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## EVALUATION OF METHODS TO OPERATE GATE VALVES USING ELAPSED TIME, RATING OF PERCEIVED EXERTION, AND ELECTROMYOGRAPHY

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EVALUATION OF METHODS TO OPERATE GATE VALVES  
USING ELAPSED TIME, RATING OF PERCEIVED EXERTION,  
AND ELECTROMYOGRAPHY

A Thesis

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
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in

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by

Francis Williams Hutchinson  
BGS Louisiana State University 1989  
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## **Abstract**

Industrial valve handwheels are in common use in many industries to block, allow, or regulate the flow of materials within a system. Significant numbers of musculoskeletal disorders have been attributed to turning valve handwheels. The torques encountered to “break” and/or turn these handwheels often exceeds 100 Nm and therefore necessitate the use of special wrenches or other aids. The literature reveals that most of the research has been done to determine the operator’s capabilities for developing the “breaking” forces. After breaking, the continuous muscular effort for as much as five to fifteen minutes required to fully open or close some valves is believed to place greater demands physically and physiologically on the operator than the initial breaking torque requirement. This study used electromyographic data taken from two different locations, the elapsed time to fully open a valve, and Borg’s subjective Ratings of Perceived Exertion (RPE) obtained from the participants to determine the optimum method for opening the valve. The data was obtained from a group of 10 participants who fully opened the valve by using their hands only, using a conventional valve wrench, and using a modified valve wrench. The tasks were repeated with the valve wheel set at two different torque requirements: 25Nm and 50Nm. The data gathered was then



analyzed and evaluated to determine if the modified wrench was the optimum method to open the valve. Although the modified wrench was demonstrated to be the most efficient under some conditions, advantages from further testing and modifications to the wrench were indicated.

## **Chapter 1 – Introduction**

Industrial valve handwheels are in common use in many industries. Petroleum, power generation, chemical, and waste process plants utilize handwheel actuated valves to block, allow, or regulate the flow of materials within a system (Wood et al., 1999,2000). Handwheels are also important in the railway industry where they are used to regulate movement of rail cars. Industrial handwheel actuation is of major concern to safety professionals in these industries. The torques encountered to “break” and/or turn these handwheels often exceeds those determined to be maximal for safe actuation (Schulze et al., 1997).

Although much research has been done to determine the torque capabilities and optimal handwheel positioning (Hoff, 2000), the literature reveals little has been done to investigate the dynamic forces and strains involved (Amell and Kumar, 2001). Amell (2000), using a musculoskeletal discomfort questionnaire, reported the result that 88% of process operators at a large petroleum refinery believed musculoskeletal discomfort they experienced was attributable to their job. The operators also believed that industrial valve handwheel actuation was the most physically demanding task they were required to perform. In addition to potential musculoskeletal damage, there is a possibility of cardiorespiratory problems (Meyer et al., 2000). This study that measured heart rate and oxygen uptake showed noticeable cardiorespiratory strains. The testing was done simulating opening or closing a valve one time, at relatively low torque resistance. The results led the authors to recommend that controls be instituted to reduce the possibility of excessive cardiac demand under actual working conditions. Prevention of handwheel related injuries include engineering and administrative controls. Engineering controls may include increasing the diameter of the valve handwheels (Schulze et al., 1997), ensuring the valve is located in an easily accessible area with the handwheel at the best ergonomic angle

(Wood et al., 1999, 2000), and/or replacing the valves with air or motor operated valves to reduce the amount of operator work. Administrative controls may include ensuring proper preventative maintenance to prevent problems with dirt and corrosion that can increase the difficulty of turning the valve wheel. Also, assigning extra operators to assist with opening or closing valves during startups, shutdowns, or emergency situations where a large number of valves must be opened or closed in a relatively short period of time could reduce some of the stresses on an individual worker. Finally, the employer should ensure that sufficient valve wrenches of the correct size for the valve wheels in the unit are readily available. As of now, not enough research has been done in these areas to effectively implement standards valve wheel size and maximum operating torque (Parks and Schulze, 1998).

This study investigates some of the variables involved in turning manual handwheel actuated valves. Since valve wheel wrenches are in wide use to both “break” the valve and to continuously turn it when the turning torque is high, testing should also include the use of these tools. The experiments are done using two hands only, a standard valve wrench, and a modified valve wrench.

In addition to a conventional valve wrench, a modified valve wheel wrench was designed by the Louisiana State University Industrial Engineering Department to determine if the stresses involved in opening and closing a valve could be reduced. Due to the motions involved using the modified wrench, more of the trunk muscles should come into play, reducing use of the arm muscles. These advantages should allow for faster valve wheel turning with less potential for fatigue. The modified wrench design is shorter than a conventional wrench and has a “spinner” handle on it. This handle would create torque multiplication over use of hands alone, but not as much mechanical advantage as the longer conventional wrench. The primary advantages should

be in the speed of turning and the shorter wrench would not have to be removed and repositioned as often due to side clearance issues which often must be done with a conventional valve wheel wrench.

The valve was opened with the turning effort necessary set at different torque requirements to simulate “real world” situations. The time required to open and close the valve along with the use of Electromyography (EMG) gives objective data to analyze the forces and strains involved. Additionally, Rating of Perceived Exertion (RPE) data using the Borg CR10 Scale was gathered based on the participants’ opinions of which method was preferred for each situation. Changes in the relative force contributions by various muscles as the turning torque requirements are increased reveal variations in work methodology for different loads.

## **Chapter 2 - Background and Literature Review**

### **2.1 Importance of Manual Gate Valves**

Manual gate type valves are in wide use throughout the petrochemical and other industries. With the inception of computerized controllers, manually operated valves are not as critical for controlling pressures and flows as they were in the past. They are, however, very important as a backup control valve, a fail-safe flow block, or a manual controller in process flows which do not have critical flow requirements. Typically, each control valve has a manual valve on the inlet and outlet side, along with another to block a bypass around the controller in case of failure. They are also used to block the suction and discharge of pumps, filters, other equipment, and alternate piping circuits for isolation purposes. The Environmental Protection Agency (EPA) requires manual valves as a safe backup for many applications. Due to their importance, there can be hundreds of these valves in a chemical process unit, ranging from pipe diameters of ½” to 24” and larger.

### **2.2 Causes of Musculoskeletal Problems Due to Use of Manual Gate Valves**

The valve handwheel is originally designed to be turned using only the hands by the average plant operator. After a valve has been in service for a while, it can often become difficult to turn due to several factors. Corrosion and contaminant buildup on the valve threads due to lack of use, and/or inadequate lubrication on the threads can increase the torque necessary to turn the wheel. Additionally, the friction between the bushing (bearing) the valve stem rides in increasing due to lack of lubrication, galling, or metal seizing can result in increased difficulty turning the valve. In some cases, a high pressure product flow can increase pressure on the

internal gate as it closes, increasing friction and the necessary turning force (Parks and Schulze, 1998). Another problem arises when the valve packing (stem seal) begins to leak. Most valves are designed with an adjustable packing that can be tightened to stop or reduce leaking around the valve stem. The normal procedure for repairing this type of leak is to tighten the packing until the leak stops. Although more cost effective than rebuilding or replacing the valve, this repair increases friction in the valve making it harder to turn, often necessitating the use of a valve wrench or an additional person due to the increased force necessary to turn the valve wheel.

There are occasions where the plant operator is called upon to open and/or close these valves many times in a short time span. This can occur when starting up or shutting down a unit, or if process problems necessitate continuous filter changes, equipment swapping, or other duties requiring repeated valve opening and closing. If the valve wheel is difficult to turn, then operator fatigue and the time required opening and closing valves become important process, environmental, and safety issues. One study of the refinery operations of a large petrochemical producer reported that 56% of low back injuries and 75% of head, neck, and face injuries over a three-year period reported by process operators were attributed to industrial valve handwheel actuation (Parks and Schulze, 1998). Another study showed that opening and closing valve handwheels was determined to be a significant cause of serious shoulder injuries at a refinery (Yoonton, 1999).

The initial “breaking” force required to start movement on a fully open or fully closed valve is often much higher than the torque required after valve movement has begun. This breaking force is usually due to increased friction caused by the binding of the valve actuation screw threads and the internal “jamming” caused by forcing the wedge-shaped valve gate into its’ seat. The

breaking force is often increased by high pressure differential present in the lines increasing the jamming force on the valve gate against the internal seat. These forces are overcome when the valve wheel has been moved enough to overcome the internal distortions in the threads and valve seat. A slight opening will also allow some pressure differential relief between the two sides of the valve. The forces are normally overcome when the valve wheel has turned a short angular distance of 1/8 revolution or so.

After the initial breaking force, the operator must often expend large amounts of turning force and physiological effort to open or close the valve to the stem limits. This continuous muscular effort for as much as five to fifteen minutes is believed to place greater demands physically and physiologically on the operator than the initial breaking torque requirement (Jackson et al., 1992).

When a valve's breaking force is high or there is a large dynamic turning force required, the process operator often has a wrench available to aid in turning the wheel. These wrenches are fairly standard in design and operation and consist of a handle with a jaw on the end that can be hooked over the valve wheel. The length of the wrench offers a torque multiplication over turning the wheel by hand. Additionally, the wrench can be positioned perpendicular to the sagittal plane and allows a more positive grip on the valve wheel than using hands alone. This positioning also allows the operator to push or pull the wrench, bringing additional core muscles into play. The combination of mechanical advantage and use of additional muscles combine to make using a valve wheel wrench less strenuous and safer for the worker when opening and closing difficult valves.

Another problem that often arises is the space available in which to open and close the valve. Unfortunately, due to space limitations or plant design, many valves are located in cramped quarters and only allow turning the wheel as little as a quarter turn or less at a time with a conventional wheel wrench. The wrench then must be taken off the valve wheel and repositioned which is time consuming, and can add to the worker's physical stress if the wheel must be turned twenty or thirty full revolutions, as is often the case to fully open or close a valve. When a valve is turned by hand, without a wrench, the effective turning angle is often less than this for efficiency and comfort while turning. In these cases, a shorter wheel wrench would allow some of the advantages of the standard wheel wrench (better grip and more muscles used) and would also allow some increased mechanical advantage while increasing the angular travel before having to reposition the wrench.

Smaller valves (1" pipe diameter or less) are typically a one hand operation, similar to a home water faucet. Larger diameters (12" and above) are often equipped with gear boxes or motor drives to aid in opening and closing. The medium sized valves (2" to 8" pipe diameter) are the focus of this study.

Most of the research on hand wheel turning has focused on static torque studies. These usually measure a maximum isometric force exerted by the operator and are useful in studying the problems with the breaking force required and determining optimal operator to handwheel positioning. One study recorded breaking forces of 336 valves of various handwheel diameters from 100 Nm to a maximum of 225 N m (Parks and Schulze, 1998). In another study, (Jackson et al., 1992) reported a breaking force of over 400 Nm on 93% of 217 valves. Some studies have concentrated on valve wheel to operator positioning. These determined that when valve position was between knee and shoulder height, little difference was observed in various operators'



torque producing capability (Wood et al., 1999; Attwood et al., 2002). Others have compared the effects of different valve wheel designs and effects of various types of gloves worn. Again, these were static tests designed to evaluate breaking force (Schulze et al., 1997; Hoff, 2000).

## **Chapter 3 - Objectives and Hypotheses**

### **3.1 Project Design**

The objective of this study was to evaluate and compare different methods of turning a valve handwheel to determine which methods are the most efficient and could minimize the potential for injuries caused by the task. In addition to turning the valve wheel by hand, the use of a conventional valve wheel wrench was included to better simulate actual work situations. A modified wrench design was included to determine if the operator's efficiency and comfort could be improved through its use.

