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STATIC SHOULDER ELEVATION WITH OR WITHOUT LIMITED RANGE OF ARM MOTION

Kayla Ericson

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by

Kayla Ericson

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Abstract

Purpose: The purpose of this study was to investigate the effect of two similar low force, upper arm holding tasks on shoulder muscle fatigue. One task involves static holding, while the comparison task involves limited up and down motions, dynamic rolling. Both tasks require the shoulder muscles to hold the combined weight of the arm, hand, and a roller brush in a manner similar to that of a painter standing on a portable ladder painting a wall.

Methods: Twenty volunteer participants from undergraduate classes performed two similar tasks. One was holding their dominant arm above their shoulder while holding a roller paint brush against a target (static holding). The other tasks was similar except the participant moved the roller brush up and down on a defined target (dynamic rolling). During each task, participants wore surface electromyography sensors placed on anterior, medial, and posterior deltoids, and on the triceps muscle of their dominant arm in the direction of the muscle fibers. For each participant, the maximum voluntary contraction of each muscle was assessed and normalized to their muscle activity for a static holding and dynamic rolling task. Muscle fatigue was assessed throughout the task by performing a median frequency analysis on the muscle activity data. Discomfort ratings were measured verbally over the task period on a 0–100 scale. The task was performed up to a rating of 80, indication of extreme discomfort.

Results: Analyses based on of median frequency recordings showed no significant difference in the rate of fatigue development between all four muscles. Rate of fatigue was also not significantly different between static holding and dynamic rolling tasks. Static holding and dynamic rolling endurance times were significantly different from one another ($p = 0.0066$). Analyses based on discomfort ratings showed static holding had a maximum endurance time of 9.5 minutes and dynamic rolling had a maximum endurance time of 6.5 minutes. Endurance times were also compared to 20 minutes—a time mentioned in the notes of the Upper Limb Localized Fatigue Guidelines of the American Conference of Governmental Industrial Hygienist saying static exertions of the upper limbs “would not be expected to exceed 20 minutes.” There was a significant difference in static holding and dynamic rolling endurance times against a 20-minute note ($p = 0.000$).

Conclusion: The results demonstrated that shoulder muscle fatigue and discomfort were present during the tasks. The endurance times differed between static holding and dynamic rolling tasks. The endurance times never exceeded 20-minutes, thereby supporting the comment within the Upper Limb Localized Fatigue Guidelines.

Keywords: Fatigue, Shoulder, Arm, Discomfort, Painting

Dedication

I wish to thank my Mom, Dad, Josh, Trisha and Zach who supported me and always believed in me.

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Glossary of Terms

Term	**Definition**
Work-related musculoskeletal disorders (WMSDs)	Injury to the muscles, blood vessels, tendons, ligaments, etc. that is related and/or caused by work.
Electromyography	Described as the muscle electric signal that is produced when a muscle contracts.
Root mean squared amplitude	An effective “average” value of a time-varying signal calculated as the square root of the average value of the signal squared over one cycle.
Endurance time	The time the experimental task was maintained until the subject reported a discomfort rating of 80.
Median frequency	The middle value of the low and high frequencies.
Static holding	A muscular contraction in which the muscle length does not change. Also called isokinetic contraction.

1. Background

Many people work long hours with arms extended upward. Some examples are found in construction, drilling, and automotive work. Working overhead requires contraction of the shoulder muscles. Extended overhead work leads to shoulder muscle fatigue and associated pain (Viikari-Juntura, 1999; Freivalds, 2011). Workers normally recover from muscular fatigue by simply resting the affected muscles (Kroemer, 2017, pp. 62–63)). As a principle of ergonomics, fatigued muscles should not carry over to a subsequent day (ACGIH, 2015).

1.1. Ergonomics and Musculoskeletal Disorders of the Shoulder

The professional field of ergonomics is often associated with the physical demands involved in manual work, although in reality, the field is much broader. The author of the textbook used for the Montana Tech course in ergonomics (OSH 456) provides the following definition.

> Ergonomics is the application of scientific principles, methods, and data drawn from a variety of disciplines to development of engineering systems in which people play significant roles. (Kroemer, 2017, p. 1)

The above reference to “a variety of disciplines” includes psychology, anatomy, physiology, physics, and engineering (Bridger, 2009). The field of ergonomics includes numerous specialties—the one recognized as occupational ergonomics focuses on occupational health and safety concerns. This specialty has developed through contributions from other professions such as industrial engineering, industrial psychologists, occupational medicine physicians, industrial hygienists, and safety engineers (Stack, 2016a, p. 8). Of the various occupational concerns, the major focus is on fitting the work to the physical capabilities and limitations of the workers. Common consequence of physical demands of work exceeding the capabilities of the worker are muscular fatigue and the development of musculoskeletal disorders (MSDs) (Stack, 2016a, p. 8–9).

MSDs are a class of disorders involving damage to muscles, tendons, ligaments, peripheral nerves, joints, cartilage, bones, and supporting blood vessels (Stack, 2016, p. 283). Not all MSDs are work related. If attributes of the worker's job caused or aggravated an MSD, the term work-related musculoskeletal disorder (WMSD) is used (Stack, 2016b, Chapter 13). Many musculoskeletal injuries and disorders develop over time and with repeated exposure. Repetition and work postures are a couple of many risk factors that can contribute to or cause a work-related MSDs in workers (Freivalds, 2011). Other common risk factors include forceful exertions, compression, vibration, insufficient rest for recovery, extended duration, intensity and work conditions (Stack, 2016, p. 283; Viikari-Juntura, 1999, p. 836–848).

Repetition is a common MSD risk factor in almost all industries, whether work is overhead or in a neutral posture, if workers perform the same task daily for an eight-hour period and continuously through a work week. Another important factor related to the development of MSDs is working posture (Widanarko, et al. 2012; Roman-Liu, 2014). Many laboratory and epidemiological studies have been conducted to increase understanding the effects of repetitive and extended muscular work including effects of muscle force distribution, fatigue and endurance levels, static loads, lack of sufficient rest and non-neutral postures (Frey-Law & Avin, 2010; National Institute for Occupational Safety and Health, 1997; Panel on Musculoskeletal Disorders and the Workplace, 2001). The exposures can range from static efforts, to insufficient recovery or rest, to non-neutral postures. A certain risk factor that can be complex especially for shoulder MSDs is repetitive overhead work, defined by Sood, Nussbaum & Hager, (2007) as working with a hand above the head.

Static prolonged muscle contractions can produce muscular fatigue and pain. There are questions, however, about static exertions being risk factors for particular MSDs. An often-quoted expert, Rohmert (1973a), states that static working posture is a major risk factor that contributes to MSDs, because the contraction causes internal muscle pressure which interrupts blood flow and leads to an oxygen shortage in the muscle. The reduced blood flow through the muscle also fails to carry away the metabolic by product lactic acid that causes feeling of discomfort and pain (Kroemer, 2016, pp. 62–63).

1.2. Measurement of Muscular Fatigue

Fatigue can be measured by objective methods and subjective methods. Both methods have positives and negatives. Subjective methods are inexpensive, convenient and can be captured with questionnaires, but subjective methods (observations or subjective judgements) have relatively lower validity than direct measurement techniques (David, 2005; Li, et al. 1999). Low reliability for subjective methods is due to data being based on subjective judgements or observations (David, 2005). Objective methods are more accurate and capture a wider range of data for specific muscles, but objective methods can be more expensive and time consuming (Takala, et al. 2010).

A common type of subjective method involves using a rating scale for subjects to indicate how a body part feels. A well-known scale is the Borg CR-10 scale (Kroemer, 2017, p. 228). It asks how intense a task feels. Another common rating scale asks subjects to rate their feeling of discomfort. It uses the body’s own feedback system. A chapter on discomfort scales by Straker (1999) indicates that discomfort is very useful in assessing situations where the impact of physical mismatch may be greatest on small muscles and where static muscle activity is required. Overall, five important fundamentals of the discomfort measurement scale are listed below (Straker, 1999).

1. Discomfort measurement is likely to be useful in the assessment of information about physical matches and mismatches
2. Consistent use of the sole noun “discomfort” will assist the validity of assessment
3. Discomfort is a subjective experience and can therefore only be measured by worker report
4. Intensity, location, and temporal pattern are important attributes of discomfort
5. A Visual Analog Discomfort Scale is probably the most widely applicable discomfort intensity scale

Straker (1999), provided an example of how a discomfort scale is used. In a study of computer operator performance, a verbal numeric rating scale was used to measure discomfort over a 20-minute task by asking “indicate to me the number between 0 and 100 that best describes your right shoulder discomfort.” Labels for the lowest and highest ends of the scale were “no discomfort” and “discomfort as bad as it could be” at your right/left shoulder (Straker, 1999).

Objective methods for measuring muscle fatigue make use of electromyography (EMG). Electromyography is described as the muscles electric signal that is produced when a muscle contracts (Chowdhury, et al. 2013). The signal of the muscle is controlled by the nervous system (Chowdhury, et. al. 2013; Kroemer, 2017, p. 53–63). Two common types of electromyography are commonly employed, surface and intramuscular EMG. Surface EMG (sEMG) is a technique that uses non-invasive electrodes attached to the skin, whereas intramuscular EMG is much more invasive, using a fine-wire electrode inserted into the muscle of interest (Soderberg, 1999). The surface measurement approach is used in occupational settings to measure the force a worker can generate in a specific posture and direction. By knowing an individual's maximum contraction force (MVC), the force needed for a regular work task being assessed as a percentage of the maximum. The percent maximum (%MAX) is the ratio of the applied force for a task to the MVC of the individual, multiplied by 100. (Chengalur, Rodgers, and Bernard, 2004, p. 114).

According to Nussbaum, et al. (2001), EMG is a common approach and can often identify physiological changes before deterioration of mechanical performance occurs. EMG has been used as a means for measuring muscle activity for static exertions and is also reliable to monitor and quantify muscle activity for dynamic tasks (Nussbaum, et al. 2001). Muscle activity can be measured with a wide array of electrodes, but for the purpose of EMG for ergonomics, surface and fine wire electrodes are most frequently used (Soderberg, 1999). A study comparing electrode types used a variance ratio that showed surface electrode recordings have a higher reliability than fine wire electrodes (Kadaba, et al. 1985).

