Effects of Work Exposure on Maximum Acceptable Repetition Rates in a Manual Torquing Task

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Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Industrial and Systems Engineering

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December 11, 2006

Blacksburg, Virginia

Keywords: Work Exposure, Maximum Acceptable Repetition Rate (MARR), Psychophysics, Ratings of Perceived Exertion (RPE), Manual Torquing Task (MTT)

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ABSTRACT

Repetitive and forceful exertions have been identified as an important risk factor for occupational injuries. One method used to determine appropriate exposures to these and other risk factors is psychophysics, which is based on individual perceptions of task demands and/or risk. Effects of work exposure have been indicated as of potential importance, but have not been well studied. Indications from an earlier study related to psychophysical limits for a repetitive manual torquing task were that five days of work conditioning had minimal effects on resulting Maximum Acceptable Repetition Rates (MARR). However, it is unknown whether and how longer work exposure durations might influence MARRs. The current study investigated the effects of work exposure on MARR and adjustment time over 10 working days (two weeks) with two days of rest after five days. Ten participants (five males and five females) performed a manual torquing (45 Nm load) task at mid-chest level in the coronal plane for a one hour test session. Starting repetition rate for each participant was set at single high and low rate on alternate days. Temporal (exposure) effects were determined, where day of exposure was the independent variable, and MARR and adjustment time were the dependent variables. Final MARRs were relatively lower during the first few exposure days (14 – 15 repetitions/min) and increased for days 5 – 7 (16 – 18 repetitions/min). On average participants made four adjustments to reach MARR . Day was not found to significantly affect MARR, though week affected both MARR and adjustment time. Thus, an exposure of two weeks may be needed to obtain stable and valid psychophysical limits for manual torquing and, perhaps, related tasks.

ACKNOWLEDGEMENTS

I would like to thank each and every person in the world I have ever met. During the academic process of this research my advisors Dr. Maury A Nussbaum and Dr. Kari L Babski-Reeves are to be mentioned first. Special thanks to Dr. Brian M Kleiner for his valuable suggestions.

I am really thankful to my parents who always trusted in me and due to their motivation I have always been successful. I am thankful to my brothers for their unconditional support.

Thanks to the whole human factors group for providing the friendly environment. Special mention is needed for Yassierli, Navrag, Linsey, Hyang, and Sunwook.

Special thanks to Munna, Singh Sahb, and Raka for motivating me at each and every step. Also, I am grateful to Daboo for his friendly support. Thanks buddies otherwise my thesis would have been incomplete.

Last but not least, thanks to Kaku, Kukz, and Golu for their dedicated support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Musculoskeletal injuries of the shoulder are common in manufacturing industries. Specifically, shoulder injuries due to repetitive motions are of major concern in the automotive manufacturing environment. In 2003, 51% of reported repetitive shoulder injuries occurred in the automotive industry (BLS, 2005). Manual torquing tasks (MTTs), tasks involving torque wrenches to tighten nuts/bolts, are repetitive in nature and involve the upper extremity and expose workers to known risk factors for injury development (i.e., repetition, non-neutral posture, force, or work exposure). A previous study of these tasks assessed the effect of work exposure (task specific training to improve operators' proficiency) for a period of up to five days on acceptable rates to reduce risk of shoulder injuries (Nussbaum et al., 2004). The limited number of studies on MTTs, and work exposure durations, suggests that further research is needed.

Motivations

Inspiration for the current research evolved from an earlier study on MTTs, which investigated the effects of work exposure on maximum acceptable repetition rate (MARR, the repetition rate at which individuals can comfortably perform the task for eight hours) over five consecutive days (Nussbaum et al., 2004). The authors suggested that although one week (five sessions) of work exposure was sufficient to stabilize MARR, the MARR patterns could show increasing or decreasing trends if extended over a period of more than one week. Therefore, studying the effects of work exposure over longer time periods is needed. The present study identified effects of work exposure on MARR over a two week (10 sessions) period. It was hypothesized that MARR would change (likely increase) with time. It has been assumed that anticipated results, if obtained, will allow more reliable and valid determination of MARRs for MTTs. Furthermore, expected results will help others use more effective methods to obtain psychophysical limits.

2.0 LITERATURE REVIEW

A review of current literature on the effects of work exposure in MTTs is presented. Since research on MTTs is limited, studies relevant to these tasks have been used to make inferences. The review begins with musculoskeletal disorders, and focuses down to the specific area of interest in this study, the effects of work exposure on MARR. A brief introduction to MTTs, psychophysical methodology, work exposure, perceived exertion, and results from previous studies is also presented. Finally, an overall summary of the review argues for the importance of the present study.

2.1 Work-Related Musculoskeletal Disorders

Work-Related Musculoskeletal Disorders (WMSDs) are illnesses which develop gradually over time due to prolonged exposure to task demands that are greater than human physical capabilities (Keyserling et al., 2003; Moore, 2002). Body parts affected include the trunk, neck or upper extremity (Keyserling et al., 2003). Carson (1993) described WMSDs as one of the major causes of disabilities, numbness, low employee morale, and poor quality of work, and suggested that ignoring these disorders could result in increased costs, such as medical bills, compensation, lost work days, and retraining employees. WMSDs of the upper extremities have been reported as a major concern in manufacturing industries (NIOSH, 1997). Upper extremity disorders include, but are not limited to carpel tunnel syndrome (CTS), tendonitis of the elbow and shoulder, and rotator cuff injuries. In manual tasks, the hand, wrist, and forearm perform the repetitive work and the shoulder stabilizes the arm, thereby introducing static loading on the muscles of the shoulder (Kilbom, 1994). This suggests that shoulder fatigue could be one of the major contributors to shoulder disorders.

The Bureau of Labor Statistics (BLS, 2005) cited that there were total of 435,180 (33% of total injuries for the year) WMSDs reported in 2003 that resulted in days away from work; of which 82,160 (19%) were in the manufacturing environment. Twenty four percent of all injuries in manufacturing industries were in the upper extremity and of these, 23% were specifically in the shoulder region. Therefore, shoulder WMSDs in manufacturing industries are a major cause of concern and should be prevented.

The shoulder joint is a complex biomechanical structure consisting of three bones, the collarbone, shoulder blade, and upper arm bone. Shoulder bones are supported through soft tissues - muscles, tendons, and ligaments. Damage to these tissues is a result of injury or from overuse related to job demands. Identified risk factors of shoulder WMSDs include task repetition, forceful exertions, non-neutral postures, extended task durations, increased shoulder movements, and static loads (Armstrong et al., 1986; Putz-Anderson, 1988; Moore et al., 1988; NIOSH, 1997; Nussbaum et al., 2001; Bjelle et al., 1981). Common WMSDs of the shoulder are supraspinatus tendonitis, shoulder tendonitis, rotator cuff tendonitis, shoulder impingement, thoracic outlet syndrome, and shoulder girdle fatigue (Fagarasanu and Kumar, 2003).

Minimizing shoulder related WMSDs is important in generating a safer working environment. Possible means to this end include implementation of engineering controls, administrative controls or the use of personal protective equipment. Implementing engineering controls is not always feasible due to the nature of the work and expenses involved. Therefore, administrative controls (such as job rotation, training, etc.) are often used to prevent shoulder WMSDs.

2.2 Manual Torquing Tasks

Torquing tasks are tasks involving torque wrenches to tighten nuts/bolts to meet safety and/or quality specifications. Non-compliance of these tasks could lead to fatal injuries (e.g., loosened nuts could dismantle motor vehicles on a road). As torquing tasks are performed in the workplace at variable heights, torque levels, postures, and repetition-rates, operators performing these tasks are at high risk of injuries. The BLS (2005) reported 940 WMSDs from repetitive use of wrenches in manufacturing industries. Severe consequences of torquing tasks, mainly shoulder disorders, have necessitated further research in this area.