Two different turning torques were used to simulate actual operating resistance. A low torque (25 Nm) was used to simulate a new or well-maintained valve with no corrosion, contamination, or other factors to increase the necessary turning force. A higher torque (50Nm) was used to simulate a valve which is still in fairly good condition but may have had the valve packing tightened to stop leaking around the stem or may be in need of cleaning or lubrication. This torque requirement is not unusual in the field. Much higher torques are often found in actual operations (Jackson et al., 1992; Yoonton 1999; Parks et al., 1998). The 50 Nm torque was decided upon as it is the maximum recommended by the Manufacturer's Standardization Society of the Valve and Fittings Industry (MSS-91-2009) for this size valve wheel. Higher torques were not tested to minimize potential injury to the participants.

### **3.2 Variables**

The independent variables used for analysis were the methods used for turning the valve wheel:

- Using a conventional valve wheel wrench with no clearance problems

- Using a conventional valve wrench while simulating “real world” clearance or interference problems.
- Using the modified valve wheel wrench.
- Using bare hands only

And the two preset torque requirements for dynamic turning of the wheel:

- 25 Nm
- 50 Nm

The dependent variables were:

- The time required to fully open the valve.
- The perceived exertion based on the Borg CR10 scale.
- The Electromyography (EMG) signals from the left bicep muscle which were normalized using the Maximum Voluntary Contraction (MVC) amplitude.
- The Electromyography (EMG) signals from the right lateral deltoid muscle which were normalized using the Maximum Voluntary Contraction (MVC) amplitude.

### 3.3 Hypotheses

The hypotheses to be tested by the analyses were:

NOTE: The hypotheses would be tested at both turning torques (25 Nm and 50 Nm). The methods are designated as:

- $\bar{u}_1$  = Using bare hands

- $\bar{u}_2$  = Using the conventional valve wrench (unrestricted protocol)
- $\bar{u}_3$  = Using the conventional valve wrench (restricted protocol)
- $\bar{u}_4$  = Using the modified valve wrench

The above protocols are discussed in Chapter 4.

1. The modified wrench would be the most efficient method due to the increased use of different muscles (i.e. the work would be divided by other muscles not normally used to complete the task with bare hands) when comparing the elapsed time to fully open a manual gate valve.

$H_0$ :  $\bar{u}_1 = \bar{u}_2 = \bar{u}_3 = \bar{u}_4$ : Results for the methods based on elapsed time are equal

$H_1$ :  $H_0$  is false

2. The modified wrench would be the method that causes the least exertion to the test participants based on a subjective evaluation by the participants using the Borg CR10 Rating of Perceived exertion.

$H_0$ :  $\bar{u}_1 = \bar{u}_2 = \bar{u}_3 = \bar{u}_4$ : Results for the methods based on evaluations are equal

$H_1$ :  $H_0$  is false

3. Surface Electromyography (SEMG) of muscles involved to turn the valve wheel would demonstrate reduced effort necessary to use the modified wrench compared to using bare hands or a conventional wrench.

$H_0$ :  $\bar{u}_1 = \bar{u}_2 = \bar{u}_3 = \bar{u}_4$ : Results for the methods based on SEMG are equal

$H_1$ :  $H_0$  is false

## Chapter 4 - Methods and Procedures

### 4.1 Equipment Used

A standard, 6" inside pipe diameter manual gate valve was obtained and mounted in a rigid stand with the valve hand wheel horizontal at a height of about 100 cm from the grade (Figure 1).

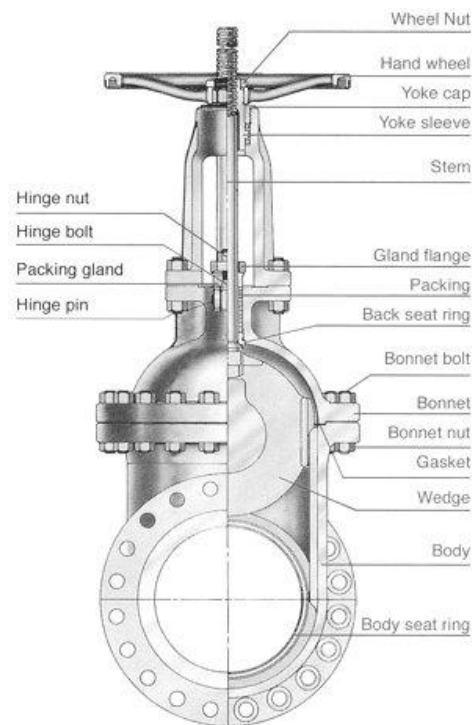


**Figure 1. 6" manual gate valve used in experiments**

The valve used was newly rebuilt and properly lubricated to ensure proper performance throughout the experiments.

Although there is no set height for these valves and few, if any, chemical plants are designed with ergonomic placement of valves in mind, the literature has shown this is a common configuration. This valve wheel height falls within the ergonomic recommendations cited in the literature (Parks and Schulze, 1998; Wood et al, 1999; Attwood et al, 2002.). Participants stood on a plywood base to reduce the potential for slips.

The design of the valve used is common in the chemical industry (Figure 1) and normally gives years of service before refurbishing or replacement is necessary. The most common problem encountered with this type valve is product leakage around the packing which seals the stem. When this occurs, the packing can be tightened against the stem by tightening down on the packing gland nuts (Hinge nut in Fig. 2) in order to stop the leak.



**Figure 2. Cutaway drawing of a typical gate valve.**

Normally, this increased pressure on the packing results in increased packing to stem friction, which increases the force necessary to turn the valve handwheel.

The valve wrench used was a Gearench 306-VW101AL. This is an aluminum/magnesium “crow’s foot” type valve wheel wrench. This wrench is approximately 34.5 cm in length and weighs approximately one kg. Two of these wrenches were obtained for the experiment. One had a hinge fabricated in the handle to allow the wrench to be hooked on the valve wheel and turned 360° without having to remove the wrench from the valve wheel if there are no clearance or obstruction problems. The other was shortened by about two cm to equalize the length of the two and ensure no difference in mechanical advantage if the hinged wrench were operated fully opened. Figure 3 shows the conventional valve wheel wrench and the modified version.



**Figure 3. Modified valve wheel wrench (top) and conventional valve wheel wrench**

The radius of the valve wheel from the center of the threaded stem to the outer rim is 17.2 cm. The radius from the center of the stem to the hinged part of the modified wrench handle is 33cm and the radius from the stem to the end of the handle of the conventional wrench is 43 cm. This means that torque multiplication when using the modified wrench is about 90% and when using the conventional wrench is about 150% over using the wheel rim with bare hands.

The valve wheel, and therefore the hands when turning the wheel, must travel about 108 cm to complete a full revolution. When using the modified wrench the hands must travel about 207 cm and when using the conventional wrench the hands travel is about 270 cm. In order to fully open this valve, the wheel must be turned approximately 17 full revolutions.

#### 4.2 Power Analysis

The table below shows the numerator and denominator degrees of freedom for the fixed effects, where T stands for torque, M for method, and T\*M for the torque and method interaction. In using five participants, the power of this study is 81.3%, which satisfies the conventional desired power of at least 80% (Cohen, 1988).

**Table 1. Results of power analysis calculations**

Effects	Num df	Den df	$\lambda=2.3$	# of obs. per level of the effect per participant	Subjects	# of obs per level of the effect	Power (ES=0.8)
T	1	4	52.9	4	5	20	99.9%
M	3	24	26.5	2	5	10	98.6%
T*M	3	24	13.2	1	5	5	81.3%



The following SAS code was used to compute the power of each fixed effect:

```
data;  
fcritical = finv(0.95, DFn, DFd, 0);  
power = 1 - probf(fcritical,DFn,DFd,noncentrality_parameter);  
run;  
proc print;  
run;
```

### 4.3 Participants

Prior to the study, an “Application for Approval of Projects Using Human Subjects” (Appendix C) was submitted to and approved by the Louisiana State University Institutional Review Board (IRB). This proposal includes a completed questionnaire and basics about the experiments, study protocols, and the subject pool. The IRB then makes a determination as to the safety of the project and offers suggestions to ensure the welfare of the participants. The experimenters were also required to complete the National Institute of Health (NIH) Office of Extramural Research online course “Protecting Human Participants” (Appendix G).

Participants were required to read and sign an approved “Informed Consent Form” (Appendix C) which outlines the basics of the study and the necessary physical requirements for the participant’s safety. The participants were also required to complete a “Physical Activity Readiness Questionnaire” (PARQ) that helps ensure the participant’s ability to complete the tasks safely (Appendix E).

Five student participants in good health, between the ages of 18 and 45, were tested. Protocols were established for each method of opening the valve wheel and are discussed in Chapter 4.

The participants were given basic instruction in the protocols to be used when completing the tasks. These protocols were determined to ensure that the actions taken when completing the tasks would be as consistent as possible to yield more consistent data. The protocols included approximate stance, grip on the handwheel or wrench, and basic motions involved.

Each participant was given five minutes time to practice each method as a “warm-up” and to familiarize himself with the tools and motions involved.

Basic anthropometric data (height, weight, and age) was recorded for each participant. Each participant’s resting heart rate (HR) was recorded by having the participant grab the touch-sensitive handles on a Nautilus Commercial Series T9 14 Treadmill. Participants’ heart rates were allowed to return to resting HR between tests to minimize the potential for fatigue or injuries.

The time required to fully open the valve was recorded. Comparing the times was used to measure the efficiency of each method. Additionally, fully opening the valve helped the participants to have a better understanding of the work involved when they were asked for a subjective evaluation of the task.

The participants were instructed in the use of the Borg CR10 rating scale to rate their perceived physical exertion for each task. An evaluation using the Borg CR10 scale was done by each participant to determine which method was perceived to be preferable for each torque setting.

Additionally, surface electromyography (SEMG) was used to determine the differences in muscle activity at different loads, using different methods. Preliminary testing was done on one participant using bare hands, a conventional valve wheel wrench, and the modified wrench at both 25 Nm and 50 Nm turning torques.

The muscles tested were:

- Left and Right Bicep
- Left and Right Triceps
- Left and Right Lateral Deltoid
- Left and Right Latissimus Dorsi
- Left and Right Multifidus
- Left and Right Upper Trapezius

The EMG data collected from the left bicep and the right lateral deltoid had the highest overall activity when performing the various tasks so these were the muscles studied in the trials.

The participants were instructed to open the valve as quickly as possible without causing extreme discomfort. The torque required to turn the valve wheel was adjusted by tightening or loosening the packing gland nuts to increase or decrease the friction on the stem of the valve. This would in turn increase or decrease the turning torque required. After adjusting the packing gland nuts, the turning torque was checked with a conventional beam type torque wrench and readjusted if necessary.

#### 4.4 Methods and Protocols

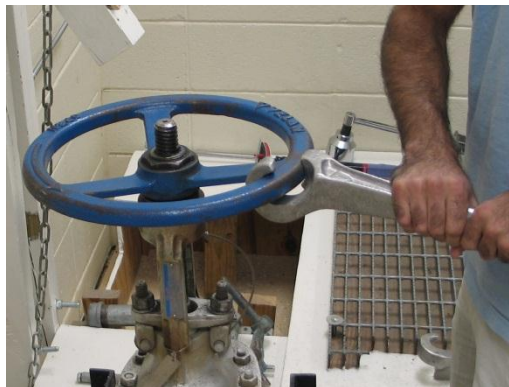
The four methods used and their associated protocols were:

- Using bare hands only - The participant was directed to stand facing the valve wheel at a distance that allowed the task to be performed comfortably. He would then grasp the valve wheel with both hands, approximately 180° apart, and turn the wheel about ¼ of a revolution (90°), and then regrasp the wheel.



**Figure 4. Participant turning valve using bare hands.**

- Using a conventional valve wrench simulating unrestricted valve location - The participant was directed to stand facing the valve wheel at a distance that allowed the task to be performed comfortably. The participant would hook the valve wrench on the valve wheel, and keeping both hands on the wrench as much as possible, open the valve. This method allowed the participant to open the valve most or all the way without having to reposition the wrench due to interference from the valve stem as the turning of the wheel forced the stem to protrude from the valve wheel.



