 19.9%)
Longer than 10s (min)	14.1 (6.4%)	10.2 (5.3%)	13.0 (4.8%)	1.8 – 29.8 (1.1 – 15.4%)
Longer than 20s (min)	8.3 (4.0%)	6.0 (3.7%)	6.6 (2.6%)	0.5 – 17.4 (0.32 – 10.5%)
Cumulative time of elevation maintained above 90°				
Longer than 5s (min)	3.0 (1.4%)	3.9 (2.1%)	1.7 (0.7%)	0 – 9.9 (0 – 5.6%)
Longer than 10s (min)	1.2 (0.7%)	2.7 (1.5%)	0 (0%)	0 – 6.7 (0 – 3.8%)
Longer than 20s (min)	0.1 (0.03%)	0.2 (0.07%)	0 (0%)	0 – 0.5 (0 – 0.16%)

* Values in parentheses are % time of a total time spent non-work-specific duties

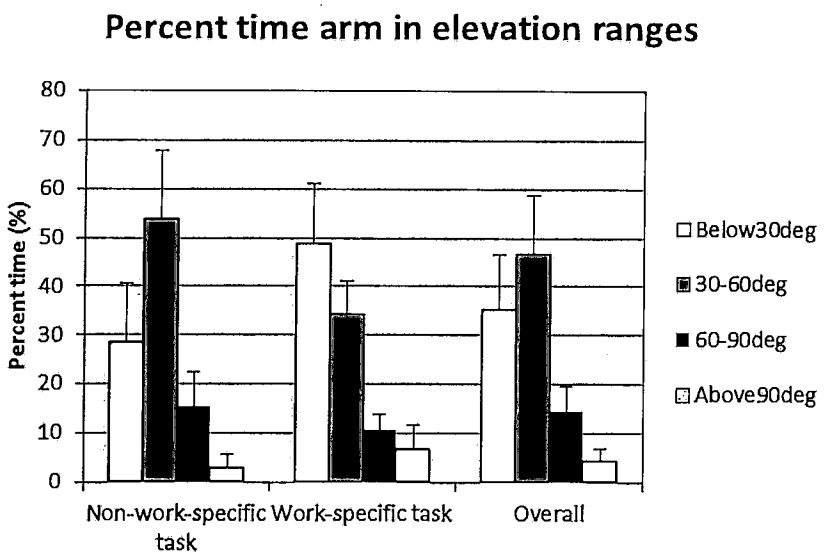


Figure 3: Percent of time arm was below 30°, 30-60°, 60-90°, and above 90° of elevation angles.

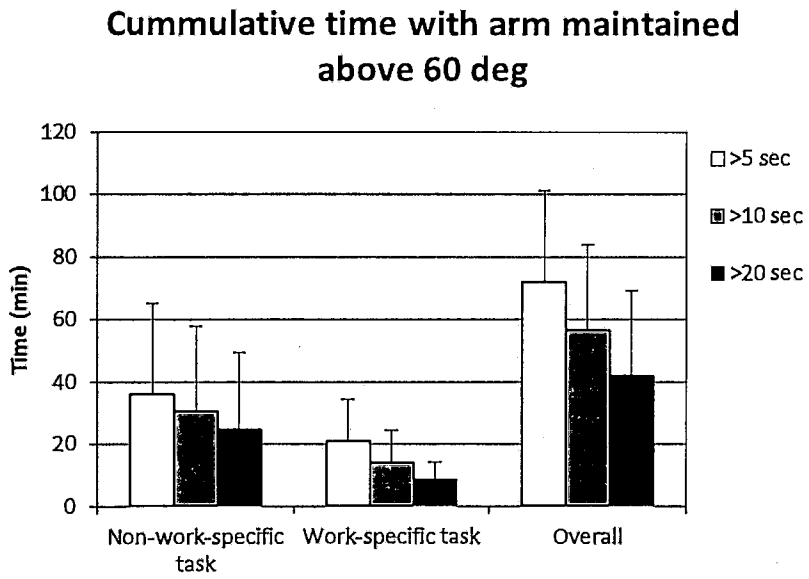


Figure 4: Time in minutes arm was maintained above 60° of elevation for more than 5, 10, and 20 seconds.