Due to the lack of evidence on manual torquing tasks, studies containing manual exertions similar to these tasks have been used to make inferences. The human operator, tool, and task are the main components in manual torquing. Experience and work exposure are related to the human component of the system. Gloves, reach distance, force/torque demands of work, duration, and work rate are some of the tool and task factors that may be linked to injury/illness risk. Work place performance can be enhanced if the influence of these factors can be determined. Armstrong et al. (1989) determined the relationship between worker's estimations and tool/task variables using the Borg CR-10 scale, and recommended vertical locations in the range of 102-153cm to be optimal. The above study also reported that the use of gloves helped operators perform the work for longer durations. A similar study (Snook et al., 1999) was conducted to determine force demands for wrist extensions and flexions performed with a pinch grip, requiring participants to grab a handle (attached to the shaft of a magnetic particle brake) and repetitively extend the wrist at 90º with a pinch grip. The authors concluded that forces with a pinch grip were smaller for wrist extensions than wrist flexions.

Further research investigating shoulder injuries in MTTs is warranted. A causal relationship between shoulder discomfort and manual torquing tasks is difficult to establish. Possible reasons could be the multi-faceted nature of musculoskeletal disorders, unknown interactions among risk-factors, or the diverse nature of tasks involved. Therefore, future research should focus on identifying and quantifying shoulder fatigue in torquing tasks. Psychophysics is one such approach which has successfully been used by past researchers for similar tasks.

2.3 Psychophysical Methodology

Psychophysics is a branch of psychology that deals with the relationship between a physical stimulus and sensory response. Psychophysical methods have an underlying assumption that people can protect themselves from injuries. These methods are less invasive, and therefore easier to implement, as compared to biomechanical or physiological techniques (Grant et al., 1994). Cost effective and less time consuming, psychophysical approaches provide realistic simulations of industrial tasks (Snook, 1985). One limitation of psychophysics is the requirement of good participant cooperation in observing and reporting the sensed events (Ehrenstein et al., 1999).

Psychophysical methods have been used to determine maximum acceptable limits for different types of tasks (such as lifting, pushing, pulling, or carrying etc.). Fernandez et al. (1995) reviewed several unpublished papers on psychophysical applications of maximum acceptable frequency (MAF) and the upper extremity, with participants required to maintain a certain percentage of the maximum voluntary contraction to estimate MAF (number of repetitions, an individual can comfortably perform for a period of eight hours). From the review, it was found that MAF varies inversely with both force and duration for gripping as well as pinching tasks. In another study on automotive trim installation tasks (use of base of the hand to impact the door trim panel), the effect of frequency on automotive trim installation tasks was investigated using the psychophysical methodology (Potvin et al., 2000). The task required participants to repeatedly strike the vertical surface of a force plate, at chest height, with the palm of their dominant hand. Authors from this study found that increases in striking frequency resulted in decreased levels of MAF. Putz-Anderson and Galinsky (1993) studied elevated manual work (above normal shoulder flexion) to determine the maximum acceptable work durations to prevent shoulder-girdle fatigue. The task in this study involved repetitive lifting and lowering of a pistol shaped tool and striking metal plates at three different height levels. Researchers concluded that repetition rate, force demands, tool weight, and reach height varied inversely with the maximum acceptable work durations.

Most psychophysical studies use shorter task durations to project discomfort levels for a longer work period. Nussbaum and Johnson (2002) reported that a 25-minute task duration is sufficient to determine force limits for single-digit tasks for a two hour period. Snook and Irvine (1967) used a one hour time period to estimate the MAF of lift for an eight hour period for lifting a box of weight ranging from 10 lb – 40 lb. Legg and Myles (1981) demonstrated that the load lifting capacities for an eight hour work day can be projected in as short as 20 minutes. Snook et al. (1995, 1997, and 1999) determined maximum acceptable limits (MALs) of forces for repetitive motions of the wrist flexion/exten5tsion, using 20 minutes time to determine MAL for an eight hour work day. Therefore, psychophysical studies can save considerable time during data collection, and are likely to produce reliable results.

The validity of psychophysical limits is an important question to answer before implementing data from these studies into useful ergonomic recommendations (Nussbaum et al., 2002; Ayoub and Dempsey, 1999). Only a few studies have validated the findings from psychophysical studies. Mital (1983) studied the validity of using 20-25 minute time periods to predict the maximum acceptable weight of lift (MAWL) for an eight hour period, and then verified the selected weight by actually performing the task for full time durations. Comparison of the results obtained indicated disagreement between predicted and actual values, as participants overestimated the weights in smaller durations, i.e. male participants lifted 65% and female participants lifted 84% of the weight estimated when performing the task for eight hours. In another study on validity of psychophysical methods, Legg and Myles (1981) investigated maximum acceptable repetitive lifting on 10 male soldiers. The task involved adjustment to weights selecting a final weight, which participants believed they could lift for eight hours at a lifting rate of five lifts up and down every two minutes. All of the participants were allowed 20 minutes to estimate MAWL, and the MAWLs were determined twice a day, for five days, once starting from initial weight of 40 kg and once starting from an initial weight of 5 kg. Average MAWL over the 10 values was calculated and participants were asked to actually perform the task for eight hours on the average MAWL. Although the participants were able to complete the eight hour lifting task without any substantial fatigue, the fatigue level was reported to rise from morning through afternoon. This study did not indicate what maximum weight level could be lifted in accordance with physiological conditions.

Application of psychophysical methods is warranted, since other methods are expensive, complex, or unavailable. Furthermore, application of psychophysical methods is helpful in subjective quantification of shoulder fatigue. A limitation of these methods (i.e. reliably expressing sensed events by participants) can be controlled by motivation and/or work exposure. Karwowski and Yates (1986) suggested that work exposure (in the form of training) is necessary to execute the psychophysical approach successfully.

2.4 Work Exposure

Work exposure, also referred to as task-specific training, is the process of making operators proficient through instructions and hands-on practice in operating equipment to be used and in the performance of assigned duties (OSHA Standard 1910.155; Knapik, 1997). Work exposure improves psychomotor skills and physical fitness of workers in material handling tasks (Asfour et al, 1984; Asfour et al., 1991; Genaidy et al., 1994; Genaidy, 1991; Genaidy et al., 1990; Genaidy et al., 1989; Guo et al., 1992; Sharp and Legg, 1988). Effective work exposure motivates workers, improves their efficiency, makes them less susceptible to injuries, and results in reduced operational costs and absenteeism rates (Carson, 1993). Previous studies have shown that work exposure in manual tasks decreases the number of upper extremity disorders and associated costs (Sawyer, 1987; Lutz et al., 1987; Ayoub et al., 1989). Scott (1999) studied the effects of a work exposure program to protect workers from injuries, which included general fitness training and task-specific training. Results of the study indicated that work exposure is needed to control the demands of manual material handling tasks.

Work exposure in manual activities, if applied effectively, can increase endurance, strength, judgment, and continuous work capacity of a worker. Genaidy (1991) studied the effects of a short training program (three days per week for six weeks) for upper extremity manual handling activities (lifting, lowering, pushing, pulling, and carrying), and concluded that endurance increases with the training. In another study, Morrissey et al. (1990) trained participants for 10 days to improve judgment for lifting of acceptable weights, and reported a substantial improvement in judgment (i.e., participants were able to estimate the weight for eight hour long day in as short durations as one hour). Matheson et al. (1996) evaluated the work capacity of individuals suffering from tissue injuries and reported a direct relationship between continuous work capacity and training duration.

Duration of work exposure has been an unresolved issue due to limited research in this area. Wu et al. (2001) gave ten days of work exposure to participants to perform load carrying tasks, and reported an increase in strength. Snook (1971) provided training for five sessions to participants to estimate the effects of age on work capacity for manual handling tasks (lifting, pushing, pulling, lowering, and carrying), and concluded that continuous work capacity does not decrease with age. Both of the above mentioned studies did not report the adequacy of exposure duration, which could be an important factor in studies involving manual tasks. Therefore, further research determining the effective durations of work exposure in manual tasks is warranted. Work exposure reduces learning-effects. Learning effects are differences in perception of an exertion/strength performing some task due to past experience. Learning effects could also limit the participation of humans to a study. Williams et al. (2002) supported the idea that learning effects could be reduced by the introduction of a familiarization period (investing initial days on instructions and motivations). Nussbaum et al. (2002) used a video sample (a movie clip showing workers performing the task) to familiarize participants to tasks, assuming all participants did not have previous industrial experience. Knapik (1997) implemented familiarization by spending more time on practice sessions to increase the manual task capability. Williams et al. (1999) suggested that learning effects could be controlled through screening of participants, which could further be helpful in reducing drop-out rates.

