ABSTRACT

WADESON, AMY ELIZABETH. Effects of Stretching on Muscle Activation in Gas Cylinder Handling. (Under the direction of Dr. David Kaber and Dr. Chang S. Nam).

Previous research has designed stretching exercises to target at-risk body segments in manual material handling (MMH) of gas cylinders. Stretching has been identified as a potential ergonomic solution for reducing occupational injury rates and severity, including overexertion injuries in MMH. A number of corporate stretching programs have been successfully implemented in MMH companies as controls for worker risk of overexertion injury. A variety of outcome metrics have been used to assess program effectiveness, including worker flexibility and performance, among others. However, no studies have made use of objective process measures, such as muscle activation levels during work tasks, for evaluation of effects of stretching programs. Electromyography (EMG) has been frequently used to assess the potential for muscle fatigue in MMH tasks. EMG has also been used to measure effects of stretching on muscle activation in athletics. It was expected that EMG might have potential for revealing the impact of stretching on muscle use and injury potential in MMH performance.

The objectives of this study were to: (1) examine acute effects of stretching on muscle activation levels, measured by EMG, in gas cylinder handling during simulated delivery operations; and (2) assess the effect of stretching on delivery driver perceived level of exertion. A within-subject experiment was designed to address the objectives. Participants were subjected to two conditions: stretching before delivery trials and no stretching. A series of standard delivery tasks were simulated as part of each trial to mimic a driver’s typical delivery day. Eight muscles were monitored for activation level during test trials using a
wireless EMG system. In regard to the second objective, following each test trial, participants reported their perceived level of exertion on a Borg perceived exertion scale (CR-10).

It was hypothesized that: (1) maximum muscle activation levels would be significantly lower for experiment trials preceded by stretching; and (2) perceived levels of exertion would be lower with stretching. In general, results were variable among muscle responses. One muscle (extensor) among eight observed muscles was found to show a significant decrease (p=0.0464) in activation level as a result of stretching. Two other muscles (anterior deltoid and trapezius) were significantly different (p<.0001) among the experimental conditions, but results were opposite to hypothesis; activation level increased with stretching. Furthermore, participants rated their perceived level of exertion significantly higher (p=0.0423) for experiment trials preceded by stretching, which was counter to the expectation. However, all participants thought introducing stretching into their daily work shift could be beneficial from performance and safety perspectives. The time duration of the regimen evaluated in this study was ~17 minutes and was not considered practical for performance at each delivery point throughout a work day but possible once a day.

Results of this research indicate a muscle stretching regimen in advance of specific MMH activities has mixed effects on activation levels across muscles. It is possible that effects are attributable to body posture positions, or manner of muscle use, during actual work activities. Findings indicate that stretching directly prior to work activity does have an impact of specific muscle activation. Related to this, there is clear evidence in the literature of long-term benefits of consistent static stretching, including increased range of motion, muscle lengthening, and stress reduction on ligaments and joints – all of which are beneficial in the prevention of overexertion injuries. As such, a recommendation of this work would be
to perform a stretch routine once daily during the gas cylinder delivery work shift with consistent application by workers over time.
Effects of Stretching on Muscle Activation Levels in Gas Cylinder Handling

by
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To:

my children, Autumn and Zeke;

my parents-in-law, Ann and Doug Wadeson;

my husband, Dan.

Your daily sacrifices made this endeavor possible and did not go unnoticed.

Thank you.
BIOGRAPHY

Amy Wadeson was born on August 8th, 1988 in Melbourne, Florida to parents Fred Markham and Patricia Bollinger. She grew up in central Florida and spent the last two years of high school abroad in Guangzhou, China. In 2006, she enrolled at The University of Florida to study communication sciences and disorders. Upon graduating Summa Cum Laude with a Bachelor’s of Arts in 2010, she and her husband Dan moved to Cary, North Carolina. After a few years of staying home with her children, Autumn and Zeke, she decided to pursue a masters degree at North Carolina State University in the Edward P. Fitts Industrial & Systems Engineering Department. She was awarded a traineeship through the National Institute for Occupational Safety and Health (NIOSH) and concentrated her studies on human factors and ergonomics. She will graduate with a Masters of Science in Industrial Engineering in May 2017.
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1. INTRODUCTION

1.1 Motivation

Industrial workers in the field of gas cylinder delivery operations are exposed to a high risk of musculoskeletal injury and illness (Morejon, 2016). While the gas cylinder industry has made many improvements in tools and personal protective equipment for workers, there are certain operations that are inherently demanding on the musculoskeletal system.

In the work by Morejon (2016), a gas cylinder distribution company requested development of a stretching regimen for delivery drivers to potentially reduce risk of work-related musculoskeletal disorders (MSDs). While the company had one of the lowest rates of injury in the gas products industry, stakeholders and employees were interested in further reducing this rate. Analysis of OSHA 300 logs (Morejon, 2016) revealed that 34% of delivery operator injuries were due to overexertion. Furthermore, 73% of those overexertion injuries were found to occur in the arms/shoulders, upper/lower back, and hands/wrists/fingers. Related to these statistics, 21.3% of employee “days away” and 35.5% of “days on restricted duty” were attributed to overexertion injuries.

Overexertion injuries occur when muscles, tendons, or ligaments are stretched beyond their limitations, or the stress of a load is beyond what a muscle can endure (Kumar, 2001). The 2017 Liberty Mutual Research Institute Workplace Safety Index cites “overexertion involving outside sources” as the mostly costly non-fatal work-related injury in 2014 (“Workplace Safety Index,” 2017). According to the most recent data obtained and published by the Bureau of Labor Statistics, in 2015, overexertion injuries had the highest incidence rate per 10,000 full-time workers compared with all other injury categories (“Injuries,
Illnesses, and Fatalities,” 2016). These injuries amount to nearly $14B per year in workers compensation claims.

Everett (1999) proposed that primary risk factors in overexertion injuries include posture stresses, forceful exertions, repetitive exertions, localized mechanical stresses, low temperature, and vibration exposure. Proper lifting techniques, mechanical support tools, job rotation, personal protective equipment, and many other controls are regularly implemented in workplaces to reduce the potential for worker risk of overexertion injuries. However, these injuries still occur at high rates and cost companies billions of dollars a year.

Using an ergonomics risk screening tool developed by The Ergonomics Center of North Carolina (Appendix A), Morejon (2016) assessed the motion, force, and posture of workers during three common gas product delivery tasks, including: rolling cylinders, pulling dewars, and lifting small cylinders. All three tasks were found to pose moderate to high risk to drivers (on a scale from 0 = “Low” to 10 = “High”). These high ratings were mainly due to posture and force ratings, as shown in Figure 1.

![Average Metric by Task Type](image-url)

*Figure 1. Average metric rating by task type (Morejon, 2016)*
Morejon (2016) subsequently identified those muscles comprising the body segments that were most negatively impacted by risk factor exposures (i.e., the segments with the highest injury rates). Among these muscles, the research also identified those that are eccentrically contracted during the moderate to high risk delivery tasks. On this basis, a stretching regimen was designed to target the muscles with the expectation of moderating activation and potential fatigue during work task performance.

In general, stretching has been found to reduce stress on ligaments and joints, lengthen muscles, and increase range of motion (Stark, 2012). Furthermore, stretching also allows muscles to relax, which increases blood flow to the muscle, allows for greater sensory awareness, and reduces fatigue, aches, and pain (Stark, 2012). Intuitively, risks of overexertion injury due to a muscle being stretched beyond its limits (Kumar, 2011) may be mitigated through muscle lengthening and increasing range of motion in advance of task performance. Increasing the length of the muscle can reduce the number of posture positions that pose a threat for overexertion injury. This intuition is supported by research focused on implementation of workplace stretch and exercise programs. Several studies have consistently reported findings of reduced MSD injury rate (Smith, 2013; Gartley & Prosser, 2011; Mehrparvar, 2014; da Costa & Vieira, 2008) and severity (McGillis, 2015; Choi & Woletz, 2010; Mehrparvar, 2014; Kellett, et al., 1991) during periods of program implementation. In addition, several other studies have reported significant decreases in employee perceptions of musculoskeletal pain (Bertozzi, et al., 2015; Rasotto, et al., 2015; Mortensen, et al., 2014). Increased strength (Guo, et al., 1992) and worker commitment to
safe work practices (Choi & Woletz, 2010; Goldenhar & Stafford, 2015) have also been cited as benefits of stretching programs.

With respect to stretching program design, the literature has indicated that programs should be tailored to specific tasks of workers (McGillis, 2015; Mortensen, et al. 2014). Related to this, Morejon (2016) not only tailored a stretching routine to the specific tasks, but to the muscles most at-risk while performing those gas products delivery tasks – those that were eccentrically contracted. However, this study, and the others focus on corporate exercise programs have not validated the potential effectiveness of stretching in terms of actual muscle responses at work when preceded by stretching or in the absence of a regimen.

As noted above, many different metrics have been used to assess outcomes of workplace stretching programs. However, no studies have made use of objective process response measures, such as muscle activation levels, for evaluation of program effectiveness. Such validation is needed before making broad recommendations for implementation of a stretching program for entire driver workforce.

With respect to process measures of physical performance, electromyography (EMG) is a commonly used tool in manual material handling (MMH) research for assessing muscle activity, as measured in voltage, during work tasks. Non-invasive EMG techniques are typically used in industrial settings to examine muscle loading and fatigue due to common requirements for worker ballistic movements and varied posture positions. Surface electrodes placed on the skin at the belly of selected muscles detect electrical signals when the muscles contract. More intense contractions result in higher voltage output, which can indicate a heavier load on the muscle, increased force output, and potential muscle fatigue.
EMG has also been used to assess the effects of stretching on muscle activation in non-industrial settings. Findings have been mixed. Studies reporting long static stretch periods prior to strength activities have found that maximum muscle force is depressed (Fowles, et al., 2000; Avela, et al., 2004) and EMG amplitude is reduced (Sekir, et al., 2010). Static stretch regimens of shorter duration have also been found to reduce muscle strength (Ryan, et al., 2008) and EMG amplitude up to 2 hours post-stretch (Power, et al., 2004). However, other studies have failed to identify significant shifts in EMG amplitude measures or muscle output due to stretching (Sozbir, 2016; Ryan, et al., 2008; Herda, et al., 2008). In general, it was expected that EMG may have the potential for revealing stretching program impact on muscle use and injury potential in MMH performance.
1.2 Literature Review

1.2.1 Workplace Stretch and Exercise Programs

Some research has shown that implementing a workplace stretch and exercise program can be a cost effective way to decrease worker risk of on-the-job MSDs. Many such programs have been implemented in a wide variety of work settings, all with differing job demands.