For studies of muscular fatigue, there are advantages to using both a subjective rating method and an objective method based on EMG. Obtaining data on both discomfort ratings and sEMG provides independent data to help understand how the muscles are affected by the particular task.

1.3. Research into Fatigue from Overhead Work

The industry of construction has a wide number of jobs, and many of these jobs are physically challenging for the musculoskeletal system (Stendlund, Lindeck, & Karlsson, 2002).

A common task within the construction field is painting. Painter’s tasks range from overhead painting of ceilings, sanding, and precise movements which can lead to a multitude of injuries. Many tasks involve elevated arm positions that are concerning due to the shoulder muscles being contracted or activated. House painters, for example, have a high incidence of shoulder pain (Stendlund, et al. 2002). In recognition of this concern, several researchers have conducted studies of overhead manual tasks.

A study by Stenlund, et al. (2002) examined work techniques and shoulder muscle strain during overhead work in house painters, to determine if there was a correlation between loads in the shoulder, reported symptoms of MSDs, and working techniques. This study involved house painters performing overhead sanding of ceilings using an extension handle. The arm position for the study involved a normal technique, reversed grip and pushing technique (Stendlund, et al. 2002). All sanding postures were done overhead with one arm about waist level and the other higher up the handle. Participant’s kinetic movements were measured with an optoelectronic motion analysis system and were also given a questionnaire to determine which tasks the workers considered to cause them the most strain. Stendlund, et al. (2002) found that the supraspinatus muscle had less strain when participants were in the pushing motion. The supraspinatus is a muscle of the rotator cuff group, a commonly injured muscle when overhead work patterns are continuously repeated (Whiting, et al. 1998). The study showed that the pushing technique resulted in less strain in the supraspinatus muscle compared to the other techniques (Stendlund, et al. 2002).

Painters routinely work while standing on a ladder. With standing on a ladder come other safety related issues such as risk of falling from heights, force distributed throughout the hand while gripping, and awkward postures. A variety of ladders are used while painting such as a vertical ladder, step ladders or ladders pitched at an angle. A study of muscles used in ladder climbing showed that forces are greater on the worker's hands with a vertical ladder compared to a ladder pitched at about 10 degrees (Bloswick & Chaffin, 1990). Another major issue or risk factor while working and standing on a ladder is the level of fatigue that workers experience. Fatigue is not only present from their job task but also the fatigue of standing on the ladder while performing that task.

A study conducted at the University of Iowa looked at the effect of overhead drilling positions on shoulder moment and EMG. The purpose of the study was to determine the effect of moving closer to overhead work while performing overhead drilling tasks on a ladder (Anton, et al. 2001). The researchers measured EMG activity of the right biceps brachii, triceps brachii, and anterior deltoid muscles obtained by surface electrodes. Results indicated that a closer reach may be more advantageous while performing overhead work (Anton, et al. 2001). The shoulder stress, specifically root mean squared amplitude on the deltoids and biceps, decreased by moving closer to the task (Anton, et al. 2001).

Nussbaum (2001) noted that studies of fatigue from dynamic tasks are less common than for static tasks. He studied static and dynamic myoelectric measures of shoulder muscle fatigue during intermittent dynamic exertions of low to moderate intensity. The purpose of this study was to examine overhead work tasks and investigate whether EMG measures can potentially serve as indicators of fatigue (Nussbaum, 2001). EMG root mean square (RMS) amplitude and mean, and median power frequencies were measured and compared in terms of the variability and sensitivity. The study showed that variability differed between muscles and EMG measures, with the lowest mean power frequencies occurring during the static task (Nussbaum, 2001). The end result of the study showed that fatigue during a dynamic task can be monitored and quantified with EMG, specifically RMS amplitude and mean and median power frequencies (Nussbaum, 2001).

Studies found on shoulder fatigue have not reported static holding for durations as long as 20 minutes. The ACGIH documentation has a footnote indicating that people in work settings are not expected to perform static holding work for as long as 20 minutes. Therefore, the guidance does not address such long durations. This may be correct, but it would be interesting to check if people will self-limit holding a static arm position for as long as 20 minutes. Therefore, a project was undertaken to examine endurance time for a specific arm position—holding an arm, extended above the shoulder, much like a painter using a roller brush while standing on a ladder.

1.4. Purpose of this Study

The purpose of this study was to investigate the effect of two similar low force, upper arm holding task on shoulder muscle fatigue. The two tasks selected for inclusion were intended to distinguish between pure static arm holding and limited up and down arm motions. Both tasks require the shoulder muscles to hold the weight of the arm, hand, and a roller brush. The impetus for the study was to provide experimental evidence to help the ACGIH Ergonomic Committee decide if they should keep or modify a comment indicating jobs do not involve static upper arm holding for more than 20 minutes. In the process of designing the experiment, the following five specific aims were developed.

1. Measure what muscle fatigued the most over the task period.
2. Determine discomfort ratings trends throughout the task period.
3. Determine if objective measures of fatigue are different between a static and a moderately dynamic task.
4. Determine if there was a difference between static and dynamic endurance times.

5. Compare endurance time to a 20-minute maximum.

2. Methods

2.1. Experimental Design

A repeated measure design was used to assess effects of static holding and dynamic rolling tasks on measures of muscle fatigue. This required measurements of muscle fatigue in upper limbs when performing arm work in static holding and dynamic rolling postures. For the purpose of this study, both subjective and objective methods were used. The subjective measure was rating on a discomfort scale. Objective measures were obtained using surface electromyography activity (sEMG).

The tasks represented a painter using a roller brush while working from a portable ladder. The static holding task involved holding the brush against a fixed target while the dynamic rolling task involved rolling the brush up and down on the target, over a 10-inch range. For each task, the hand holding the brush was held above their shoulder height, while the target was at or above their head level. Measures of muscle fatigue consisted of electromyography of upper arm and shoulder muscles as well as reported feelings of discomfort. This design provided data for examining effects of tasks (static holding versus dynamic rolling) and time on each measure of fatigue.

Dynamic tasks are very common and performed regularly as a part of work duties. This study examined both a static holding exertion and dynamic rolling exertion. The dynamic tasks used the same arm postures as the static task except with a bit of movement (dynamic) up and down to desired points on a target. The purpose of analyzing dynamic was to compare fatigue, endurance times, and discomfort ratings and see how they differ from a static exertion to a dynamic exertion.

The experimental design involved having subject's pose as workers painting a wall with a roller brush while standing on a portable ladder. The three dependent variables measured were: (1) surface electromyography activity of four shoulder muscles, (2) subjective ratings of shoulder discomfort, and (3) total duration performing the task before reaching a discomfort rating of 80 on a 100 point scale. The dichotomous experimental independent variable was using a static holding or a dynamic rolling stroke. Continuous dependent variables were duration on task, discomfort rating, and EMG indicators of fatigue. The null hypothesis was that none of the three dependent variables will be significantly affected by any of the independent variables. The results of this study may be useful for the Ergonomics Committee of ACGIH when an update to the upper limb localized fatigue TLV is under consideration.

2.2. Subjects

Twenty college students were recruited with regard to grade level and degree type using a University of Montana Institutional Review Board approved script. Ten participants were males and ten participants were females, all majoring in Occupational Safety and Health, Applied Health and Safety Sciences, or Industrial Hygiene. All subjects provided informed consent prior to beginning the study. Students had a choice of extra credit or nominal payment. Nineteen students received extra credit for participation, while one student chose to receive nominal payment.

2.3. Equipment and Materials

The Natural Resource Research Center (NRRC) on the Montana Tech campus was used to complete the study. All preparatory and experimental procedures took place in the NRRC OSH lab during school hours.

Materials for the study included a portable extension ladder pitched at 75.5 degrees, DBI Sala ExoFit full body construction safety harness, standard roller paint brush, Delsys Trigno© Wireless sEMG system, and a moveable target to achieve desired arm position for varying heights of participants. To protect participants in event of a fall, a retractable lifeline connected the participant's harness D-ring to a cable secured to an anchor in the ceiling. The ceiling anchor was designed by an architectural engineer to hold a load up to 5,000 Pounds.

2.4. Procedures

Each participant's weight and height were measured to determine appropriate safety harness size. Harness size was determined by using the Full Body Harness Sizing Chart (DBI Sala Fall Protection, 2019).

2.4.1. Electromyography Procedures

For the purposes of this study, sEMG was used due to the easy, safe and non-invasive technique. Electrode placement for medial deltoid and triceps muscles was determined by using the method described by Soderberg, VanderLinden, and Zierman (1988). Medial deltoid was found by measuring the distance between the acromion to the epicondyle and dividing this distance by four. From the acromion down the specified distance is where the Delsys sEMG surface electrode was placed (Soderberg, et al. 1988). The anterior and posterior deltoids were determined from the medial deltoid sensor placement by measuring 2-4 inches in each direction (posterior towards the back of the shoulder and anterior towards the front of the shoulder). The measuring distance varied depending on the participant's size. The triceps muscle was determined by measuring from the acromion to the olecranon and dividing this distance by three. From the olecranon up the specified distance is where the Delsys sEMG surface electrode was placed (Soderberg, et al. 1988). All muscles were also palpated by the participant and the researcher to ensure the location was accurate for each muscle. Figure 1 shows electrode placement. The smaller Delsys sEMG surface electrode are measuring muscle activity the three pictured are posterior deltoid, medial deltoid, and triceps. The anterior deltoid is toward the front of the arm and not pictured. The large references are strictly for skin attachment and did not measure any muscle activity. All Delsys sEMG surface electrodes were placed in the same direction as the muscle fibers.