The review presented here indicates that duration of work exposure may vary depending upon the nature of task, despite some studies showing that a longer training period provided reliable results. Therefore, further research on sufficient work exposure durations is warranted. Also, consistent instructions and motivation during the course of work exposure will be helpful in obtaining reliable data, reducing the learning effects, and minimizing the drop-out rate. Although work exposure increases the total cost of a project, the long-term benefits make its implementation worthwhile. Work exposure is also useful for operators/employees in perceiving maximum acceptable limits (such as force, repetition, or weight etc.).

2.4.1 Effects of Work Exposure on Maximum Acceptable Limits

Maximum acceptable limits (MALs) are defined as upper bounds of acceptance for a particular task without developing discomfort or pain. MALs are used in developing guidelines for manufacturing tasks to control the risk of injuries. In manual tasks these limits can be associated with tool weight, required force, repetition rate, or posture. Nussbaum and Johnson (2002) described gender and frequency as major factors affecting MAL in single-digit tasks. In addition to the factors discussed above, work exposure also has a significant effect on MAL.

Several studies investigated the effects of work exposure on acceptability limits. Legg and Myles (1981) investigated the effects of lifting training on maximum repetitive lifting capacity by having participants perform ten lifting sessions at the rate of five lifts, up and down, each for two minutes. The researchers in this study found an increase of 25% in lifting capacity. Knapik (1997) studied the effects of a training program on maximum acceptable weight of lift (MAWL), and participants reported a 17% increase in MAWL after training for 14 weeks (42 sessions). Ciriello et al. (2004) compared maximum acceptable forces (MAFs) for pushing tasks using two different methods, magnetic brake treadmill and a high-inertia push cart. During the course of this study, frequency was held constant and work exposure lasting three sessions was provided for participants to obtain experience in adjusting weight. The authors found substantial differences in MAF associated with the methods. The study also suggests the possibility that work exposure could have direct impact on MAF. These findings support the idea that acceptable limits increase directly with work exposure, although in the presence of other factors (such as repetition, forceful exertions, or non-neutral postures) the relationship between the two could be effected.

Top-down and bottom-up approaches for initialization, used in previous MAWL studies, also affect the final weight selected. Oberg et al. (1994) studied shoulder muscle fatigue for an arm abduction movement by splitting the participants into two groups (even numbered and odd numbered) based on starting lifting weights. One group started with heaviest load level (two kg) and another with minimum (zero weight). Muscle fatigue during lifting was evaluated using the Borg CR-10 scale. This study concluded that for higher load levels Borg scales ratings' increase directly with weight. In another study on accuracy of weight estimation for the muscles of human upper limb, Gandevia et al. (1990) started half of the participants with a load heavier than the reference weight (fixed weight), and the other half with the variable weight lighter as compared to the reference weight. Participants lifted the reference weight in one hand and a variable weight in the other, and they were not informed about the invariability of reference weight. The participants were asked to match the weight in both the hands by adjusting the weights. The researchers found that, for a particular muscle, accuracy of perception was higher when heavier weights were lifted. Furthermore, accuracy of weight estimation could also depend on individual strength.

Screening of participants is an important factor which could influence the relationship between work exposure and MAL. Screening ensures that selected participants represent the actual targeted population. This procedure minimizes the threat to external validity, and allows the results obtained to be generalized. In studies determining effects of work exposure on MAWLs, it is very difficult to recruit actual industrial workers as participants. For this reason, college students generally serve as participants in simulation studies, which can introduce errors in results. Garg et al. (1979) and Snook (1978) compared MAWL for college students and actual industrial workers. Participants in this study were exposed to ten sessions and maximum acceptable loads lifted by college students were found to be lower than what industrial workers lifted. In another study on MAWL, Mital (1987) compared industrial and trained workers over a period of eight hours. This study indicated that MAWL estimation by students was lower than that judged by industrial workers (student males = 89% of industrial males, and student females = 94% of industrial females). Therefore, a countermeasure ensuring recruited participants are representative of actual industrial workers is needed. Work exposure is one such method which stabilizes the MAWL values. Work exposure and its duration play an important role in the MAWL stabilization process.

It has been hypothesized that longer work exposures are associated with higher MAL values. Ciriello et al. (1990) provided 10 hours of training to participants to determine MAWL and reported that training of 10 hours is sufficient to determine reliable MAWL values for manual handling tasks within the frequency range of 4.3/min. Potvin et al. (2000) determined acceptable limits of forces for automotive trim installation (use of base of the hand to impact the door trim panel) tasks by recruiting skilled as well as unskilled participants, and training them for four hours and eight hours, respectively. Results from this research did not show considerable differences between the two groups, suggesting the training was sufficient.

Short durations can be used to predict MAL for longer durations. Ciriello et al. (1990) determined MAWLs for manual handling tasks in four hours by providing work exposure to participants for five days prior to the start of experiment. The authors found that results obtained after 40 minutes were not different from those obtained after four hours, indicating MAWL can be predicted in 40 minutes for manual handling tasks. Wu et al. (2001) gave work exposure for 10 consecutive days and observed that duration as small as 20 minutes can be used to determine the MAWL for one hour.

This review suggests that work exposure helps in ensuring that the maximum acceptable limits obtained are representative of actual task demands and human physical capabilities. Studies investigating effects of work exposure on MAL should consider other factors that may influence MALs, such as repetition rate, posture, or work height. Work exposure in the form of increased training days could raise levels of MAL. Also, experimenters should be careful while recruiting and screening participants, to ensure that selected participants represent the targeted population.

2.5 Ratings of Perceived Exertion and Borg Scale

Perceived exertion is defined as the subjective intensity of effort, strain, discomfort or fatigue, experienced during physical exercise (Robertson and Noble, 1997). Perception of exertion levels is often quantified using different scales. Most commonly used scales are: Borg's 15-partition scale, the University of Pittsburg 9 partitions scale, and Borg's 10-partition category-ratio (CR) scale (Robertson et al., 1997). Of these, the Borg CR-10 scale is most frequently used, as it can be interpreted easily. The Borg CR-10 scale is an 11-point scale ranging from 0 (nothing at all) through 10 (maximum).

Work exposure helps in decreasing ratings of perceived exertion (RPE). Sharp and Legg (1988) studied the effects of psychophysical lifting training on maximum repetitive lifting capacity over a four week period and reported a decrease in ratings of perceived exertion. Ekblom and Goldbarg (1971) studied the influence of eight weeks of physical training on RPE for bicycling, running, swimming, and arm work. The authors found that RPE reduced significantly after training for all the tasks. Both these studies indicate that individuals tend to rate lower on the Borg CR-10 scale after work exposure.

Industrial task simulation studies commonly use the Borg CR-10 scale for rating fatigue and discomfort. Armstrong et al. (1989) studied worker assessments of the hand tools used in an automobile assembly. The workers in this study were asked to rate tool mass, grip force, handle size, and work location on the Borg scale. In another study, Ulin et al. (1990) studied perceived exertion for a screw-driving task, at three different reach heights (elbow, knee, and the shoulder), and recommended the elbow height for performing the task based on RPEs.

This section highlights the fact that ratings of perceived exertions have broad applications in industrial tasks. With repeated exposure, humans give lower RPE values for the same exertion. Thus, work exposure plays an important role in decreasing the RPE values.