*Stretching in manufacturing environments*

With the objective of reducing work-related musculoskeletal injury rates in an industrial work setting, Gartley and Prosser (2011) developed and introduced a pre-shift stretch regimen for workers of two large manufacturing and delivery companies. The stretches targeted body segments that were commonly injured in workers. Nine stretches, held for 10-15 seconds each were performed at the beginning of every work shift for 4 months. All participating employees were trained in proper stretch posture and technique and large posters of the stretches were placed throughout the companies’ facilities. Only employees without prior musculoskeletal injury were invited to participate in the study. Of the 1,327 eligible employees, 79 volunteered for participation. All participants, except for one that incurred a musculoskeletal injury during the experiment, completed the stretching regimen every day. The impact of the program was assessed by comparing the rate of injury for all eligible, non-participating workers to the rate of injury in the participant pool during the experiment period. They found a significantly lower risk of musculoskeletal injury for workers who participated in the stretching routine as compared to those that did not (p=.01). However, participants were compensated additionally for taking part in the experiment and adherence to the stretch regimen was self-reported, which could have inflated the reported adherence rate. Additionally the incentive could have led to participants, either consciously
or subconsciously, to reduce risky work behaviors. While this could be interpreted as a benefit of the program, the results may not be strictly attributable to the stretching regimen.

In an effort to reduce the prevalence of low back muscle strain in a pharmaceutical manufacturing environment, Moore (1998) implemented a two month long stretching program with the goal of increasing worker flexibility and “physical self-perception”. Increasing flexibility was expected to reduce the risk of muscle strain. The stretching program targeted the neck, shoulders, arms, back, hips and legs and took approximately 5 to 8 minutes to complete. Muscles comprising these segments were chosen based on worker flexibility assessments and not body areas identified by worker injury reports. There were 36 scheduled sessions during work hours over a 2 month period. On average, the 60 participants attended 20 of the 36 sessions. Prior to the start of the implementation of the stretching intervention, participants were measured for flexibility through sit and reach, body rotation, and shoulder rotation tests. Forty-six of the 60 participants also completed The Physical Self Perception Profile (PSPP). The PSPP questions participants on self-perception of sports competence, physical strength, body attractiveness, physical conditioning, and overall self-worth. Participants who attended between 13 and 27 sessions saw the greatest improvement in flexibility ratings, with significant improvement on all four measures. Those attending less than 13 sessions did not see significant differences in body rotation test outcomes. There was, however, a significant increase in the self-worth, body attractiveness, and physical conditioning portions of the PSPP across participants. With respect to the stretching program design, the duration of each stretch was limited relative to other programs and the number of stretches was limited in frequency. Despite these program features, flexibility gains were still
achieved even when participants only stretched an average of two times per week. Low-back
strain incidence rates were not reported prior to or during the intervention period; so while
worker flexibility improved, it was unclear how stretching might have affected the risk of
low-back muscle strain.

Kellett, et al. (1991) investigated the effectiveness of an exercise program
implemented in a Swedish kitchen manufacturing company by studying the rate and length of
sick days taken due to acute back pain. Employees of the company were only included in the
experiment if they had self-reported back pain and had not taken sick leave due to pain
longer than 50 days in a 1.5 year period prior to the experiment. One group (n=48) acted as a
control and no interventions were assigned. Another group (n=37) was assigned an exercise
routine that included a warm up, gentle stretch, cardio and strength training, cool down, and
ended with a more focused stretch session. The stretches focused on the legs and lower- and
upper-back. The routine was led by a physical therapist or personal trainer 1 hour per week
during work hours. As the experiment lasted for 1.5 years, every 6 months the routine was
changed to maintain participant interest and increase exercise intensity level. On average,
sessions realized a 77% attendance rate. In addition to the at-work routine, participants were
instructed to exercise for 30 minutes at home each week. For each group, the rate and length
of sick days attributable to back pain were recorded for a 1.5 year period prior to the
experiment (Period 1) and for the 1.5 year period during the experiment (Period 2). The
differences in rate and length between the two time periods were compared across groups.
Significant differences were found between the groups for both the rate and length of sick
days attributable to back pain, favoring the exercise group. Additionally, the exercise group
had a reduction in both rate and length of sick days in Period 2 compared to Period 1; whereas, the control group saw an increase in both measures. While stretching was not the only type of exercise included in the interventions, this article supports the claim that corporate exercise programs can be beneficial to reducing the rate and severity of musculoskeletal disorders.

Smith (2013) evaluated the effectiveness of a workplace stretching regimen implemented in a large manufacturing plant. All employees were invited to participate in a 6-10 minute flexibility regimen every day for about 1 year. The stretching intervention was not implemented as a research study, but instead as a workplace health and wellness routine. Therefore experimental controls, such as inclusion criteria and randomized placement into experimental groups, were not used. However, regular flexibility measurements of workers who participated were taken over the course of the year, allowing for general analysis of the efficacy of the program. In addition to flexibility measurements, OSHA records were also analyzed for employees that chose to participate and those that did not for the year prior to the intervention and during the intervention period. Only overexertion type injuries and illnesses were counted, as a stretching regimen was not expected to reduce the risk of falls or other such injuries possibly attributable to work environment conditions. The stretching regimen was designed to fit the needs of the overall workforce based on the jobs workers regularly performed. Significant increases in flexibility of the neck, shoulders, fingers, and hamstrings were found between the start of the year and the end of the year. Furthermore, based on the OSHA records, it was found that employees not participating in the workplace
stretching regimen were five times more likely to suffer a musculoskeletal injury than those who participated.

While tailoring an exercise routine to specific job tasks has been recommended throughout the literature, Rasotto, et al. (2015) took it a step further by tailoring the exercise routine to individual workers. Over the course of 6 months, female precision manufacturing workers participated in a stretch and strength training session two times a week for 30 minutes. Compared to the control group, who received no intervention at all, those who participated in the exercise sessions experienced significant reductions in pain and improvements in upper-body flexibility, handgrip strength, shoulder flexibility, elevation and abduction, as well as head rotation and lateral inclination. The benefits of a customized exercise routine were seen in the results of this experiment; however, it is likely infeasible for most companies to have an exercise specialist on staff to develop routines to address the current physical needs of each individual worker.

*Stretching for light-duty repetitive work*

Long work shifts spent in static, awkward posture positions performing small repetitive motions can cause musculoskeletal pain, illness, and injury. Industrial workers involved in pipetting, computer work, and preparing vial samples were invited to participate in a yearlong at-work intense strength training program with the objective of reducing reported neck and shoulder pain due to work-related tasks. Zebis, et al. (2011) recruited 537 company employees for participation with random assignment to either a control group or training group. At-work training sessions lasted 1 hour a week and included high-intensity strength training for the neck and shoulder muscles. Outcome measures were subjective
ratings of neck and shoulder aches, pain or discomfort, as reported on a modified version of the Nordic questionnaire prior to and at the end of the training period. The training group saw a significant reduction in pain intensity in the neck compared to the control group. While pain intensity in the shoulder was not significantly different between pre- and post-intervention responses for the training group, the general trend was a decrease in pain ratings.

In a follow-up to Zebis et al. (2011) study, Mortensen, et al. (2014) examined whether the neck pain reduction achieved during the initial yearlong study was maintained for 2-year period following the initial study. Some of the companies whose employees participated in the initial study decided to maintain a training regimen without guidance from the researchers. Each company pursued different strategies in modifying the training regimen to fit employee needs. The follow-up study was not planned until a few months before a questionnaire was emailed to participants; therefore, participants of the initial study were not incentivized to continue training by knowledge of an impending follow-on investigation. The results of the 3-year follow-up study showed a slight (insignificant) increase in neck pain in specific companies; however, shoulder, elbow and wrist pain reductions were maintained from the first year.

*Stretching for fitness training and injury prevention*

Coppack, et al. (2011) implemented a strength and stretch program in British army recruit training with a focus on the lower limbs. Anterior knee pain in recruits was found to occur regularly during basic training, many times resulting in medical discharge or recruits being deemed “unfit for service”. The stretching program was developed in an effort to reduce recruit incidence of anterior knee pain. All participants were actively involved in a
14-week basic military training program and the intervention period overlapped with this training. Participants were randomly assigned to either a prevention training program group or the control group. Eight exercises were added to the prevention training program group daily physical training lesson, while the control group did not receive any interventions. Four strengthening exercises were performed prior to the physical training, and four stretching exercises were performed after the physical training. The total additional time for the eight exercises was approximately 15 minutes. The stretching portion of the intervention remained consistent for the entire 14 weeks, while the strengthening exercises were incrementally increased in duration at the end of every 3 weeks. Outcome measures were reported as incidence of anterior knee pain as well as “occupational endpoints” for participants (completion of basic training, medical discharge, voluntary discharge, being held back for an additional training period, or deemed unfit for service). Risk of anterior knee pain in the prevention training program group was reduced by 75% compared to the control group, as indicated by a ratio of anterior knee pain incidences between the two groups. Significant differences in medical discharge rate, as well as the rate of those “deemed unfit for service” were also found between the prevention training program group and the control group, favoring the prevention group. This study suggests that targeted training exercises can be successful in terms of reducing injury rates during an intervention period. Any long-term effects on participants after training were not reported.

