ABSTRACT

MOREJON, OLIVIA NICOLE. Ergonomic Risk Assessment of Gas Delivery Operations and Job Readiness Recommendations (Under the direction of Dr. David Kaber).

Performing manual material handling tasks often exposes workers to injury. This study focused on risk exposure and injury prevention for product delivery drivers in an industrial gases company. An analysis of company recorded injuries (2013 - September 2015) revealed a set of 157 incidents, which was comprised as 34% overexertion injuries. These injuries primarily affected the hands/fingers/wrist, the arm/shoulder, or the back of workers. Further analysis revealed the hands/fingers/wrist injuries to primarily (43 of 48) result from being struck against an object, or compressed or caught in equipment. On this basis, the present study conducted an assessment of manual material handling tasks to identify body segments most exposed to ergonomic risks and to make recommendations for preventing potential injuries.

The study consisted of two parts. The first part involved developing a hierarchical task analysis for delivery duties of drivers, based on direct observations of task performance, videos capturing driver performance, and safety videos detailing standard company operating procedures. The second part of the study was an ergonomic risk analysis of those tasks posing the greatest number of risk factors for operators. Results revealed job screening scores for each of the tasks. Among all gas product delivery tasks, pulling a dewar (600-1000 lbs. cylinder), rolling two cylinders (by hand), and manually lifting small cylinders were found to pose the highest risk scores. Body segment risk levels were also determined for each of these tasks with results indicating priority for the back, shoulders, arms/elbows, and hands/wrists. These results corresponded with the results of the OSHA injury analysis.

Based on the ergonomic risk analysis and the OSHA injury analysis, the tasks and the body segments with the highest priority for ergonomic interventions were compiled. Recommendations were made for a job-readiness program, including muscle stretches in advance of manual material handling and a reminder card illustrating the stretches. The stretches included in the program were designed to target those muscles used in high risk tasks and in moving at-risk body segments. The reminder card was pilot tested for usability and identified issues were addressed in a final design.

Ergonomic Risk Assessment of Gas Delivery Operations and Job Readiness Recommendations

by
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BIOGRAPHY

Olivia Morejon was born in Memphis, TN on June 6, 1992. She grew up in Ormond Beach, FL. In August 2010, she started her undergraduate degree at the University of Miami. She graduated with a Bachelor's of Science in Industrial Engineering from the University of Miami's program in May 2014. After graduation, she decided to continue her education and enroll in a masters program at North Carolina State University's Edward P. Fitts Industrial & Systems Engineering Department. She was supported in her studies by a traineeship through the National Institute for Occupational Safety and Health (NIOSH). She will graduate with a M.S.I.E. in August 2016.

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1. Introduction

In manual material handling (MMH) tasks, workers are often at risk for musculoskeletal diseases (MSDs), as well work-related injuries. This study examined compressed gas cylinder delivery operations involving various types of cylinders and handling at customer sites. Throughout a typical workday, gas cylinder delivery drivers handle a variety of cylinder types, including: small oxygen tanks weighing approximately 10 lbs., cylinders containing nitrogen or propane that weigh about 35-70 lbs., larger liquid "dewars" that weigh up to 1,200 lbs. In performing delivery duties, drivers often must exert high forces on cylinders and lifting equipment. Their bodies are often put into awkward posture positions, exposing them to ergonomic hazards.

An analysis of delivery company recordable injuries over a 2-year period revealed trends of MSDs specific to the company and workers. Common injury types included falls and compression injuries, as well as injuries due to overexertion. Ergonomic risk factors, such as repetition of tasks, high forces and awkward postures, can contribute to such MSDs. On this basis, an ergonomic risk assessment (ERA) of the delivery operations was conducted as part of the present study.

Ergonomic interventions can help reduce exposure to job risk factors. The delivery company previously implemented several interventions, including requiring handcarts for moving cylinders longer than a certain distance and supplying all drivers with personal protective equipment (PPE), such as gloves and metatarsal boots. Subsequently, the company approached North Carolina State University to help design a job readiness program to further mitigate ergonomic risk exposure. The program was to include a muscle stretching protocol and exercise reminder card. The stretching protocol was to target muscles used in high ergonomic risk tasks performed by employees on a daily basis. The job readiness program is also documented in this thesis.

1.1. "Ride-Alongs"

In order to identify gas delivery operation tasks posing high ergonomic risks, delivery "ride-alongs" were organized for researchers to view daily driver work. Two ride-alongs were organized for the researchers, including observation of one driver employed at a nearby delivery facility. An additional driver was also observed moving product at the delivery facility. In total, 10-12 deliveries were observed and videotaped. Prior to the ride-alongs, the researchers familiarized themselves with the standard operating procedures (SOPs) of the gas delivery company by viewing company training videos. Researchers then accompanied drivers as they made deliveries during 8-12 hrs. shifts. The researchers did not handle any of company equipment or products on ride-alongs and were provided with personal protective equipment (PPE), as a precautionary measure, to prevent any possible injury.

During the ride-alongs, the researchers videotaped the drivers performing their delivery duties. Tasks included moving cylinders with a handcart, rolling a cylinder, rolling two cylinders, pushing dewars, loading and unloading propane tanks, and transporting small cylinders, among other tasks. The videotapes also allowed the researchers to determine aggregate task times as well as levels of repetition after the ride-alongs.

In general, the observations from the ride-alongs revealed the manual material handling tasks to pose ergonomic risks for operators. Furthermore, the video analysis revealed specific tasks to pose extended periods of risk exposure and repetition, motivating the need for additional evaluation.

1.2. Motivation for Study

In MMH operations, overexertion injuries can plague workers. These injuries can lead to significant time away from work or on restricted duty, costing companies money (Choi & Woletz, 2010). One approach to identifying the impact of MMH operations on worker health is to perform an analysis of Occupational Safety and Health Administration (OSHA) injury and illness summary (300) logs for a company. These logs can reveal the frequency of occurrence of injuries as well as the severity of outcomes. Some measures of severity include worker days away and days on restricted duty. Beyond this, various formal methods of ergonomic risk analysis (ERA) can be used to identify the presence and intensity of specific ergonomic risk exposure in jobs with high frequency and severity of recordable injuries. Such ERAs can be organized by using hierarchical task analyses (HTA) for breaking-down a job into steps and operations and identifying risk factors for each step, etc. Use of these methods can support identification of ergonomic interventions to help mitigate risk exposure, such as the use of handcarts or requiring PPE.