2.6 Summary

From the above literature review, shoulder WMSDs are a major issue related to manual tasks in manufacturing industries. Identified risk factors for shoulder WMSDs are repetition, force, and non-neutral posture. Limited research has been conducted on manual torquing tasks, therefore further research is warranted to understand the pathways for injury mechanisms and to develop acceptable guidelines for work practices to minimize injury and discomfort. Psychophysical methods are helpful in determining the maximum acceptable limits (MALs) and in designing task recommendations. Work exposure increases endurance, continuous work capacity, judgment and also controls learning effects and drop out rate, and has been found to be linked with MALs. Thus, use of the psychophysical methodology in manual torquing task will be helpful in determining the relationship between work exposure and maximum acceptable repetition rates (MARR).

3.0 RATIONALE, OBJECTIVES, AND HYPOTHESES

3.1 Rationale

Shoulder disorders are common to torquing tasks in automotive industries. Torquing tasks are generally performed at high frequencies (repetition); hence, an increased risk of injury is likely present. Since these tasks are simple to perform, training is generally avoided, which may further increase injury risk. Interrelationships between exposure and repetition rates could be helpful in determining the acceptable task parameters. This relationship can be investigated using psychophysical methods. Putz-Anderson and Galinsky (1993) used psychophysical techniques for studying elevated manual tasks, and concluded that repetitive lifting or lowering of hand-tools to the target height, increases the likelihood of shoulder girdle fatigue. In another study Wu et al. (2001) gave work exposure of performing load carrying tasks for ten days to participants and found that load carrying frequency has a significant effect on judgment (i.e. participants were able to perceive smaller changes in weights after work exposure). Most studies, with the exception of Sood et al. (2004), did not focus specifically on the development of shoulder disorders due to task repetitions for manual torquing tasks. Sood et al. (2004) investigated trends in MARRs over five days of work exposure, which may or may not be valid for longer durations. Therefore, further research on work exposure lasting longer than five days is needed to identify patterns of MARRs. The proposed study is expected to fill these gaps and could be helpful in developing guidelines to reduce shoulder disorders in MTTs.

3.2 Objectives

(i) To determine the effects of work exposure on psychophysically determined maximum acceptable repetition rate (MARR) in a manual torquing task. Final MARR and adjustment time (time to reach final MARR) were analyzed to determine the trends over two weeks of work exposure.

(ii) To determine the minimum adjustment time on a particular day to assess performance for eight hours.

3.3 Hypotheses

(i) Work exposure will increase final MARR in an MTT.

(ii) Adjustment time will be lower for individuals with longer work exposure.

4.0 METHODS

The current study investigated the effects of work exposure on maximum acceptable repetition rate (MARR) using psychophysical methods. This study was an extension of a previous project, where MARRs were analyzed to determine effects of work exposure over five days, with participants exposed to a two hour session each day (Sood et al., 2004). The effects of 10 exposure sessions (five consecutive days, two days of break, and five consecutive days) on MARR and adjustment time were determined. Participants performed one hour of work each day, which is sufficient to reach final MARR (Nussbaum et al., 2004). Participants were asked to estimate the repetition rate at which they could perform the task for eight hours without 'unusual discomfort, pain, or numbness in their fingers, hands, wrists, arms and/or shoulders'. Subjective ratings of discomfort were collected to ensure that participants did not exert near the maximum discomfort level. Each participant started alternately with single high and low repetition rates, to minimize order effects.

4.1 Participants

A power approach was chosen to estimate the number of participants. The proposed study hypothesized that duration of work exposure could have an effect on MARR. MARR estimations from Nussbaum et al. (2004) were used in the current study to determine the number of participants. Means and standard deviations (σ) of final MARRs (13.85 ± 1.05rep/min) were obtained from the previous study. The difference between maximum and minimum values was used to obtain a minimum range (Δ) of final MARR. The number of work exposure days gave the factor level (r) value. Using the values $\Delta/\sigma = 1.5$, $r = 10$, and corresponding to significance level ($\alpha = 0.1$ and $\alpha = 0.05$), sample size values were directly calculated for different power values (Neter et al., 1996). The relationship between sample size and power values is shown in Figure 1.

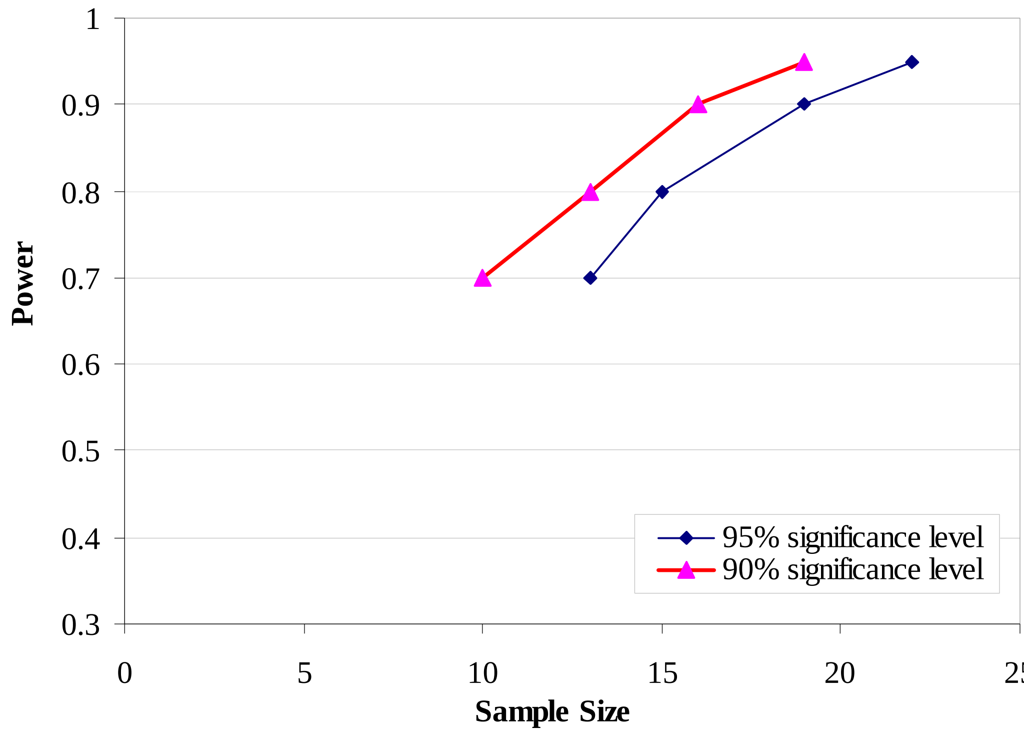

Figure 1. Sample sizes and corresponding power values at 95% and 90% significance level

Each participant was required to participate in 10 sessions on different days, which made participant recruitment difficult (high chances of drop-out). Furthermore, collecting data for a large number of participants can lead to difficulties with resources and be time intensive. A cost-benefit approach was applied, thereby compromising power, in order to have a shorter data collection period. A sample size of 10 was selected based on balance between power and resources, and yielded a reasonable combination of significance level and power (i.e. $\alpha = 0.1$ and power = 0.7).

Participants were selected from individuals with recent experience in manual work or those that performed upper extremity exercise on a regular basis. Participation was limited to those with no history of musculoskeletal injuries in the past year. All participants were recruited from the local community. Participants were compensated at a rate of $10/hour for participation, and a bonus of $10 was awarded on successful completion of all sessions.

4.2 Procedures

Upon arrival, participants were given brief instructions about the experiment, and a written consent form, approved by Virginia Tech Institutional Review Board (Appendix I), was completed. A five minute video of operators working in a real automotive environment was shown to help participants understand and visualize the torquing task. Participants completed forms comprising demographic and musculoskeletal data. Anthropometric measurements were obtained: weight, stature, shoulder height (floor to acromion), and waist height (floor to hip joint). Participants wore the same shoes throughout the course of the experiment to avoid intra-session height variability. Furthermore, to avoid hand discomfort or abrasions, and to mimic the use of gloves on the assembly line, participants wore light cotton gloves during the experimental sessions.