Many studies have assumed that increased flexibility due to stretching regimens would lead to a reduced risk of work-related MSDs. As such, some research focused on measures pre- and post-intervention flexibility for workers but without capturing injury rates
or severity. For example, Muyor et al. (2015) implemented a 12 week long stretching regimen that targeted hamstrings, hip flexors, and low-back body segments in an effort to increase female worker population hamstring flexibility. Participants were split into control and intervention groups, including 58 adult women workers at a tomato company. All workers with 8-hour shifts in a standing position were included in the experiment. Three stretches were performed three times a week at the end of the work shift and were supervised by a physical therapist. All participants were instructed to not exercise outside of work hours so as not to influence results. The control group did not experience any significant changes across flexibility measures. The intervention group saw significant increases in toe-touch scores, straight leg raise angles for both legs, and a decrease in thoracic curvature during the toe-touch test. As hamstring inflexibility has been proposed to be a precursor for low-back disorders, increasing hamstring flexibility may result in fewer worker injuries. Injury rates and severity before or during the intervention period were, however, not measured or reported in this study.

*Stretching for injured workers*

Unlike the majority of studies that have focused on preventative exercise programs for healthy workers, Bertozzi, et al. (2015) implemented a program designed for workers that were already suffering from MSDs in an effort to reduce pain and disability levels. Only workers that had been diagnosed with non-specific back pain lasting longer than 3 months, but without serious spinal injuries, diseases or nerve damage, were included in the study (n=40). The treatment group (n=20) received a 1 hour stretching and exercise intervention conducted by a physical therapist, two times a week for 5 weeks. This routine was performed
before or after work, but not during work hours. Furthermore, an at home routine was also
assigned, which included relaxation, stretching and postural exercises that targeted the low
back and legs. The control group was also assigned the at home routine but did not receive
dedicated sessions with the physical therapist. Phone interviews were used to ensure
participant adherence to experiment protocols. Program success was measured by changes in
two disability indexes as well as pain drawings associated with a Visual Analogue Scale
(VAS) for ratings of lumbar physical discomfort. While there were no significant outcome
differences between groups, there were significant main effects of time for all measures.
Findings indicated that the exercise routine positively impacted disability scores and lumbar
physical discomfort. Additional treatment sessions under the guidance of a physical therapist
only slightly, and non-significantly, improved outcome measures, suggesting that additional
one-on-one treatment may be superfluous when at-home adherence levels are high.

Maher et al. (2011) examined the difference in effectiveness of standard medical
treatment compared to targeted exercises for pain reduction in employees complaining of
work-related shoulder pain. Nine participants were randomly assigned to a control group that
received standard medical treatment for generalized shoulder pain or an exercise group that
received an at-home training regimen. The exercise group saw an improvement in two
measures of strength in manual muscle tests and one measure of disability on the Disability
Index (DI) survey when compared to the control group. However, there were no significant
effects of time for either group for any measure.
Stretching and strength training exercises

Guo et al. (1992) sought to examine the difference in effect of a flexibility protocol and a strength-flexibility protocol on strength, endurance, and flexibility in manual material handlers. Twenty-four hospital maintenance workers were split into four groups. Two of the groups were only assigned stretches, while the other two groups were assigned stretches and strength exercises. The strength training portion was designed to mimic tasks that the subject pool performed daily, and the stretching routine concentrated mostly on back, shoulders, arms, wrists, and knees. Success of the program was measured by changes in participant endurance, dynamic and static strength, and flexibility. During the first 4 weeks of the experiment, participants performed their assigned exercises every day. Significant gains were found across all groups in all measures without significant differences between the groups or the protocols, suggesting that a stretching regimen alone may be sufficient to increase physical capacity of workers. The second 4 weeks of the experiment was designed to test a maintenance program. Participants continued performing the same exercises but only two times a week, instead of five. Significant decreases in flexibility as well as dynamic strength were found at the end of the 4 weeks. Researchers concluded that 2 days a week was not enough to maintain positive gains of stretching and, therefore, exercises should be done on a daily basis.

Stretching vs. ergonomic design interventions

Often companies have budgetary constraints limiting their ability to invest in ergonomic tools that could potentially impact worker risk of injury and pain. In these cases, implementation of a stretching or exercise regimen may be beneficial and cost effective.
Mehrparvar, et al. (2014) conducted a study of video display terminal (VDT) workers in order to compare the effectiveness of limited ergonomic modifications to workstations vs. a workplace exercise routine on musculoskeletal pain. One group received ergonomic modifications to their VDT workstations. Modifications included rearrangement of desktop equipment and addition of a foot stool when necessary. The other group participated in a stretching routine that concentrated on muscles in the neck, shoulder, wrist, and back, two times a day for 15 minutes. The frequency of pain in the neck, shoulder, low back, elbows, and wrists, as well as the severity levels of the pain, were assessed prior to interventions and at the end of a 1 month period. Results were compared within and between groups. In general, both groups saw a similar significant decrease in pain frequency and severity in all body parts. However, the stretching intervention group saw a significantly greater reduction in elbow pain severity and frequency of low back pain compared to the ergonomic modification group. The utility of a stretching regimen when faced with a limited budget should not be overlooked as a method of controlling frequency and severity of pain in worker populations.

Systematic reviews of stretching literature

To determine overall effectiveness of workplace stretching programs in reducing work-related MSDs, da Costa & Vieira (2008) performed a systematic review of the literature. Studies were included in the review provided there was investigation of stretching regimens as a preventative measure for work-related MSDs. Review screening criteria also included the requirement that at least one study group only received stretching as an intervention. All studies included in the review were also peer reviewed and published in
English language journals. Of the 334 references identified through their literature search, da Costa & Vieira (2008) identified only seven studies meeting all inclusion criteria. These studies revealed benefits of stretching to include prevention of work-related MSDs, especially in high-intensity work environments, due to physiological effects of stretching. However, the review suggested that stretching should not be used as a sole control measure for prevention of MSDs, and that any pain relief reported by individuals from stretching may actually decrease worker awareness of ergonomic risks at work; thus, leading to increased injury severity when injuries do occur.

Worker perception of stretching programs
Goldenhar and Stafford (2015) conducted a survey study of construction worksite “stretch and flex” programs. Online surveys were conducted with 113 safety and health professionals working in the construction industry along with 19 phone interviews. Stretch and flex programs were reported by 56% of respondents. Approximately half of the respondents stated that employees were required to perform 8-9 stretches daily, while the other half stated employees were required to perform 5-7 stretches. Nearly 80% of the programs were conducted in the morning and 60% of the programs took under 10 minutes to complete. Injury rates of the participating companies were not analyzed and the safety and health professionals interviewed were not convinced that stretching and flexibility programs were the only factors in reducing injury rates to construction workers. Many did believe, however, that the programs led to reduced injury severity, particularly among older workers, though no injury data was provided to support this claim.
Worker perception of safety interventions can greatly influence adherence to, and the success of, ergonomic interventions. Choi and Rajendran (2014) surveyed an unknown number of construction workers from five large construction companies (annual revenue > $20 million) and five large projects (budget > $50 million). Of 315 respondents, over 94% participated in stretching programs on a daily basis as part of their work shift. Among these respondents, 97.7% believed stretching programs reduced worker risk of musculoskeletal disorders.

**Summary of Workplace Stretch and Exercise Programs**

Workplace stretching regimens are often implemented with the assumption that increased worker flexibility will mitigate the risk of musculoskeletal injury and illness. The analysis of success of these programs varies widely across studies, ranging from a reduction in worker injury rates, to a decrease in days away from work due to work-related pain, to lowered pain levels, to increased range of motion and other flexibility measures. All the studies reviewed here found benefits in the implementation of workplace stretch and exercise programs, though not all studies have objectively demonstrated programs mitigate the risk of work-related MSDs.

The reviewed studies focused on stretch and exercise routines that were performed at the workplace either prior to, or during, the work shift. Including the regimen in daily shift work may be a simple way to keep adherence levels high. While some studies reported significant flexibility gains and significant decreases in injury rate and severity while requiring participation in the stretch routines only two times per week, other studies showed that participation five times per week results in better strength and flexibility gains –
potentially leading to reductions in injury rate and severity through increasing muscle ability. Group stretch sessions lead by a trained employee or physical therapist showed similar effects to one-on-one coaching sessions, suggesting that individual sessions may be unnecessary.

Many studies did not report specific type of stretch or stretch holding length and repetition used in the interventions, but other literature has suggested that for best results stretches should be held for 15-20 seconds and repeated three to five times (Smith, 1994).

1.2.2 Stretching and EMG
Few studies have been conducted on the effects of stretching on muscle activation levels in follow-on leisure or work tasks. This section provides an overview of relevant literature and summary of findings.

Sekir et al. (2010) examined the effect of static and dynamic stretching of leg muscles on peak torque (a measure of strength) and muscle activation levels (as a percentage of maximum ability). A within-subjects experiment design was used such that 10 elite female athlete participants were subjected to three different experimental conditions: dynamic stretching, static stretching and a no-stretch control condition. The experimental trials involved four maximal contractions of the hamstrings and the quadriceps for both eccentric and concentric contractions. EMG electrodes were placed on the belly of two major muscles in the quadriceps as well as two major muscles in the hamstrings. Four stretches (either static or dynamic), were performed prior to experimental trials during their respective conditions. EMG maximums during the static stretching condition significantly decreased for all combinations of contraction types, the four measured muscles, and all angular velocities.
EMG maximums during dynamic stretching conditions significantly increased for all combinations besides one muscle of the quadriceps. This study showed that static stretching decreases EMG amplitude maximums for isokinetic contractions.

