MUSCLE RESPONSE TO DIFFERENT SOCKET WRENCH CONFIGURATIONS

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Evaluation of manual hand tools play an important role in producing better designs that are targeted to fit the user, maximize comfort, and minimize the risk of injury. The goal of this study was to evaluate and quantify the muscle response due to a horizontal wrenching task while using four socket wrench configurations: two handle types and two handle lengths. Eleven participants in this study were instructed to loosen a bolt three times using each of the tool combinations in a random order. Activity from twelve muscles was recorded using wireless surface EMG sensors. Both the handle length and the grip type were observed to have a significant effect on the overall muscle activity. Between 5-32% reduction in muscle activity was seen in all muscles due to the longer handle, and the padded handle further reduced muscle effort by up to 13%. These findings indicate the importance of tool configuration selection in order to reduce the required force application, improve posture and reduce muscle effort required for the wrenching task.

Introduction

Manual hand tools are used across industry for both assembly and maintenance tasks. Over the past few decades the performance of many mechanical and power tools was studied and evaluated. For example, a considerable effort in research has focused on the ergonomic analysis of screwdriver handle shape and material (Yuh-Chuan 1996, Kong 2007), in order to maximize the torque production of the tool, as well as some power tools (McDowell 2009). Nevertheless, there have been very few studies related to manual wrenches or wrenching tasks (Xiao 2011).

There are obvious differences between the tool type studied in Kong (2007) and wrenches. The screwdriver utilizes either a power or precision grip, depending on the task, to create a frictional force and typically requires a twisting motion of the forearm. The limits on torque are the grip the worker can exert on the handle, the size of the handle, and handle material. By comparison, wrenches require a power grip, which primarily exerts force in the direction of the wrenching motion, and typically requires flexion/extension at the elbow and shoulder.

There are also a number of problems that existing hand tool studies have in regards to the measurement of grip force on the tool handle. Four methods exist to measure or estimate grip force, subjective methods, strain gauge handles, pressure sensors, and muscle activity. Subjective methods of estimating grip pressure have mostly been shown to be unreliable (McGorrey 2010). Strain gauge handles allow for comparative measures, but have a minimum handle size and cannot always replicate the handle size and design to be studied (McGorrey 2010, Koppelaar 2005). Muscle activity measured by surface EMG sensors on the forearm risk the muscle moving beneath the skin, causing the results to be inaccurate. Pressure sensors can interfere with coupling, particularly for screw driver studies, however they are the most reliable if a strain gauge handle cannot be used.

Methods

11 healthy male subjects participated in this study. Subjects ranged in age between 18 and 60 years, and all of them were right handed. After signing the IRB approved consent form the subjects were instructed on the use of the tools used in the study and given practice time with the test rig.

The test rig (Figure 1) consisted of a steel frame with a bolt holder set to a 50” height for all trials. The bolt was tightened to 50(±2) ft*lbs before each repetition.

Figure 1: Experimental set up of the test rig.
Four tools were selected for this study. The tool combinations consisted of: two handle types - a steel and a rubber padded handle (Figures 2A and 2B) and two handle lengths - 11" (short) and 18" (long).

The subjects were asked to loosen the bolt three times in the horizontal direction with a given wrench combination. The wrench combination orders were randomized. The wrenching motion consisted of the worker pushing away with the shoulder abducted and flexing and elbow extending.

Electromyographic data was collected on the following twelve muscles: Biceps Brachii (BB), Triceps Brachii (TB), Posterior Deltoid (PD), Anterior Deltoid (AD), right and left Trapezius (RT, LT), Latissimus Dorsi (LD), Pectoralis Major (PM), right and left Erector Spinae (RS, LS), and right and left Rectus Abdominis (RRA, LRA). EMG data was collected using wireless surface electrodes (Delsys Trigno System, Boston, MA) with a sampling frequency of 2000 Hz, and processed using a 4th order bandpass Butterworth filter, corner frequencies of 20 and 500 Hz and a 60 Hz notch.

All data was processed using a custom written MATLAB program (MathWorks, Natick, MA) and all measured values were normalized to the average baseline using the following equation:

\[
\frac{\text{Average Baseline} - \text{Trial}}{\text{Average Baseline}} \times 100
\]

The Average Baseline value in the percent difference equation was the average of the three trials using the short handle length as the baseline to compare to the long handle, and the steel handle as the baseline to compare to the rubber handle. Due to a high degree of variability in the data, median results are presented.

ANOVA tests were performed, one for each wrenching orientation, using a general linear model, blocking the effects of the subjects, with the confidence level set at 95% using MINITAB v.17 software (Minitab Inc, State College PA).

**Results**

There was an overall reduction observed in muscle activity while using the longer handle in comparison to the shorter handle (Figure 3). A statistically significant decrease in all muscles activity, except BB, AD, and LT, was observed due to the increase in the handle length from 11” to 18”. The percent reduction in muscle effort varied between 5 and 32 percent. This is as expected, as the pure mechanics of increasing the handle length without adjusting the required torque to undo the bolt reduces the force the worker needs to exert.

The change in grip type from the steel to rubber handle revealed a less expected result (Figure 4). The change in grip type was anticipated to only affect those muscles associated with grip. However, overall reduction ranging between 3-13% was observed in all muscle activity due to use of the rubber padded handle. Significant reductions were seen in the LD, RRA, and LRA muscles, while other differences in muscle activity were not found to be significant.
**Discussion**

Both the handle length and the grip type were observed to have an effect on the overall muscle activity. The handle length results were in line with expectations, since increasing handle length, and thus moment arm, reduced the force required to produce the required 50 ft-lb of torque. The muscles primarily involved in the wrenching task experienced decreases of approximately 30%. This is less than what would be predicted based on mechanics, which is a 63% reduction in force. The difference is potentially due to one or a combination of factors. First, the relationship between muscle EMG activity and force generation is nonlinear and a doubling of force does not necessarily result in a doubling of EMG activity. Second, although the experiment was designed to force the subject to use their arms to complete the wrenching task, it is possible that some use was made of body weight, thus reducing the effect of handle length.

While the changes in muscle activity due to changing the handle type are low, it is surprising that the grip type had a significant effect on activity in some muscles. As no muscles that are directly involved in grip strength are measured in this study, the size of the grip was expected to have no impact from a mechanics standpoint. It is hypothesized that the larger grip reduced the amount of force required to control the wrench and hand/arm motion to the horizontal direction, resulting in less overall muscle activity. Additionally, changes in posture due to the more comfortable handle may have led to a more direct load path, also resulting in a reduction of force. This study was also limited to only wrenching task in a horizontal direction. The effect of handle length and type on muscle activity during wrenching may differ for vertical or any other angular positions of the bolt. This study also looked into only single height, whereas the vertical location of the bolt may require postural adjustment and overall affect the muscle activity of the subject. Another factor that may potentially affect the results is the experience of the subjects. No significant differences were found between the experienced and in-experienced subjects, however this is a factor that may influence other factors such as grip pressure.

Research is needed to investigate additional factors to allow estimation of the overall effectiveness and advantages of one handle type over another during the wrenching task. Future studies should focus also on other conditions, such as variable working heights, orientation or other handle shapes.

**Conclusion**

Both the handle length and grip type have an effect on muscle activity. The results indicate that the correct choice of handle length and type can reduce the demands on arm muscles during wrenching, potentially leading to a reduction in fatigue and overexertion injuries.

**References**


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