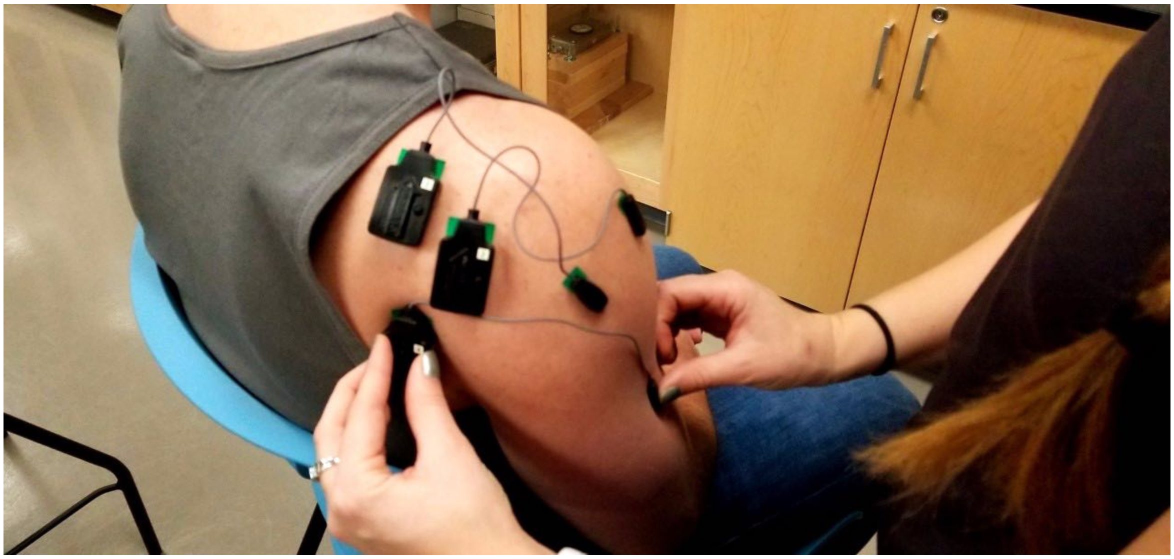

Figure 1. Surface electrode placement for triceps, posterior deltoid, and medial deltoid.

The skin was then prepped to ensure adequate adhesion for the sensors. Each participant's skin was cleansed with alcohol pads, shaved with a safety razor (if applicable), exfoliated with athletic tape to remove dead skin cells, cleansed with alcohol pad again and allowed to dry.

2.4.2. Maximum Voluntary Contraction Procedures

The participants completed four separate tasks for each muscle. Participants were asked to complete each task as hard as they could to provide their maximum voluntary contraction

(MVC) to serve as a reference value for sEMG signal normalization. Three MVC tasks made use of a fixed ladder in the laboratory. Padding was provided so that participants would not limit their contraction due to contact pressure. Ladder rungs at different heights were used to allow for various heights and specific arm positions. To achieve the desired arm position for participants of different heights, wooden blocks were stacked as needed under their feet.

For medial deltoid, participants placed their dominant arm through the ladder rung and positioned the wrist at the rung as shown in Figure 2(a). The arm was at 100 degrees prone horizontal abduction with the palm facing outward (Reinold, et al. 2004). Participants had to push up against the ladder rung as hard as possible. Anterior deltoid MVC required participants to place their dominant arm under the ladder rung at a 90-degree angle with forearm bent up and pushing up against rung as hard as possible as shown in Figure 2(b) (Qaisi, et al. 2015). Posterior deltoid required participants to place their dominant arm horizontally out in front of the ladder with elbow touching the ladder as shown in Figure 2(c). The arm was abducted at 90 degrees with the palm facing down and pushing the arm back against the ladder rail (Reinold, et al. 2004). The triceps MVC was done with participants back side against a pole. A canvas was wrapped around the individual's arm that was tied off at an anchor point. The arm was measured at a 90-degree angle before extending the arm against the strap as hard as possible. The photo in Figure 2(d) shows the test position.

Each MVC task was done as hard as possible for five seconds to achieve the maximum voluntary contraction. Each five second contraction was performed three times, separated by a ten second rest period in between each contraction. When participants changed from one position to another, there was approximately two minutes of rest in between.

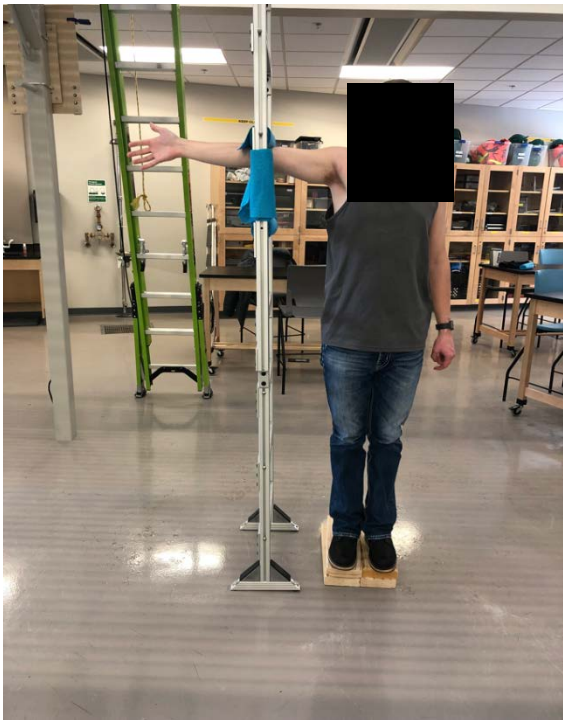

Figure 2a: Medial Deltoid MVC

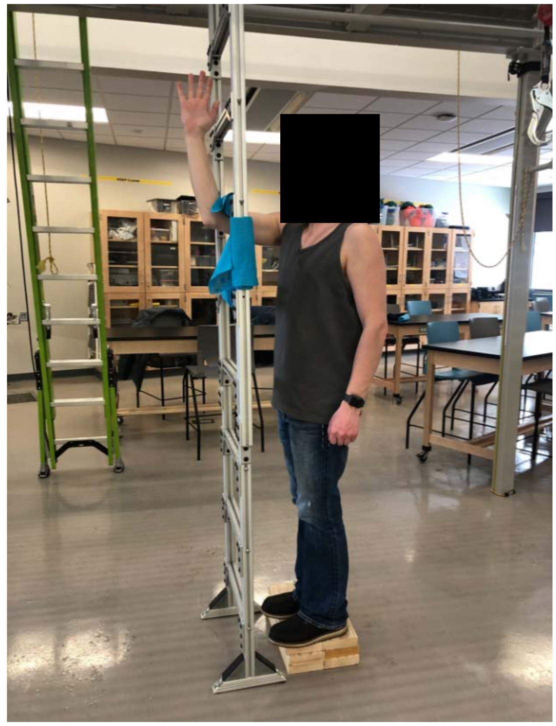

Figure 2b: Anterior Deltoid MVC

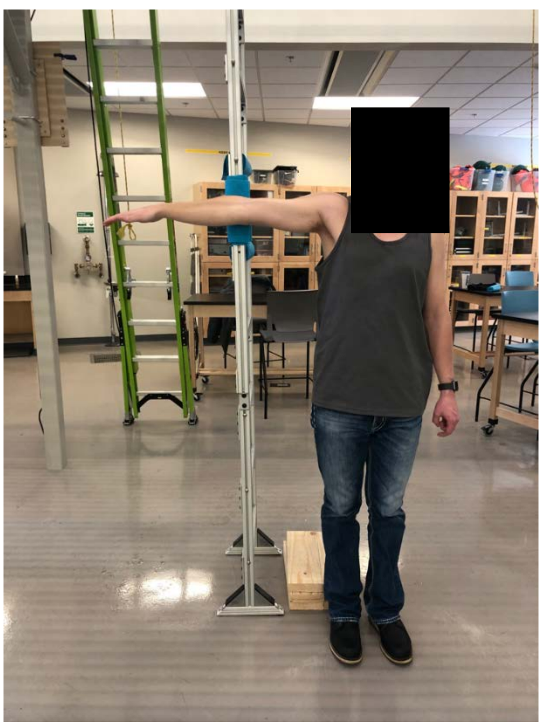

Figure 2c. Posterior deltoid MVC

Figure 2d. Triceps MVC

Figure 2. Maximum voluntary contraction arm positions using the ladder and arm strap.

2.4.3. Experimental Procedures

Participants began by hooking the D-ring on the harness to the snap hook of the retractable lifeline. They then stepped on the first ladder rung. They were given a standard roller paint brush to hold in their dominant hand. They were instructed to perform a static holding and dynamic rolling task. The order of the tasks was alternated for all participants to minimize ordering effects, such as learning and fatigue. The static holding posture required participants to hold the arm posture in the middle square on the target until the discomfort reached the extreme level. A photo in Figure 3 depicts a right-handed participant performing the static holding task using the target. The dynamic rolling task required participants to paint to the top line of the target and down to the bottom of the target continuously until the discomfort was extreme.

Figure 3. Right-handed participant performing the static holding task.

While the tasks were performed, a 0–100 discomfort rating was collected every 30 seconds. The question stated, “Please indicate to me the number between 0 and 100 that best describes your right/left shoulder discomfort.” (Straker, 1999). The participants completed both tasks until a discomfort rating of 80 was reached, which is the start of the extreme discomfort range. Once a rating of 80 was reached the participant came down off the ladder for a five to ten-minute rest period before performing the second task.

2.5. Data Preparation

Data were processed and stored in the Delsys EMG Works version 4.5.4 and analyzed in Delsys EMG Analysis version 4.7.1, copyright Delsys Inc., Natick, MA, USA. All data were stored on a laboratory computer. Members of the research team independently reviewed the raw EMG signal from the MVC efforts to determine if there were three maximal efforts that were clearly distinguishable from the rest period in between. Initially two members reviewed the MVCs, but if they disagreed, a third member also reviewed MVCs to break the tie. Eighty total MVC efforts were evaluated. All participants had four efforts each. Eleven of twenty participants had one or more of their MVC efforts that were not distinct and lacked three discernable efforts. Most of the non-distinguishable efforts were for the triceps muscle. Amplitude analysis was computed to normalize static holding and dynamic rolling tasks to the EMG signal of the subject’s muscle.

Median frequency analysis was performed on dynamic holding and static rolling task raw data for each muscle, providing a measure of the participant’s rate of fatigue over time. The median frequency data was extrapolated from the EMG analysis software and provided the participants median frequency in hertz for the duration of the task. The median frequency in hertz was graphed against the time in seconds with a fitted line plot showing the slope.

Discomfort rating data for static holding and dynamic rolling postures were also graphed with a line plot for all participants combined. The plotted discomfort rating were normalized as percentage of the individual's endurance time and graphed against the time in seconds for every 30 seconds of the task duration.