**Figure 5. Participant turning valve with conventional wrench.**

- Using a conventional valve wrench simulating restricted valve location - The participant was directed to stand facing the valve wheel at a distance that allowed the task to be performed comfortably. The participant would hook the valve wrench on the valve wheel, and keeping both hands on the wrench as much as possible, open the valve about 2/3 of a revolution

Then, in order to simulate a real-world scenario where there was interference due to piping, structure, or other valves, he would unhook the wrench and rehook it at the original starting point.



**Figure 6. Participant unhooking, then rehooking valve wrench on wheel.**

- Using the modified wrench - The participant was directed to stand facing the valve wheel at a distance that allowed the task to be performed comfortably. The participant would hook the modified valve wrench on the valve wheel, and keeping both hands on the wrench as much as possible, open the valve. The shorter reach required to move the valve wheel through a complete revolution made it possible for the participants to fully open the valve without repositioning the wrench on the wheel.



**Figure 7. Participant turning wheel using modified wrench.**

The participants were given a rest period between trials to allow their heart rate to return to the resting rate. The objective and subjective data was then collected, compared, and analyzed.

## **Chapter 5 - Data Collection and Analysis**

### **5.1 Elapsed Time for Each Task**

Each task was timed from the valve in the fully closed position being turned counterclockwise to the valve in the fully open position. Participants were not required to initially “break” the valve open. Preliminary tests indicated that “cracking” forces can vary from trial to trial on the same valve. Also, the “breaking” force required at the higher torques may affect the performance of participants. The valve was fully closed then opened just past the breaking point (approximately 1/8 turns). Asking the participants to open the valve as fast as possible simulated “real world” conditions as when a hurried or emergency condition is called for and numerous valves must be opened or closed quickly. This is done to minimize the potential for process problems that may occur when flows and/or pressures go unchecked for too long a time. This should also help ensure that participants were using as much force as possible to complete the task.

### **5.2 Subjective Rating of Perceived Exertion**

After the completion of each task, the participants were asked to rate the task just finished using a rating of perceived exertion, specifically Borg’s category-ratio based CR10 scale. Perceived exertion has been defined as the subjective intensity of effort, strain, discomfort or fatigue, experienced during physical exercise (Robertson and Noble, 1997). The CR-10 scale has been proven useful when estimating perceived exertion based on the intensity of exertion measured (Meyer et.al. 1999, Borg & Borg, 2001, Copodaglio, 2001). This is the result of the non-linear scale which is graduated more slowly at the higher exertion end of the scale. The participants were given a brief introduction to the use of ratings of perceived exertion (RPE) and an

explanation of the categories described on the CR10 scale. The importance of ensuring that subjects understand the proper use of the scale was stressed by the developer of the scale, Gunnar Borg. In his book, Borg's Perceived Exertion and Pain Scales (1998, Human Kinetics, USA), Borg outlined basic instructions to be explained to subjects (Appendix A). He also specified complementary instruction for the modality to be tested such as exertion, pain, etc. Each participant was asked to read and understand these instructions before the trials were done.

### 5.3 Surface Electromyography (SEMG)

Electromyography (EMG) is a method for detecting and recording the electrical activity of muscles during contractions. In the case of Surface Electromyography (SEMG) a surface electrode is affixed to the skin, normally over the belly of the muscle being tested. When muscle activity occurs the electrode detects a change in electric potential across the skin. This change is transferred to an oscilloscope or other electrical apparatus which displays and/or records the amplitude of the electrical impulses. This activity is normally a fairly reliable indicator of the amount of force contribution of individual muscles when performing a task

The EMG system normally consists of an interface between the muscle and the collection system, or electrode. The electrode system is designed to detect the difference in electric potential produced by the ionic movement caused by motor neuron activity. The two most common types of electrodes in use are needle electrodes (invasive) which are inserted directly into the targeted muscle and surface electrodes (noninvasive) which are adhered to the skin over the targeted muscle. The signal received by the electrodes is transferred by coaxial cable through a preamplifier to an amplifier. The signal is then read out on an oscilloscope or computer and recorded for analysis (Kumar & Mital, 1996).



### 5.3.1 Delsys Wireless Myomonitor

For this experiment the EMG system used was an eight channel Myomonitor system by Delsys of Boston, MA. The electrodes used in this system are surface mounted electrodes affixed to the skin by interface tape which has adhesive on both sides. The signals from the eight electrodes and the reference electrode are channeled through a belt mounted input module to the main amplifier unit. The amplified signal is transmitted wirelessly to a laptop where they are displayed and recorded. The signals are then processed using EMGworks acquisition and analysis software designed for the Delsys systems.

### 5.3.2 Electrode Placement

Turning a valve hand wheel becomes increasingly difficult as the torque requirements are increased. In an actual work environment, as the difficulty increases, the operator's body will attempt to bring additional muscles into play by bending or twisting the trunk. This action can reduce some of the load on the arm and shoulder muscles that normally will do most of the work in turning the wheel. Similarly, when using a valve wrench, the motions are changed with increasing load. As with many other tasks, one who is experienced in turning a valve wheel may use trunk muscles in a motion that combines pushing, pulling, and twisting to turn a valve wheel only a part of a rotation. These extreme variations of motion, position, and muscles used at any given point make it difficult to model which muscles would be targeted for dynamic EMG studies.

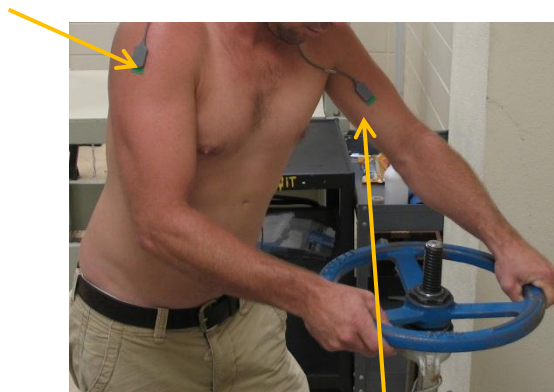
In order to determine which muscles to include in the experiment, preliminary trials were conducted to determine which muscles were most active when performing the tasks. Several arm and shoulder muscles, along with upper, mid, and lower back muscles were experimented

with to predetermine which seemed to give the greatest overall EMG activity while performing the included tasks.

The electrode placement sites experimented with were those illustrated on the “Clinical SEMG Electrode Sites” chart (Appendix C). This chart was developed and published by Noraxon, a manufacturer of electromyography equipment to provide a visual overview of common SEMG electrode placements. The electrodes were placed as indicated on the chart, taking care to locate the electrode over the belly of the muscle with the electrode bars perpendicular to the muscle fibers. It should be noted that not all locations resulted in strong activity which indicated that the muscles which were primarily used during one task may have little or no role in another. This may have been due to the method of turning the wheel, the load on the wheel or both.

The electrode placement sites used were:

- Right Lateral Deltoid (Appendix C, #55)



- Left Bicep (Appendix C, #38)

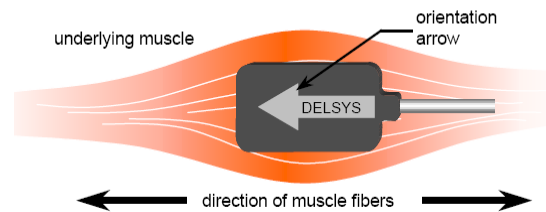
**Figure 8. Electrode placement on participant**

### 5.3.3 SEMG Data Collection Procedure

The procedure for gathering the EMG data was as follows:

- a. The EMG Myomonitor Unit contains surface electrodes which are connected to different receptacles on the Delsys interface module. The electrode cables are five feet long and allowing the module to be mounted at waist level.
- b. The interface module is connected by cable to the amplifier unit which is in turn connected wirelessly to a laptop computer that has been loaded with the EMGworks acquisition software.
- c. Placement of the Surface Electrodes on the Skin:
  - 1) The EMG surface electrodes have two silver bar contacts to detect the electromyography signal at the skin surface of the test subject. The surface electrodes silver bars must be perpendicular to the muscle fibers which are being taken into account. The arrow label on the surface electrode is perpendicular to the silver bars; with the label parallel to the muscle fibers.
  - 2) To ensure accurate data, the surface skin of the subject should be as clean, free of oil or any other type of interference between the skin and the surface electrodes. This was accomplished by cleaning the skin with dilute isopropanol (rubbing alcohol) and, where necessary, shaving the skin to remove body hair.
  - 3) To attach the surface electrodes to the subject's skin using a Delsys Electrode Interface :
    - Peel the clear liner to expose the first layer of the adhesive of the interface
    - Attach the adhesive to the electrode with the alignment of the silver bars.

- Peel the white liner to expose the second layer of adhesive
- Locate the placement sites and direction of electrode alignment according to the SEMG chart (Appendix B).
- Attach the exposed adhesive to the muscle site.



**Figure 9. Placement of electrode over muscle.**

d. EMG data Collection

- 1) Turn the system ON by locating the power switch on the side of the Amplifier Unit.
- 2) Click on the EMG Acquisition icon on the desktop from the computer where the program has been installed.
- 3) Define Test Configuration
- 4) A test was defined as VALVE WHEEL to collect the data from 8 different trials for one participant.

e. Click on the “TEST” from the file menu and click start to begin the data collection.

f. Maximum Voluntary Contraction – Maximum Voluntary Contraction (MVC) is the peak force produced by a muscle as it contracts while pulling against an immovable object. When EMG signals of a muscle at MVC are obtained they are

useful in normalizing EMG test results by yielding a percentage of the muscle's maximum potential activity. MVC testing was performed on a modified home gym which had weights and cables replaced with chains of adjustable lengths to provide resistance for isometric exercises. Participants were instructed to perform the exercise, exerting as much force as possible. They would then relax and perform the exercise two more times. The highest EMG signal was the one used for MVC.

- 1) Left Bicep – Preliminary testing revealed that some participants had higher bicep activity (Figure 10) performing a “pull down” than when doing



**Figure 10. Lat pull-down MVC**



**Figure 11. Left Bicep MVC**

conventional bicep curls (Figure 11). Because of this participants were asked to do both exercises and the highest resulting EMG readings were used.

The pull down exercise was performed by using a seat belt to secure the participant to the bench on the apparatus. The upper arms were horizontal with the participant grasping the ends of a pull down bar and pulling down. The bicep curl was done with the arm at the participant's side and his elbow at

a 90° angle. The forearm was parallel to the sagittal plane with the participant grasping a handle. The participant would then perform a “bicep curl” by pulling up on the handle.

- 2) Right Lateral Deltoid – The participant stood with right arm straight, palm down, and apparatus handle about waist high (Figure 12). Participant would then pull up on handle.



**Figure 12. Right Deltoid MVC**

g. Physical Test

- 1) The order of the tests was randomized by using slips of paper with the description of each task put in a box and drawn out to determine the order of the tests for each participant. This was done to preclude data errors that may have been encountered by having all subjects follow the same testing order.
- 2) Have participant connected to the EMG Delsys amplifier.
- 3) The experimenters regulated the valve turning torque by loosening or tightening the valve packing gland nuts to decrease or increase the friction on the valve stem. The turning torque was then tested with the beam type torque

wrench to verify the turning force required. If necessary, this procedure was repeated until the desired turning torque was accomplished.

4) Test

- a. The experimenters adjusted the packing gland to attain the turning torque required for the first test.
- b. The test subject was required to open the valve wheel counter-clockwise as fast as possible using one of the four methods.
- c. The experimenters would simultaneously start the timer and the EMG acquisition test when proceeding.
- d. Proceed with experimentation using one of the four methods:
  - Bare hands
  - Conventional wrench (unrestricted valve location)
  - Conventional wrench (restricted valve location)
  - Modified wrench

At one of the two desired turning torques:

- 25 Nm
  - 50 Nm
- e. The timer was stopped when the test subject had completely opened the valve wheel.
  - f. The elapsed time for completion was recorded.
  - g. After a two minute interval and every two minutes after, the participants pulse was taken. When participant's resting heart rate had returned to

normal the test was repeated using another randomly selected torque and method.