On this basis, the present study involved: (1) review of gas delivery company OSHA logs and analysis for injury/illness trend identification; (2) a hierarchical task analysis (HTA) for decomposition of gas delivery operations; (3) an ERA on driver delivery tasks for high risk exposure identification; and (4) recommendation of specific types of ergonomic interventions for risk exposure reduction, including a muscle stretching program and safety reminder card.

2. OSHA Injury Analysis

All U.S., companies with 11 or more employees (influencing interstate commerce) are required by law to record specific types of occupational injuries and illnesses (29 CFR 1910.146). One form used for recording purposes is the OSHA 300 log. This log is used to capture recordable injuries, i.e. injuries that require medical care beyond first aid, as well as injuries resulting in deaths, days away from work, or restricted duty. For the present study, this information was requested from the gas delivery company. The company responded with approximately 2 years of data for analysis. Records included injury date, a description of the injury, a total number of worker days away, and a total number of worker days on restricted duty. All records were reviewed and injury descriptions were categorized in order to facilitate some statistical and trend analyses. In general, we classified the types of injuries occurring within the company as well as the body parts and areas impacted by incidents. The categories for the injury type and the body part affected classifications were taken from the categories used in the Liberty Mutual Annual Occupational Injury and Illness Index.

The statistical and trend analyses applied to the codified injury data included the following: 1) descriptive statistics on the severity of injury cases, 2) histograms on worker days away and days on restricted duty, and 3) Pareto analysis to identify the most significant categories of injuries and body parts for targeting ergonomic interventions.

2.1. Descriptive Statistics

The gas delivery operations worker injury/illness database was initially analyzed using descriptive statistics. A summary is presented in Table 1. The analysis was conducted with a subset of data from 2015. Related to this, in the course of any injury/illness recording period, there may be open cases for which the final number of worker days away or days on restricted duty have yet to be recorded. The total number of cases include in the dataset for analysis was 157. Of these cases, 10.8% and 62.4% involved days away or restricted duty for the injured employee, respectively. Of the cases that involved days away, the average duration was 51.7 days. In the cases with restricted duty, the average duration was 21.4 days.

Total Number of Cases (2013-Sept. 2015)	157
Percentage of cases involving days away (Count)	10.8% (17)
Percentage of cases involving restricted duty (Count)	62.4% (98)
Average number of days away	51.7
Average number of days on restricted duty	21.4

Table 2.1: Descriptive Statistics

2.2. Histogram Analysis of Injuries

Histograms were generated on the worker days away and restricted duty counts for various levels of injury severity. Figure 2.1 shows the distribution of values for the days away cases and Figure 2.2 presents the distribution for the restricted duty cases. The plots reveal the numbers of cases involving between 1 and 6 months away from work or on restricted duty. In general, it can be observed that most cases resulted in less than 1 month of days away with a few more significant injuries requiring more days away for recovery.

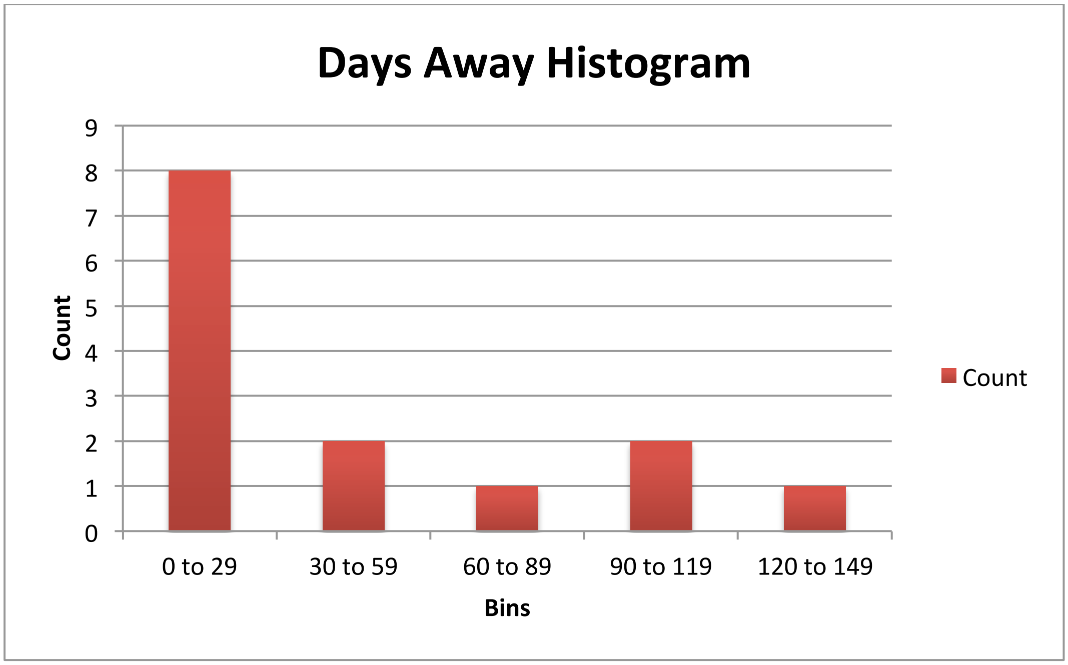

Figure 2.1: Days away histogram

Cases involving restricted duty were more common than cases involving days away from work (67.4% vs. 10.8%). As can be seen in the plot in Figure 2.2, the majority of these cases involved restricted duty of less than 1 month.