2.6. Statistical Analysis

Statistical analyses of the data were performed in Minitab Statistical Software, version 18 copyright, State College, PA, USA, Minitab Inc. All four muscles were analyzed with an analysis of variance model (ANOVA), to determine if there were any significant differences in fatigue between each muscle. This was done for all four muscles for the static holding task as well as the dynamic rolling task. Endurance times were compared to the 20-minute maximum mentioned in the ACGIH upper limb localized fatigue guidelines. For data set distributed normally, a t-test was used, if not normally distributed, a one sample sign test was used. Endurance times between static and dynamic, and median frequencies between static and dynamic, were statistically tested with paired t-tests. The null hypotheses for these analyses are listed below.

- Dynamic holding and static rolling discomfort slopes will not differ from zero.
- Dynamic holding and static rolling median frequency slopes will not differ from zero.
- There will be no significant differences in endurance times between dynamic rolling and static holding tasks based on discomfort ratings.
- There will be no significant difference in endurance times between static holding and moderately dynamic rolling tasks compared to the 20-minute comment in the documentation for the ACGIH TLV on upper limb localized fatigue.

3. Results

A total of twenty participants were recruited to participate in this study. One participant who clearly did not understand the instructions and had abnormal data was removed from all data sets and analysis. Since one participant was removed there was a total of 10 females and 9 males for all analysis purposes. Participant attributes are in Appendix A. The Results section has five subsections that match the five specific aims of the study.

3.1. Fatigued Muscles

Table I below shows all median frequency slopes for each muscle for static holding and dynamic rolling tasks. Appendix B has individual median frequency slopes for each participant.

Table I. Average Median Frequency Slopes for Each Task and Muscle

Task	Anterior Deltoid (Hz/s)	Medial Deltoid (Hz/s)	Posterior Deltoid (Hz/s)	Triceps (Hz/s)
Static Holding	-0.123	-0.105	-0.102	-0.085
Dynamic Rolling	-0.138	-0.139	-0.103	-0.099

ANOVA was used to compare slopes of the four muscles for the two tasks. The independent variable tested was the muscles and the dependent variable tested was the median frequency slopes. There was no statistically significant difference between the rate of fatigue (slope) of the four arm muscles during static holding ($F = 0.85$, $p = 0.47$) or dynamic rolling ($F = 1.23$, $p = 0.31$) tasks. Since no muscle was found to fatigue more than the other, the mean values of the median frequency slopes for static holding and dynamic rolling tasks were evaluated. Figures 4 and 5 below show that there was no significant difference in means of the median frequency slopes between the four muscles. To further evaluate a specific fatigued muscle, all participant slopes for each muscle were averaged together to provide the mean value, the muscle with the most negative median frequency slope was determined to be the muscle of interest. Anterior deltoid provided the largest slope and was further considered as the muscle of interest, or the most fatigued muscle.

The boxplots below show several areas of the data. The dot in the middle of each box is the mean value and the line in the middle of the box is the median value. The lower vertical line is the lower 25th percentile and the upper vertical line is the upper 25th percentile. The lower horizontal line at the bottom of the box indicates the range of the 25th percentile and the higher horizontal line at the top of the box indicates the 75th to 100th percentile. The asterisk indicates an outlier of the data sets.

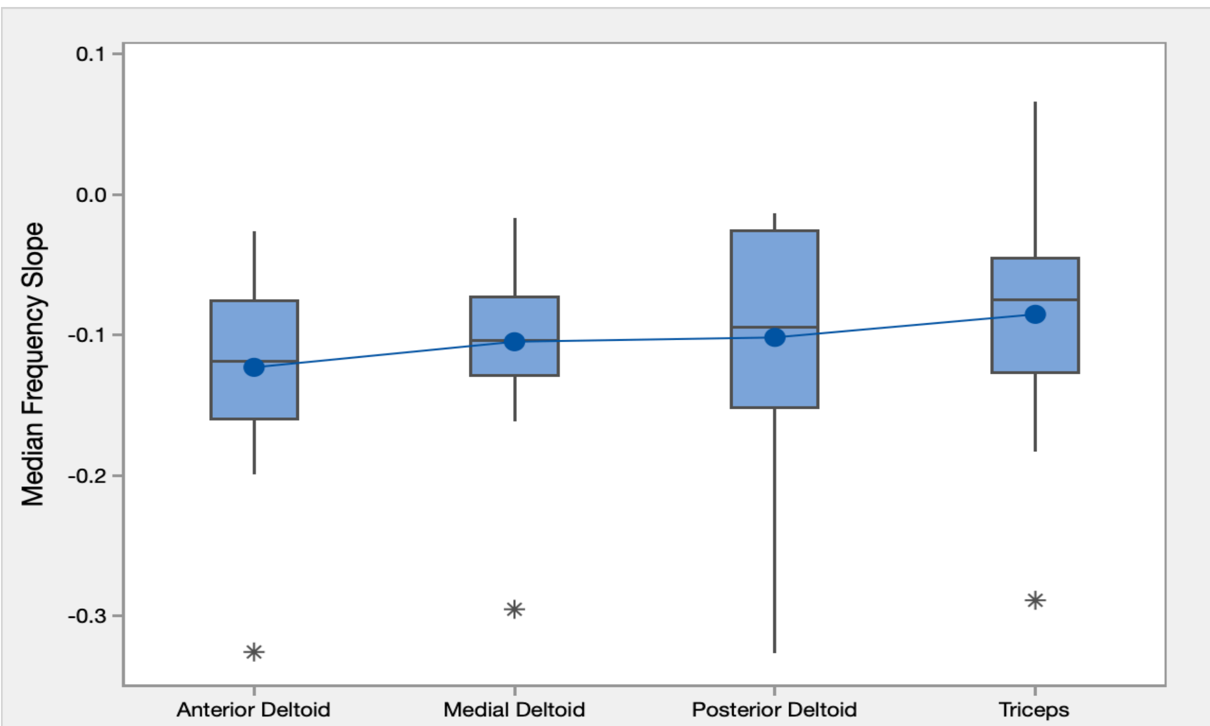

Figure 4. Median frequency slopes for each muscle during a static holding task.

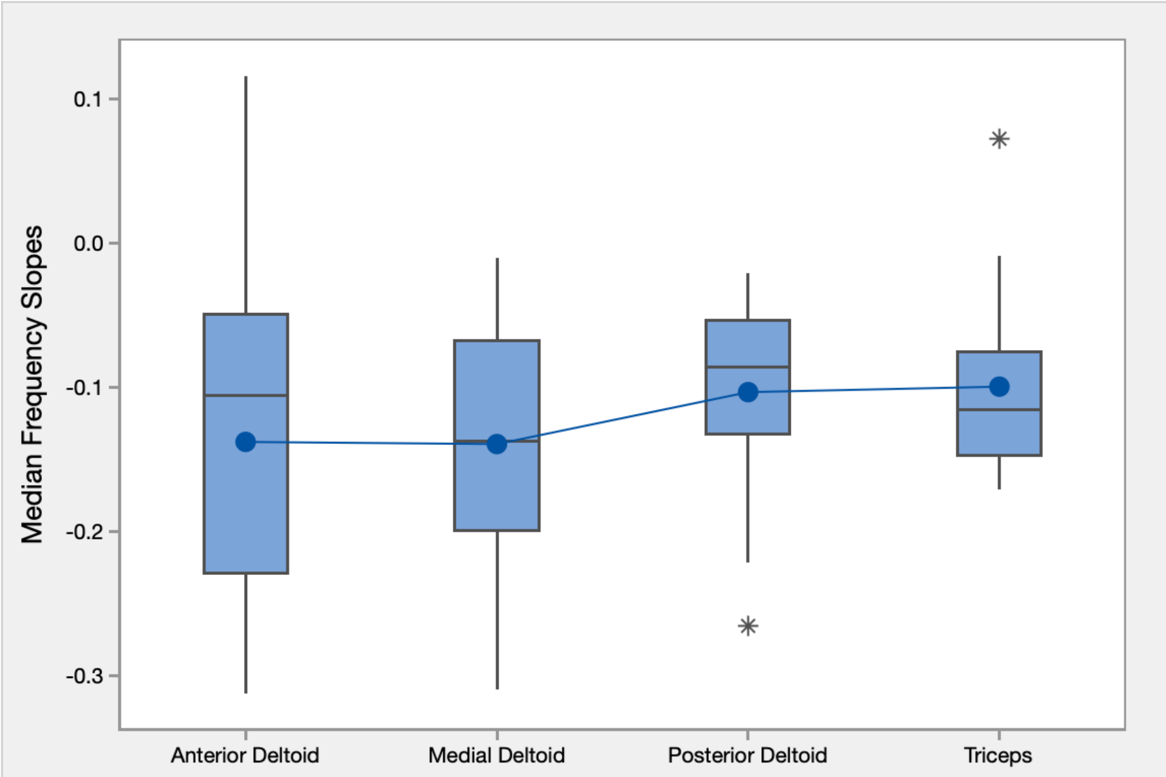

Figure 5. Median frequency slopes for each muscle during a dynamic rolling task.

3.2. Discomfort Rating Trends

Discomfort data ratings were from a scale based on 0 to 100. All participants ended the task when 80 was reached. The range of participants discomfort ratings for both static holding and dynamic rolling was from 0 to 80, with some greater than 80. The mean discomfort rating for static posture was 39.65, and the dynamic mean discomfort rating was 41.67, on average the discomfort rating was higher for the dynamic rolling task then the static holding task.

All participants had different endurance times. In order to look at how discomfort changed from the start of a task to the end, the time was normalized to the individual, and expressed as a percentage of their endurance time. This enabled development of scatter plots depicting overall patterns. Figures 6 and 8 show discomfort rating values obtained during the start and end time of individuals. The figures show data for:

- Genders combined doing the static holding task
- Genders combined doing the dynamic rolling task

Discomfort ratings appear to follow a linear trend between the first ratings obtained at 30 seconds, to the last rating obtained when the individual felt their discomfort had reached 80 on the discomfort scale. All below figures were examined with a linear regression and produced p-values of less than 0.001 for both tasks, both genders, and combined genders. ANOVA tables for the regression are presented in Tables II and III. These findings are consistent with expectations.