Sozbir et al. (2016) conducted a small sample study on the differences between static stretching and contract-relax proprioceptive neurofeedback (CRPNF) stretching on EMG activity, range of motion (ROM), and jump height, of two sedentary males. Each participant was subjected to the static and CRPNF stretching conditions on 2 days, separated by 1 week. Each stretch condition included one stretch each for the hamstrings, quads, triceps surae, and lower back. All stretches lasted for 30 seconds and were repeated four times per muscle with a 30 second break given between each repetition. Prior to and immediately following the stretches, participants were instructed to jump as high as possible. EMG activity was recorded for the vastus lateralis, vastus medialis, and gastrocnemius medialis muscles. Jump height and EMG amplitude (as a percentage of MVC) were compared for pre- and post-stretch jumps. Both techniques were found to produce similar effects on increased hip ROM, decreases in jump height, and decreased EMG amplitude. Hip ROM and jump height were the only measures significantly influenced by CRPNF. Although the decrease in EMG amplitude was not significant, the trend follows the previous study’s finding that static stretching leads to decreases in muscle activation levels.

Many studies that have examined the effects of static stretching on muscle output have used extremely long duration stretches (Fowles, et al., 2000; Avela, et al., 2004). Power, et al. (2004) examined the effects of a more realistic stretching protocol, including six stretches with three repetitions of 45 seconds on quadriceps and plantar flexor (PF) muscle
strength, vertical jump height and time, and EMG measurements. Furthermore, they recorded the same measurements at multiple time intervals (pre-stretch, immediately post-stretch, and 30, 60, 90, and 120 minutes post-stretch) to study how long the effects of stretching lasted for each measure. The PF did not exhibit a decrease in force compared to the control condition at any time interval, nor did the EMG activity show any significant differences at any time interval. The quadriceps, however, showed a decrease in EMG activity compared to the control both immediately after the stretch as well as 120 minutes post-stretch. ROM was significantly higher at every time interval following the stretches compared to the control.

Ryan, et al. (2008) also examined changes in plantar flexor muscle strength, activation, and ROM following a reasonable stretching period. Four stretch length conditions (2, 4, 6, and 8 minutes) and a control condition (no stretch) were required of all participants. Only one type of stretch was performed with a 30 second duration with 20 seconds of rest between repetitions. The number of repetitions depended on the length of the experimental stretch condition (e.g., 2 minutes stretch condition required 4 repetitions; 6 minute stretch condition required 12 repetitions). Pre- and post-stretch measurements were taken on ROM, isometric strength, and muscle activity (EMG). During the control condition, 15 minutes of rest was given between the pre- and post-test measurements to mimic a similar time period as in the 8 minute stretch condition. ROM increased for the 2 minute, 4 minute, and 8 minute stretch conditions immediately following the stretch period, but then returned to pre-stretch values at 10 minutes and for the remaining measurements. EMG amplitude remained unchanged for all conditions, suggesting that shorter stretch durations may not impact muscle activity.
Herda et al. (2008) also conducted a study of isometric EMG amplitude following static stretching in the biceps femoris muscle. Similar to Ryan et al. (2008) and Power et al. (2004), short stretch durations were implemented. In addition to a static stretch condition, participants were also subjected to a dynamic stretch condition. Isometric force, EMG amplitude, and mechanomyography (MMG) were measured. Both dynamic and static stretch routines included three stretches, repeated four times, for 30 seconds each. Analysis of the measurements showed a significant decrease in maximum isometric force following static stretching for specific postures. MMG amplitude increased from pre- to post-dynamic stretching at all angles and pre- to post-static stretching for a specific posture. EMG amplitude increases were seen after dynamic stretching in specific postures.

Summary of Stretching and EMG studies
Very few studies have examined the effects of static stretching on muscle activation levels. Among the studies reviewed above several have reported increases in ROM, reductions in muscle strength and decreased EMG muscle activation levels due to static stretching. Studies that employ more realistic static stretching regimens also report benefits of increased ROM but also report smaller or insignificant decreases in muscle activation levels and strength. All studies included in this review focused solely on muscles of the lower limbs, which are generally larger and stronger than muscles of the upper limbs.
2. PROBLEM STATEMENT

Occupational injury analysis for gas cylinder operations has revealed on-the-job overexertion injuries (Morejon, 2016). Previous research identified stretching as a potential ergonomic solution to decrease overexertion injury risk for workers. Many corporate stretching and exercise programs have been successfully implemented and variety of outcome metrics have been used to assess program effectiveness, such as changes in injury rate, injury severity and flexibility scores, among others. However, no studies have made use of objective process response measures, such as muscle activation levels, for evaluation of industrial worker stretching program effectiveness. Electromyography (EMG) has been frequently used to assess the potential for muscle fatigue in MMH tasks and injury. EMG has also been used to measure effects of stretching on muscle activity in athletes but not in industrial settings. It is expected that EMG may have potential for revealing stretching program impact on muscle use and injury potential in MMH performance. This study explored the potential utility of a stretching regimen to decrease injury risk to gas cylinder handlers as a result of muscle exertion by using EMG to monitor muscle activation levels during mock gas cylinder deliveries.
3. METHODS

3.1 Participants

Eight male gas cylinder delivery drivers volunteered to participate in this experiment. Average age was 48.4 years with a standard deviation of 9.5 years. Driver height was 70” ± 2.4” and weight was 224.7 lbs ± 29.7 lbs. The demographics of participants resembled overall demographics of the company’s delivery driver population. Data on one driver was removed from analysis due to unrelated and unforeseen interruptions in experimental trials. Recruits were excluded from the study if they presented with a history of arm, shoulder, or back injuries or disorders. All participants had received previous training in safety and handling procedures for cylinder delivery operations. Six of the eight participants were once employed as delivery operators with an average experience of 7.6 years ± 6.4 years. Two participants regularly performed delivery operations as part of their job duties. The company assisted in recruiting employees for participation in the experiment and those employees were flown to Raleigh from multiple locations throughout the United States. Participants received their typical salary for the experiment and were not additionally compensated for participation.

3.2 Apparatus and Facility

The experiment was conducted at an actual gas product company retail and operations facility located in Raleigh, North Carolina. Figure 2 depicts the facility and experiment layout. Researchers occupied the space for 3 weeks for data collection.

![Figure 2. Experiment layout](image-url)
The equipment used in the experiment was provided by the host company and was consistent with equipment used in actual delivery operations. Equipment items included: 10 small oxygen cylinders (height: 25.5”, diameter: 4.3”, weight: 7.9 lbs.; see Figure 3), 10 large helium cylinders (height: 55”, diameter: 9.3”, weight: 146 lbs.; see Figure 4), 2 liquid nitrogen dewars on wheels (height: 53”, diameter: 26”, weight: 664 lbs.; see Figure 5), and a small cylinder hand cart.

3.3 Tasks

Based on the ergonomic risk assessment (ERA) in gas delivery operations previously conducted by Morejon (2016), three moderate to high risk tasks were selected for testing muscle activation levels as part of the experiment, including: lifting small cylinders, rolling cylinders, and pulling dewars. These are not only the riskiest tasks for delivery operators but also the most commonly performed during typical delivery operations.
3.3.1 Lifting Small Cylinders
Ten small oxygen cylinders were situated on the ground next to the wheeled handcart prior to the start of the experiment. Using their right hand, participants lifted five cylinders, one at a time, and placed them into the handcart. Once five cylinders had been placed in the cart, participants pushed the cart fifteen feet to a marked ending location and unloaded the cylinders one at a time, using their right hand. This cycle was repeated a total of four times per trial (mock delivery operation). Figure 6 shows a host company employee placing a cylinder into the handcart.

Figure 3. Placing small cylinder into handcart

3.3.2 Rolling Cylinders
Ten large helium cylinders were placed on a pallet prior to the start of the experiment. Participants removed one cylinder using their right hand and, following standard operating procedures for cylinder delivery, rolled the cylinder fifteen feet before placing it on another pallet. Participants used their left hand only for support and stability. The standard operating procedure for rolling a cylinder is as follows:
(1) Tilt a cylinder until it is resting just on its edge and hold the cylinder at the top with the right hand.

(2) Use a foot to kick the cylinder forward while simultaneously twisting the cylinder in the forward direction with the right hand.

(3) Place the cylinder upright in the desired location and stabilize.

During the experiment, this cycle was repeated a total of ten times during each mock delivery trial. Figure 3.6 shows a host company worker rolling one cylinder. It is important to note that this task was designed to comply with the host company’s safety policies, which state that cylinders may not be moved a distance greater than fifteen feet without the use of a handcart.

Figure 4. Rolling one cylinder
3.3.3 Pulling Dewars
Two liquid nitrogen dewars on wheels were situated at marked starting locations prior to the experiment. Participants placed one hand on the upper handle of the dewar and one hand on a side handle, and then walked backwards while pulling the dewar for 30 feet. The dewar was then placed on at a marked ending location. This cycle was repeated a total of four times during a single mock delivery trial. Figure 8 shows a worker pulling a dewar on a flat surface.

![Pulling a dewar](image)

Figure 5. Pulling a dewar

3.3.4 Trial
A trial was defined as a random combination of all three of the above described tasks. Participants were instructed to complete trials without breaks between tasks. For example, during one trial a participant might first pull four dewars, then roll 10 cylinders, and then lift and push 20 small cylinders. In the next trial, a participant might roll 10 cylinders, then lift
and push 20 small cylinders, and then pull four dewars. Each participant completed three trials per experiment condition.

3.4 Independent Variables

3.4.1 Stretching Regimen

A stretching regimen was developed to target muscles that are eccentrically contracted during the three identified gas products delivery tasks; lifting small cylinders, rolling cylinders, and pulling dewars (Morejon, 2016). The general body segments targeted were also the most commonly injured, as evidenced by Morejon’s (2016) analysis of gas products company OSHA 300 logs from January 2013 to September 2015. A total of eight stretches were chosen for the regimen. Illustrations of each stretch, including identification of target muscles, are presented below. It is important to note that while stretches were chosen to target the muscles that are eccentrically contracted during tasks, surrounding muscles may also be affected by the stretching motions. Written and illustrated instructions for the stretch motions are provided in Appendix B. These instructions were also provided to participants for use during the experiment.