Each participant practiced the torquing task in the coronal plane using a 45 Nm torque wrench (Figure 2). Selection of this torque level helped in comparing and determining the patterns over longer durations, since the previous study on manual torquing tasks (Nussbaum et al., 2004) also employed the same torque level for exposure over five days. The task was performed at mid-chest height. Participants practiced the task for two minutes, prompted with computer generated tones, at the minimum repetition rate of one repetition/min. Participants were also trained to use the Borg CR-10 scale, by having them 'sit' with their knees bent at 90º and their back supported against the wall. Maintaining this posture, participants' had to rate their level of discomfort at the thighs every five seconds, and they continued this until exhaustion (RPE ³ 9 was attained). Instructions on using the Borg scale were also provided prior to the start of the experiment.

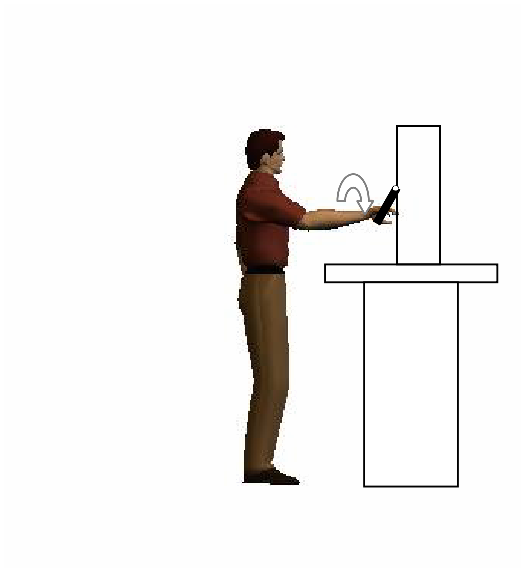

Figure 2. Manual torquing task performed at mid-chest height in coronal plane

Participants were given consistent instructions on adjustment of repetition rate (Appendix II). These instructions were modified from an existing set (Snook et al., 1967). Participants had the freedom to make adjustments at any time simply by asking the experimenter to increase or decrease the repetition rate accordingly. The auditory tones were adjusted, via software in LabVIEW (National Instruments Corporation, Austin, Texas, USA).

After a short break, participants performed the task and continued for one hour or until participants reported an extreme fatigue level (RPE exceeds 9). RPE data (numerical values corresponding to exertion level on Borg scale) for the right shoulder was collected every other minute on a data sheet, as verbally indicated by the participant. Fatigue ratings for the left shoulder and other body parts were noted as reported by participants. Repetition rates were stored continuously and used to estimate the relationship between MARR and time.

Ten sessions were conducted for each participant, and each session was separated by 24 hours. The experiment lasted over a period of 12 days, five consecutive days followed by two days of rest, and five more consecutive days doing the task. Starting repetition rates (SRR, repetition rate at which participants started the torquing task) are presented in Table 1. A specific duration of ten working days was selected to simulate two weeks in an industrial environment. All sessions for a participant were conducted at approximately the same time of day to reduce possible confounding effects. All sessions were of equal duration, except the first session, which involved instructions and completion of forms.

Table 1. Starting repetition rates for participants on different days

Participants	Starting Repetition Rate (rep/min)											
	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**	**D11**	**D12**
P1, P3, P5, P7, P9	30	1	30	1	30	Break		1	30	1	30	1
P2, P4, P6, P8, P10	1	30	1	30	1			30	1	30	1	30

Note: D represents day

4.3 Instrumentation

A height adjustable fixture was constructed in the laboratory to simulate the torquing task in the laboratory. The torquing task was performed using a click type torque wrench (TOHNICHI, Model no. QSP 100N3, Japan) calibrated with a force plate (Bertec Corporation, Model no.

4550-08, Columbus, OH) prior to each experimental session. Interfaces created in LabVIEW (Version 7 Express, National Instruments Corporation, Austin, TX) were used for data collection. An anthropometric kit (GPM, Switzerland) was used to measure body dimensions, and a scale (DETECTO, Webb City, MO, USA) to measure body weight.

4.4 Experimental Design

A single-factor experiment with repeated measures was employed. The effect of work exposure was studied over time to determine the MARR patterns. The independent variable in this study was *work exposure* (10 levels), where each level represented a separate exposure day. Effects of work exposure were studied over ten exposure days (12 days in total including breaks). The dependent variables were *final MARR* and *adjustment time*. Final MARR was the repetition rate at which participant worked for most of the time. Changes made to repetition rates in the last minutes of particular session were ignored, to control for possible fatigue or anticipation effects. Adjustment time was the time at which the participant selected the final MARR.

4.5 Statistical Analysis

A single factor, repeated measures analysis of variance (ANOVA) was used, the structural model for which is:

$$Y_{ij} = \mu_{..} + \alpha_i + \gamma_j + \varepsilon_{(ij)}$$

Y_{ij} = Measure of MARR

$\mu_{..}$ = Overall mean, and is a constant

α_i = Fixed effects of work exposure, subjected to ordinal scale restrictions $\Sigma\ \alpha_i = 0$

γ_j = Random effects of participants and are independent $N(0, \sigma_\gamma^2)$

$\varepsilon_{(ij)}$ = Error terms and are independent $N(0, \sigma^2)$

Post-hoc pairwise comparisons of work exposure were done using Tukey's HSD test. Linear regression analysis was also used to investigate the effect of days of exposure on MARR. The relationship between adjustment time and work exposure was developed using regression analysis. Separate ANOVAs were performed to determine the effects of days and adjustment time on MARR. Participants reporting extreme levels of perceived effort (i.e. RPE ³ 9) were classified as outliers and removed from the data analysis (Kim et al., 2004). A p-value below 0.10 was used to determine statistical significance (liberal value used given the small sample size). Transformations were performed to achieve normality of the dependent variables as needed.

5.0 RESULTS

5.1 Participants

Mean (SD) and median values of age, weight, and other anthropometric measures are provided in Table 2. All participants were right hand dominant and had at least average general fitness, based on self reported fitness and physical exertion levels. None of the participants reported any musculoskeletal problems that might have impeded their performance on the experimental task. All participants had previous manual work experience involving either lifting heavy equipment, general shop tasks, construction work, or work as a mechanic. Data from one participant was eliminated from analysis, as this particular participant performed the task at an extremely high speed, always at the maximum possible repetition rate, and even requested to increase the frequency beyond the maximum limit.

Table 2. Participant age and anthropometric data (n=9)

Anthropometric Parameter	Mean (SD)	Median
Age (years)	23.4 (2.5)	24.1
Weight (kg)	71.6 (12.6)	70.1
Stature (cm)	172.5 (6.3)	172.4
Shoulder Height (cm)	142.6 (5.4)	144.2
Upper Arm Length (cm)	28.4 (2.2)	29.2
Lower Arm Length (cm)	24.7 (1.5)	24.7
Hand Length (cm)	18.6 (1.6)	18.7
Task Height (cm)	122.3 (5.3)	125.2

5.2 Effects of Work Exposure on MARR

Day of exposure effects on MARR were not found to follow a linear trend based on second order regression analysis (p=0.40, Figure 3). ANOVA performed to determine the days effect also did not yield significant results (p=0.83). A trend was observed, however, showing that final MARR increased from day 1 through day 7 and then stabilized (at 17 rep/min) for the rest of the work exposure.