- h. This procedure was repeated until the participant completed the task using all four methods at both torque settings.

5) Repeat all procedures for the rest of the participants.

#### 5.3.4 SEMG Data Analysis

The EMG data obtained was collected and exported to an Excel spreadsheet. The signal was demeaned to remove any bias caused by any low amplitude voltage offset present in the hardware. This was done by taking an overall average of the signals and adjusting the signal values by this amount to attain an average of zero. The signal was then full wave rectified by obtaining the absolute value of each data point. The signal was normalized with respect to the Maximum Voluntary Contraction (MVC) obtained by performing the isometric task. In order to minimize the effects of random “spikes” in the data, the resultant was filtered by calculating a .5 second moving average and then using the highest figure as the mean absolute value (MAV). Since the role of the muscles change throughout the task due to the changes in the direction of forces on the valve wheel when using bare hands or the tools, this “moving window” MAV was used rather than the average of the total signal for completing the task. The .5 second window was settled upon after comparison of several different window lengths as it eliminated several “spikes” in the data which would have yielded erroneous results. This gave a better indication as to the maximum amount of effort done by each muscle during the trials.

Pairwise comparisons using Differences of Least Squares Means was used to compare the action of the muscles throughout the experiments. This same analysis was also done on the elapsed



time necessary to complete the task and the rating of perceived exertion based on the Borg CR10 scale.

A comparison of the speed to complete the task, the rated perception of exertion, and the EMG statistical data revealed much about which muscles are used during the task of turning a valve handwheel and how the worker compensates for increased force demands by distributing the forces using additional muscles.

## Chapter 6 – Results

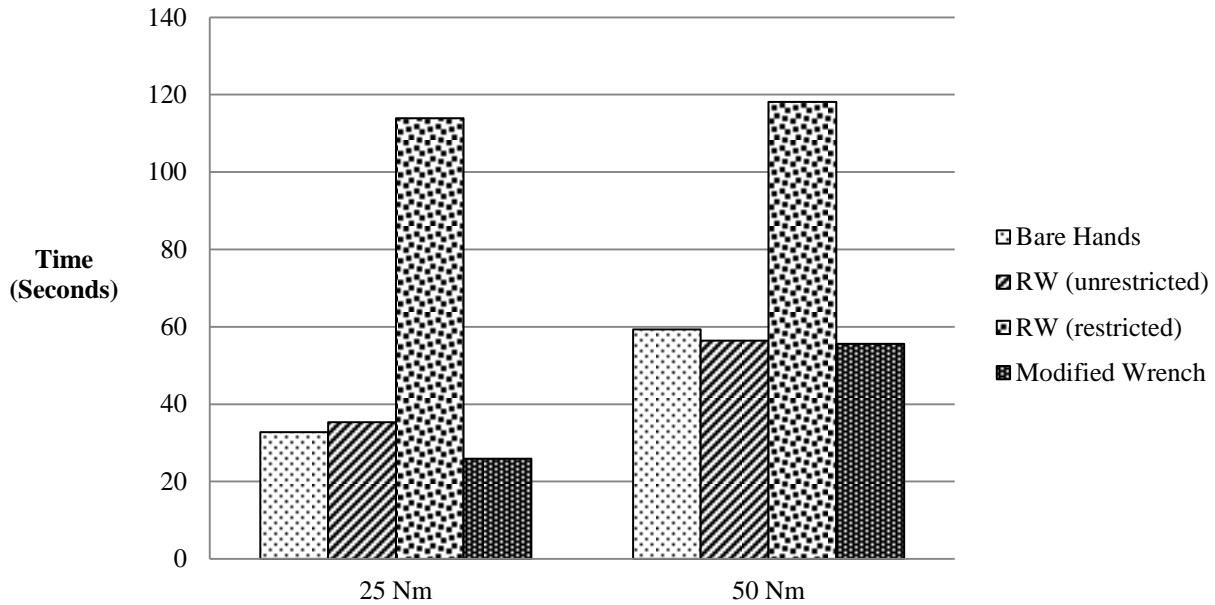
### 6.1 Time to Complete the Tasks

The elapsed times for the participants to complete the tasks along with the average time are listed in Table 1. When comparing the average times for the participants to complete the tasks, it can be seen that the modified wrench was the fastest method at both torque settings.

**Table 2. Elapsed Time to Complete Trial (by subject)**

Subject #	1	2	3	4	5	Avg
Bare Hands, 25 Nm	24	40	44	26	29	<b>32.8</b>
Conventional Wrench (unrestricted protocol), 25 Nm	28	39	50	32	28	<b>35.3</b>
Conventional Wrench (restricted protocol), 25 Nm	99	112	97	106	82	<b>113.9</b>
Modified Wrench, 25 Nm	22	22	41	22	22	<b>25.9</b>
Bare Hands, 50 Nm	54	48	100	59	36	<b>59.3</b>
Conventional Wrench (unrestricted protocol), 50 Nm	49	59	74	59	41	<b>56.4</b>
Conventional Wrench (restricted protocol), 50 Nm	104	139	143	124	81	<b>118.1</b>
Modified Wrench, 50 Nm	48	49	102	54	25	<b>55.6</b>

The graph below (Figure 9) summarizes the average time to complete the task. At both torque settings the modified wrench took the least time to complete the task of fully opening the valve while the conventional wrench using the restricted protocol took the longest time. At the lower torque setting (25 Nm) using bare hands was the second fastest method. At the higher torque setting (50 Nm) the conventional wrench using the unrestricted protocol was second fastest.



**Figure 13. Average Time to Complete Trial**

## 6.2 Borg CR10 Scale - Rating of Perceived Exertion

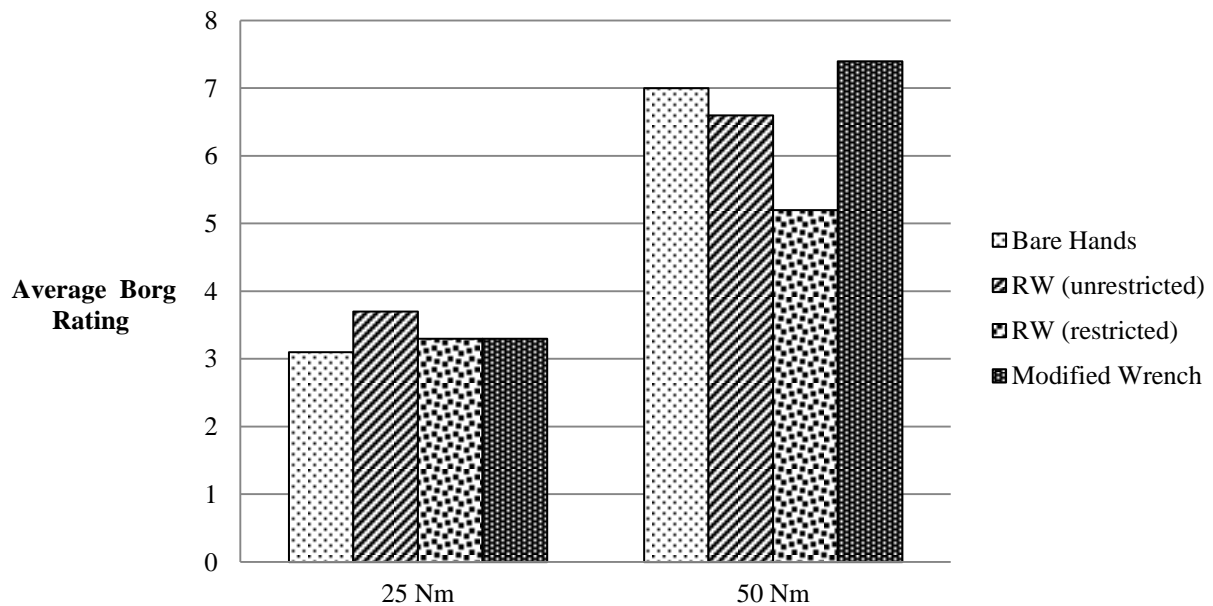
When the participants were asked to rate their perceived exertion using the Borg CR10 Rating of Perceived Exertion scale (RPE), using bare hands was the preferred method when testing at the lower (25 Nm) torque (Table 2). Using the modified wrench and using the conventional wrench with the restricted protocol were the second preferred methods.

At the higher (50 Nm) torque, using the conventional wrench with the restricted protocol received the best rating. Using the conventional wrench with the unrestricted protocol had the next lowest perceived exertion at the higher torque. Using the modified wrench had the highest rating of perceived exertion.

**Table 3. Rating of Perceived Exertion**

Subject #	1	2	3	4	5	AVG
Bare Hands, 25 Nm	3	2	2.6	3	5	<b>3.1</b>
Conventional Wrench (unrestricted protocol), 25 Nm	5	3	2.6	4	4	<b>3.7</b>
Conventional Wrench (restricted protocol), 25 Nm	5	2.5	2	4	3	<b>3.3</b>
Modified Wrench, 25 Nm	7	1.5	2.1	3	3	<b>3.3</b>
Bare Hands, 50 Nm	10	7	6	6	6	<b>7.0</b>
Conventional Wrench (unrestricted protocol), 50 Nm	10	6	4.5	7	5.5	<b>6.6</b>
Conventional Wrench (restricted protocol), 50 Nm	8	4	3.2	6	4.8	<b>5.2</b>
Modified Wrench, 50 Nm	9	9	8.5	6	4.5	<b>7.4</b>

The graph comparing average RPE (Figure 11) indicates that at the 25 Nm torque, the conventional wrench using the unrestricted protocol was the least favored while the other methods had ratings close to each other.



**Figure 14. Average Rating of Perceived Exertion**

At the higher torque setting the conventional wrench using the restricted protocol was clearly the favored method while the other three methods had ratings close to each other.

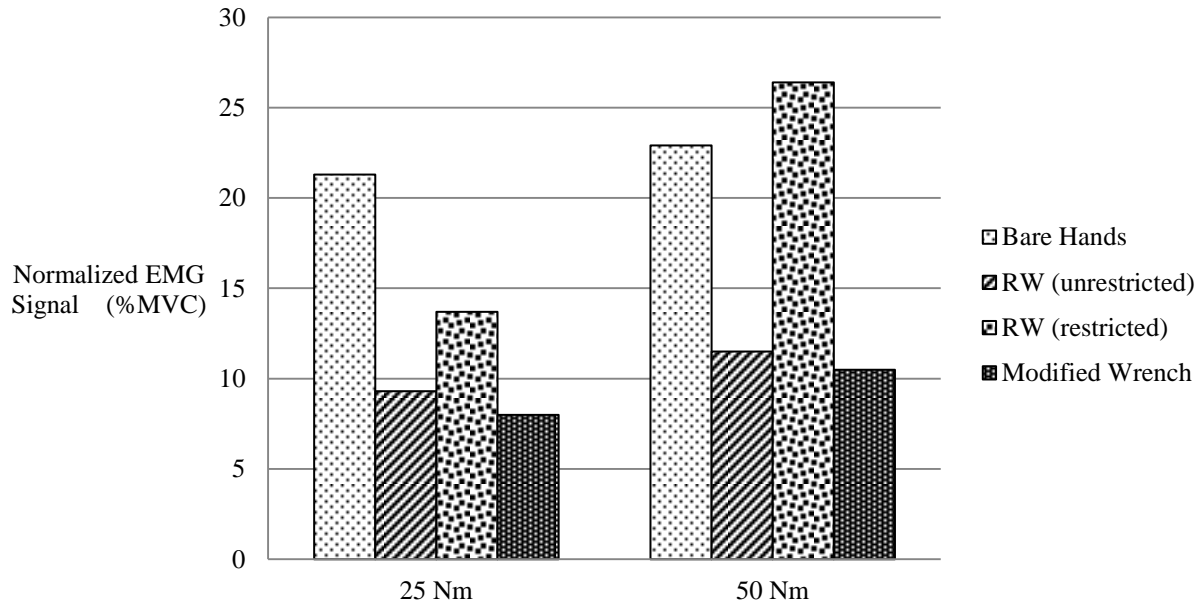
### 6.3 Left Bicep SEMG Results

The data (Table 3) indicates that the modified wrench results in the least activity from the left bicep at either torque. At the lower torque the when turning the valve wheel by hand the left bicep exerted more force to complete the task than when using any of the other methods.