*Stretch 1 – Upper Arm Shoulder Stretch*

Figure 9 depicts the stretching motion for an upper-arm shoulder stretch. This stretch targeted the triceps brachii, but also stretched other muscles in the shoulder, upper-arm, and back. The triceps brachii was identified as being eccentrically contracted during pulling dewars and lifting small cylinders.
Stretch 2 – Parallel Arm Shoulder Stretch

Figure 10 depicts the stretching motion for the parallel arm shoulder stretch. This stretch was chosen to target the medial deltoid and triceps brachii muscles, which were identified as being eccentrically contracted during rolling cylinders (medial deltoid only), lifting small cylinders, and pulling dewars.

Stretch 3 – Chest and Bicep Stretch

Figure 11 depicts the stretching motion for a chest and bicep muscle stretch. The biceps brachii and anterior deltoid were identified as being eccentrically contracted during lifting small cylinders, rolling two cylinders (biceps brachii only), and pulling dewars (biceps
brachii only). This stretch was chosen to specifically target those muscles, but other chest muscles are also affected by the stretching motion.

**Figure 8. Chest and bicep stretch**

*Stretch 4 – Finger Extensor Stretch*

Figure 12 depicts the stretching motion for a finger extensor stretch. This stretch was chosen to target muscles in the hand and forearm. More specifically, it was intended to stretch the extensor digitorum communis and the extensor carpi ulnaris muscles, which were identified as being eccentrically contracted during pulling dewars and lifting small cylinders.

*Figure 9. Finger extensor stretch*
Stretch 5 – Finger Flexor Stretch
Figure 13 depicts the stretching motion for a finger flexor stretch. This stretch targeted the flexor carpi ulnaris and flexor digitorum superficialis muscles, which were identified as being eccentrically contracted during rolling cylinders and pulling dewars.

![Figure 10. Finger flexor stretch](image)

Stretch 6 – Arm Wrap Shoulder Stretch
Figure 14 depicts the stretching motion of an arm-wrap shoulder stretch. This stretch was chosen to target muscles in the upper back. More specifically, it was intended to stretch the upper trapezius muscle, which was identified as being eccentrically contracted during pulling dewars, rolling cylinders, and lifting small cylinders.

![Figure 11. Arm wrap shoulder stretch](image)
**Stretch 7 – Hamstring and Low Back Stretch**
Figure 15 depicts the stretching motion of a hamstring and low-back stretch. This stretch was chosen to target the erector spinae, biceps femoris, and semitendinosus muscles, which were identified as being eccentrically contracted during pulling dewars and lifting small cylinders.

![Hamstring and low back stretch](image1.png)

**Figure 12. Hamstring and low back stretch**

**Stretch 8 – Quad Stretch**
Figure 16 depicts the stretching motion of a quadriceps femoris stretch. Although the quadriceps were not identified as being eccentrically contracted during any of the delivery operations, this stretch was chosen in an effort to balance the hamstring and low-back stretch (as described above; #7).

![Quad stretch](image2.png)

**Figure 13. Quadriceps stretch**
3.5 Response Measures

3.5.1 Physiological – EMG

Voluntary muscle contraction is initiated by a signal from the nervous system. This signal, or action potential, is transmitted through a motor neuron. Each motor neuron terminates in a motor unit which is comprised of cells and a bundle of muscle fibers. The action potential, stemming from the motor neuron, spreads through the muscle membrane in the motor unit which causes the muscle to contract. EMG surface electrodes placed on the skin can be used to detect and monitor the level of action potentials of the contracted muscle.

In the present experiment, electrodes were placed on eight muscles that were eccentrically contracted during the riskiest delivery operations and, therefore, those that were targeted by the stretching regimen. The muscles included the upper trapezius, medial deltoid, extensor, flexor, bicep, triceps, erector spinae, and anterior deltoid. The type of electrode used in the experiment (DelSys) is shown in Figure 17, and the placements of the electrodes on the body are depicted in Appendix E.

EMG signal capture was started at the beginning of each task repetition and ended at the completion of each repetition. For example, the EMG response for pulling a dewar began when a participant reached up to grab the handles. The signal measurement was terminated when the dewar was positioned at its marked endpoint.

If equipment issues arose in the middle of a task repetition, a note was made in the participant’s experiment file for reference during data analysis and the participant completed the task repetition uninterrupted. Researchers made necessary equipment adjustments between repetitions and no repeat task performances were required due to equipment issues.
3.5.2 Perceptual – BORG
Participants were also asked to rate their perceived level of exertion at the end of every experiment trial. The Borg CR-10 (continuous rating, 10-point) Scale (Borg, 1990) was administered. This scale has previously been validated and used in many MMH studies to gauge participant perception of physical exertion. The highest numerical value on the scale, 10, represents the highest exertion a participant has ever experienced. The verbal identifier “maximal” appears just above the value of 10 on the scale and represents an exertion level greater than any previously maximal exertion a participant has experienced. The lowest value, 0, represents absolutely no effort at all. The complete scale, as presented to the participants, can be found in Appendix C.

3.6 Experimental Design
This study followed a within-subject design. Each participant experienced both experimental conditions: stretching and no-stretching. Studies that use EMG as a response measure typically follow a within-subject design due to individual differences in muscle mass and strength. As previously mentioned, task exposure was randomized within each trial within each stretching condition. The order of tasks in any one trial was not repeated in another trial.
under the same stretching condition. Additionally, the order of the muscle stretches (1-8) was randomized before each trial under the stretching condition.

3.7 Procedures

3.7.1 Consent Form
This experiment was approved by the Internal Review Board of North Carolina State University. Participants were emailed an information packet that included an overview of the experiment, consent form, and demographic surveys in the weeks leading up to the experiment. Each participant presented at the host company facility with a signed consent form for the researcher to endorse. An additional copy was made for participant records.

3.7.2 Demographic and Anthropometric Survey
Participants were asked a series of questions regarding their years of experience with delivery operations, including but not limited to: “how many years were you employed as a gas cylinder delivery driver?”, “how long has it been since your last delivery?”, “did/do your typical job duties include lifting small cylinders, rolling cylinders, and pulling dewars?”. Researchers then measured participant height and upper-body segment lengths. Weight was self-reported. Demographic surveys and anthropometric data collection forms can be found in Appendix D.

3.7.3 Orientation
Tasks and Trials
Due to host company safety policies, researchers did not have approval to move company materials. Therefore, tasks were described in detail and were not demonstrated. However, all participants had prior training in proper cylinder safety and handling techniques and the tasks
did not deviate from these standards. A practice session was also offered to each participant, but all declined (based on their prior work experiences).

**Stretching**
The illustrations and directions of all eight stretches were printed on a 48” by 36” poster board. Researchers instructed participants to look at the pictures, read the directions of each stretch and attempt the stretches to their best ability. Researchers then critiqued their stretching posture as needed and ensured that the stretch did not cause any pain or discomfort.

*3.7.4 EMG Electrode Placement*
On the first day of the experiment for each participant, researchers located the necessary muscles and used permanent marker to mark the electrode placement positions. Using permanent marker ensured the electrode was placed in the same location on both days of the experiment. Pictures of electrode placements can be found in Appendix E. A new and unused Bic disposable razor was provided to participants if there was hair at the electrode site and they were instructed to shave a 1 inch by 2 inch rectangle to reduce impedance to the system. All electrode sites were then wiped down with rubbing alcohol and an abrasive scrub. Electrodes were attached using double-sided tape and were secured with medical tape. Once the electrodes were in place, participants were asked to move their arms and shoulders to check ROM and comfort level. Adjustments were made as necessary. A signal check was then performed to ensure the electrodes were capturing action potentials at the motor neuron endplates and muscle membrane.
3.7.5 Experimental Conditions
In an attempt to balance the order of stretching conditions across participants, four persons received the stretch condition first, and three received the control condition first. There was a 24 hour period between the start of the first and second condition for each participant.

3.7.6 Control Condition
Participants were initially instructed to lie down on the floor and remain completely still in order to capture resting muscle activation levels (3 repetitions x 3 seconds). Participants then completed the first test trial followed by a 10 minute break. During the break, researchers asked participants to identify their level of exertion using the Borg scale. After the final test trial, participants completed Maximum Voluntary muscle Contractions (MVCs) in order to provide a baseline response for normalizing all test EMG data. The MVC procedure is discussed in detail below. Researchers carefully removed all electrodes and, if it was necessary, researchers remarked the electrode placement sites with permanent marker.

3.7.7 Stretching Condition
The stretching day followed the same order activities as the control day. However, immediately prior to every trial participants performed the stretching regimen in its entirety. The 10 minute breaks began at the end of each trial and ended at the start of the stretching regimen.

3.7.8 Maximum Voluntary Contractions
In order to obtain a reference level of maximum muscle output to normalize muscle output captured for the experiment trials, MVCs were performed with the eight muscles monitored by the wireless EMG system at the end of each day of the experiment. A standardized MVC procedure was used, including recording the maximum signal amplitude achieved during
three muscle contractions of 3-5 seconds each. The specific tasks for the MVCs are listed in Appendix F.

3.8 Hypotheses

As observed in the literature review section, there are few studies that have assessed the effects of stretching on muscle output, as measured by EMG. However, one study found significant decreases in EMG maximum amplitude following static stretching (Sekir, et al., 2009), and another study reported a similar trend (Herda, et al., 2008). Furthermore, the intent of the stretching program evaluated in this study was to reduce worker risk of overexertion injuries. A decrease in EMG maximum amplitude would indicate a reduction in the amount of work a muscle is performing, potentially reducing the likelihood of muscle fatigue and overexertion.

Hypothesis (H)1: It was expected that maximum EMG amplitude would be lower for trials that were preceded by the stretch routine.

H2: Based on the expectation for reduced EMG amplitude with stretching, indicating reduced muscular contraction, it was also expected that perceived level of exertion on the Borg CR10 scale would be lower following trials that were preceded by the stretch routine.
4. DATA ANALYSIS

4.1 Data Processing

The EMG system used in this study (Delsys) recorded muscle activation responses at 1000 Hz. This sampling rate resulted in approximately 30,000 data points per task repetition per muscle per participant. Additionally, rest and MVC collection resulted in approximately 9,000 data points each per muscle per participant.