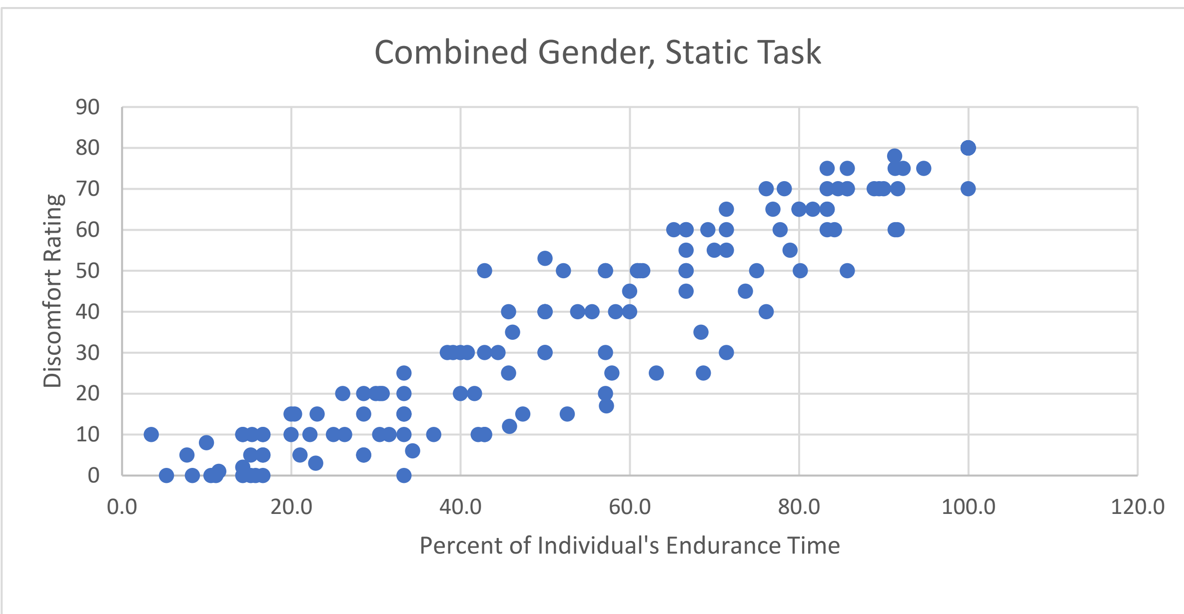

Figure 6. Discomfort ratings for all subjects performing the static holding task.

For the data plotted in Figure 6, the assumptions of a linear regression were tested and are shown in the Figure 7. The normal probability plot showed a strong match with the regression line for static rolling. The residual plots compared well with the fitted line. The residual histogram displayed a clear normal distribution with a mode slightly above zero for static holding. Observation order did not show a trend in the residuals either upward or downward from the fitted line for both tasks.

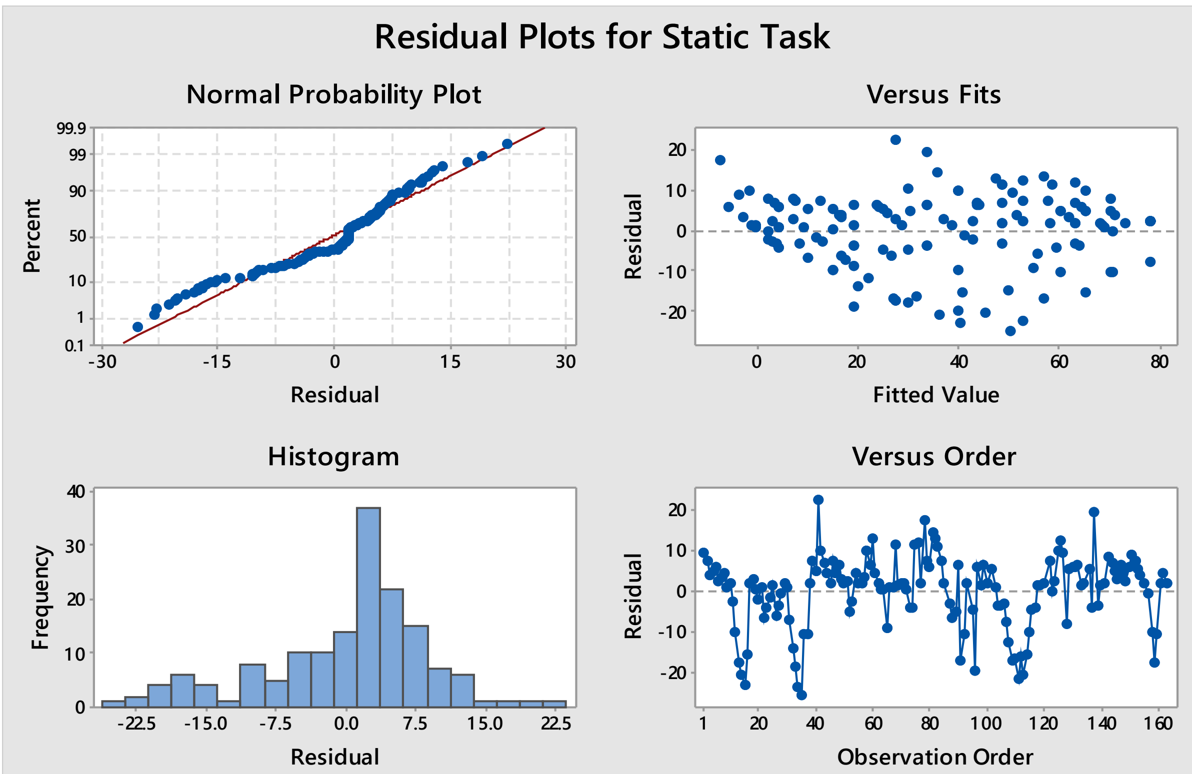

Figure 7. Residual plots of fitted line for static holding with both genders.

Table II provides the statistical outputs from the best fit, linear regression. The equation relating discomfort ratings to percent endurance time is Discomfort = − 10.26 + 0.8835 (%ET). It has an R-squared of 89.4% and an adjusted R-squared of 89.3%.

Table II. ANOVA Table for Combined Gender Static Task

Source	DF	SS	MS	F	P
Regression	1	101,870	101,870	1,299.16	0.000
Error	154	12,076			
Total	155	113,946			

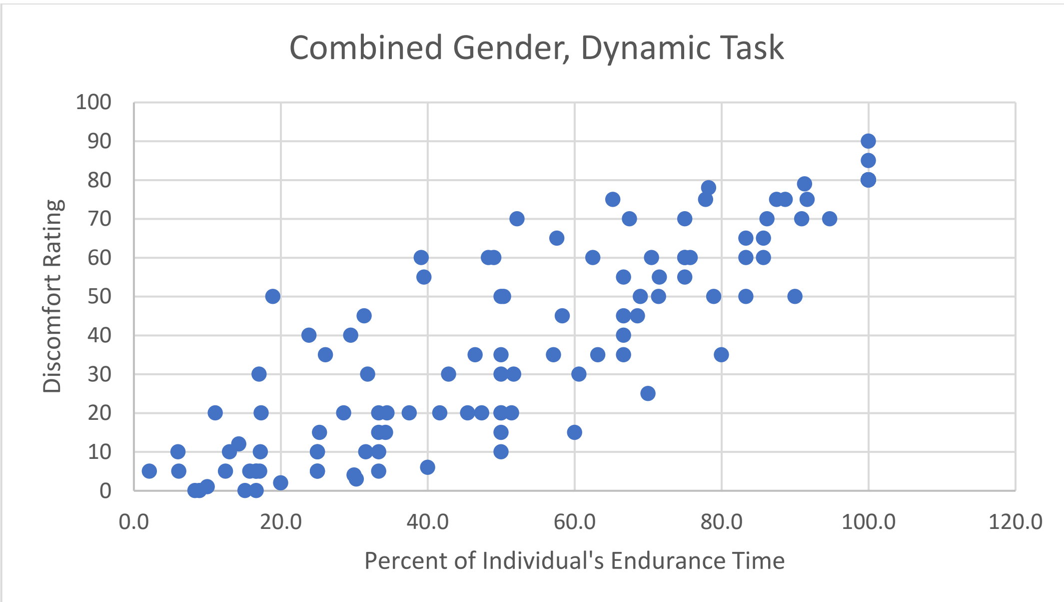

Figure 8. Discomfort ratings for all subjects performing the dynamic rolling task.

Table III provides the statistical outputs from the best fit, linear regression. The equation relating discomfort ratings to percent endurance time is Discomfort = − 4.22 + 0.821 (%ET). It has an R-squared of 77.94% and an adjusted R-squared of 77.56%

Table III. ANOVA Table for Combined Genders Dynamic Rolling Task

Source	DF	SS	MS	F	P
Regression	1	74,914.9	74,914.9	432.10	0.000
Error	121	20,978.5	173.4		
Total	122	95,893.3			

For the data plotted in Figure 8, the assumption of a linear regression were tested and are shown in the Figure 9. Normal probability plot showed strong match to regression line in Figure 9. The residual plots compared well with the fitted line. The residual histogram displayed a clear normal distribution with a mode at zero. Observation order did not show a trend in the residuals either upward or downward from the fitted line for both tasks.