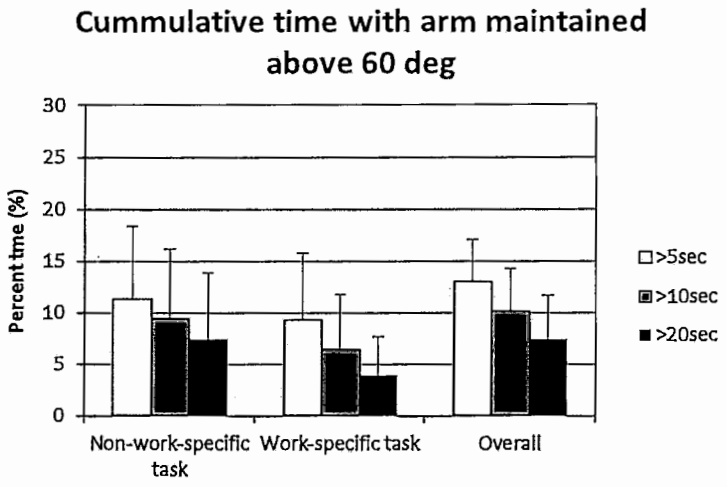


Figure 5: Percent of time arm was maintained above 60° of elevation for more than 5, 10, and 20 seconds.

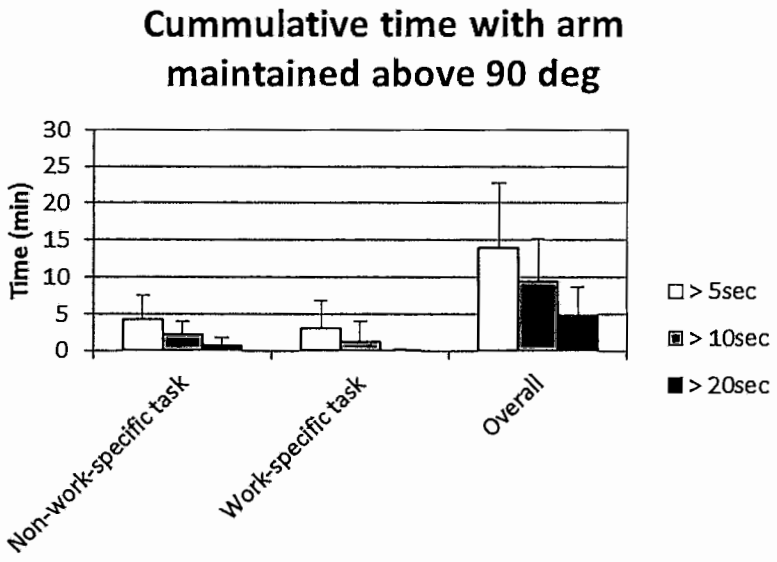


Figure 6: Time in minutes arm was maintained above 90° of elevation for more than 5, 10, and 20 seconds.

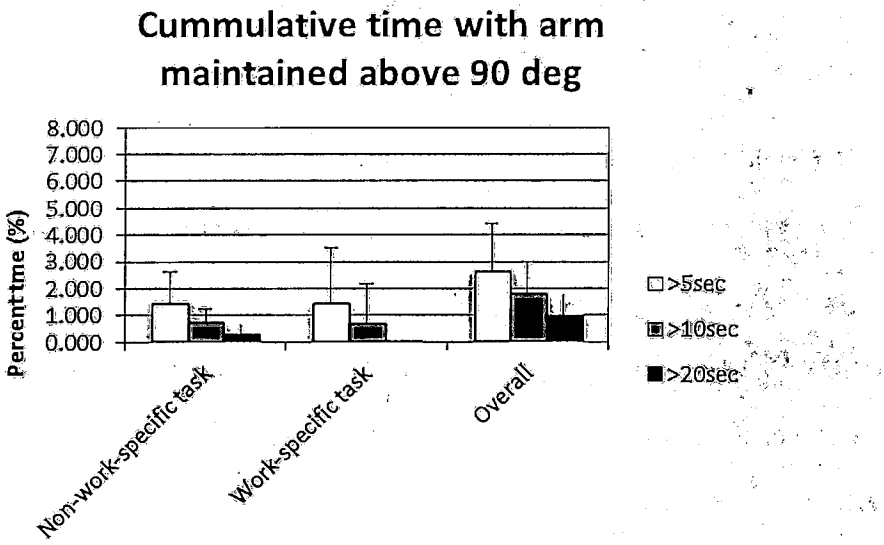


Figure 7: Percent of time arm was maintained above 90° of elevation for more than 5, 10, and 20 seconds.