Not all collected EMG data is necessary or appropriate for analysis. EMG signals can be corrupted by ambient electromagnetic radiation, electrode shifts on the skin, or electrical noise of recording equipment. With these issues in mind, various filters were applied to the EMG signals including a cutline of 2.5 mV, which removed data points whose absolute values were greater than 2.5 mV. Following the cutline, data was passed through a 4th order butterworth bandpass filter (high pass set as 20 Hz, low pass set as 450 Hz) and then a 4th order notch butterworth filter (bandtop set as 58 ~ 62 Hz). The filtered data was then rectified and smoothed by a 50 ms moving window.

Given the nature of the experimental tasks and data collection time window during the tasks, it was necessary to select a specific EMG measurement that gave a precise indication of muscle work during the tasks. Standard amplitude measurements used in EMG analysis throughout the literature are often summarized in terms of mean and standard deviation or maximum responses. The mean and standard deviation of EMG responses in this experiment were influenced by observations from periods of rest as well as intense work and were, therefore, not considered to be accurate indicators of muscle output for task
performance. Consequently, the maximum EMG values for each muscle in each test trial were extracted from the response data set and used as a basis for the muscular work analysis.

Additionally, the raw maximum EMG signals could not be used to compare between individuals as each individual has different muscle ability. A signal from a stronger, larger muscle is much higher than one from a weaker, smaller muscle. Finding a percentage of personal maximum ability is a standard way to normalize data to allow for comparisons between individuals. Therefore, the absolute maximum EMG values for each participant for each muscle were extracted from either the MVC or test trial data. This procedure was necessary because participants did not always reach their maximum potential for some muscles during MVCs and instead reached their maximum during experimental trials. The three lowest resting muscle activation levels were also extracted for every muscle among the rest periods and averaged. All maximum EMG test trial responses were then then normalized using Equation 1 based on the absolute maximum muscle response during the experiment and the lowest average resting response for each participant.

\[
Max_{Norm} = \frac{Repetition-Rest}{Absolute\ Max}
\]

The result of the normalization procedure was one data point per participant per repetition per muscle (6048 data points). Each data point represented the highest proportion of maximum amplitude a muscle achieved during one repetition. Due to equipment issues during the experiment the erector spinae was removed from analysis leaving 5292 for
analysis with 756 observations per muscle. Response data from the Borg survey did not require any post-processing.

4.2 Diagnostics and Transformations
Using JMP Pro 12, diagnostic tests for normality and homoscedasticity of the data were performed on the normalized EMG response data and the Borg survey response data prior to statistical analyses. The Borg data were found to be normal and homoscedastic. All muscle responses violated normality assumptions and only four of the seven muscle responses were found to be homoscedastic. Appropriate transformations were applied to the EMG response data and diagnostics were conducted on the transformed data set. For all transformations, the muscle responses remained in violation of the normality assumption and while some muscles were found to be homoscedastic, the results were inconsistent. Therefore, a rank averaged transform was applied to the responses in order to perform non-parametric analyses.

4.3 Physiological Response (EMG)
Descriptive statistics were generated on the EMG responses; i.e., the task muscle activation level as a proportion of maximum muscle output for each muscle observed in the study under each stretching condition. An analysis of variance (ANOVA) was then conducted on the rank transformed data to identify effects of the stretching routine on muscle output. Tukey’s honest significant difference (HSD) tests were performed on task type and trial number when those effects were found to be significant.

4.4 Psychosocial Response (Borg Survey)
Participants rated their perceived level of exertion after each experimental trial. Therefore, there were three observations per condition per participant, resulting in 42 total Borg
observations. Descriptive statistics were generated on these observations for each stretching condition. An ANOVA was conducted to determine the effect of stretching on participants’ perceived exertion during the experimental trials.
5. RESULTS

5.1 Descriptive Statistics

Table 1 and Figure 18 present the mean and standard deviations of the proportion of maximum muscle activation amplitude by stretching condition for each muscle across participants. The trend for five of the seven muscles shows an increase in muscle activation during stretching trials as compared to control trials.

Table 1. Mean (SD) of proportion of maximum amplitude by stretching condition

<table>
<thead>
<tr>
<th>Muscle Groups</th>
<th>Condition</th>
<th>Trapezius (Mean, SD)</th>
<th>Medial Deltoid (Mean, SD)</th>
<th>Extensor (Mean, SD)</th>
<th>Flexor (Mean, SD)</th>
<th>Biceps (Mean, SD)</th>
<th>Triceps (Mean, SD)</th>
<th>Anterior Deltoid (Mean, SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>0.2012 [0.12]</td>
<td>0.2452 [0.182]</td>
<td>0.3844 [0.182]</td>
<td>0.4085 [0.198]</td>
<td>0.4126 [0.230]</td>
<td>0.1920 [0.148]</td>
<td>0.2335 [0.148]</td>
</tr>
<tr>
<td></td>
<td>Stretch</td>
<td>0.2795 [0.183]</td>
<td>0.2331 [0.173]</td>
<td>0.3734 [0.199]</td>
<td>0.4117 [0.213]</td>
<td>0.4186 [0.241]</td>
<td>0.1985 [0.109]</td>
<td>0.3585 [0.206]</td>
</tr>
</tbody>
</table>

Figure 15. Stretch effect on EMG amplitude (% of max)

The mean and standard deviation of the Borg perceived exertion responses are shown in Table 2. The mean response for the stretch condition was higher than the control condition.
5.2 EMG Results

The statistical model used for the analysis of EMG muscle responses is presented in Equation 2.

Equation 2. Statistical model for EMG Maximum amplitude response

\[
y(\text{muscle response}) = \\
\mu + \text{Participant}[\text{Group}] + \text{Group} + \text{Stretch} + \text{Trial} + \\
\text{Task Type} + \text{Stretch} \times \text{Trial} + \text{Stretch} \times \text{Task Type} + \\
\text{Trial} \times \text{Task Type} + \text{Stretch} \times \text{Trial} \times \text{Task Type} + \text{Error}
\]

JMP Pro 12 imposes a zero-sum constraint on the model which ensures that the effects across all levels of the nominal predictors sum to zero. Although this constraint implies that there are no other levels of the selected independent variables introduced as part of the experiment, the JMP analysis has the capability to reveal limitations of models in terms of lack of specification of “third variables” that might otherwise account for additional fractions of response variability. Table 3 presents ANOVA results (significance levels) for effects tests for each muscle response. The null hypothesis for all tests was equivalence of condition

<table>
<thead>
<tr>
<th>Mean [Standard Deviation] of Borg Responses by Stretching Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Stretch</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Table 2. Mean (SD) of Borg responses by stretch conditions
means. The significance level for the study was set to $\alpha=0.05$, which is a common significance level for EMG studies (e.g., Sekir et al., 2010; Power et al., 2004). P-values smaller than the significance level were interpreted as the rejection of the null hypothesis. Exploration of effect details was conducted to validate whether statistical rejection was in support of, or opposite to, stated hypotheses. P-values coded in “green” are of statistical significance and are in support of hypothesis (H1). P-values coded in “red” are of statistical significance but are opposite to hypothesis. P-values coded in “orange” are significant factors but not addressed by experiment hypothesis. P-values coded in blue are statistically significant findings on “nuisance” variables, such as observed ordering effects, which were also not addressed by hypothesis, and are not discussed further.

**Table 3. ANOVA results of model components for each muscle response**

<table>
<thead>
<tr>
<th>Model Components</th>
<th>Trapezius</th>
<th>Medial Deltoid</th>
<th>Extensor</th>
<th>Flexor</th>
<th>Biceps</th>
<th>Triceps</th>
<th>Anterior Deltoid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant[Group]</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Group</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Stretch</td>
<td>&lt;.0001</td>
<td>0.5654</td>
<td>0.0464</td>
<td>0.5995</td>
<td>0.2111</td>
<td>0.3701</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Trial</td>
<td>0.009</td>
<td>0.0029</td>
<td>0.0004</td>
<td>&lt;.0001</td>
<td>0.568</td>
<td>0.2501</td>
<td>0.4017</td>
</tr>
<tr>
<td>Task Type</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Stretch*Trial</td>
<td>0.6916</td>
<td>0.3718</td>
<td>0.4983</td>
<td>0.3853</td>
<td>0.3184</td>
<td>0.2961</td>
<td>0.1541</td>
</tr>
<tr>
<td>Stretch*Task Type</td>
<td>0.9153</td>
<td>0.3492</td>
<td>0.1961</td>
<td>0.5744</td>
<td>0.4648</td>
<td>0.3353</td>
<td>0.8395</td>
</tr>
<tr>
<td>Trial*Task Type</td>
<td>0.7864</td>
<td>0.4828</td>
<td>0.4348</td>
<td>0.5186</td>
<td>0.0134</td>
<td>0.9078</td>
<td>0.2594</td>
</tr>
<tr>
<td>Stretch<em>Trial</em>Task Type</td>
<td>0.7373</td>
<td>0.109</td>
<td>0.8743</td>
<td>0.7773</td>
<td>0.5852</td>
<td>0.513</td>
<td>0.4235</td>
</tr>
</tbody>
</table>

**5.2.1 Stretching Effects**

Table 4 presents ANOVA results on the effect of the stretching condition on muscle activation level for various muscles as well as the trend of findings. In general, three major muscles were found to be statistically significant in response to the exercises. The trapezius, extensor, and anterior deltid were found to be significantly different in response among the
stretch and control conditions. Further investigation into the condition variations for each muscle revealed that the trapezius and anterior deltoid (Figures 19 and 20, respectively) responded counter to the hypothesis (H1).

Figure 17. Stretch effect on trapezius EMG amplitude (% of max)

Figure 16. Stretch effect on anterior deltoid EMG amplitude (% of max)
The extensor was the only muscle whose responses to the stretch routine supported the stated hypothesis (H1; p=0.0454; see Figure 21).