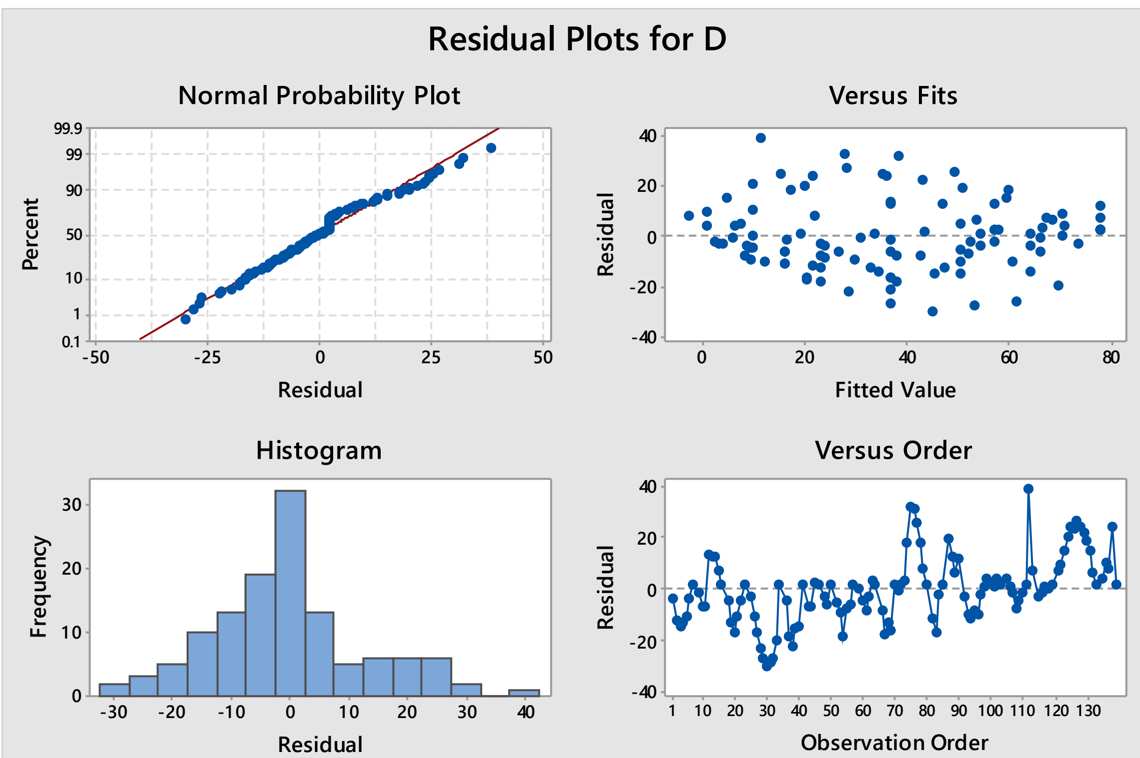

Figure 9. Residual plots of fitted line for dynamic rolling with both genders.

3.3. Comparing EMG Measures for Static and Dynamic Tasks

The difference between median frequency slopes for static holding and dynamic rolling tasks were analyzed to see if there was a difference between the rates of fatigue. The differences between static holding and dynamic rolling median frequency slopes were tested for normality. A p-value of 0.2047 was produced, showing that the data was normal, and a paired t-test was required. The paired t-test produced a p-value of 0.5807, showing that there was no significant difference between rate of fatigue for static holding and dynamic rolling tasks.

3.4. Comparing Endurance Times for Static and Dynamic Tasks

The static holding and dynamic rolling tasks were expected to not exceed 20 minutes (1200 seconds) because of the current comment by ACGIH in the Upper Limb Localized Fatigue Guideline. The longest static task duration was 570 seconds and the longest dynamic task duration was 390 seconds. The static mean duration was 244 seconds and the dynamic mean duration was 197 seconds.

Total duration times of the 19 participants were evaluated with a paired t-test to determine the difference in endurance times between the tasks. The paired t-test was performed due to the static holding and dynamic rolling endurance times being normally distributed ($p = 0.0580$). The paired t-test produced a p-value of 0.0066, showing that there was a significant difference between static holding and dynamic rolling endurance times.

Figure 10 below shows the endurance time frequencies for both tasks. As shown, the dynamic rolling task had endurance times mostly in the 100 to 200 bin, whereas, the static holding task had endurance time evenly spread in the 200 to 300 bin and the 300 to 400 bin.

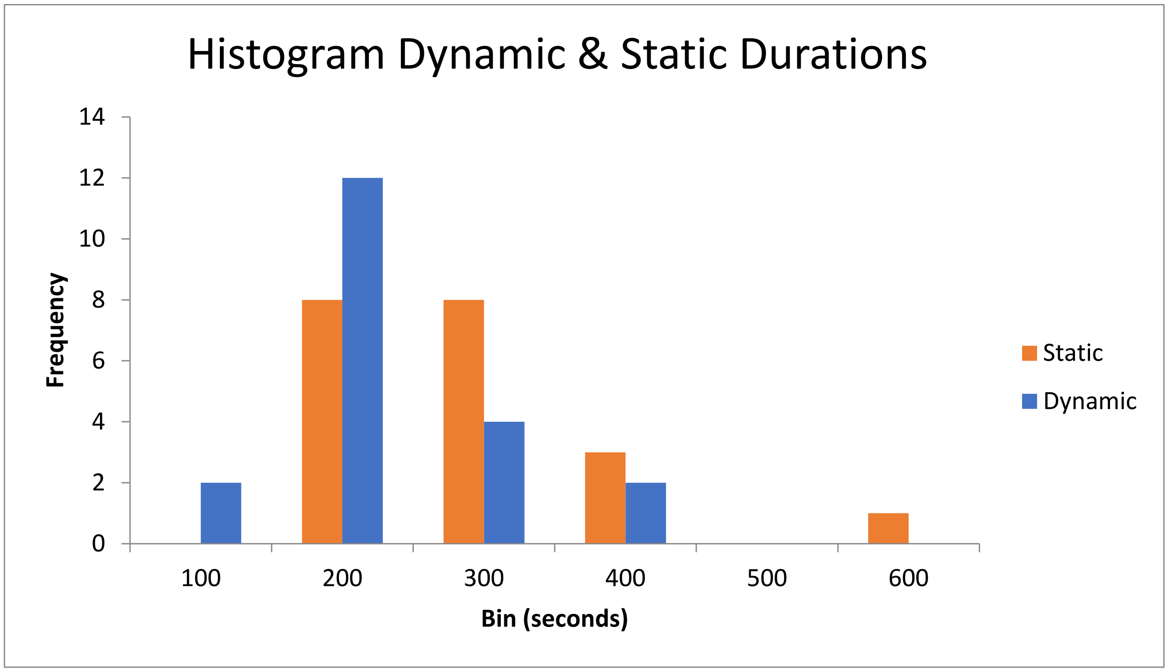

Figure 10. Distribution of endurance times for combined gender and both tasks.

3.5. Do Endurance Times Exceed 20 Minutes?

Since task durations relative to fatigue were not to exceed 20 minutes, the durations were tested against the maximum time comment. Static holding and dynamic rolling tasks were tested using a one-sample sign and one-sample t test as the dynamic rolling data was normal and the static holding data was not normal. A test median of 1200 seconds was used, as all task durations were evaluated in seconds. Static holding durations had a median value of 210, where dynamic rolling durations had a median value of 180. Both static holding and dynamic rolling durations produced p-values less than 0.0001 showing that task durations from this study were significantly different from the 20-minute comment. Table IV shows the means, range and standard deviations of static holding and dynamic rolling task durations.

Table IV. Task Duration Data for Static and Dynamic Tasks

Parameter	Static	Dynamic
Mean (s)	251.4	193
Range (s)	147–570	90–390
Standard deviation	105.32	80.74

The table IV suggests that on average the static holding task lasted longer than the dynamic rolling task. The task durations ranged from 147 seconds to 570 seconds for static holding tasks and 90 seconds to 390 seconds for dynamic rolling tasks. The static holding task had a longer total duration, which could be due to less muscle activity required to perform the task compared to muscle activity with the dynamic rolling task. As shown, no durations surpassed the 20-minute maximum time (1200 seconds).

4. Discussion

The majority of the findings of this study were consistent with the expected results. The expected results were:

- Muscle fatigue would increase as time increased for the task duration
- Static holding and dynamic rolling fatigue times would differ
- Discomfort ratings would increase as time increased for the task duration
- No task duration would exceed a 20-minute maximum

4.1. Muscle Fatigue

Fatigue in four muscles was measured during a static holding and dynamic rolling task. The four muscles examined were the anterior deltoid, medial deltoid, posterior deltoid, and triceps. The similar study, by Anton, et al. (2001), examined three muscles during overhead drilling work. Their three muscles examined were the biceps brachii, triceps brachii, and anterior deltoid. The reason for sampling the anterior deltoid is because it is a prime flexor of the shoulder (Kadefors, et al. 1976). Another study suggested that the anterior deltoid, medial deltoid and upper trapezius were adequate muscles to examine during overhead work due to their recruitment and susceptibility to fatigue (Gerdle, et al. 1988; Nussbaum, 2001). This study examined all sections of the deltoid as all three were tested initially before beginning the study data collection, and data showed that muscle activity was present in all three areas of the deltoids with substantial differences in the activity of each deltoid muscle. If the data for all three would have been the same and no initial difference of activity in the deltoid muscles, only the anterior deltoid would have been examined due to being the prime flexor of the shoulder. The triceps muscle was examined, as during the initial phases of testing the deltoids, the triceps muscle was producing muscle actions. As Anton states, the triceps brachii muscle allows a comparison of antagonistic muscle actions while performing overhead work (Anton, 2001).

The fatigue between the four muscles examined was not significant after data collection. Due to this, further analysis was strictly done on the anterior deltoid, which according to Kadefors, et al. (1976) is a major flexor of the shoulder. The anterior deltoid was known as the muscle that fatigued the most. In a study reported by Nussbaum, et al. (2001) the anterior and middle portions of the deltoid were determined to be the most susceptible to fatigue. A different study by Nussbaum, et al. (2001) suggested that the attention be focused on the deltoid muscle as signs of fatigue were more frequently apparent compared to the trapezius and infraspinatus. This suggests that the further analysis of the anterior deltoid was validated.

4.2. Endurance Times

The results of this study indicate that static holding tasks can be performed longer than dynamic rolling tasks. According to Rohmert (1973b), endurance time has an inverse relationship with muscle activation. This results in extreme reaches being expected to lead to more accelerated fatigue development and decreased endurance times (Sood, et al. 2007). This helps to explain why the static holding task was performed longer than the dynamic rolling task. More muscle activity was required to perform the dynamic rolling task, so as the muscle activation required to complete the task increased the duration time decreased, and in turn resulted in faster development of fatigue.

Endurance times were outlined in the results by task type and combined genders (males and females separated are in Appendix C). Average durations for females for static holding task was 228.6 seconds and 184.7 seconds for dynamic rolling task. The male’s average durations for static holding task was 260.8 seconds and 210.3 seconds for dynamic rolling task. This contradicts findings from a study by Nussbaum, et al. (2001) as the gender differences suggested females developed fatigue less rapidly than males when performing at similar percentage of capacities.