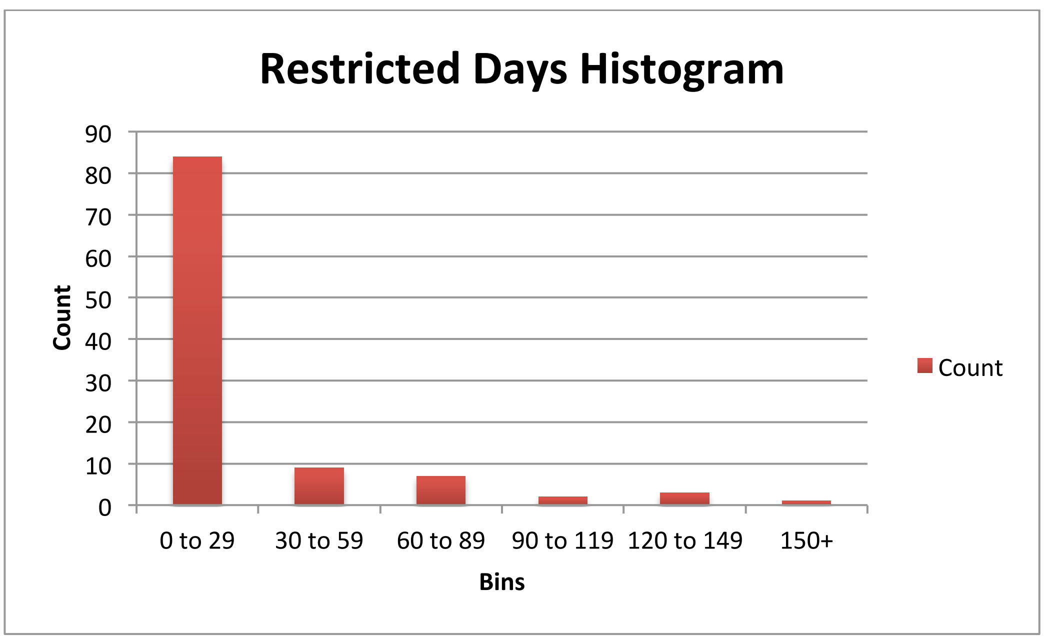

Figure 2.2: Restricted days histogram

2.3. Pareto Analysis

2.3.1. Injury Type

Based on the injury case descriptions include in the gas delivery company's OSHA 300 logs, each injury event was coded according to the categories presented in Table 2. The categories were taken from the categories used in the Liberty Mutual Index. Due to a lack of information recorded in some of the descriptions as part of the company's logs, similar categories were grouped together in the Pareto analysis. Grouped categories included: (1) overexertion and other exertions or bodily reactions, (2) struck by object or equipment and struck against object or equipment, and (3) falls at the same level and falls to a lower level. In general, initial descriptions of incidents should include more comprehensive information to allow for proper categorization and more thorough analysis of injury data. (This recommendation was made to the gas delivery company.)

Category	Code
Overexertion	A
Falls on same level	B
Struck by object or equipment	C
Falls to lower level	D
Other exertions or bodily reactions	E
Roadway incidents involving motorized land vehicle	F
Slip or trip without fall	G
Caught in/compressed by equipment or objects	H
Repetitive motions involving micro-tasks	I
Struck against object or equipment	J
Not enough info./ not classified	X

Table 2.2: Liberty Mutual Index of Injury Categories

As can be seen in Figure 2.3, overexertion and other exertions account for 34% of the total injury cases, more than any other category. It is important to note that in this analysis, 14 injury cases were classified as, "Not enough information," due to a lack of sufficient incident descriptions in the OSHA 300 logs. On the basis of this analysis, and the prevalence of overexertion injuries, it was inferred that an exercise or stretching program, in advance of strenuous MMH task performance, might be an appropriate tool for further promoting worker safety in the gas cylinder delivery operations.

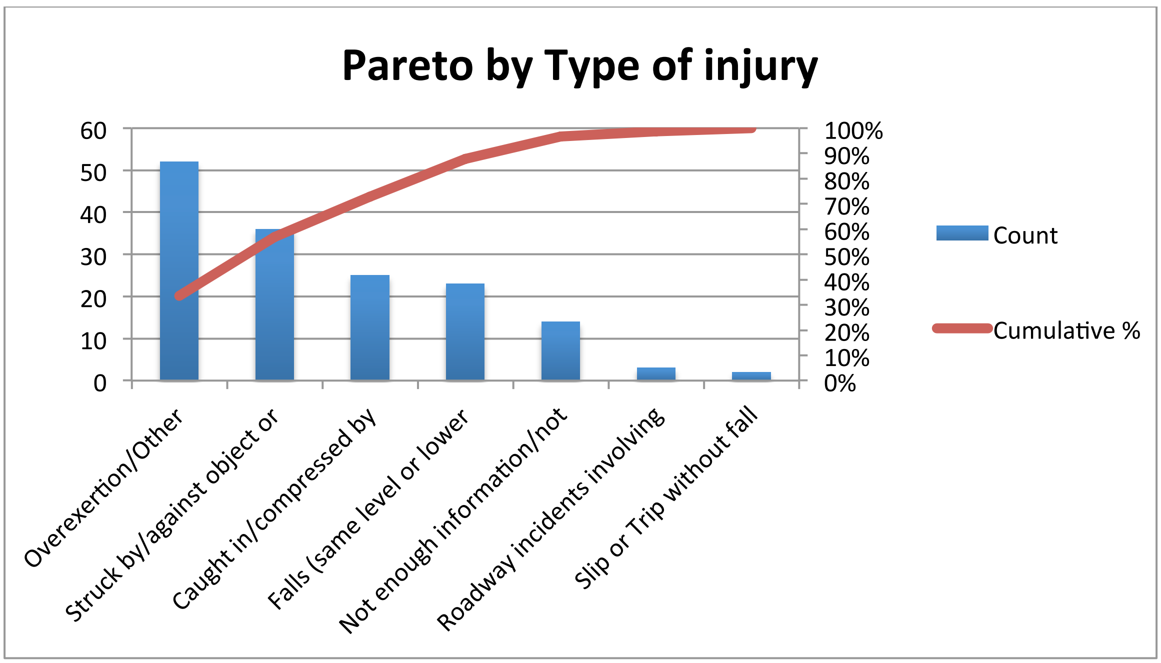

Figure 2.3: Pareto Graph for Type of Injury

2.3.2. Body Parts Affected

Based on the descriptions included in the OSHA 300 logs, each gas delivery company worker injury case was also coded according to the body parts affected in an incident. The codes presented in Table 3 were used for this purpose. The categories in the table were also pulled from the list of categories used in the Liberty Mutual Index.

Category	Code
Head/CNS (central nervous system)	A
Neck	B
Leg	C
Hip/Thigh/Pelvis	D
Arm/Shoulder	E
Lower Back	F
Upper Back	G
Chest/Organs	H
Knee	I
Face	J
Ankle	K
Foot/Toes	L
Multiple Trunk/Abdomen	M
Hands/Fingers/Wrist	N
Multiple	O
Not enough information	X

Table 2.3: Liberty Mutual Index of Body Part Codes

Due to a lack of information in some of the injury descriptions as part of the OSHA 300 logs, injuries involving similar body parts or anatomically adjacent body parts were grouped together in the Pareto analysis. Combined categories included: (1) upper and lower back, and (2) head/CNS and face. Again, more accurate descriptions in the initial report of incidents would allow for proper categorization and more accurate analysis of injury data.