<table>
<thead>
<tr>
<th>Muscle</th>
<th><strong>Stretch Effects</strong></th>
<th>ANOVA Statistics</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezius</td>
<td>F(1, 734) = 28.2341</td>
<td>p&lt;.0001</td>
<td>Stretch &gt; Control</td>
</tr>
<tr>
<td>Extensor</td>
<td>F(1, 734) = 3.9792</td>
<td>p=.0464</td>
<td>Control &gt; Stretch</td>
</tr>
<tr>
<td>Anterior Deltoid</td>
<td>F(1, 734) = 19.7711</td>
<td>p&lt;.0001</td>
<td>Stretch &gt; Control</td>
</tr>
</tbody>
</table>

5.2.2 Task Type Effects
Table 5 presents ANOVA results and trend analyses on the effect of gas delivery task type on muscle EMG responses. In general, all muscles activation levels appeared to significantly influenced by the task manipulation (p<.0001). Post-hoc (Tukey’s) analyses were conducted for each muscle response to identify task type trends. The Table summarizes the comparative
intensity of the work tasks, including lifting small cylinders (L), rolling cylinders (R) and pulling dewars (P). The table makes clear that lifting was consistently the most demanding task across all muscles, while pulling dewars elicited the least amount of muscular effort.

Table 5. Significant task type effects and post hoc analysis results

<table>
<thead>
<tr>
<th>Muscle</th>
<th>ANOVA Statistics</th>
<th>Tukey Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezius</td>
<td>F(2, 734)=73.0945, p&lt;.0001</td>
<td>L&gt;R&gt;P</td>
</tr>
<tr>
<td>Medial Deltoid</td>
<td>F(2, 734)=47.2561, p&lt;.0001</td>
<td>L≈R&gt;P</td>
</tr>
<tr>
<td>Extensor</td>
<td>F(2, 734)=146.0054, p&lt;.0001</td>
<td>L&gt;R&gt;P</td>
</tr>
<tr>
<td>Flexor</td>
<td>F(2, 734)=239.4858, p&lt;.0001</td>
<td>R&gt;L&gt;P</td>
</tr>
<tr>
<td>Bicep</td>
<td>F(2, 734)=139.1786, p&lt;.0001</td>
<td>R&gt;L&gt;P</td>
</tr>
<tr>
<td>Triceps</td>
<td>F(2, 734)=11.3088, p&lt;.0001</td>
<td>L≈R&gt;P</td>
</tr>
<tr>
<td>Anterior Deltoid</td>
<td>F(2, 734)=49.3885, p&lt;.0001</td>
<td>R&gt;L&gt;P</td>
</tr>
</tbody>
</table>

Figure 22 presents the percentage of maximum amplitude reached by each muscle during performance of each task type across participants.

Figure 19. Task type effect on muscle amplitude (% of max)
5.2.3 Other Findings
The order of experiment trials was also found to be significant for the trapezius, medial deltoid, extensor, and flexor muscles. Post-hoc analyses were conducted for each muscle in order to identify differences among condition settings. Table 6 summarizes the ANOVA and Tukey’s test results. It is clear from the results that muscle activation levels were greatest in the first mock delivery operation across days of the study. That is to say, workers may have become more efficient in muscle use across the experiment trials with task performance being consistent (e.g., no cylinder mishandling, no drops, and no loss of control).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>ANOVA Statistics</th>
<th>Tukey Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezius</td>
<td>F(2, 734)=4.7397, p=.0009</td>
<td>1&gt;2≈3</td>
</tr>
<tr>
<td>Medial Deltoid</td>
<td>F(2, 734)=5.8850, p=.0029</td>
<td>1&gt;3≈2</td>
</tr>
<tr>
<td>Extensor</td>
<td>F(2, 734)=7.9101, p=.0004</td>
<td>1&gt;2≈3</td>
</tr>
<tr>
<td>Flexor</td>
<td>F(2, 734)=15.8458, p&lt;.0001</td>
<td>1&gt;2≈3</td>
</tr>
</tbody>
</table>

5.3 Borg Ratings
The statistical model used for analysis of the Borg survey responses is presented in Equation 3. It is important to recall that Borg ratings were only collected at the close of each mock delivery including all three task types. Therefore, it was not possible to asses a task type effect with this particular response measure.

Equation 3. Statistical model for Borg survey response

\[
y(\text{borg response}) = \mu + \text{Participant}[\text{Group}] + \text{Group} + \text{Stretch} + \text{Trial} + \text{Stretch} \times \text{Trial}
\]
Counter to hypothesis (H2), Borg ratings were significantly higher following stretching trials as compared to control trials (F(1, 30)=4.4969, p=.0423). Figure 23 presents the differences between conditions in terms of the Borg survey results. In general, stretching in advance of the mock delivery operations led to higher ratings of perceived exertion.

![Stretch Effect on Borg Scale Rating](image)

*Figure 20. Stretch effect on Borg scale rating*
6. DISCUSSION

Based on the limited findings in the literature, the first hypothesis of this study (H1) postulated that EMG maximum amplitudes for major upper-extremity muscles would decrease during experimental trials following the stretching regimen. Results were variable among muscles, with one muscle (the extensor) showing a significant decrease in maximum amplitude in trials during the stretching condition compared with the control condition (no stretching). That is, targeted stretching of the muscle may ultimately serve to reduce contraction levels in follow-on work tasks making use of the muscle as well as the potential for fatigue. Alternatively, two muscles showed significant increases in maximum activation level amplitude (trapezius and anterior deltoid), and the remaining muscles did not show any significant differences between the two conditions. In some studies of stretch effects on athletic performance, increased EMG signals were found to be beneficial in terms of performance and increases in activation level was shown to correlate with increases in muscle strength and force output (Sekir, et al., 2010). However, the increase in EMG maximum amplitude of the trapezius and anterior deltoid could indicate a quicker path to fatigue for gas delivery operators for those muscles.

With respect to the design of the driver exercise program, the original intent was to specify and test a stretching routine that could be implemented before work at every delivery site throughout the course of a work day. In an attempt to follow widely supported stretching practices, and to ensure all at-risk, eccentrically contracted and frequently used muscles were targeted by stretching, Morejon (2016) created a regimen that was approximately 17 minutes in duration. During the experiment, participants expressed interest in including a stretch
routine in their daily work shift and believed it would be beneficial in terms of follow-on task performance and job safety. However, due to duration of the stretches, operators did not consider the designed regimen practical for performance at each delivery point throughout a work day but possible once a day. Participants, who were all employed by the host company either as delivery drivers, driver trainers or safety professionals, all agreed that delivery drivers throughout the company would be interested in regularly implementing the stretches. Related to this, performing a subset of the identified stretches at each delivery site is a potential solution for decreasing the stretching time. Stretches could be selected based on the type of tasks to be performed during the bulk of a delivery. For example, at a customer site requiring multiple helium cylinders to be delivered, drivers could perform the chest and bicep stretch and the flexor stretch, targeting the biceps, anterior deltoid, and flexor – muscles that are highly activated during rolling cylinders. The total stretching time for this reduced regimen would amount to approximately 3 minutes and drivers might feel more prepared for work after a long truck ride to a customer site.

Although some literature suggests that acute static stretching can cause performance deficits (Young & Behm, 2003; Winchester, et al., 2008), other studies have shown that long-term, consistent static stretching improves athletic performance (Joke, 2007) and muscle strength (Guo, et al., 1992). Improved ROM, muscle lengthening, and reduced stress on ligaments and joints have also been shown as benefits of stretching (Stark, 2012) – all of which are beneficial in the prevention of overexertion injuries. It is possible that consistent, long-term application of the stretching regimen investigated here could have beneficial effects for specific muscles used in gas delivery tasks. It is also possible that observed effects
of stretching on specific muscles with trends opposite to stated hypothesis could change with muscle conditioning over time. Ryan, et al. (2008) reported an immediate increase ROM after just 2 minutes of stretching of the plantar flexor muscles, but effects wore off within 10 minutes of the stretch. The stretch routine assessed in this study was created to target individual body parts for approximately 1.5 minutes total during the entire routine. It is possible that the effect of the stretches performed at the beginning of the routine wore off prior to the start of the experimental trials. If this is true, consistent application of such stretching over time and further muscle conditioning might be necessary for observing at-work effects of the exercise.

The second hypothesis (H2) of this work posited that participants’ would perceive lower levels of exertion, in terms of the Borg CR-10 scale, when trials were preceded by stretches. However, results showed that participants’ perceived exertion levels actually increased under the stretching condition. Ratings increased from an average of 1.7, just below “weak”, to 2.8, just below “moderate”. Many participants commented throughout the experiment that the stretching regimen was physically demanding. Although data was not collected on participants’ daily exercise routines, it is important to note that on average participants were considered “obese” in terms of the Body Mass Index scale (computed based on driver height and weight). Data from the previously performed ERA (Morejon, 2016) on gas delivery operations was parsed by body part and task type. Figure 24 shows the average ratings by body part for pulling dewars, rolling two cylinders, and lifting small cylinders. The general trend of risk ratings was for higher observations for upper-body muscles as well as greater risk for appendicular muscles vs. axial.
Task type trends observed through the analysis of the EMG maximum amplitude responses revealed similar trends for the muscles of the right shoulder (trapezius, medial deltoid, and anterior deltoid), arms/elbows (bicep and triceps), and hand/wrist (extensor and flexor). Pulling dewars with those body segments was consistently rated as lower risk than rolling cylinders and lifting small cylinders, and this trend was mirrored in the post-hoc analyses on task type for EMG responses.

The highest average percentage of EMG maximum amplitude achieved by participants in the dewar task was approximately 25%. However, dewar ratings in the initial ERA assumed a much higher force requirement for that task. The liquid nitrogen dewars used in the experiment weighed upwards of 650 lbs, and as such, one would expect that pulling a dewar across a floor would require substantial muscular work. However, it was found during the experiment that once the dewar started moving across the flat concrete floor, the inertia
carried the dewar the rest of the way to the destination mark without much effort on behalf of a driver. Dewars are not always pulled on flat surfaces and pulling a dewar up a ramp would likely result in much higher muscle activation levels at the arms and back, which would more closely resemble the ERA ratings.