**Table 4. Normalized EMG Signal of Left Bicep (%MVC)**

Subject #	1	2	3	4	5	AVG
Bare Hands, 25 Nm	13.4	46.2	15.6	26.7	4.7	<b>21.3</b>
Conventional Wrench (unrestricted protocol), 25 Nm	5.7	24.6	1.3	8.9	6.0	<b>9.3</b>
Conventional Wrench (restricted protocol), 25 Nm	2.9	31.8	3.5	17.9	12.3	<b>13.7</b>
Modified Wrench, 25 Nm	2.0	24.7	5.5	5.4	2.3	<b>8.0</b>
Bare Hands, 50 Nm	13.4	55.7	27.0	13.7	4.5	<b>22.9</b>
Conventional Wrench (unrestricted protocol), 50 Nm	2.5	32.3	4.0	3.1	15.6	<b>11.5</b>
Conventional Wrench (restricted protocol), 50 Nm	6.1	24.7	6.0	2.5	92.9	<b>26.4</b>
Modified Wrench, 50 Nm	4.8	24.6	4.0	7.3	11.8	<b>10.5</b>

The graphed results (Figure 12) indicate that use of the modified wrench resulted in less bicep activity than the other three methods at both torques. At the higher torque, both using bare hands and using the conventional wrench following the restricted protocol were rated much higher in perceived exertion than the other two methods.



**Figure 15. Average Normalized EMG of Left Bicep**

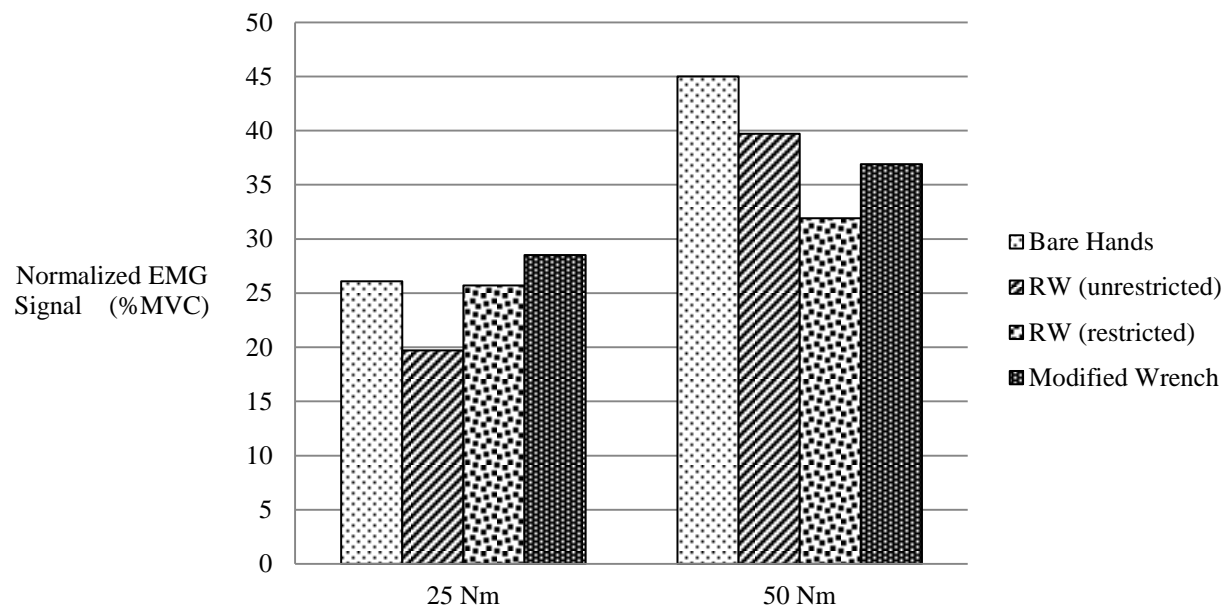
#### 6.4 Right Deltoid SEMG Results

When comparing the results of muscle activity for the right deltoid (Table 4), it can be seen that muscle activity using the conventional wrench with the unrestricted protocol is higher than the other three methods at the lower torque while the modified wrench resulted in the highest muscle activity at the higher torque.

**Table 5. Normalized EMG Signal of Right Deltoid (%MVC)**

Subject #	1	2	3	4	5	AVG
Bare Hands, 25 Nm	17.3	61.6	5.3	11.1	8.3	<b>26.1</b>
Conventional Wrench (unrestricted protocol), 25 Nm	15.5	68.7	6.5	11.9	13.4	<b>19.7</b>
Conventional Wrench (restricted protocol), 25 Nm	10.0	61.6	8.2	18.6	10.5	<b>25.7</b>
Modified Wrench, 25 Nm	15.0	61.6	13.1	12.3	6.1	<b>28.5</b>
Bare Hands, 50 Nm	15.0	64.6	12.2	19.4	19.3	<b>45.0</b>
Conventional Wrench (unrestricted protocol), 50 Nm	12.1	92.6	19.7	96.2	15.3	<b>39.7</b>
Conventional Wrench (restricted protocol), 50 Nm	4.9	61.6	6.7	16.4	51.5	<b>31.9</b>
Modified Wrench, 50 Nm	12.2	83.1	10.3	2.5	22.1	<b>36.9</b>

When comparing the results for the lower torque in the graph (Figure 13), the conventional wrench using the unrestricted protocol generated less activity than the other methods while use of the modified wrench resulted in the highest muscle activity. At the higher torque, use of the conventional wrench with the restricted protocol resulted in the least muscle activity while the bare hands method generated the highest muscle activity.



**Figure 16. Average SEMG of Right Deltoid**

## 6.5 Statistical Analysis

The results displayed above were analyzed using SAS 9.3 statistical analysis software. Differences of Least Squares Means testing was done to compare the four methods used at the two different torques. The statistical tests were done based on the elapsed time for each method, the participants' subjective ratings of perceived exertion using the Borg CR10 scale, and the SEMG results for the left bicep and the right deltoid.

The SAS results tables have been shortened to only include the results that were used for the analysis. These results are the “Type 3 Tests of Fixed Effects” and the “Differences of Least Squares Means” results for pairwise comparison of the torques, methods, and methods within a given torque, since pairwise comparisons between torques would not give useful results.

For the type 3 Tests the null hypothesis ( $H_0$ ) and the alternate hypothesis ( $H_A$ ) tested would be:

- 1) Tests for Torque -  $H_0 : \bar{u}_1 = \bar{u}_2$  : The results for the torques are equal  
 $H_A : H_0$  is false
- 2) Tests for Method -  $H_0 : \bar{u}_1 = \bar{u}_2 = \bar{u}_3 = \bar{u}_4$  : The results for the methods are equal  
 $H_A : H_0$  is false
- 3) Test for interaction between Torque and Method (Torque\*Method) where  $\bar{u}_{ij}$  is the average result for the trials if Torque =  $i$  and Method =  $j$ .  
 $H_0 : \bar{u}_{11} - \bar{u}_{12} = \bar{u}_{21} - \bar{u}_{22} = \bar{u}_{13} - \bar{u}_{23} = \bar{u}_{14} - \bar{u}_{24}$  : There is no interaction between torque and method : ( $i$  and  $j$ ) are independent  
 $H_A : H_0$  is false

For the pairwise comparisons (Differences of Least Squares Means):

- Torque 1 is compared against Torque 2 (First line of results):
  - $H_0 : \bar{u}_1 = \bar{u}_2$  : The torques are equal
  - $H_A : H_0$  is false : The torques are not equal
- The methods are tested after averaging over both torques (Next 6 lines of results):
  - $H_0 : \bar{u}_{.j} = \bar{u}_{.j'}$  : The methods are equal
  - $H_A : H_0$  is false : The methods are not equal



- The methods within a given torque are compared pairwise (Last 12 lines of results):
  - $H_0: \bar{u}_{ij} - \bar{u}_{ij'} = 0$  : The methods are equal
  - $H_A: H_0$  is false : The methods are not equal

NOTE: In the results tables:

Torque 1 = 25 Nm

Torque 2 = 50 Nm

Method 1 = Using bare hands

Method 2 = Using a conventional wrench assuming unrestricted movement

Method 3 = Using a conventional wrench simulating restrictions to wrench movement

Method 4 = Using the modified wrench

#### 6.5.1 Statistical Results – Elapsed Time to Fully Open the Valve Wheel

The “Type 3 Tests of Fixed Effects” for elapsed time to fully open the valve (Table 5) indicate the test for Torque is statistically significant ( $p < .05$ ) and results in rejecting the null hypothesis that torques are equal. The test for Method also is statistically significant ( $p < .05$ ) and results in rejecting the null hypothesis that the methods are equal.

The test for interaction between torque and method was not statistically significant ( $p > .05$ ) and we cannot reject the null hypothesis that there is no interaction between torque and method.

**Table 6. Type 3 Tests of Fixed Effects for Elapsed Time**

Effect	Num DF	Den DF	F Value	Pr > F
Torque	1	6	14.44	0.0090
Method	3	36	179.60	<.0001
Torque*Method	3	36	1.46	0.2420

The pairwise comparisons (Table 6. Differences of Least Squares Means for Elapsed Time) indicate there is statistical significance between Torque 1 and Torque 2 and we reject the null hypothesis that the torques are equal.

Pairwise comparisons of the methods averaged over the two torques using Differences of Least Squares Means indicate a statistical significance ( $p < .05$ ) between method 3 (conventional wrench simulating restricted movement) and the other three methods at the combined torques. This means we can reject the null hypothesis that these methods are equal. This indicates that method 3 was significantly slower than the other methods.

Pairwise comparisons between methods 1 and 2 show no statistical significance ( $p > .05$ ) between methods so we cannot reject the null hypotheses for these comparisons. The comparisons between methods 1 and 4 and methods 2 and 4 have a p value higher than the critical value (.05) but do not present strong evidence to reject the null hypothesis.

**Table 7. Differences of Least Squares Means for Elapsed Time**

Effect	Torque	Method	_Torque	_Method	Estimate	Standard Error	DF	t Value	Pr >  t
Torque	1		2		-20.3250	5.3483	6	-3.80	0.0090
Method		1		2	0.09286	3.2290	36	0.03	0.9772
Method		1		3	-59.2571	3.2290	36	-18.35	<.0001
Method		1		4	5.1571	3.2290	36	1.60	0.1190
Method		2		3	-59.3500	3.2290	36	-18.38	<.0001
Method		2		4	5.0643	3.2290	36	1.57	0.1255
Method		3		4	64.4143	3.2290	36	19.95	<.0001
Torque*Method	1	1	1	2	-1.8143	4.5665	36	-0.40	0.6935
Torque*Method	1	1	1	3	-64.5000	4.5665	36	-14.12	<.0001
Torque*Method	1	1	1	4	6.1857	4.5665	36	1.35	0.1840
Torque*Method	1	2	1	3	-62.6857	4.5665	36	-13.73	<.0001
Torque*Method	1	2	1	4	8.0000	4.5665	36	1.75	0.0883
Torque*Method	1	3	1	4	70.6857	4.5665	36	15.48	<.0001
Torque*Method	2	1	2	2	2.0000	4.5665	36	0.44	0.6640
Torque*Method	2	1	2	3	-54.0143	4.5665	36	-11.83	<.0001
Torque*Method	2	1	2	4	4.1286	4.5665	36	0.90	0.3720
Torque*Method	2	2	2	3	-56.0143	4.5665	36	-12.27	<.0001
Torque*Method	2	2	2	4	2.1286	4.5665	36	0.47	0.6439
Torque*Method	2	3	2	4	58.1429	4.5665	36	12.73	<.0001

Pairwise comparisons of the methods over Torque 1 (25 Nm) indicate a statistical significance ( $p < .05$ ) between method 3 and the other three methods so we can reject the null hypotheses that these methods are equal. Again, This indicates that method 3 was significantly slower than the other methods. The comparison between methods 1 and 2 no statistical significance so we cannot reject the null hypothesis that these methods are equal. The comparison between methods 1 and 4 and methods 2 and 4 show no statistical significance so we cannot reject the null hypothesis that

these methods are equal. However, these numbers are not large enough to present strong evidence that we do not reject the null hypothesis.