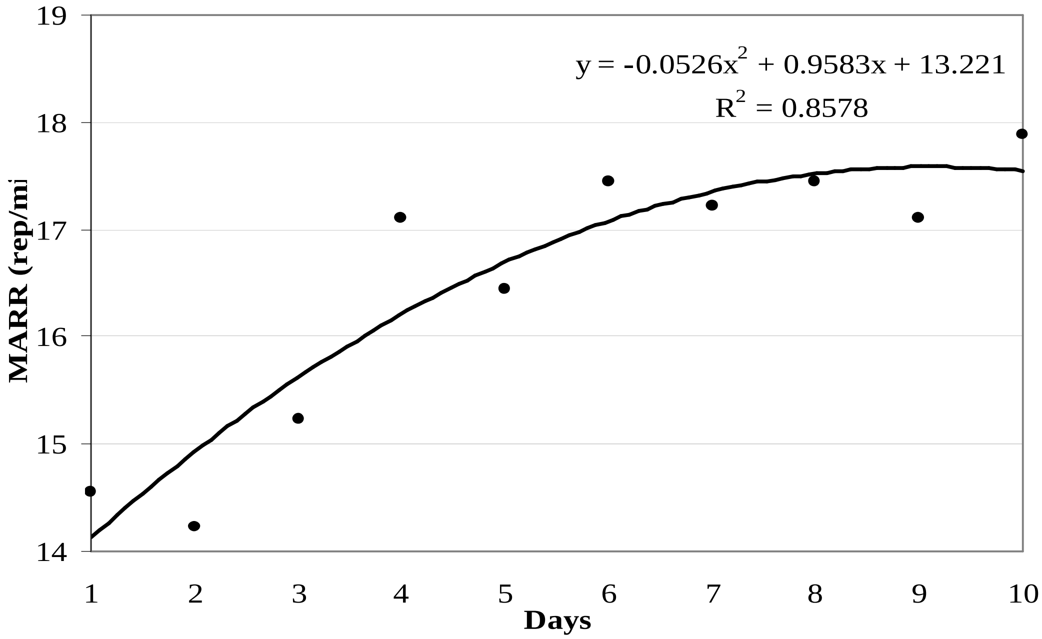

Figure 3. Effect of Days of Exposure on MARR

5.3 Adjustment Time (Time to Attain Final MARR)

The average number of adjustments made by participants to reach final MARR is indicated in Figure 4. Though a total of 100 sessions were recorded (10 for each of the 10 participants), 12 outlier sessions were omitted for data-processing (10 due to working at the highest possible rate, and 2 for a participant that worked at the lowest possible rate for 2 sessions). Effectively 88 sessions were considered for analysis. Each participant made at least one adjustment to achieve MARR, and a minimum of two adjustments were observed in 89% of the participants. Approximately 18% of the participants made 6 – 9 adjustments to attain final MARR. Oneparticipant took especially high number of adjustments (12) to reach final MARR. On average, participants required four adjustments to finalize their MARR. The distribution of the number of adjustments made to achieve final MARR is shown in Figure 5.

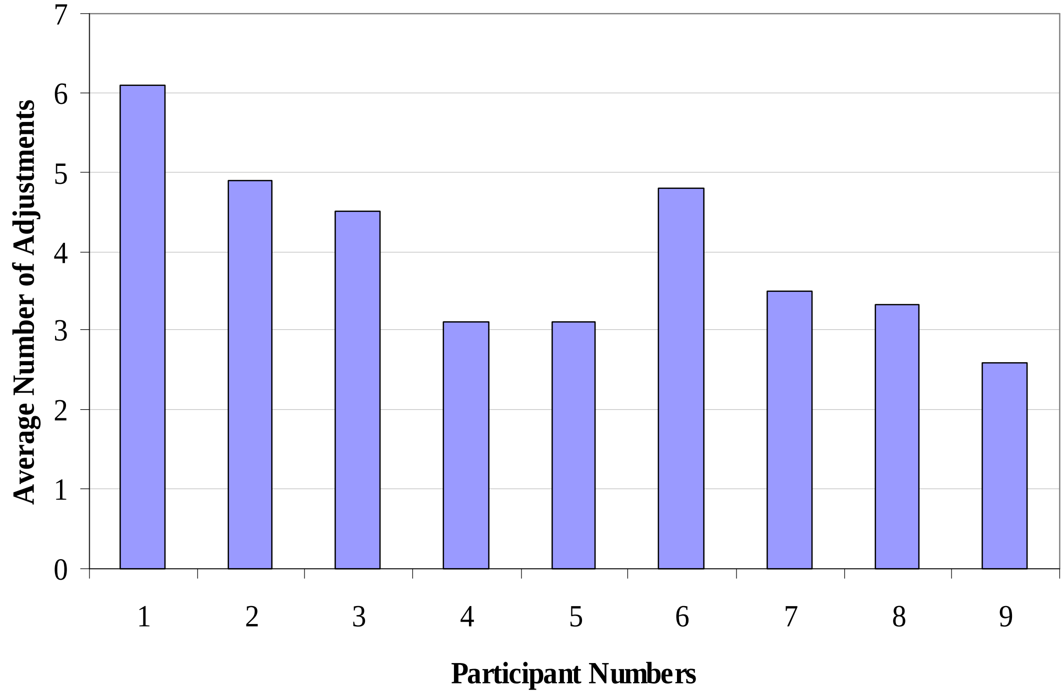

Figure 4. Average number of adjustments for participants

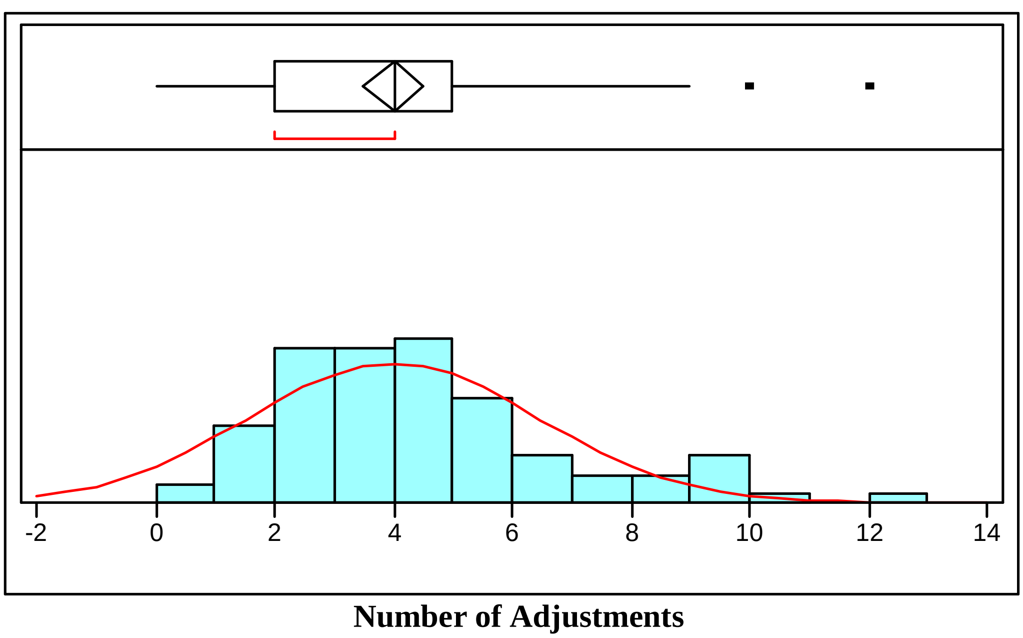

Figure 5. Distribution of adjustments made by participants across sessions

The average adjustment time in relation to corresponding adjustment numbers, days, and subjects is shown in Figure 6. Participants took the most time to make the 3rd, 4th, and 5th adjustment.