For the time period between January 2013 and September 2015, the gas products company reported that 34% of worker injuries resulted from overexertion. However, the maximum muscular demand levels (EMG values) observed during simulation of the common delivery tasks as part of the present study did not appear sufficiently high to be the sole contributing factor in overexertion injuries. The exceptions to this are the biceps and flexor during rolling cylinders and the extensor during lifting small cylinders, all of which exceeded 50% of maximum muscle capacity. It is likely that for other muscles, awkward and strained posture positions as well as repetitive motions may be contributing factors in the observed rate of overexertion injuries at the gas products company.
7. CONCLUSION

This study sought to assess the effectiveness of a targeted stretching regimen on reducing gas delivery operator muscle activation during follow-on work tasks, potential for muscular fatigue, and consequently risk of overexertion injury. An analysis of muscular EMG amplitude was conducted during simulated delivery operations in an effort to make appropriate recommendations for implementation of a stretching regimen at a gas cylinder delivery company. Results indicated that a stretching regimen in advance of specific manual handling activities has mixed effects on muscle activation levels across major muscles used in gas cylinder handling. One muscle showed a decrease in maximum EMG amplitude while two others showed a significant increase in maximum amplitude. Other muscles showed no significant changes in response during task performance under stretching vs. no stretching conditions. In general, it was expected that reduced muscle activation would be indicative of reduced potential for fatigue and risk of overexertion. It is highly likely that the nature of the stretching exercises (manner of muscle stretching) as well as the specific follow-on task posture positions had a substantial influence on the relevance of the stretching to muscle activation levels during the work tasks. For this reason, further refinement of the stretching regimen, based on task performance demands may be merited.

There is clear evidence in the literature of long-term benefits of consistent static stretching including increased ROM, muscle lengthening, and stress reduction on ligaments and joints – all of which are beneficial in the prevention of overexertion injuries. Furthermore, many workplaces with stretch programs have identified decreases in worker pain rates and severity, improved worker commitment to safety, and reduced days away due
to work-related pain and injuries, among others. It is possible that implementation of the stretching regimen investigated in this study over an extended period time might serve to reduce activation levels for broader range of muscles during follow-on gas delivery operations.

Considering the findings of the current experiment in conjunction with the relevant literature, the following recommendations are made for potential implementation of the muscle stretching routine for gas products delivery operations:

1. Workers should perform the stretch routine one time daily, in its entirety, preferably at the beginning of the work shift. Consistent adherence to the program may lead to greater benefits in terms of muscle conditioning and reduced potential for overexertion injury.

2. It is suggested that workers perform a small subset of stretches targeting muscles most commonly used during tasks to be performed at specific delivery sites.

7.1 Practical Limitations
It is possible that the experiment results could have been impacted by the small sample of workers (n=7) participating in the study. All participants were experienced in gas delivery operations and were voluntarily recruited from the host gas products company. Some of the participants were not current delivery operators and the diversity of the sample size might have also contributed to variations in the muscle responses. It is possible that a larger sample size with more consistent demographics could have yielded different results.

The stretching routine designed for this study took 17 minutes to complete. Completing the routine one time daily might be feasible and could prove to be cost beneficial
to the company if the implementation served to reduce injury rates and severity. However, if drivers have a high number of deliveries in a day and perform the stretching regimen at every stop, the regimen would likely interfere with delivery schedules and it is possible that more time would be spent stretching than performing job duties.

7.2 Future Work

Follow-on studies to the present investigation should analyze any changes in worker injury rates and severity following the implementation of the stretching program. The workplace stretch regimen may need to be modified as drivers’ muscles adjust to the stretches over time. It would also be worthwhile to conduct a longitudinal investigation for any potential changes in muscle activation levels over time as a result of consistent application of the stretching regimen.
REFERENCES


Herda, T. J., Cramer, J. T., Ryan, E. D., McHugh, M. P., & Stout, J. R. (2008). Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and


Appendix A: ERA

Ratings guide for the Industrial Ergonomics Screening Tool created by The Ergonomics Center of North Carolina

<table>
<thead>
<tr>
<th>Motion Ratings</th>
<th>Force Ratings</th>
<th>Posture Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low</strong></td>
<td><strong>Low</strong></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Moderate</strong></td>
<td><strong>Moderate</strong></td>
<td><strong>Moderate</strong></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td><strong>High</strong></td>
<td><strong>High</strong></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>9</td>
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<tr>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>General Situation</strong></th>
<th><strong>Motion Ratings</strong></th>
<th><strong>Force Ratings</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

**Ergonomic Risk**: Rating scale 1 = Low, 2 = Moderate, 3 = High

**Posture**: 1 = Acceptable, 2 = Uncomfortable, 3 = Unhealthy
Appendix B: Stretching routine as used in the experiment.
Originally published by Morejon (2016).

1. Stretch one arm above head. Bend arm at elbow, bring hand behind head/neck. Using opposite arm grab bent elbow, pull behind head towards opposite shoulder. Bend shoulder at waist, leaning torso in direction of stretch. Repeat on opposite side.
   - Duration: 20 seconds
   - Repetition: 3 times per side

2. Bring one arm straight across chest at shoulder height and grab truck for support. Twist torso toward the arm. Repeat on opposite side.
   - Duration: 20 seconds
   - Repetition: 3 times per side

3. Bring one outstretched arm out to the side at shoulder height and grab truck for support. Twist torso away from arm. Repeat on opposite side.
   - Duration: 20 seconds
   - Repetition: 3 times per side

4. Stretch arm in front of body. Bend hand at wrist with fingers pointing downward, palm facing body. Use opposite hand to pull fingers towards body. Repeat on opposite side.
   - Duration: 20 seconds
   - Repetition: 3 times per side

5. Stretch arm in front of body. Bend hand at wrist with fingers pointing upward, palm facing away from body. Use opposite hand to pull fingers towards body. Repeat on opposite side.
   - Duration: 20 seconds
   - Repetition: 3 times per side

   - Duration: 20 seconds
   - Repetition: 3 times

7. Standing on left foot while holding truck for support. Bend right leg at knee. Use right hand to grab right foot, pull towards buttocks.
   - Duration: 20 seconds
   - Repetition: 3 times per side

8. Bend at hips. Touch toes, if possible.
   - Duration: 20 seconds
   - Repetition: 3 times
Appendix C: Borg CR-10 Scale

Borg CR10 Scale (1982)\textsuperscript{12}

0  Nothing at all
0.5 Extremely weak (just noticeable)
1  Very weak
2  Weak (light)
3  Moderate
4  Somewhat strong
5  Strong (heavy)
6
7  Very strong
8
9
10 Extremely strong (almost max)
   * Maximal
Appendix D: Demographic surveys and anthropometric data collection form

Demographic Survey

Age: ______

Job Title: ______________

Length of time in this job position: ____________ (years, months)

Delivery operations part of job duties? Yes / No (circle one)

Typical shift length: ____________ (hrs)

Typical number of days at work per week: ___________

Typical amount of hours spent delivering in one work shift (do not include time spent driving): ____________

(Optional) Have you ever been injured on the job? Yes / No (circle one).

If yes, please describe the nature of your injury:

___________________________________________________________________________

___________________________________________________________________________

__________

Demographic Survey Cont.

Has your job role ever included delivery operations?

During these delivery operations did you handle: (check all that apply)

□ Rolling Cylinders?
□ Pulling Dewars?
□ Lifting Small Cylinders?

For how long were you involved in delivery operations?

How long ago was your last delivery?
Have you ever worked as a gas cylinder deliverer at a company other than Praxair?

If so, did your delivery operations include: (check all that apply)

☐ Rolling Cylinders?
☐ Pulling Dewars?
☐ Lifting Small Cylinders?

How long were you in that job role?

How long ago was your last delivery for that company?

_________________________________________

**Anthropometric Data Collection Form**

Stature: _____________ cm

Seated Height: _____________ cm

Hand Length: _____________ cm

Seated Shoulder Height: _____________ cm

Shoulder to Elbow Length: _____________ cm

Elbow to Wrist Length: _____________ cm
Appendix E: Electrode Placement

- Trapezius
- Bicep
- Medial Deltoid
- Triceps
- Extensor
- Anterior Deltoid
- Flexor
- Erector Spinae
Appendix F: MVC Procedures

All MVC procedures described below were performed for 3-5 seconds and repeated three times.

*Trapezius:*

Participant stood upright on a dynamometer. The handle was placed such that participant could grab it without bending their back. On the researchers command, participant shrugged their shoulders towards their ears as hard as possible.

*Medial deltoid:*

Standing upright with feet shoulder length apart, participant gripped a 1 inch diameter stick at their side with palm facing inward. A researcher applied resistance to the stick while participant attempted to lift arm laterally.

*Extensor:*

Participant was seated at a table. Seat was adjusted such that participant’s elbow was flush with the table surface. Elbow was bent at 90° and arm was resting on table with palm facing downward. Participant gripped a 1 inch diameter stick in the center and forcefully lifted it up by bending their wrist while a researcher applied equal pressure on the stick in the opposite direction.

*Flexor:*

Participant was seated at a table. Seat was adjusted such that participant’s elbow was flush with the table surface. Elbow was bent at 90° and arm was resting on table with palm facing upward. Participant gripped a 1 inch diameter stick in the center and forcefully lifted it
up by bending their wrist while a researcher applied equal pressure on the stick in the opposite direction.

*Bicep:*

Participant stood upright with palm facing forward while gripping a 1 inch diameter stick. Participant bent arm at elbow to 90°. Researcher applied downward force to stick once elbow reached 90° angle while participant attempted to perform a bicep curl.

*Triceps:*

Standing in an upright position with arm at 90° angle and palm facing inward, participant gripped a 1 inch diameter stick and attempted to straighten arm. A researcher applied resisting force on the stick to keep arm at 90°.

*Anterior deltoid:*

Participant stood upright approximately 1 foot from a wall. Participant bent elbow to 90°, raised shoulder laterally to 90°, and placed palm flat against the wall. Participant then attempted to forcefully push the wall with their palm.