Based on the Pareto analysis (see Figure 2.4), the most injured body parts included the hands/fingers/wrist. Most of these injuries (43 of 48) were due to being struck against an object, or compressed by or caught in equipment. The next two most commonly injured body parts, the arm/shoulder and the back, were primarily impacted by overexertion accidents. It is important to note that in this analysis, 13 injury cases were classified as, "Not enough information," due to limited descriptions in the OSHA 300 logs. On the basis of this analysis, and the prevalence of injuries at the hands/fingers/wrists, arms/shoulders and back, it was inferred that any exercise or stretching program, shoulder target those muscle involved in movement of the identified body parts in order to further promote worker safety in the gas cylinder delivery operations.

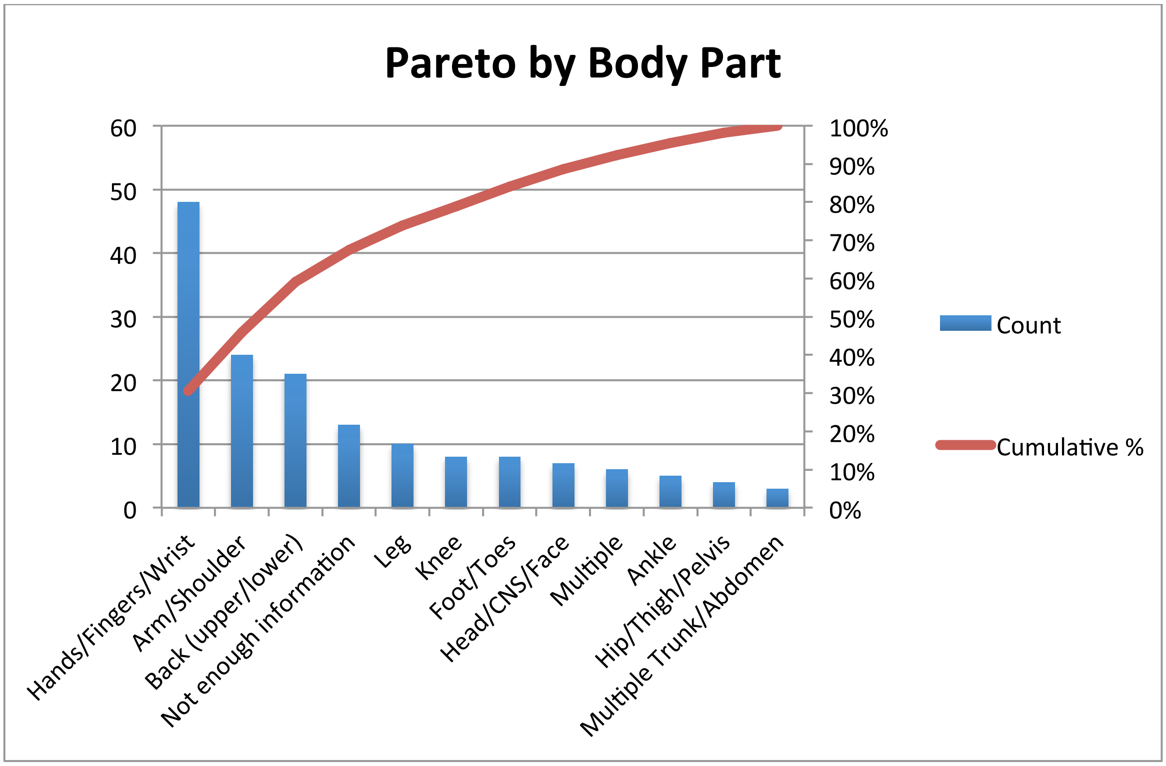

Figure 2.4: Pareto Graph for Body Part Affected

3. Literature Review on Job-Readiness Programs

3.1. Corporate Exercise programs

3.1.1. Design

Many corporate exercise programs have been designed to combat occupational injuries and illnesses, as well as improve the overall health of the workforce. This section provides a review of literature on the development of exercise programs for workforces and the design of specific aspects of programs.

A number of studies have focused on the design of corporate exercise programs or provided reviews of programs in order to formulate general design recommendations. Drennan & Edwards (2012) identified five processes essential to developing programs including strength and flexibility exercises (SAFE). The intention of these programs is to improve the overall health of the workforce. The first process is to manage provide flexibility in employee schedules, such that they have enough time during work to perform the exercises and adhere to the program. The second process that Drennan & Edwards (2012) recommended is to provide employees with feedback on their progress by taking periodic measurements on exercise performance. The third process that Drennan & Edwards (2012) recommended is to shape employee behavior and promote fitness with progressive exercises, meaning that they recommend that programs account for increasing fitness goals for employees. The fourth recommended process is to motivate the workforce by making learning and exercise fun. The authors suggested that motivation can be accomplished through some sort of contest or reward system. The last recommended process was to audit the exercise program frequently, making changes to continuously improve the program and the fitness of the workforce.

Huhn & Volski (1985) also made recommendations for designing a corporate exercise program. They recommended that the development of a program be divided into five sections, including: (1) a history questionnaire, (2) an evaluation, (3) a consultation, (4) performance, and (5) a progress assessment. Similar to Drennan & Edwards (2012), they recommend that any program include an assessment process to account for employee improvement. Huhn & Volski also provided a list of characteristics of successful corporate exercise programs that they had observed. Included on the list was the recommendation to involve top-level management in creating the program. The authors also recommended a strengthening and flexibility program along with endurance exercises and recreational activities. Their recommendations also included a performance agreement for participants with exercise logs and an optional competition aspect with a small award.

In a review of literature regarding the benefits of implementing a stretching program, McGillis (2015) identified common characteristics of successful stretching programs. McGillis said that stretches should target a specific set of tasks and exercises should create a balance in the muscles by stretching in the opposite direction of the work being performed. Mortensen et al. (2014) supported this recommendation with their study finding success of an exercise program targeting muscles used by a workforce. Beyond this, McGillis (2015) noted that exercise program success was also attributable to employees taking ownership of the program.