4.3. Discomfort Ratings

Subjective data was measured by having participants rate their discomfort over the task duration. A study reported by Sood, et al. (2007) showed the subjective measure of rating perceived discomfort provided reliability and was a valid indicator of localized muscle fatigue. The rating scale used in this study worked well for English speaking individuals, but there was some misunderstanding with non-English speaking individuals.

The results provided by the discomfort ratings showed that as duration of the task increased so did the discomfort rated by the participants. Static holding and dynamic rolling tasks both followed the same discomfort scale, but the dynamic rolling task had a higher mean discomfort rating than static holding. This follows in sync with the endurance times. The static holding task was longer than the dynamic rolling task, in a sense causing the dynamic rolling task to be rated at a higher discomfort value. These results compare with earlier studies that showed the development of discomfort is well correlated with endurance time in static tasks (Dedering, et al. 1999) and comparable overhead tasks (Nussbaum, et al. 2001).

Linear regressions were done on both tasks for each gender as well as the genders combined for both tasks. The fitted line plots showed that discomfort increased the longer the arm was held overhead.

4.4. Fatigue Time Relative to 20 Minutes

The data found in the study was to be related back to the expected maximum time for statically holding the shoulder, elbow, or hand. The comment for maximum time for upper limb localized fatigue for static exertions expressed an expectation that workers do not exceed 20 minutes in a static upper arm position. This study set out to see if the maximum time comment warranted further investigation as 20 minutes seemed excessive.

Both static holding and dynamic rolling tasks were performed to evaluate the difference between the two. No participant was able to withstand either task for the 20 minutes. The longest duration totaled 9.5 minutes (570 seconds) for static holding and 6.5 minutes (390 seconds) for dynamic rolling. The data showed there was a significant difference between both static holding and dynamic rolling task durations compared to the 20 minutes. This finding is consistent with the note in the ACGIH TLV upper limb fatigue about people do not hold a static upper arm posture for more than 20 minutes.

4.5. Study Limitations

The findings of this study could potentially have some limitations, specifically methodological and sample limitations. Subject size was limited to 20 with only 19 analyzed, and only junior, senior and graduate students were included as participants. This also meant that no participants were painters and the tasks performed were not their daily jobs, like it would be for painters. The tasks also involved one arm position out of many potential arm positions. EMG procedures provided some issues with the sensors on the triceps muscles during MVC tasks. The triceps were difficult to find on some participants which could have potentially led to misplacement. Other participants triceps were simple to find and palpate, resulting in a true MVC effort.

In addition, four muscles were tested and compared but only one muscle was further tested for all statistical analysis due to no significant differences between median frequency slopes of muscles. Males and females were not statistically compared against one another, instead all comparisons were done between static holding and dynamic rolling tasks.

Participants did not experience other ergonomic risk factors like heat, cold, awkward body postures, repetition (only performed study once), and long periods of standing. These factors could potentially be seen in the daily task's painters perform and increase the development of fatigue. The study limited participants to two tasks in a normal overhead posture, in normal temperatures, and only for a maximum of 40 minutes (two tasks at a maximum limit of 20 minutes mimicking the comment within the guideline).

4.6. Study Strengths

A main strength of this study was measuring fatigue in four muscles that could potentially fatigue and/or become injured from working overhead. This helped show which out of the four muscles fatigued the most over the task period. During the study both subjective and objective data was obtained to measure a relationship between discomfort over time as well as fatigue over time.

A previous study by Anton, et al. (2001) gave participants practice rounds. For the purpose of this study no practice round was given, which in turn did not lead to a bias or preconceived notion. This study also did not try to minimize fatigue in the deltoids, instead the bottom rung on the ladder was used to maximize the participants arm reach. The Anton, et al. study, showed that moving up a step helped decrease fatigue in participant's deltoids, but for the purposes of this study fatigue was not minimized.

4.7. Future Work

If this study were to be repeated in the future, findings would be more relevant to work if painters served as subjects. Future studies could be performed with subjects doing different tasks with different arm positions. The finding in this study about endurance time being longer for static arm holding than for moderately dynamic arm rolling should be examined to determine if this finding is repeatable. Another matter suitable for a future study is different levels of arm movement so that static holding could be compared with more dynamic rolling arm movements.

For the purposes of this study the discomfort rating was asked every 30 seconds while participants completed both the static holding and dynamic rolling tasks by using a target as a performance measure. If future experiments are performed this same interval could be used. This is helpful to have a 30 second time interval when graphing discomfort, especially for those participants who might not last as long, to still see how the discomfort changed over time. If this seems to be disrupting to the participant/worker, then a 1-minute interval could be used. For future studies, a performance measure should be used. This is to help keep the roller brush within a target range as the duration extends. This ensures there are no variations within subjects, as all subjects were verbally reminded to keep within the target range for both static holding and dynamic rolling tasks.

5. Conclusion

The purpose of this study was to investigate the effect of a particular low force static holding/dynamic rolling task on upper arm muscle fatigue and relating those findings to the ACGIH 20-minute comment on static loading. This required an experiment involving measurements of muscle fatigue in upper limbs when performing arm work in pure static holding and dynamic rolling postures. The four muscles measured were the anterior, medial, and posterior deltoids, and the triceps muscle. Discomfort ratings were also verbally measured during the task period.

The anterior deltoid was the most fatigued muscle studied. The data also showed that participants experienced fatigue and discomfort over the task period for both static holding and dynamic rolling postures. As expected, median frequency decreased as time of the task increased. The discomfort ratings provided by participants increased as the task duration increased and was ended when perceived discomfort reached 80.

The results showed that there was a significant difference between the endurance times compared to 20-minutes for both static holding and dynamic rolling postures. Static holding durations for both males and females were longer than the dynamic rolling durations. All durations were shorter than the 20 minutes.

Many occupations include tasks being done with limbs overhead and repetitively over time. This poses a risk for developing WMSDs. Repetition is a common MSD risk factor whether working posture is overhead or neutral. If repetition of these tasks and awkward body postures continued for long periods and every day, this could potentially contribute to a WMSDs.

The original impetus for this study was to provide documentation for the ACGIH TLV comments to the effect that a TLV is not needed for static durations longer than 20 minutes because workers will not hold a static arm position for more than 20 minutes. Results of this study are consistent with that comment.

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7. Appendix A: Participant Demographics

Table V provides demographic data on the participants. The number of participants includes the 19 individuals. Data from one participant out of the 20 recruited was omitted because of failing to understand the instructions.

Table V. Participant Demographics

Height (cm)	Weight (kg)
167	66.7
173	70.1
176	68.6
165	57.1
167	60.3
164	67.7
168	60.0
168	61.1
169	79.9
172	79.2
178	60.4
179	66.1
164	68.5
183	66.3
179	95.7
170	80.9
175	72.5
198	101.1
176	70.8

8. Appendix B: Participant Specific Median Frequency Slopes

8.1. Static Holding Slopes

Table VI provides detail on the median frequency slopes for each participant and each muscle.

Table VI. Static Holding Participant Median Frequency Slopes

Participant	Static Anterior Deltoid	Static Medial Deltoid	Static Posterior Deltoid	Static Triceps
1	-0.10	-0.13	-0.17	-0.09
2	-0.19	-0.12	-0.18	-0.18
3	-0.06	-0.09	-0.02	-0.05
4	-0.09	-0.06	-0.01	-0.06
5	-0.20	-0.13	-0.11	-0.06
6	-0.33	-0.30	-0.33	-0.29
7	-0.15	-0.09	-0.08	-0.06
8	-0.14	-0.13	-0.04	-0.11
9	-0.08	-0.10	-0.22	-0.05
10	-0.09	-0.13	-0.13	-0.10
11	-0.04	-0.08	-0.04	-0.04
12	-0.16	-0.10	-0.05	-0.13
13	-0.12	-0.11	-0.09	-0.07
14	-0.03	-0.02	-0.01	-0.02
15	-0.17	-0.16	-0.15	-0.14
16	-0.13	-0.10	-0.15	-0.16
17	-0.10	-0.07	-0.01	-0.01
18	-0.03	-0.03	-0.03	0.07
19	-0.14	-0.05	-0.10	-0.09

8.2. Dynamic Rolling Slopes

Table VII provides detail on the median frequency slopes for each participant and each muscle.

Table VII. Dynamic Rolling Participant Median Frequency Slopes

Participant	Dynamic Anterior Deltoid	Dynamic Medial Deltoid	Dynamic Posterior Deltoid	Dynamic Triceps
1	-0.11	-0.18	-0.18	-0.12
2	-0.16	-0.16	-0.09	-0.17
3	-0.11	-0.06	-0.13	-0.08
4	-0.09	-0.07	-0.02	-0.01
5	-0.23	-0.18	-0.12	-0.12
6	-0.23	-0.19	-0.04	-0.15
7	-0.31	-0.20	-0.08	-0.14
8	-0.28	-0.20	-0.09	-0.11
9	-0.17	-0.14	-0.10	-0.13
10	0.05	-0.14	-0.27	-0.15
11	-0.08	-0.07	-0.04	-0.03
12	-0.30	-0.31	-0.22	-0.15
13	-0.08	-0.09	-0.08	-0.10
14	-0.05	-0.06	-0.05	-0.03
15	-0.22	-0.22	-0.11	-0.15
16	-0.05	-0.04	-0.06	-0.12
17	-0.23	-0.24	-0.17	-0.12
18	-0.01	-0.01	-0.02	0.07
19	-0.22	-0.09	-0.08	-0.07

9. Appendix C: Gender Specific Regressions

The main text contains the combined gender scatter plots, regression fit, and residual plots. The same items for males and for females are presented in this Appendix.