Chapter 5: Discussion and Conclusion

5.1 Discussion

Mechanical installation workers, such as HVAC technicians, are significantly affected by work-related MSD at the shoulder.[3-5] However, no study specifically described exposure to arm movement in HVAC technicians. The purpose of this study was to describe arm elevation angle amongst HVAC technicians throughout a work shift using IMU monitors. We observed that HVAC technicians spend significant amount of time with their arms above 60°. Additionally, the cumulative time they spend with arm kept elevated above 90° was higher during work-specific tasks, than while performing non-work-specific tasks.

We observed that the percentage of time that HVAC technicians' arm was positioned above 60° and above 90° during the work shift were similar to what was reported in previous studies on electricians. We observed a that HVAC technicians spend an average of 18.5% of their total workday with arm elevated above 60°, 13.0% of total work time maintaining arm elevation above 60° for more 5 seconds, 10.1% for more than 10 seconds, and 7.4% for more than 20 seconds. Manual laborer's work not only include work-specific tasks (ex. mounting ceiling vents, installing and repairing air conditioning units) but also includes break and time spent performing non-work-specific supporting tasks (ex. preparing/organizing equipment), which does not typically include repetitive arm motions. As we expected, the percentage time spent with arm above 90° was higher for the work-specific tasks. However, time that arm was maintained above 60° and 90° for more than 5, 10, and 20 seconds was similar between the work-specific and non-work-specific tasks. One possible explanation for this observation is that the data may have been skewed by the time the service electricians spent driving a truck, which kept their arms elevated for a prolonged period of time. The two service electricians drove an

average of 4.8 hours each, with on driving 3.4 hours and the other driving 6.1 hours during their day of participation. If data collection was performed on days the two service technician's job required less time driving, the data could have presented different findings.

While the overall exposure to arm elevation over a course of a day was similar between our HVAC technicians and the electricians in previous studies, we observed that HVAC technicians spend significantly less time with arm elevated above 90° compared to electricians during the time spent performing work-specific tasks. The study by Moriguchi et al.[25] described the exposure to arm movement for work and break time, and further divided work into planning, support, and wire-draw tasks. Their planning tasks were equivalent of the non-work-specific task in our study, and support and wire-draw tasks were equivalent to our work-specific-tasks. During work tasks (support and wiredraw tasks), percent of time with arm positioned above 60° were similar between HVAC technicians in our study and the electricians in the study by Moriguchi et al.[25] (17.2% vs. 19.9%). However, the percent of time with arm positioned above 90° were much lower for the HVAC technicians in our study compared to the electricians in the study by Moriguchi et al. (6.8 % vs. 10.4%).[25] This difference is likely because wiredraw tasks, which requires arm to be kept over head accounted for a majority of the work-specific tasks in Moriguchi's study.[25] While electricians perform wiredraw throughout an entire construction site HVAC technicians typically only perform wiredraw tasks when installing an air handler.

Previous studies on manual laborers identified arm exposure as a risk factor for shoulder musculoskeletal disorders. Specifically, maintaining arm elevation above 90° for more than 10% of the work shift has been linked to in increased risk of chronic or recurrent shoulder disorders.[6] Additionally, the greater time spent with arm maintained above 60° for more than 5 seconds has been correlated shoulder pain.[4,34] Our HVAC technician maintained arm elevation above 90° for