Like Huhn & Volski (1985), Strauss (1992) addressed how a corporate exercise program could be designed for corporate employees. Similar to Mortensen et. al. (2014) and

McGillis (2015), Strauss (1992) recommended designing corporate exercise programs to address the specific needs of a target worker population (i.e., targeting specific muscles based on worker tasks) and the goals of the program. Strauss (1992) presented a set of rules for designing expert corporate fitness programs. The rules categorized workers based on specific characteristics and made recommendations for exercise programs for individuals. For example, when considering a worker's age, Strauss (1992) recommended that older workers (60-65) should begin exercise with a longer warm-up period and pursue a lower intensity workout.

Studies have also provided specific guidelines for duration and repetition of exercises or stretches as part of exercise programs. O'Sullivan, Murray, & Sainsbury (2009) examined the effects of warm-up, static stretching, and dynamic stretching on hamstring flexibility. Participants were assigned to a control group (warm-up only), a static stretching group, or a dynamic stretching group. Passive knee extension range of motion was measured at baseline (before warm-up), after the warm-up, and after exercise intervention. The study developed a program for the participants that involved stretches being carried out for 30 seconds each and repeated three times on each leg.

Some articles, like Faville (1996), have presented case studies of a particular company implementing a corporate exercise program. Faville (1996) described the approach that the Boeing Company's Everett Division chose to take during the development of their ergonomics program. As a part of their overall ergonomics program effort, the company developed and implemented a corporate exercise program. Like Huhn & Volski (1985) and Drennan & Edwards, the program described in Faville (1996) relied on the involvement and support of both management and employees. In addition, similar to McGillis (2015) and

Mortensen et. al. (2014), the program described by Faville (1996) was designed to specifically target muscles used by the workers in the task. In this case, exercises were developed to stretch and strengthen the back muscles. The Boeing Company also provided a back anatomy and training class to cover the mechanics of the back and proper lifting techniques to accompany their exercise program. The production shops within Boeing were encouraged to perform the stretches at the beginning of a shift; however, participation in the program fluctuated and was not recorded. Due the lack of records on participation, the effectiveness of the program was not determined.

Smith (1994) reviewed literature regarding stretching with the aim of defining its role during an exercise warm-up. The article presented guidelines for stretching for development of an effective corporate exercise program. The guidelines, similar to the recommendations from Faville (1996), McGillis (2015) and Mortensen et. al. (2014), propose designing developing a stretching routine that is suitable to the specific needs of the person. However, Smith (1994) made recommendations on how stretching should be performed. The article recommends performing the stretching routine 15-20 minutes before work is to be completed and performing slow, static stretches. Smith (1994) also makes more specific recommendations regarding duration and repetition of the stretches; specifically, that stretches should be held for 15-20 seconds and each muscle group should be stretched 3-5 times. Smith (1994) also makes recommendations to stretch agonists and antagonists alternatively and to stretch consistently for the best results.

3.1.2. Effectiveness of Exercise Programs

While many corporate exercise programs have been implemented in companies, their relative effects remain a question. This section reviews literature examining the effectiveness of corporate exercise programs in reducing injury rates in the workforce.

Most exercise program effectiveness analyses have focused on specific applications within industry. This review covers studies that have implemented a corporate exercise or stretching program for a specific worker population. For example, Bertozzi et. al. (2015) assessed the effectiveness of an exercise program designed to reduce MSDs in slaughter houses in the poultry industry. The study recruited 40 workers who had a diagnosis of non-specific back pain for at least 3 months. The participants were split into two groups, including an intervention group and a control group. The intervention group was assigned a program of exercises and body weight exercises over 10 treatment sessions, as well as an at home exercise program. Demographic information was collected on the participants, including height, weight, Body Mass Index (BMI) and lifestyle information. The study looked at perceived level of disability as an outcome measure, assessed by two self-administered evaluation scales, including the Roland Morris Disability Questionnaire (RMDQ) and the Oswestry Disability Index (ODI). The study also evaluated lumbar physical discomfort using a pain drawing associated with a Visual Analog Scale (VAS). Results of the study showed that there was a significant decrease in pain in the lumbar region and a near significant reduction in disability. These results demonstrate that a program of preventative exercise could have a positive effect on improving MSDs for the parameters evaluated.

Considering sewing machine work tasks, Halpern & Dawson (1997) described a participatory ergonomics program developed to control and reduce workers compensation costs within an automobile products manufacturing company. The company found success in implementing the participatory program in terms of improving work quality, productivity, safety, and cost containment. As a part of the program, the company implemented a stretching program in which stretches occurred three times per day. The specific stretches performed as part of the program and the duration and repetition of stretches were not included in the article. However, the company did see a significant decrease in the number of MSD claims over time. It should be noted that implementing a stretching program was only one intervention as part of the participatory ergonomics program.

Lee & Waikar (1991) performed a review of recommended exercises proposed for reduction of MSDs in Video Display Terminal (VDT) operation and similar types of work. The review covered 15 exercise programs and 123 individual exercises that were intended to relieve stresses to the musculoskeletal system associated with awkward postures, highly repetitive tasks, sedentary work, or static effort. The review categorized exercises by body part affected (e.g., wrist, shoulder) and by activity (e.g., rotate, bend). The review found that the exercises covered all body parts affected by the muscular stress of VDT work, and the body parts targeted were typically the back, legs, neck, shoulders, sides, and upper extremities. Of the exercises reviewed, those targeting the shoulder muscles were the most popular (35.8%) followed by exercises targeting the upper extremities (17.9%). Most of the exercises focused on stretching and relaxation.

Mortensen et al. (2014) conducted a 3-year follow-up from a randomized controlled trial lasting 1 year. The trial involved investigating the effects of implementing a group exercise program in both the public and private sector. The exercise program was specific to the worker population. The follow-up examined whether participants were able to maintain the positive effects achieved during the trial. Mortensen et al. reported positive effects, including reduced musculoskeletal pain (e.g., in the wrist, neck, shoulder, and elbow), training adherence, and improvements in various self-reported health parameters. The study included 537 participants, who were assigned to a cluster for training (n=282 in 30 clusters) or a control (n=255 in 27 clusters). Baseline pain registrations were collected on the participants. At the 3-year follow-up, 473 participants responded. Among those that reported pain at the baseline measurement, the pain reduction achieved during the trial was either maintained or decreased. The results of this study indicate that exercise could be implemented successfully on a long-term basis with a lasting effect. The study identified key factors for the success of an exercise program to include high intensity and specific exercise selection based on the worker population and tasks.