Pairwise comparisons of the methods averaged over Torque 2 (50 Nm) again indicate a statistical significance ( $p < .05$ ) between method 3 and the other three methods so we can reject the null hypotheses that these methods are equal. The pairwise comparisons between methods 1 and 2, methods 1 and 4, and methods 2 and 4 indicate that we cannot reject the null hypothesis that these methods are equal.

#### 6.5.2 Statistical Results – Borg CR10 Rating of Perceived Exertion

The “Type 3 Tests of Fixed Effects” for the Borg rating (Table 7) indicate the test results for Torque are statistically significant ( $p < .05$ ) and result in rejecting the null hypothesis:

$H_0 : i_1 = i_2$ : The results for the torques are equal

The tests for Method averaged across both torques are not statistically significant ( $p > .05$ ) so we cannot reject the null hypothesis:

$H_0 : i_1 = i_2$ : The results for the methods are equal.

The tests for interaction between method and torque (Torque\*Method) are not statistically significant ( $p > .05$ ) so we cannot reject the null hypothesis:

$H_0$ : There is no interaction between torque and method : ( $i$  and  $j$ ) are independent.

**Table 8. Type 3 Tests of Fixed Effects for Borg CR10 Rating**

Effect	Num DF	Den DF	F Value	Pr > F
Torque	1	6	72.13	0.0001
Method	3	36	1.61	0.2050
Torque*Method	3	36	1.52	0.2249

The pairwise comparisons (Table 8. Differences of Least Squares Means for Borg CR10 Rating) show a statistical significance ( $p < .05$ ) between the two torques indicating we reject the null hypothesis that the torques are equal.

The pairwise comparisons between the methods averaged over both torques show a statistical significance ( $p < .05$ ) between methods 3 and 1, and methods 3 and 2, which indicates we can reject the null hypotheses that these methods are equal. The pairwise comparisons between methods 1 and 2, 1 and 4, 2 and 4, and 3 and 4 are not significant ( $p > .05$ ) and indicate we cannot reject the null hypotheses that these methods are equal.

The pairwise comparisons of methods averaged over the lower torque show no statistical significance ( $p > .05$ ) between all methods. This indicates we cannot reject the null hypotheses that the methods are equal.

The comparisons averaged over the higher torque show a statistical significance between method 1 and method 3 ( $p < .05$ ) so we can reject the null hypotheses that these methods are equal. Other pairwise comparisons between methods show no statistical significance and indicate we cannot reject the null hypotheses that the methods are equal.

**Table 9. Differences of Least Squares Means for Borg CR10 Rating**

Effect	Torque	Method	_Torque	_Method	Estimate	Standard Error	DF	t Value	Pr >  t
Torque	1		2		-3.2036	0.3772	6	-8.49	0.0001
Method		1		2	0.1786	0.4772	36	0.37	0.7104
Method		1		3	0.9000	0.4772	36	1.89	0.0674
Method		1		4	0.7143	0.4772	36	1.50	0.1431
Method		2		3	0.7214	0.4772	36	1.51	0.1393
Method		2		4	0.5357	0.4772	36	1.12	0.2690
Method		3		4	-0.1857	0.4772	36	-0.39	0.6994
Torque*Method	1	1	1	2	-0.1429	0.6748	36	-0.21	0.8335
Torque*Method	1	1	1	3	0.1571	0.6748	36	0.23	0.8172
Torque*Method	1	1	1	4	0.9286	0.6748	36	1.38	0.1773
Torque*Method	1	2	1	3	0.3000	0.6748	36	0.44	0.6593
Torque*Method	1	2	1	4	1.0714	0.6748	36	1.59	0.1211
Torque*Method	1	3	1	4	0.7714	0.6748	36	1.14	0.2605
Torque*Method	2	1	2	2	0.5000	0.6748	36	0.74	0.4635
Torque*Method	2	1	2	3	1.6429	0.6748	36	2.43	0.0200
Torque*Method	2	1	2	4	0.5000	0.6748	36	0.74	0.4635
Torque*Method	2	2	2	3	1.1429	0.6748	36	1.69	0.0990
Torque*Method	2	2	2	4	-372E-17	0.6748	36	-0.00	1.0000
Torque*Method	2	3	2	4	-1.1429	0.6748	36	-1.69	0.0990

### 6.5.3 Statistical Results – SEMG Results for Left Bicep

The “Type 3 Tests of Fixed Effects” for the Left Bicep SEMG results (Table 9) indicate that none of the three tests are statistically significant ( $p > .05$ ) and we cannot reject the null hypotheses:

- 1)  $H_0 : i_1 = i_2$  : The results for the torques are equal.
- 2)  $H_0 : j_1 = j_2 = j_3 = j_4$  : The results for the methods are equal.

NOTE: Although the  $p$  value is greater than the critical value of .05, there is no very strong evidence to accept the null hypothesis.

- 3)  $H_0$  : There is no interaction between torque and method : ( $i$  and  $j$ ) are independent.

**Table 10. Type 3 Tests of Fixed Effects for SEMG Results for Left Bicep**

Effect	Num DF	Den DF	F Value	Pr > F
Torque	1	5.7	0.11	0.7487
Method	3	33.4	0.36	0.7811
Torque*Method	3	33.3	0.20	0.8943

The results of the “Differences of Least Squares Means for SEMG Results for Left Bicep” (Table 10) show the first test, which compares the torques, is not statistically significant ( $p > .05$ ) so we cannot reject the null hypothesis that the torques are equal.

**Table 11. Differences of Least Squares Means for SEMG Results for Left Bicep**

Effect	Torque	Method	_Torque	_Method	Estimate	Standard Error	DF	t Value	Pr >  t
Torque	1		2		3.9543	11.7586	5.7	0.34	0.7487
Method		1		2	-2.2600	8.5557	33.1	-0.26	0.7933
Method		1		3	-5.4768	9.0122	33.4	-0.61	0.5475
Method		1		4	3.8135	8.7876	33.2	0.43	0.6671
Method		2		3	-3.2168	9.0122	33.4	-0.36	0.7234
Method		2		4	6.0735	8.7876	33.2	0.69	0.4943
Method		3		4	9.2902	9.2510	33.8	1.00	0.3224
Torque*Method	1	1	1	2	-2.8971	12.0996	33.1	-0.24	0.8122
Torque*Method	1	1	1	3	0.3437	12.7453	33.4	0.03	0.9786
Torque*Method	1	1	1	4	5.5529	12.0996	33.1	0.46	0.6493
Torque*Method	1	2	1	3	3.2409	12.7453	33.4	0.25	0.8008
Torque*Method	1	2	1	4	8.4500	12.0996	33.1	0.70	0.4898
Torque*Method	1	2	2	3	5.2091	12.7453	33.4	0.41	0.6854
Torque*Method	1	2	2	4	-1.6229	12.0996	33.1	-0.13	0.8941
Torque*Method	1	3	1	4	-11.2973	12.7481	33.4	-0.89	0.3819
Torque*Method	2	1	2	2	2.0741	12.7470	33.4	0.16	0.8717
Torque*Method	2	1	2	3	-9.6744	12.7481	33.4	-0.76	0.4532
Torque*Method	2	1	2	4	3.6969	12.7470	33.4	0.29	0.7736
Torque*Method	2	2	2	3	13.3713	13.4264	33.8	1.00	0.3264
Torque*Method	2	2	2	4	3.9543	11.7586	5.7	0.34	0.7487
Torque*Method	2	3	2	4	-2.2600	8.5557	33.1	-0.26	0.7933

When comparing the methods averaged over both torques, no statistical significance is indicated

( $p > .05$ ) so we cannot reject the null hypothesis that the methods are equal.



The pairwise comparisons of the methods when averaged over the lower torque show no statistical significance for all comparisons so we cannot reject the null hypotheses that the methods are equal.

The pairwise comparisons of methods when averaged over the higher torque show no statistical significance indicating we cannot reject the null hypothesis that the methods are equal.

#### 6.5.4 Statistical Results – SEMG Results for Right Deltoid

The “Type 3 Tests of Fixed Effects” for the Right Deltoid SEMG results (Table 11) indicate the test results for Torque are statistically significant ( $p < .05$ ) and result in rejecting the null hypothesis:

$H_0 : i_1 = i_2$  : The results for the torques are equal.

The tests for Method averaged across both torques are not statistically significant ( $p > .05$ ) so we cannot reject the null hypothesis:

$H_0 : i_1 = i_2$  : The results for the methods are equal.

The tests for interaction between method and torque (Torque\*Method) are not statistically significant ( $p > .05$ ) so we cannot reject the null hypothesis:

$H_0$  : There is no interaction between torque and method : ( $i$  and  $j$ ) are independent.

**Table 12. Type 3 Tests of fixed Effects for SEMG Results for Right Deltoid**

Effect	Num DF	Den DF	F Value	Pr > F
Torque	1	35	4.46	0.0419
Method	3	35	1.36	0.2696
Torque*Method	3	35	0.92	0.4412

**Table 13. Differences of Least Squares Means for SEMG Results for Right Deltoid**

Effect	Torque	Method	_Torque	_Method	Estimate	Standard Error	DF	t Value	Pr >  t
Torque	1		2		-8.4729	4.0127	35	-2.11	0.0419
Method		1		2	-9.8417	5.6748	35	-1.73	0.0917
Method		1		3	-1.2717	5.6748	35	-0.22	0.8240
Method		1		4	-0.3175	5.6748	35	-0.06	0.9557
Method		2		3	8.5700	5.6748	35	1.51	0.1400
Method		2		4	9.5242	5.6748	35	1.68	0.1022
Method		3		4	0.9542	5.6748	35	0.17	0.8674
Torque*Method	1	1	1	2	-2.1483	8.0254	35	-0.27	0.7905
Torque*Method	1	1	1	3	-0.8350	8.0254	35	-0.10	0.9177
Torque*Method	1	1	1	4	-0.6850	8.0254	35	-0.09	0.9325
Torque*Method	1	2	1	3	1.3133	8.0254	35	0.16	0.8709
Torque*Method	1	2	1	4	1.4633	8.0254	35	0.18	0.8564
Torque*Method	1	3	1	4	0.1500	8.0254	35	0.02	0.9852
Torque*Method	2	1	2	2	-17.5350	8.0254	35	-2.18	0.0357
Torque*Method	2	1	2	3	-1.7083	8.0254	35	-0.21	0.8327
Torque*Method	2	1	2	4	0.05000	8.0254	35	0.01	0.9951
Torque*Method	2	2	2	3	15.8267	8.0254	35	1.97	0.0565
Torque*Method	2	2	2	4	17.5850	8.0254	35	2.19	0.0352
Torque*Method	2	3	2	4	1.7583	8.0254	35	0.22	0.8278

The results of the “Differences of Least Squares Means for SEMG Results for Right Deltoid”

(Table 12) show the first test, which compares the torques, is statistically significant ( $p < .05$ ) so

we can reject the null hypothesis that the torques are equal.

When comparing the methods averaged over both torques, there is no statistical significance ( $p >$

$.05$ ) so we cannot reject the null hypotheses that the methods are equal.