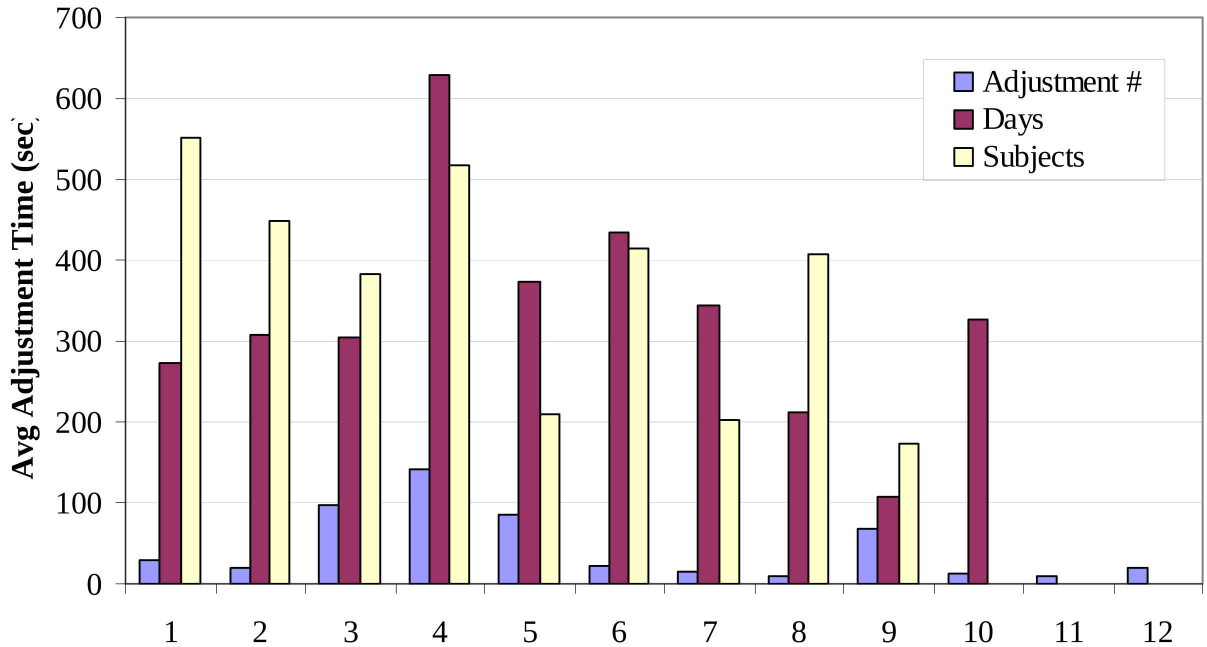

Figure 6. Average adjustment time for Adjustment Numbers, Days, and Subjects

The average adjustment time decreased from day 6 to day 9 (as anticipated), in other words, increasing exposure led to more rapid final MARRs. On day 10, the average adjustment time increased, which may be due to boredom among the participants.

ANOVA performed to determine the effect of days on adjustment time did not indicate significant effects ($p = 0.84$).

6.0 DISCUSSION

The purpose of the study was twofold. First, to determine the effects of work exposure on psychophysically determined maximum acceptable repetition rates (MARRs) in a manual torquing task and second, to determine the trends over 10 days of exposure. The main findings of the study were: (i) Days of work exposure had no effect on MARR, and (ii) Work exposure did not effect the adjustment time.

6.1 Summary and Interpretation of Results

Adjustment time and MARR were used as the measurement criteria to determine the effects of work exposure. Day effects on adjustment time were not found to be significant and these results were consistent with Sood et al., 2004, where the same task was studied for five consecutive days. An important observation from the previous study (Sood et al., 2004) was that the adjustment time on day 1 was maximum, and then decreased and almost stabilized, whereas the current study indicated that maximum adjustment time is needed on day 4. Further, the present study showed an increase in adjustment time on the last day of the experiment, which is in agreement with the previous study's results where the adjustment time increased on the conclusion day of the experiment. This could possibly be due to the behavioral aspect involved in the laboratory experiment, as the participating individuals were aware of the temporary nature of the task and they just had a desire to finish the experiment. Another finding from the present study was the average adjustment time for the day immediately after the break was higher compared to the previous day, although it was expected that adjustment time would decrease across testing days. One exception to the current study was that two participants had relatively higher adjustment time, which could be due to the underestimation in reporting the observed events (Ehrenstein et al., 1999).

Although there were no significant effects of work exposure on final MARR over 10 experimental days, qualitatively there was a difference in average MARR values (i.e. a 20% increase in MARR values over two weeks of work exposure). A linear contrast, to compare final MARRs between the first and second weeks of exposure, indicated this difference was significant ($p<0.05$). These results were in agreement with the Sharp and Legg (1988) study which showed a 26% increase in maximum repetitive lifting capacity upon conclusion of four weeks of training. Therefore, week effects on average MARR were found to be significant.

SRR (high and low) on alternate days could have influenced the effects of work exposure on MARR and adjustment time. Although Figure 7 and Figure 8 indicated increased MARR and adjustment time for high starting repetition rate, still these findings were not statistically significant (for MARR $p=0.68$ and for adjustment time $p=0.38$). This could possibly be due to the small sample size.

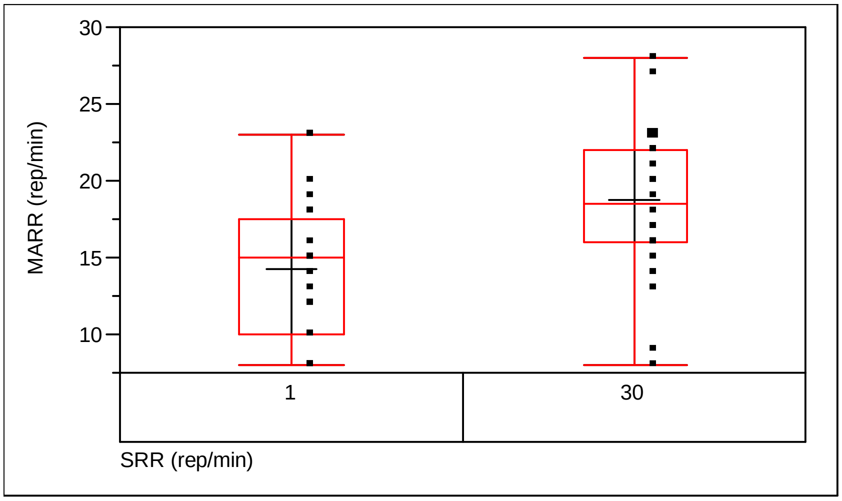

Figure 7. Effect of starting repetition rate on MARR

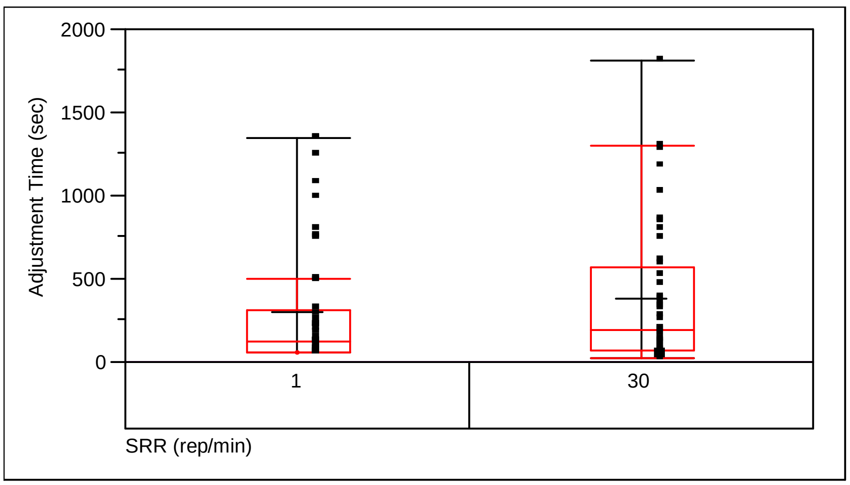

Figure 8. Effect of Starting Repetition Rate on Adjustment Time

SRR could have possibly affected the accuracy of MARR perception. Accuracy of weight estimation was studied by Gandevia et al. (1990) for the upper extremity, where one half of the participants started with lifting a load heavier than the reference weight (fixed weight), and the other half started with a variable weight lighter as compared to reference weight. The accuracy of perception was higher when heavier weights were lifted. A possible interpretation of this is that, with higher SRR, participants tend to finish at an accurate MARR and vice-versa, which is not in accordance with results of current study (since the results are not statistically significant).

Incorporating shorter study durations is generally considered acceptable in psychophysical studies (Johnson and Nussbaum, 2002; Legg and Myles, 1981; Snook and Irvine, 1967; Snook et al., 1999). The experimental duration of one hour was selected from the data analysis of the previous study (Nussbaum et al., 2004), where MARR data indicated that none of the participants took more than 56 minutes to reach their final MARR (except for two sessions). Snook et al. (1995, 1997, and 1999) used 20 minutes to determine maximum acceptable limits (MALs) of forces for repetitive motions of the wrist flexion/extension. Further, Legg and Myles (1981) determined the load lifting capacities for an eight hour work day in as short as 20 minutes. Furthermore, Wu et al. (2001) determined MAWL for one hour using 20-min and in the last four days from a total of 10 days, used the full one hour to determine the MAWL and reported that results obtained from 20 minutes and one hour were similar. Thus, assumption that all the participants will be able to determine their eight hour final MARR in one hour seems valid.