Muyor, López-Miñarro and Casimiro (2012) investigated the effect of a stretching program on women working in a private fruit and vegetable company. The authors specifically studied hamstring muscle extensibility and sagittal posture of adult women. Fifty-eight participants volunteered for the study. Participants were randomly assigned to either a control group (n=31) or experimental group (n=27). The experimental group participated in the program of hamstring stretches for 12 weeks. The stretching occurred three times per week after the work shift for a period of 30 minutes. Participants who missed more than two sessions were removed from the data analysis. The control group did not participate in any exercise program. The outcome measure, hamstring muscle extensibility, was assessed using a passive straight leg raise and toe-touch tests. Sagittal spinal range of motion and inter-segmental angles were also measured. At baseline, the two groups did not show any significant differences in the outcome measures. After the 12 weeks of stretching, the data showed significant increases in toe-touch score and straight leg raise for the experimental group. The control group showed a non-significant increase for the same measurements. This study supports a corporate stretching program for use as a tool in increasing flexibility of a workforce.

In another study of a specific worker population, Park, Lee and Ko (2013) investigated the effects of various exercise programs, targeting chronic, work-related low back pain (LBP) in a population of workers from a tire factory. The study included 24 participants randomly assigned to one of three groups: (1) a control group (CG), (2) a lumbar stabilization group (LSE), or (3) a Nintendo Wii exercise group (NWE). In every group, the participants received physical therapy in the form of "physical agent modalities" (e.g., hot pack, deep heat). After this physical therapy, the LSE and NWE groups performed an additional exercise program. Participants repeated the exercise program three times a week for 8 weeks, with each session lasting 30 minutes. The LSE session contained seven stretching positions, focusing on the back. Each position was held for 15 seconds and repeated three times. The NSE sessions included the use of the Nintendo Wii sports package, which included swinging, rotating and tilting remote controls in order to "wake board", "play Frisbee" and "jet ski". The NSE group participants took a 2-minute break from the program every 10 minutes. Before and after the exercise program intervention, participants were evaluated for pain using a VAS, for back strength measured as maximum isometric lifting weight, balance ability measured as how long they could maintain a one-legged stand, and health-related quality of life (QOL) measured with the RAND-36 Health Status inventory. Pain significantly decreased in the LSE and NWE groups. All groups showed a significant improvement in back strength. The control and LSE groups showed significant improvements in balance. In a physical health composite of the QOL, all groups improved significantly. In a mental health composite of the QOL, the NWE group showed significant improvement. Although this study focused on the Nintendo Wii Exercises, it showed improvements for the LSE group as well, providing further support for success of a corporate exercise program.

Pillastrini et al. (2009) assessed the effectiveness of a corporate exercise program for nursery school teachers to prevent and manage neck and low back pain. The study recruited 71 participants. Each school was randomly selected to participate in the experimental group (n=35 teachers) or the control group (n=36 teachers). Before participating in the exercise program, demographic information was collected on the teachers along with a baseline assessment of low back pain occurrence and disability. The control group was given an ergonomic brochure, and the experimental group received the same brochure along with an extension-oriented exercise program. The exercise program consisted of six 1-hour long sessions for three consecutive weeks. After the 3 week period, participants were asked to repeat their exercises during working hours for a number of months. The primary measurements were the RMDQ and the ODI. A secondary measurement evaluated cervical and lumbar physical discomfort using a VAS. At the follow-up, the primary and secondary measures showed significant improvement in the exercise group, providing support for exercise program effectiveness in prevention and management of low back and neck pain as well as reductions in functional disability. The study did not show effectiveness of the ergonomic brochure, suggesting that more training may be necessary for an effective corporate exercise program.

Smith (2013) evaluated a stretching program and its effects on increasing flexibility of industrial workers. The study recruited 892 employees with two groups including a stretching program group (n=530) and control group (n=362). The stretching program was designed by an occupational therapist to target three work groups, who were identified as being most at risk for musculoskeletal injuries. Flexibility was evaluated with five measures: (1) neck flexion (measured in degrees), (2) neck extension (measured in degrees), (3) shoulder flexibility (ability to touch the lower part of the scapulae with the hand; yes/no), (4) finger flexibility (ability to touch the top of the palm with the fingertips of the same hand; yes/no), and (5) hamstring flexibility (ability to touch the floor with straight legs, measured in inches from the ground). The stretching program occurred for 6-10 minutes at the beginning of each shift. Measurements were taken on participants on a quarterly basis for 1 year. A survey was also distributed to participants to gather subjective opinions on the stretching program. The results of the survey indicated that 85% of participants found the program to be helpful. The study also found that those not in the stretching program were five times more likely to sustain a musculoskeletal injury. Changes in flexibility were measured with paired t-tests. Overall flexibility of the stretching program group showed significant improvements over the course of the study, providing additional support for corporate stretching programs.

Zebis et. al. (2011) examined the effectiveness of an exercise program designed to relieve pain in industrial workers who perform repetitive tasks, such as pipetting work, preparing vials for analysis, and mouse work on a computer. The study examined implementation of a strength training program for neck and shoulder pain, and recruited 537 volunteer participants. Participants were randomly assigned to clusters within either an intervention-training group or a control group. The training-intervention took place over 20 weeks, and questionnaires were sent out at the beginning and end of the intervention. The training group was permitted to use 1 hour of work-time each week for the training program. Experienced instructors introduced the program to small groups of participants, but after the program was introduced, participants could train on an individual basis or in self-organized groups. The training included exercises specifically for the neck and shoulder muscles, which were stressed by the work tasks. The outcome measure for the study included reporting musculoskeletal symptoms, using a modified version of the Nordic questionnaire, with a focus on trouble in the neck and shoulders. Intensity of pain was rated subjectively from 0 to 9. Results indicated that pain intensity decreased significantly for the training group, and pain in the shoulder tended to decrease, supporting the implementation of a corporate exercise program. It should be noted that the researchers indicated a high adherence to the exercise program among their study population.