The pairwise comparisons of the methods when averaged over the higher torque between Method 2 and Method 1 and also between Method 2 and Method 4 result in a statistical significance ( $p < .05$ ) so we can reject the null hypothesis that the methods are equal. The pairwise comparisons of the methods when averaged over the higher torque between Method 2 and Method 3 results in no statistical significance based on the standard significance level of  $p = .05$ . However, since the p value for this comparison is close to that level ( $p = .0565$ ) there is not enough evidence to reject the null hypothesis. For all the other pairwise comparisons over both torques, there is no statistical significance ( $p > .05$ ) so we cannot reject the null hypotheses that the methods are equal.

## **Chapter 7 - Discussion**

### **7.1 Time to Complete the Tasks**

The modified wrench was the most efficient at both torques (Figure 9). Using the conventional wrench (assuming restrictions) was the slowest. At the lower (25 Nm) turning torque, using bare hands was faster than using the conventional wrench with no restrictions. At the higher torque the unrestricted conventional wrench was faster than the bare hands method. This difference is due to the increased mechanical advantage afforded by the conventional wrench.

The advantage of the modified wrench is likely due to the fact that the modified wrench never had to be repositioned on the valve wheel as did the bare hands or the modified wrench simulating restricted movement in addition to the increased mechanical advantage from the wrench. This repositioning of the hands and/or wrench occurred one or more times per revolution, increasing the time per revolution. The modified wrench also had an advantage over the conventional wrench (assuming no restrictions) due to the reduced distance the hands traveled per revolution based on the shorter length.

Informal questioning of the participants after the testing indicated that in both cases, but primarily at the higher torque, participants experienced discomfort due to friction between the hands and the wrench, possibly causing times to be slower.

### **7.2 Borg CR10 Scale Rating of Perceived Exertion**

When comparing the Borg Rating of Perceived Exertion for the 25 Nm torque (Figure 11), all four methods were perceived in the “Moderate” range (Appendix A). At the 50 Nm torque, use of the conventional wrench with the restricted protocol received the best (lowest) rating which

was considered “Strong”. The other three methods were in the “Very Strong” range with the modified wrench receiving the highest (worst) rating. Again, this was possibly due to the discomfort observed at the higher torque. The statistical pairwise comparisons back up these findings, but the evidence to reject the null hypothesis that the methods are equal is not very strong.

### 7.3 Left Bicep SEMG Results

Comparisons of the normalized maximum average values (MAV) for the left bicep show that use of the modified wrench resulted in slightly more than the lowest activity for the low torque (Figure 11) and the lowest activity for the higher torque. This result is likely due to use of the modified wrench employing other muscles such as shoulder and trunk muscles. The statistical pairwise comparisons of the methods indicate that none of the methods are equal except for methods 1 (bare hands) and 4 (modified wrench) at the higher torque.

### 7.4 Right Deltoid SEMG Results

Comparisons of the normalized maximum average values (MAV) for the right deltoid (Figure 12) indicate that use of the modified wrench resulted in the activity only slightly higher than use of the conventional wrench simulating restrictions. At the higher torque the modified wrench induced the highest activity from the right deltoid, possibly due to the reduced mechanical advantage when the wrench was at a position approximately 180° away from the body. At both torques the conventional wrench simulating restricted movement showed the least activity for the right deltoid. This is likely due to the wrench being removed and repositioned rather than turning it when furthest away from the body. This is the portion of a revolution where the wrench is disconnected from the valve wheel and reconnected at approximately an angle 120°

further along when simulating a clearance problem. At this point, the participant is bending over and reaching to turn the wrench, forcing the shoulders to do more of the work. The increased force required at the higher torque is thought to be due to increased effort by the shoulder when transitioning between the pushing and pulling phases of the motion. The advantage of the modified wrench is lessened, probably due to the same factors as using the regular wrench but the participant does not have to reach as far, lessening the use of the shoulders.

## 7.5 Conclusions

The above results indicate that use of the modified wrench can improve the efficiency of an operator who is called upon to open and close manual gate valves quickly. At the turning torques required in these trials the modified wrench seems to have an advantage over using bare hands or a conventional wrench from a standpoint of elapsed time to open the valve. It should be noted that these were dynamic tests that did not incorporate the “breaking” forces required to start opening or closing the valve wheel. The design of the wrench should, when the handle is moved out in line with the main part of the wrench, afford the same mechanical advantage as the conventional wrench to overcome this initial force. Based on the results of the trials, the modified wrench is the most efficient method of turning the valve wheel at the lower of the two torques tested. This method did not show a clear advantage at the higher torque, but this may have been due to reported discomfort because of friction between the participants’ hands and the handle of the modified wrench. This friction would reduce the advantage of the handle “spinning” in the hands as it rotates. This result may also be due to the increased mechanical advantage while using the conventional wrench. The differences in the muscle activity of the two muscles tested (Left Bicep and Right Deltoid) for both torques and all methods indicate that

the muscles' activities differed throughout the trials. This would indicate that other muscles are active at different points while turning the valve wheel.

## 7.6 Recommendations for Future Studies

Based on the results and observations, several recommendations for future studies are:

- Further changes to the modified wrench to allow the handle to rotate, such as a freely rotating sleeve around the handle that would eliminate friction between the handle and the hand. An early prototype of the modified wrench (Figure 14) incorporated this feature and no discomfort was reported when it was used.



**Figure 17. Spinner handle on prototype**

- Extensive biomechanical modeling to determine which other muscles are involved in the motions necessary to complete the tasks.
- Dynamic testing of these muscles to determine how the forces are distributed throughout the musculoskeletal system during the various trials. This would give a better indication as to which muscles, if any, are more at risk to injury during the completion of the tasks.

- Testing using experienced operators who are accustomed to the motions involved in turning a valve wheel. The advantages of this familiarization have been demonstrated and may yield more useful “real-world” data (Shih and Wang, 1997; Meyer et al., 1999).



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## Appendix A - Borg CR10 General Instructions for Use

0	Nothing at all	
0.3		
0.5	Extremely weak	Just noticeable
0.7		
1	Very Weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very Strong	
8		
9		
10	Extremely Strong	“Maximal”
11		
●	Absolute maximum	Highest possible

### Borg CR10 General Instructions for Use

Use this rating scale to report how strong your perception of the potential exertion is. First look at the verbal expressions. Start with them and then the numbers. Of these ten (10) or “Extremely strong”, “Maximal”, is a very important intensity level. This is the most intense perception or feeling you have ever had. If your experience or feeling is “Very weak”, you should say “1”, if it is “Moderate”, say “3”. Note that “Moderate” is “3” and thus weaker than “Medium”, “Mean” or “Middle”. If the experience is “Strong” or “Heavy” (it feels “Difficult”) say “5”. Note that “Strong” is about half of “Maximal”. Is your feeling “Very strong”, choose a number from 6 to 8. If your perception or feeling is stronger than “10”, - “Extremely strong”, “Maximal” – you can use a larger number, e.g. 12 or still higher (that’s why “Absolute maximum” is marked with a dot (“•”). It’s very important that you report what you actually experience or feel, not what you think you should report. Be as spontaneous and honest as possible and try to avoid under- or overestimating. Look at the verbal descriptors and then choose a number.

## BORG CR10 Complementary Instructions

**0** "Nothing at all", means that you don't feel any exertion whatsoever, e.g. no muscle fatigue, no breathlessness or difficulties breathing.

**1** "Very weak" means very light. As taking a shorter walk at your own pace.

**3** "Moderate" is somewhat but not especially hard. It feels good and not difficult to go on.

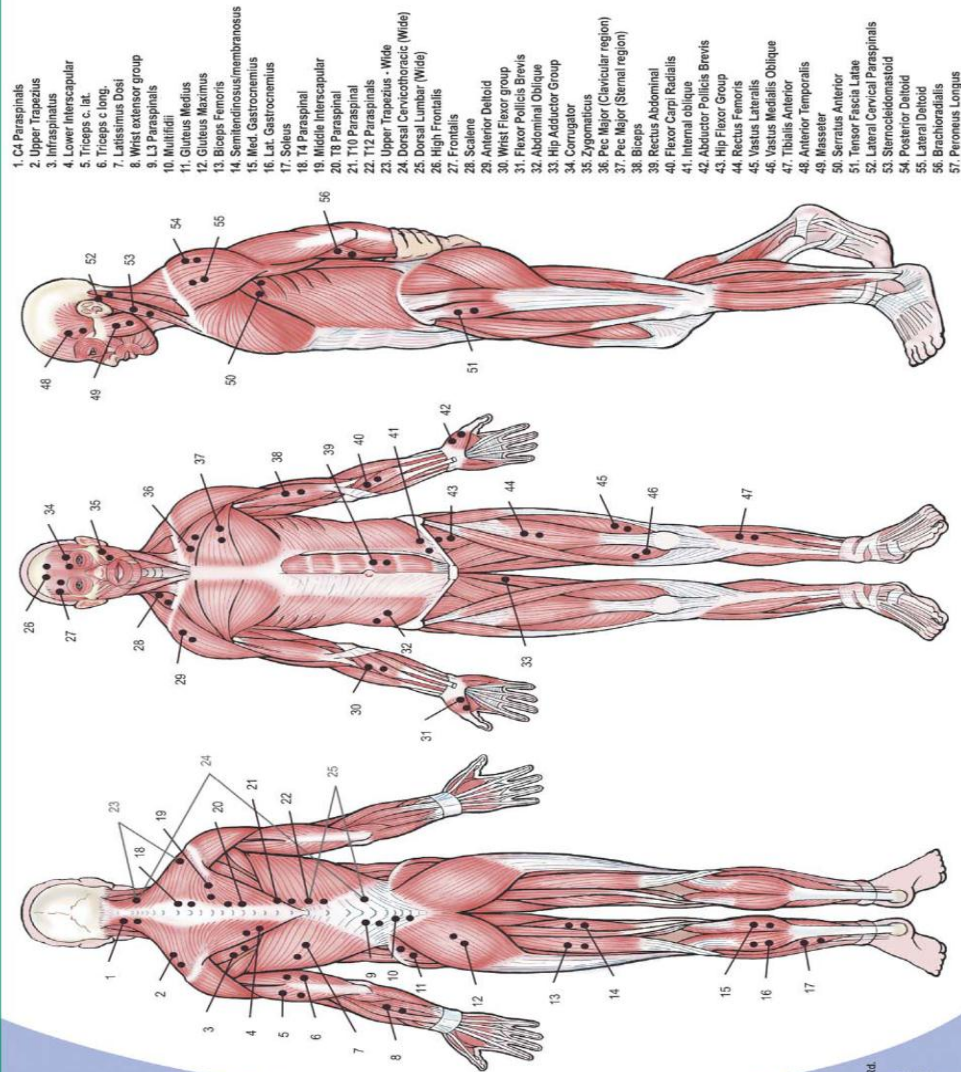
**5** "Strong". The work is hard and tiring, but continuing isn't terribly difficult. The effort and exertion is about half as intense as "Maximal".

**7** "Very strong" is quite strenuous. You can go on, but you really have to push yourself and you are very tired.

**10** "Extremely strong – Maximal" is an extremely strenuous level. For most people this is the most strenuous exertion they have ever experienced.

- Is "Absolute maximum – Highest possible", for example "12" or even more.

When rating perceived exertion, give a number that corresponds to how hard and strenuous you perceive the work to be. The perception of exertion is mainly felt as strain and fatigue in your muscles and as breathlessness or any aches. You should consider the effort in terms of having to be repeated multiple times in a short time period, possibly with no rest period between. The purpose of this rating is to determine which method of turning the valve wheel you feel would be preferable during periods of multiple exertions, such as an emergency shutdown of a chemical plant.