only 4.2% percent of the time. This may suggest that risk of developing shoulder injury from arm-exposure may not be as high as compared to the workers in the other manual labor occupations. However, awkward body positions they must assume while working in small spaces (ex. attic) may also increase physical demand, fatigue, and thus injury risk in HVAC technicians. Many attics, that technicians perform installation in, have low ceiling clearance and require slouched postures, which may contribute to development of shoulder pain as well. Additionally, HVAC technicians spend much of their time in attics, installing air handlers and air vents, where there is a significant increase in temperature. High temperatures would increase stress on the autonomic nervous system, thus increasing physical demands and accelerating fatigue.[35] Future studies should consider the addition of electromyography (EMG) to better characterize the muscle loading along with arm elevation and postural orientation. The percent of time our HVAC technicians spent with their arm elevated above 90° was below the previously identified threshold for injury development. However our group of participants spent 7.1 – 18.5% of the work shift maintaining arm above 60° for more than 5 seconds, which is comparable to the ranges reported in a previous study (2 – 21%).[7] Considering that 27% of the participants in the previous study developed shoulder pain within 2.5 years of the follow up period, similar proportion of HVAC technicians may develop injuries over time.

Limitations of this study include the capabilities of the IMU monitors, the sample size, and variability among participants. Theoretically, IMU systems are capable of measuring three-dimensional orientation of the monitors; however, the magnetometer within the IMU is severely affected by outside electromagnetic interference. Overcoming this technical challenge would be very helpful in conducting biomechanical studies outside of the laboratory setting. We were only able to recruit 7 participants due to restrictions in time, constraints in our study that made it

difficult to recruit participants. Increasing the number of participants may lead to findings with more accurate representation of arm-elevation-exposure in HVAC technicians. Furthermore, collecting data from three different types of HVAC technicians (supervisor, laborer, and service) may have resulted in heterogeneous data that does not accurately characterize arm exposure for all HVAC technicians. Lastly, the arm exposure may vary day-to-day depending on their workload.

5.2 Conclusions

Exposures to arm movement in HVAC technicians were similar to what has been reported in previous studies on electricians. Since high exposures to arm movement have been linked to shoulder musculoskeletal disorders, HVAC technicians may be at risk for developing pain and additional dysfunctional pathology. However, factors other than exposure to arm elevation may affect development of shoulder pain in HVAC technicians. Further studies should consider quantifying muscle load, environmental conditions, and cumulative exposure over a longer period (i.e. over multiple days) in understanding HVAC technicians' work-condition and injury risk.

REFERENCES

1. Waehrer GM, Dong XS, Miller T, Haile E, Men Y. Costs of occupational injuries in construction in the United States. *Accident Analysis & Prevention.* 2007;39(6):1258-1266.
2. Cheng C-W, Leu S-S, Lin C-C, Fan C. Characteristic analysis of occupational accidents at small construction enterprises. *Safety Science.* 2010;48(6):698-707.
3. Albers J, Estill C, MacDonald L. Identification of ergonomics interventions used to reduce musculoskeletal loading for building installation tasks. *Applied Ergonomics.* 2005;36(4):427-439.
4. Svendsen SW, Bonde JP, Mathiassen SE, Stengaard-Pedersen K, Frich L. Work related shoulder disorders: quantitative exposure-response relations with reference to arm posture. *Occupational and Environmental Medicine.* 2004;61(10):844-853.
5. Örtengren R, Cederqvist T, Lindberg M, Magnusson B. Workload in lower arm and shoulder when using manual and powered screwdrivers at different working heights. *International Journal of Industrial Ergonomics.* 1991;8(3):225-235.
6. Punnett L, Fine LJ, Keyserling WM, Herrin GD, Chaffin DB. Shoulder disorders and postural stress in automobile assembly work. *Scandinavian journal of work, environment & health.* 2000:283-291.
7. Hanvold TN, Waersted M, Mengshoel AM, Bjertness E, Veiersted KB. Work with prolonged arm elevation as a risk factor for shoulder pain: a longitudinal study among young adults. *Applied ergonomics.* Mar 2015;47:43-51.
8. BLS. Nonfatal Cases Involving Days Away From Work: selected characteristics. Injuries, Illnesses and Fatalities. *Bureau of Labor Statistics.* 2004;US Department of Labor.
9. Marklin RW, Lazuardi L, Wilzbacher JR. Measurement of handle forces for crimping connectors and cutting cable in the electric power industry. *International journal of industrial ergonomics.* 2004;34(6):497-506.
10. Dong W, Lim KY, Goh YK, et al. A low-cost motion tracker and its error analysis. Paper presented at: Robotics and Automation, 2008. ICRA 2008. IEEE International Conference on2008.
11. Oberlander KD. Inverse Kinematics: Joint Considerations and the Maths for Deriving Anatomical Angles. 2015.
12. Prescher A. Anatomical basics, variations, and degenerative changes of the shoulder joint and shoulder girdle. *European journal of radiology.* 2000;35(2):88-102.
13. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clinical biomechanics.* 2003;18(5):369-379.
14. Miller MD, Cooper DE, Warner JJ. *Review of sports medicine and arthroscopy.* Saunders Book Company; 2002.
15. Chang WK. Shoulder impingement syndrome. *Physical medicine and rehabilitation clinics of North America.* 2004;15(2):493-510.
16. NEER CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder. *The Journal of Bone & Joint Surgery.* 1972;54(1):41-50.
17. Rossi F. Shoulder impingement syndromes. *European journal of radiology.* 1998;27:S42-S48.
18. Kamkar A, Irrgang JJ, Whitney SL. Nonoperative management of secondary shoulder impingement syndrome. *Journal of Orthopaedic & Sports Physical Therapy.* 1993;17(5):212-224.
19. Nordt WE, Garretson RB, Plotkin E. The measurement of subacromial contact pressure in patients with impingement syndrome. *Arthroscopy: The Journal of Arthroscopic & Related Surgery.* 1999;15(2):121-125.
20. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Physical therapy.* 2000;80(3):276-291.