Additional studies assessed the effects of exercises associated with specific body parts. For example, Areeudomwong et. al. (2012) studied the effects of core stabilization exercises in the treatment of participants with clinical lumbar instability. Twenty participants were included in the study. Participants inclusion criteria were low back pain for at least 3 months, present with the Instability Catch Sign (ICS) pain intensity over 5 out of 10. Subjects were randomly assigned to either a core stabilization exercise group (CSE) or control group (CG). All CSE participants exercised for two 20-minute sessions each week. The CSE program progressed from low-load isolation of the transversus abdominis and lumbar multifidus muscles to heavier loading positions with a 10-second hold for 10 contraction repetitions. The CG program included an exercise where one knee was brought to the chest from a lying position as well as side-bending in a standing position; participants in the CG program performed exercises once per day for 5 minutes, holding positions for 10 seconds and repeating 10 times. Results indicated significant differences in both pain intensity of ICS and in functional disability for both groups. When differences between the two groups were analyzed, significantly greater reductions in pain intensity during ICS and functional disability were found in the CSE group over the CG.

Coppack, Etherington and Wills (2011) studied the use of a corporate exercise program for prevention of overuse anterior knee pain (AKP), specifically in army recruits undergoing a 14-week training program. The program randomly assigned each recruit to a prevention-training program (PTP) group (n=759) or to a control condition (n=743). Training groups had 41 members on average. Baseline measurements of height, weight and BMI were recorded, and participants filled out a questionnaire with personal history questions such as their past smoking habits and their history of lower-limb disease. A baseline fitness assessment was also performed using a timed 2.4 km run. The PTP consisted of eight exercises delivered in subsets of four during a warm-up and warm-down, as part of each formal physical training session. Each exercise was performed in sets of 10-14 repetitions for the warm-up, and the warm-down stretches consisted of three repetitions of 20-second stretches. Results showed the risk of AKP over training was reduced 75% in the intervention group as compared to the control group, indicating support for an exercise-based training program to prevent recruit injury/pain over time.

O'Sullivan, Murray and Sainsbury (2009) examined the effects of an exercise program on hamstring flexibility. Their study examined short-term effects of warm-up, static stretching, and dynamic stretching on hamstring flexibility on both previously injured and uninjured participants. Thirty-six participants were included in the study. The participants were randomly assigned to one of the stretching interventions (static stretching or dynamic stretching). The outcomes of test trials included measurement of passive knee extension range of motion (PKE ROM). During the experiment, a baseline assessment of PKE ROM was taken for both legs. Participants then performed a warm-up, after which PKE ROM was measured again. Subsequently, participants performed the assigned stretching intervention for 30 seconds with three repetitions for each leg. Participants then rested for 15 minutes prior to the final PKE ROM assessment. Results indicated that a warm-up alone significantly increased hamstring flexibility. Static stretching also significantly increased hamstring flexibility, while dynamic stretching did not. These findings also supported implementation of an exercise program involving static stretches.

Maher et. al. (2011) studied the effectiveness of home exercise programs with standard medical treatment for individuals with shoulder injuries in an industrial setting. Nine participants completed the study, and all participants performed work that involved repetitive overhead motions. Participants were excluded from the study if they had torn rotator cuffs, recent shoulder surgery, injuries that required future surgery, current involvement in physical therapy, or other comorbidities that could impact shoulder function. Participants were randomly assigned to either a control group, that included standard medical care, or an exercise group, that included a home exercise program as well as standard medical care. Baseline measurements were taken of disability (Disability Index survey), range of motion (ROM), and manual muscle tests (MMTs). These measurements were reassessed at 3 and 6 month intervals. Results indicated significant improvement for the exercise group in two strength measures and one measure of disability. Trends of improvement were shown for both the strength and disability measurements within the exercise group providing support for home exercise programs for workers.

A few studies also reviewed the overall effectiveness of corporate exercise programs. For example, Hess and Hecker (2003) reviewed studies that evaluated flexibility among worker populations and corporate stretching programs. The study also investigated any possible associations between corporate stretching programs and work-related musculoskeletal disorders (WMSDs). Articles included in the review had to meet four criteria: (1) pertain to flexibility or stretching for the purpose of improving flexibility, (2) have been published in a peer reviewed journal, (3) have examined populations of working adults rather than athletes or military recruits, whose results may not generalize to a working population, and (4) include a control group, if cross-sectional in design. Given these criteria, few studies were found that were specific to corporate stretching programs. The results of the review did not find definitive proof either for or against a stretching program. The review, however, did suggest that additional benefits beyond reducing incidence of WMSDs may occur with the implementation of a stretching program. These benefits could include decreasing the severity and cost of treating musculoskeletal injuries.

Goldenhar & Stafford (2015) specifically studied the effectiveness of corporate exercise programs in the construction industry, with a focus on stretching programs. The study examined how the programs were structured and implemented, the associated costs, the perceived goals, and the benefits of implementing these programs. An online survey was given to safety and health professionals working for a construction company or a related entity, and 133 responses were received. Nineteen semi-structured interviews were also conducted with safety and health professionals. A guide to the interview questions was sent to the interviewees prior to phone communication with a researcher, which lasted 30-45 minutes. The questions asked during the interview were similar to the questions from the survey, but they were left open-ended. Of the survey respondents, 56% said their company had a stretching program. Approximately 25% of the survey respondents said these programs asked participants to complete 5-7 stretches, and 85% of respondents stated that a foreman led the stretching program. Eighty percent of programs were held in the morning (or at the beginning of work), with more than 60% of programs lasting 6-10 minutes. The review did not find scientific evidence of stretching programs reducing the number of WMSDs and injuries, and interviews revealed that most companies had not completed a cost analysis to support the effectiveness of the program. However, they reported other possible benefits, such as a renewed focus on safety due to the routine foreman led stretches, or reduced severity of injuries.

da Costa & Vieira (2008) reviewed literature to clarify the physiological effects of stretching as well as any possible benefits of stretching to reduce musculoskeletal disorders. The review included 34 studies. Eligible studies met five criteria: (1) investigate the use of stretching to prevent WMSDs, (2) include a group receiving only stretching as an intervention, (3) be peer-reviewed, (4) be published in English, and (5) be published in full-text. The review found that stretching could reduce discomfort and pain; however, stretching, without proper precautions, could suppress awareness of risk or aggravate injuries if performed improperly. Careful analysis of programs should be taken to ensure that program design mitigates these risks. Overall the review found some beneficial effects of introducing stretching as a measure to prevent WMSDs.

The articles reviewed in this section are summarized in the Literature Summary Table below (Table 3.1).