Overall, the results of this study showed that work exposure of 10 days in the form of two weeks helped in reducing the adjustment time and the participants were quickly able to reach their MARR. Starting repetition rate did not influence the effects of work exposure on MARR. Also, the starting repetition rate did not affect the accuracy of MARR perception. The session duration of one hour was reasonable to determine the MARR for manual torquing task as none of the participants were making adjustments at the conclusion of the sessions.

6.2 Limitations

Small sample size might have been a limitation to the study. Results obtained from smaller sizes could have high inter-subject variability and possible threat to generalization. Maintaining the small value for sample size could partially be attributed to the time and budget constraints. Also, participants' working postures were not standardized and they adjusted posture at any moment. This probably could have given participants' more level of comfort, at the expense of adjustment time (from shoulder discomfort perspective). Although liberal working posture might be more representative of the real world, it could have affected the adjustment time data. Results may also be confounded, to some extent, with a lack of concentration due to the over-exposure, towards the end of the study. This could be due to the job monotony, as the participants were aware of the last day of their participation to the study and they might just want to finish the study for monetary compensation.

6.3 Applications

Results of this study can be used to study similar and other occupational tasks. The work exposure values determined can be directly applied to studies involving similar tasks for validation. The results could also be helpful in designing a job rotation system. A job rotation system assists operators by reducing injuries, thus saving medical, compensation, and retraining costs. A field study could be designed to validate the current psychophysical findings, involving experienced individuals performing an occupational torquing task for the projected hours.

6.4 Future Research

This study focused only on one condition, the moderate level i.e. mid-chest level, strength of 45 Nm, coronal plane. Further research is warranted with a combination of torque strengths and heights. This study could also serve as a basis for sample size estimation in the future. Also, exposing individuals to task conditions for a greater number of days could provide tighter confidence intervals. Future studies can focus on determining the effects of longer work exposure on MARR and adjustment time.

6.5 Conclusions

This study determined the effects of work exposure on MARR and adjustment time. No significant effects of days were found on MARR and adjustment time. The effects of weeks of work exposure were significant in determining the MARR and adjustment time. Starting repetition rate (given a larger sample size) could play an important role in determining the effects of work exposure on MARR. It is highly likely that participants will make at least four adjustments before achieving final MARR. Another important observation is that when the participants returned after a rest period of two days within the work exposure schedule, they took longer to achieve final MARR, but retained a faster adjustment within a day.

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Appendices

Appendix I Institutional Review Board (IRB) Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING (ISE)

Informed Consent for Participants of Investigative Projects

Title of Project:	Effects of Work Exposure in Manual Torquing Tasks
Principal Investigators:	Ravi Kant, Graduate Research Assistant, ISE Department Dr. Maury A. Nussbaum, Associate Professor, ISE Department

I. THE PURPOSE OF THIS RESEARCH

You are invited to participate in a study of a certain type of manual work related to automotive assembly tasks. You will be required to use a torque wrench to exert torque at a selected combination of task height and torque plane. A height adjustable fixture has been built to simulate the industrial task in the laboratory.

Experiment will involve working for 1 hour at the same simulated task for 10 days (with break of two days after 5days). Approximately 10 participants will participate in this study.

II. PROCEDURES

The procedures used in this study are as follows:

The task will involve exerting a specified torque for a given combination of torque height and torque plane for 10 experimental sessions. You will be asked to determine your maximum acceptable rate of repetition for the given treatment condition. You will begin working at a randomly selected repetition rate, between 2 to 30 exertions per minute. Computer-generated audio cues will be provided to control the pacing of torque exertions. You will be given standardized instructions on how to determine the maximum acceptable repetition rates. You will adjust the repetition rate to what is considered your maximum level; one that you believe is safe and comfortable to perform for 1 hour period. You will be asked to make as many adjustments as required during the experimental duration. You can make the changes by either increasing or decreasing the repetition rate. Also, we will be asking you to rate your discomfort and pain on a scale during the experiment, which also will be explained before beginning the experiment.

The total estimated time of participation is 10 hours.

III. RISKS AND BENEFITS OF THIS RESEARCH

Your participation in this study will provide information that will be used to develop design guidelines for automotive work. These feelings should not be severe and you may feel some discomfort for up to 24 hours after the experiment. This is similar to what you will experience after normal exercise. In addition, an investigator will continuously monitor your condition to minimize any opportunity of strain.

There is minimal risk involved in this study.

IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The information you provide will have your name removed and only a subject number will identify you during analysis and any written reports of the evaluation.

V. COMPENSATION

If you decide to participate in this study, you will be paid $10.00 per hour for the time you participate. Also, $10 will be given as bonus for completing all the experimental sessions. The experiment is expected to last 10 hours. You will be paid at the conclusion of the testing session.

VI. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason without penalty. If you choose to withdraw during the study, you will be compensated for the portion of the testing which has been completed.

VII. APPROVAL FOR THIS RESEARCH

This research project has been approved, as required, by the Institutional Review Board for projects involving human participants at Virginia Polytechnic Institute and State University, and by the Grado Department of Industrial Engineering.

VIII. PARTICIPANTS RESPONSIBILITIES

I know of no reason why I cannot participate in this study. I have the following responsibilities:

- To notify the investigator at any time about a desire to discontinue participation.

- To notify the investigator of any medical conditions that may be negatively influenced by extended muscular exertion. This may include heart disease, conditions influenced by blood sugar levels, or any other medical problems that may interfere with results or increase the risk of injury or illness.

____

Signature of Participant

IX. PARTICIPANT PERMISSION

Before you sign the signature page of this form, please make sure that you understand, to your complete satisfaction, the nature of the study and your rights as a participant. If you have any questions, please ask the investigator at this time. Then, if you decide to participate, please sign your name above and on the following page (please repeat for your copy).

Signature Page

I have read a description of this study and understand the nature of the research and my rights as a participant. I hereby consent to participate, with the understanding that I may discontinue participation at any time if I choose to do so.

Signature ____________________________

Printed Name____________________________

Date ____________________________

Research team members may be contacted at the following address and phone number:

______Ravi Kant__________________________ _540-230-2730/ravikant@vt.edu___
Investigator(s) Telephone/e-mail

_____Maury A. Nussbaum__________________ _540-231-6053/nussbaum@vt.edu__
Faculty Advisor Telephone/e-mail

_____Maury A. Nussbaum__________________ _540-231-6053/nussbaum@vt.edu__
Departmental Reviewer/Department Head Telephone/e-mail

In addition, if you have detailed questions regarding your rights as a participant in University research, you may contact the following individual:

Dr. David Moore
Chair, Institutional Review Board
CVM Phase II (Pathobiology)
Virginia Tech
Blacksburg, VA 24061
(540) 231-4991

Appendix II   Instructions on Repetition Rate Adjustment

All participants are to be given exactly same instructions. These instructions have to be given before starting the experiment.

You are going to be asked to determine a maximally comfortable repetition rate for a manual torquing task. You should arrive at the Maximum Level of Repetition Rate that you would feel comfortable doing for a one-hour segment of an eight-hour shift**.**

This should be the repetition rate that will allow you to go on to another task at work and still go home at the end of the day without unusual discomfort, pain, or numbness in your finger, hand, wrist, arms and shoulders. You will adjust the repetition rate for your work by asking the experimenter to either increase or decrease the repetition rate.

Do not be afraid to make adjustments. If you feel you are working too hard and could experience pain, numbness, or injury, reduce the repetition rate. If you feel you could work a bit harder without increasing your risk of pain or injury, increase your repetition rate.

You can never make too many adjustments, but you can make too few. Adjusting your repetition rate is not an easy task since only you know how you feel. Also you can make change at any time during the trial.

This is not a contest. We are not looking for the maximum amount of repetition rate at which you can work. Everyone is not expected to do the same amount of work. We want **YOUR** judgment on how hard **YOU** can work without exposing yourself to pain or injury.

Do you have any questions?

VITA

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