21. Conroy DE, Hayes KW. The effect of joint mobilization as a component of comprehensive treatment for primary shoulder impingement syndrome. *Journal of Orthopaedic & Sports Physical Therapy.* 1998;28(1):3-14.
22. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *The American Journal of Sports Medicine.* 2000;28(5):668-673.
23. Dashottar A, Borstad J. Posterior glenohumeral joint capsule contracture. *Shoulder & elbow.* 2012;4(4):230-236.
24. Phelan D, O'Sullivan L. Shoulder muscle loading and task performance for overhead work on ladders versus Mobile Elevated Work Platforms. *Applied ergonomics.* 2014;45(6):1384-1391.
25. Moriguchi CS, Carnaz L, Veiersted KB, et al. Occupational posture exposure among construction electricians. *Applied ergonomics.* 2013;44(1):86-92.
26. El-Gohary MA. Joint angle tracking with inertial sensors. 2013.
27. Roux E, Bouilland S, Godillon-Maquinghen A-P, Bouttens D. Evaluation of the global optimisation method within the upper limb kinematics analysis. *Journal of biomechanics.* 2002;35(9):1279-1283.
28. Welch G, Foxlin E. Motion tracking survey. *IEEE Computer graphics and Applications.* 2002:24-38.
29. El-Gohary M, Holmstrom L, Huisinga J, King E, McNames J, Horak F. Upper limb joint angle tracking with inertial sensors. Paper presented at: Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE2011.
30. Zhu R, Zhou Z. A real-time articulated human motion tracking using tri-axis inertial/magnetic sensors package. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on.* 2004;12(2):295-302.
31. Lebel K, Boissy P, Hamel M, Duval C. Inertial measures of motion for clinical biomechanics: comparative assessment of accuracy under controlled conditions-effect of velocity. *PloS one.* 2013;8(11):e79945.
32. Schall Jr MC, Fethke NB, Chen H, Oyama S, Douphrate DI. Accuracy and repeatability of an inertial measurement unit system for field-based occupational studies. *Ergonomics.* 2015:1-12.
33. Cutting-Edge Wearable Sensors. 2015. Accessed March 25 2016, 2016.
34. Hanvold TN, Wærsted M, Mengshoel AM, Bjertness E, Veiersted KB. Work with prolonged arm elevation as a risk factor for shoulder pain: A longitudinal study among young adults. *Applied ergonomics.* 2015;47:43-51.
35. Matthews D, Pesola G, Campbell R. Effect of epinephrine on amino acid and energy metabolism in humans. *American Journal of Physiology-Endocrinology And Metabolism.* 1990;258(6):E948-E956.