**ACTION ON PROTOCOL APPROVAL REQUEST**



Institutional Review Board  
Dr. Robert Mathews, Chair  
131 David Boyd Hall  
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**TO:** Fereydoun Aghazadeh  
CMIE

**FROM:** Robert C. Mathews  
Chair, Institutional Review Board

**DATE:** March 5, 2010  
**RE:** IRB# 3042

**TITLE:** "Testing and Evaluation of Methods to Open Manual Gate Valves Using Electromyography of Core Muscles"

**New Protocol/Modification/Continuation:** New Protocol

**Review type:** Full ☒ Expedited ☐ **Review date:** 3/5/2010

**Risk Factor:** Minimal ☒ Uncertain ☐ Greater Than Minimal ☐

**Approved\*** ☒ **Disapproved** ☐


**Approval Date:** 3/5/2010 **Approval Expiration Date:** 3/4/2011

**Re-review frequency:** (annual unless otherwise stated)

**Number of subjects approved:** 10

**Protocol Matches Scope of Work in Grant proposal:** (if applicable) N.A.

**\*Approval Note:** Your study is not to begin until your Certificate of Confidentiality is approved and on file with the LSU-BR Institutional Review Board

**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>*

**Application for:  
Approval of Projects Which Use Human Subjects**

This application is used for projects/study's that cannot be reviewed through the exemption process.



Institutional Review Board  
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203 B-1 David Boyd Hall  
Baton Rouge, LA 70803  
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irb@lsu.edu | lsu.edu/irb

- Applicant, Please fill out the application in its entirety and include two copies of the completed application as well as parts A-E, listed below. Once the application is completed, please submit it to the IRB Office for review and please allow ample time for the application to be reviewed. Expedited review usually takes 2 weeks. Carefully completed applications should be submitted 3 weeks before a meeting to ensure a prompt decision.
- A Complete Application Includes All of the Following:
  - (A) Two copies of this completed form and two copies of parts B thru E.
  - (B) A complete copy of any grant proposal relevant to the project.
  - (C) Copies of all instruments to be used.
    - If this proposal is a part of a grant application, include a copy of the grant proposal, the investigative brochure (if one exists) and any recruitment materials including advertisements intended to be seen or heard by potential subjects.
  - (D) The consent form that will be used. A copy of the Waiver of Signed Informed Consent is attached and must be completed only if there is the intention to use an unsigned consent form. The **script to be used as the unsigned consent script MUST be included** with the waiver of signed informed consent.
  - (E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB. Training link: <http://phrp.nihtraining.com/users/login.php>.

1) Principal Investigator\*: Fereydoun Aghazadeh Rank: Professor

\*PI must be an LSU Faculty member

Dept.: CMIE Ph: 578-5367 E-Mail: aghazadeh@lsu.edu

2) All Co Investigators: please include department, rank, phone, and e-mail for each

Francis Hutchinson, CMIE, graduate student, (225) 505-9911,  
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3) Project Title: Testing and Evaluation of Methods to Open Manual Gate Valves Using Electromyography of Core Muscles

4) Proposed Start Date: 2/15/2010 5) Proposed Duration Months: 2

6) Number of Subjects Requested: 10 7) LSU Proposal# N/A

8) Funding Sought From: None

IRB# <u>2012</u> LSU Proposal# _____
<input type="checkbox"/> Full
<input checked="" type="checkbox"/> Expedited
<input type="checkbox"/> Complete Application
<input type="checkbox"/> Human Subjects Training

Study Approved By: Dr. Robert C. Mathews, Chairman Institutional Review Board Louisiana State University 203 B-1 David Boyd Hall 225-578-8692   <a href="http://www.lsu.edu/irb">www.lsu.edu/irb</a> Approval Expires: <u>3-4-2011</u>
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## Appendix D: Approval of Informed Consent Form

### **INFORMED CONSENT FORM**

#### **Testing and Evaluation of Methods to Open Manual Gate Valves Using Electromyography of Core Muscles**

**Performance site:** Louisiana State University Department of Construction Management and industrial Engineering; Work Evaluation Laboratory, 3413 Patrick Taylor Hall

**Investigators:**

Dr. Fereydoun Aghazadeh, (225) 578-5367, 3132-B Patrick Taylor Hall

Francis W. Hutchinson, CMIE Graduate Student, (225) 505-9911

**Purpose of the Study:** The purpose of this study is to test and evaluate various methods of opening manual gate valves using electromyography of core muscles.

**Subject Inclusion:** Experienced chemical plant operators, ages 18 – 60, or others who are familiar with the task of opening and closing a valve handwheel.

**Exclusion Criteria:** Individuals that have the following conditions:

Cardiovascular diseases (including the use of a pacemaker or other electronic implant)

Musculoskeletal disorders (Pain due to muscles, joints, tendons, ligaments, or nerves)

History of chronic back, shoulder, or other musculoskeletal disorder

Current pain that would affect performance of the tasks involved in the study

Any answers of “yes” on the PAR-Q (to be given after this form is signed)

**Number of Subjects:** 10

**Study Procedures:** You will first read this consent form and be given a verbal explanation of the study. If you agree to the terms of participation, you will sign the informed consent form and complete the PAR-Q (Physical Activity Readiness Questionnaire). Your resting heart rate will be recorded. You will be connected to an electromyograph which is an instrument that measures the activity of muscles. You

will wear eight adhesive electrodes, located over the arms, shoulders, and back muscles. You will then be directed to perform the tasks of opening and closing the valve handwheel.

You will be asked to open and close the valve a total of nine times. There will be three sets of three trials with the force necessary to turn the wheel set at three different difficulties. Each set will be done first using hands only, then using a common valve wrench, then using a modified “spinner” type wrench. The first set will be with the necessary force set at 20 Newton meters (N\*m) of force (~15 ft-lb). The next set will be with the necessary force set at 35 N\*m (~25 ft-lb). the final set will be with the force set at 55 N\*m (~40 ft-lb). There will be a rest period between each trial to allow your heart rate to return to resting rate. If you desire a longer rest period, it will be provided.

After each set of three trials at the various difficulties, you will be asked to evaluate the methods used based on the scenario where the task would have to be done several times in a short period. The evaluation will be done using a rating of perceived exertion. It is estimated that each session of nine tasks will last no more than two hours.

**Benefits:** There are no direct benefits; but this experiment may provide information that will yield future improvements in the task of opening and closing valve wheels through improved tools, standards, and/or workplace modifications.

**Risks/Discomforts:** There may be some discomfort during performance of the tasks which may lead to fatigue and/or aching of the muscles. The tasks have been designed to fall within the normal job performance for a chemical plant operator, so the potential physical discomfort is not expected to be any greater than that after a hard work session. Participants are encouraged to inform the experimenter if discomfort or pain occurs.

**Right to Refuse:** At any time during the experiment, you have the right to not participate or withdraw from the study. There will be no penalties for withdrawal.

**Privacy:** The LSU Institutional Review Board (which oversees university research with human subjects) may inspect and/or copy the study records.

Results of the study may be published, but no names or identifying information will be included in the publication.

Other than as set forth above, participant identity will remain confidential unless disclosure is legally compelled.

**Financial Information:** You will be compensated \$50 for participation at the end of the session.

**Withdrawal:** If you choose to withdraw from the study, you will be compensated at the rate of \$20/hour for the time you participated.

**Removal:** You are expected to comply with the investigator's instructions. If you fail to comply, you will be removed by an investigator from the experiment, and you will be compensated for the amount of time you participated.

**Signatures:**

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participant's rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

\_\_\_\_\_  
Subject Signature

\_\_\_\_\_  
Date

\_\_\_\_\_  
Print name

**Study Approved By:**  
Dr. Robert C. Mathews, Chairman  
Institutional Review Board  
Louisiana State University  
203 B-1 David Boyd Hall  
225-578-8692 | [www.lsu.edu/irb](http://www.lsu.edu/irb)  
Approval Expires: 3-4-2011

## Appendix E – PARQ Form

### Physical Activity Readiness Questionnaire (PAR-Q)

For most people, physical activity should not pose any problem or hazard. This questionnaire has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the suitable type of activity.

- |    |  |     |    |
|----|--|-----|----|
| 1. | Has your doctor ever said you have heart trouble?  | Yes | No |
| 2. | Do you frequently suffer from chest pains?   | Yes | No |
| 3. | Do you often feel faint or have spells of severe dizziness?  | Yes | No |
| 4. | Has a doctor ever said your blood pressure was too high  | Yes | No |
| 5. | Has a doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by, or might be made worse with exercise | Yes | No |
| 6. | Is there any other good physical reason why you should not follow an activity program even if you want to?   | Yes | No |
| 7. | Are you 65 and not accustomed to vigorous exercise   | Yes | No |

If you answer "yes" to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.

I have read this questionnaire, I understand it does not provide a medical assessment in lieu of a physical examination by a physician.

Participant's signature \_\_\_\_\_ Date \_\_\_\_\_

Investigator's signature \_\_\_\_\_ Date \_\_\_\_\_

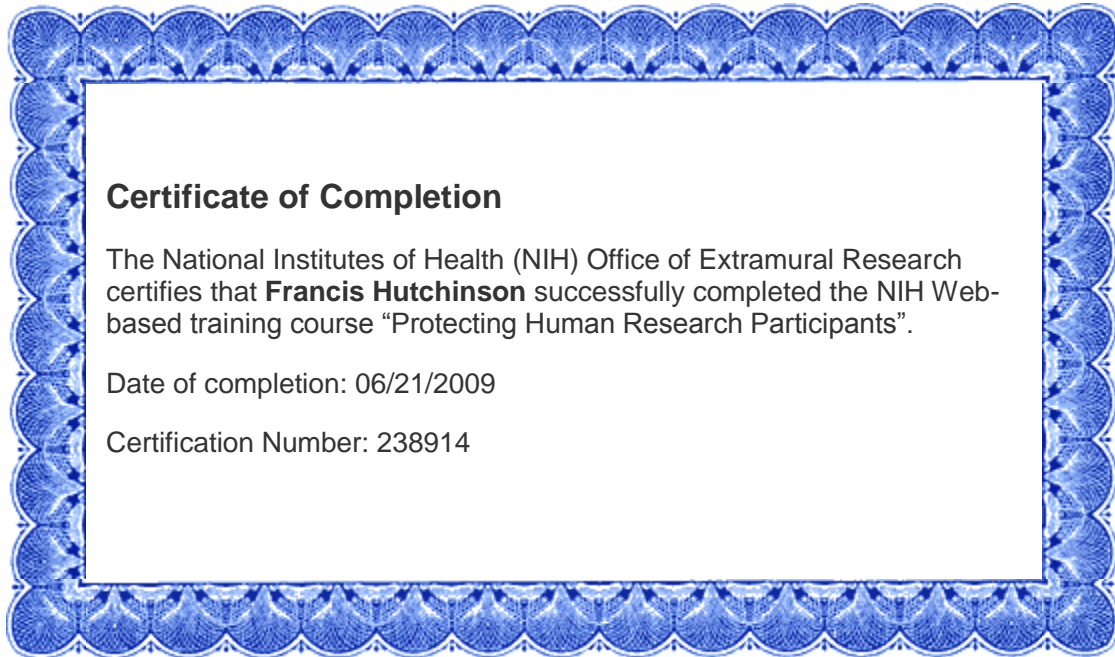
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Adapted from PAR-Q Validation Report, British Columbia Department of Health, June, 1975.

#### Reference:

Hafen, B. Q. & Hoeger, W. W. K. (1994). Wellness: Guidelines for a Healthy Lifestyle. Morton Publishing Co: Englewood, CO.

## Appendix F - NIH Course Certificate of Completion



## **Vita**

Francis Williams Hutchinson was born in October, 1949 to Gordon and Virgie Hutchinson. He was born and raised in Baton Rouge Louisiana. He originally began Louisiana State University in Fall, 1969. After completing his second year, he began working full time at the family business, Hutchinson's Tire Service. He continued to attend LSU part time for several years. In 1987 he returned to LSU on a part time basis. In 1989 he left the family business and took a job at Uniroyal Chemical Company as a chemical plant technician. He also graduated from LSU with a Bachelor of General Studies. After graduation he continued taking classes to work on his Master's degree in Industrial Engineering.