9.1. Male Data

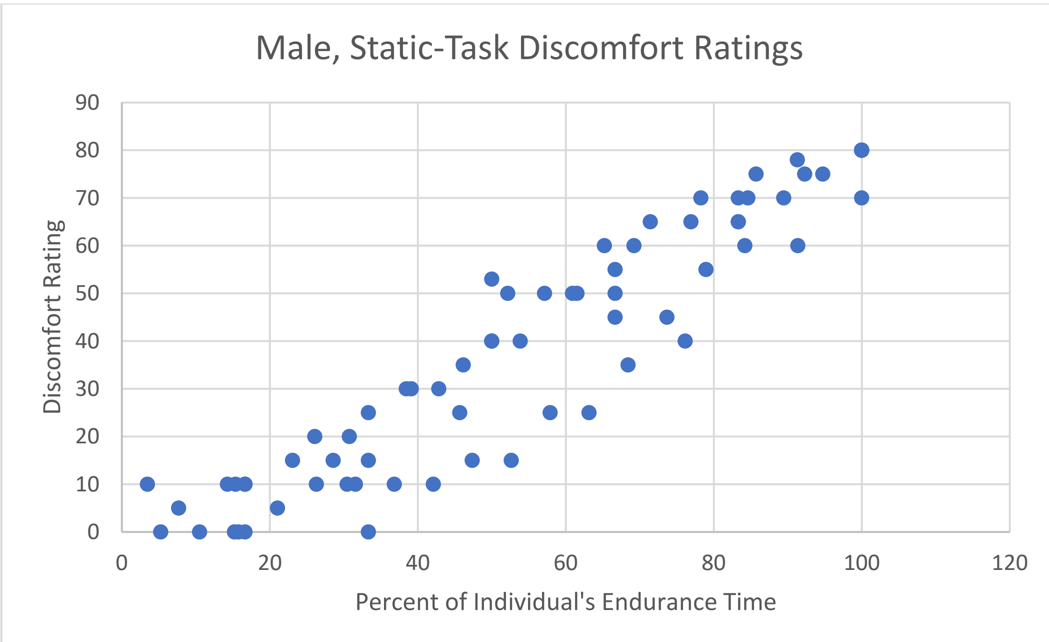

Figure 11. Discomfort ratings by male participants performing the static arm task.

Table VIII. ANOVA Table for Male Static Task

Source	DF	SS	MS	F	P
Regression	1	52,400.7	52,400.7	642.66	0.000
Error	77	6,278.4	81.5		
Total	78	58,679.0			

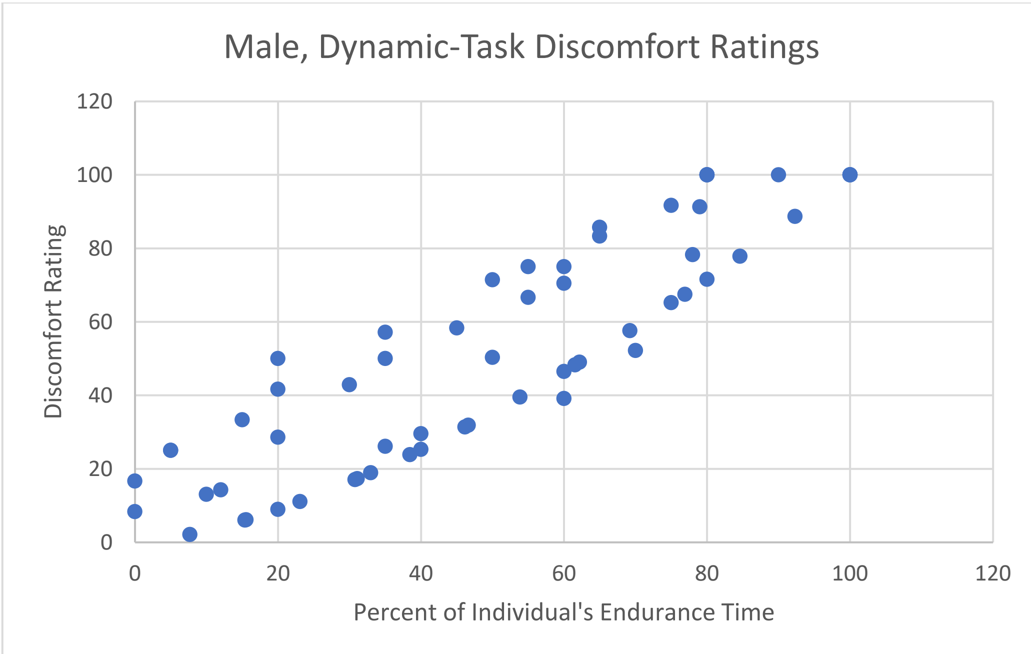

Figure 12. Discomfort ratings by male participants performing the dynamic arm task.

Table IX. ANOVA Table for Male Dynamic Task

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	1	35,485.0	35,485.0	240.15	0.000
Error	58	8,570.0	147.8		
Total	59	44,055.0			

9.2. Female Data

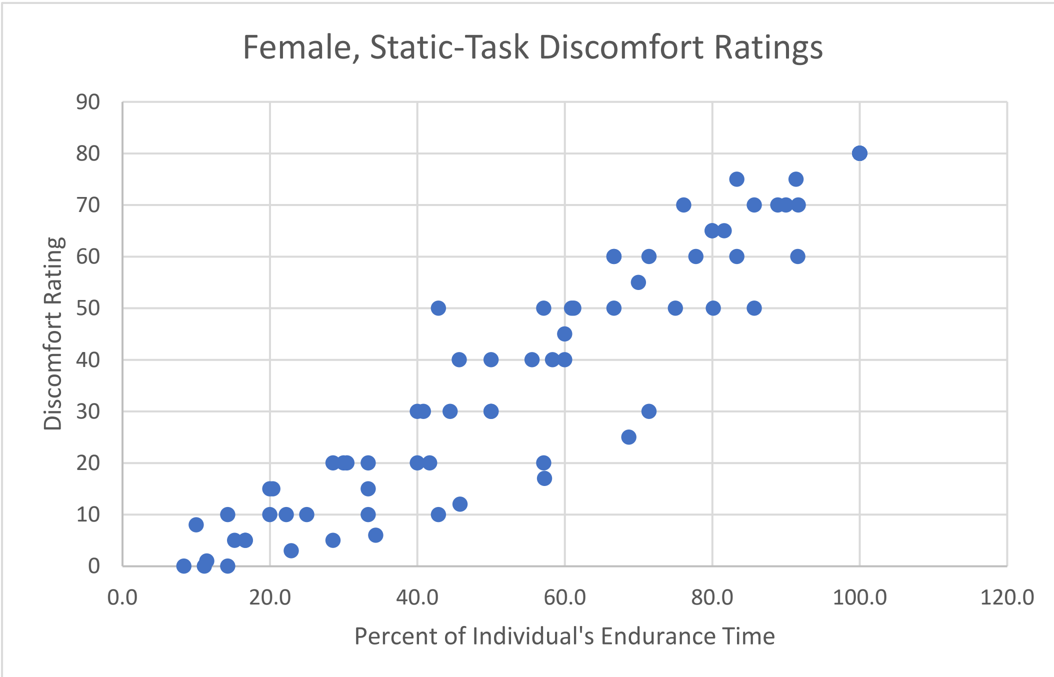

Figure 13. Discomfort ratings of females performing the static arm task.

Table X. ANOVA Table for Female Static Task

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	1	49,465.5	49,465.5	640.56	0.000
Error	75	5,791.6	77.2		
Total	76	55,257.2			

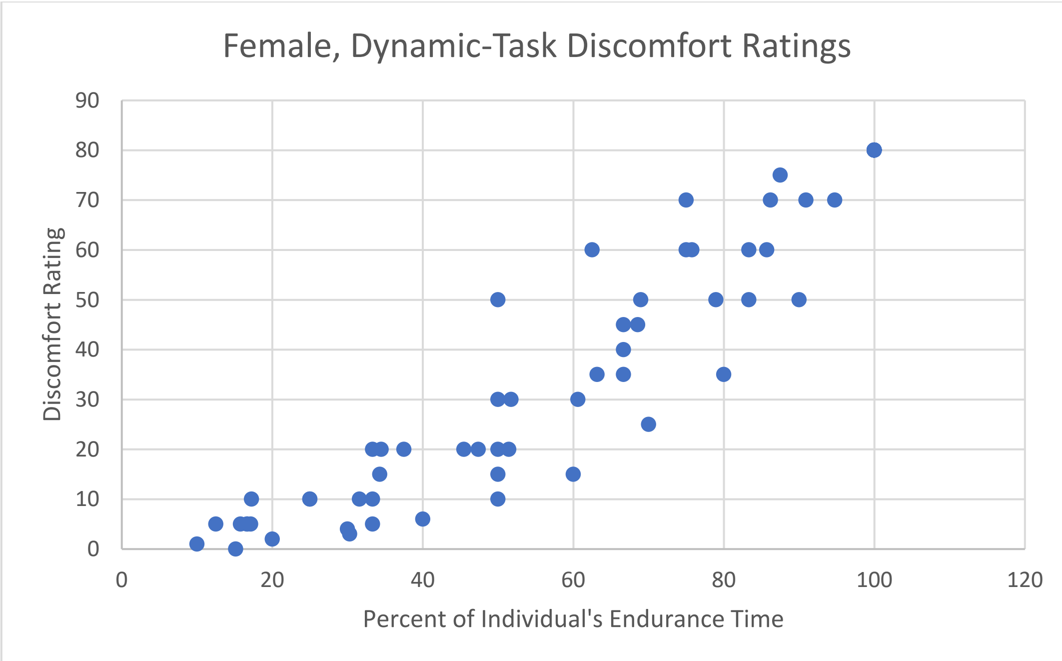

Figure 14. Discomfort ratings of females performing the dynamic arm task.

Table XI. ANOVA Table for Female Dynamic Task

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	1	43,660.2	43,660.2	471.77	0.000
Error	61	5,645.2	92.5		
Total	62	49,305.4			

SIGNATURE PAGE

This is to certify that the thesis prepared by Kayla Ericson entitled "Static Shoulder Elevation With or Without Limited Range of Arm Motion" has been examined and approved for acceptance by the Department of Safety, Health and Industrial Hygiene, Montana Technological University, on this 5th day of April, 2019.

Roger Jensen, PhD, Professor
Department of Safety, Health and Industrial Hygiene
Chair, Examination Committee

Dan Autenrieth, PhD, Associate Professor
Department of Safety, Health and Industrial Hygiene
Member, Examination Committee

Theresa Stack, MS, Associate Professor
Department of Safety, Health and Industrial Hygiene
Member, Examination Committee

Angela Johnston, MS, Instructor/Director of Biological Sciences Labs
Department of Biological Sciences
Member, Examination Committee