Authors	Key Findings
Areeudomwong et al. (2012)	1. Participation in the stretching group (ICS) showed significant decreases in pain intensity. 2. Participation in the core stabilization group (CSE) showed significant decrease in functional disability.
Bertozzi et al. (2015)	1. Positive effect in improving MSDs for stretching group for metrics of disability and pain in lumbar region.
Coppack et al. (2011)	1. Exercise program reduced incidence of anterior knee pain.
da Costa & Vieira (2008)	1. Review showed beneficial effect of stretching to prevent MSDs.
Goldenhar & Stafford (2015)	1. Little evidence of stretching programs reducing number of injuries. 2. Stretching programs may be successful in reducing the severity of injuries.
Halpern & Dawson (1997)	1. Implementation of the stretching program decreased number of MSD claims. 2. Stretching program involved stretching multiple times per day.
Hess & Hecker (2003)	1. The review did not show significant support either for or against a stretching program.
Lee & Waikar (1991)	1. The study supports stretching exercises as beneficial in reducing musculoskeletal stress.
Maher et al. (2011)	1. The study shows effectiveness of an exercise program through strength and disability measures.
McGillis (2015)	1. Exercises should target the tasks of specific workers. 2. Exercise programs could have non-cost benefits.
Mortensen et al. (2014)	1. Exercise programs are beneficial to workers, specifically when developed for the worker.
Muyor et al. (2012)	1. Stretching programs showed effectiveness in increasing flexibility of the workforce.
O'Sullivan et al. (2009)	1. Exercise programs should include static stretching to increase flexibility. 2. Stretches should last 30 seconds, be repeated for each muscle, and be performed bilaterally.
Park et al. (2013)	1. Exercise programs can provide benefits to the workforce.
Smith (2013)	1. Exercise programs can be effective when designed for the worker. 2. Exercise programs can yield additional benefits (e.g. focus on safety)
Zebis et al. (2011)	1. Corporate exercise programs can have beneficial effects, particularly with high adherence.

Table 3.1: Exercise Program Effectiveness Literature Summary Table

3.1.3. Benefits

Many corporate exercise programs have been designed with the intent of reducing injury or MSD rates; however, some studies have found additional benefits to implementing these programs. This section reviews literature that has found additional benefits of implementing corporate exercise programs, such as increased job performance, decreased severity of injury, or increased overall health of workers.

Choi and Woletz (2010) reviewed literature on industry specific stretching programs. Results revealed that stretching could improve flexibility and range of motion; however, stretching did not reduce WMSDs. The study highlighted other potential benefits to implementing a corporate stretching program. In particular, the review found that corporate stretching programs could also lead to a decrease in costs associated with musculoskeletal and workplace injuries, as well as reduced injury recovery time (i.e., days on restricted duty or days away from work). Choi and Woletz (2010) also suggested improved function of workers as another possible benefit.

Hess and Hecker (2003) also conducted a review of corporate stretching programs. While they did not find conclusive evidence either for or against corporate stretching programs, they did find other possible benefits to implementing stretching programs. One benefit was enhanced worker health and, like Choi &Woletz (2010), they also noted decreased severity of musculoskeletal injuries and costs to treat such injuries. Overall, Hess and Hecker (2003) recommended a corporate stretching program could be one part of a worker injury prevention plan.

Kellett, Kellett and Nordholm (1991) conducted a study to evaluate the effect of a weekly exercise program on short-term sick leave (<50 days) attributable to back pain and to determine whether changes in absenteeism were related to changes in fitness. The study recruited 111 participants and randomly assigned participants to an exercise group (n=58) or control group (n=53). Due to attrition, the final sample sizes for the exercise and control groups were 47 and 48 participants, respectively. Participants had to have written permission to participate in the exercise program during work hours and a willingness to exercise once per week outside of work for 1.5 years. Participants were excluded if they had sick leave longer than 50 days (for any reason) in the 1.5 years prior to the study. The exercise group was split into two sessions, which met once per week. Each exercise session consisted of 30-35 minutes of exercise followed by 5-10 minutes of relaxation. The days of sick leave due to pain and the number of back pain episodes were measured during the study and compared with similar data from the 1.5 years prior to the study. Fitness of participants was also measured before and after the study by using a computerized exercise cycle. In addition, after the study, participants subjectively rated (on a five-point scale) the effect of the exercise program on back pain by anonymously answering the question, "How has the exercise program affected your back pain?" Results revealed a significant difference in the number of sick days attributable to back pain for the exercise group, but no significant difference in the number of back pain episodes. The control group did not show any significant changes. The post-study survey found that 81% of participants in the exercise group reported symptoms improving after participation in the program. Results of this study were similar to Hess and Hecker (2003) and Choi and Woletz (2010), indicating an exercise program can have a significant effect on severity of musculoskeletal injury/illness, including reduced days away from work. The study also concluded that it is possible that the number of workers developing chronic back pain can also be reduced with a corporate exercise program.

Still other studies have found that corporate exercise programs yield benefits such as an improvement in overall health of workers. For example, Elberson, Daniels and Miller (2000) studied the effects of implementing different corporate exercise programs on physiological outcomes. The study recruited 374 participants. Participants were divided into two groups, including a structured exercise group (n=54) and an unstructured exercise group (n=320). Both groups were required to participate in the study for 12 consecutive months. Baseline physiological data was collected from all participants at the beginning of the program, along with demographic information. At the end of the program, corresponding physiological data was collected from all participants. Demographic variables included age, race, education, and gender. The physiological variables measured were BMI, cholesterol, total cholesterol, triglycerides, and HDL ratio. T-tests were conducted on all response measures to compare beginning and ending data. Results revealed the HDL ratio to decrease significantly and mean HDL to increase significantly for the structured exercise group. In the unstructured exercise group, all five of the physiological variables showed significant changes. Elberson, Daniels and Miller (2000) concluded that a corporate exercise program, particularly an unstructured program can lead to overall health benefits for workers.

Kabaroff et. al. (2013) evaluated the use of a group-mediated cognitive behavioral (GMCB) exercise program within a corporate environment. The study recruited 20 participants. A GMCB protocol uses group dynamics (e.g., developing a group name and group goals) to encourage group interaction and participation while also teaching individual cognitive-behavioral skills (e.g., self-regulatory skills). Weekly meetings were set up, and participants were given a logbook with which to self-record anthropometric measures including weight, body-fat percentage, and BMI. The researchers also recorded waist girth. A survey was also distributed to participants to determine those aspects of the program they considered successful or unsuccessful. The program lasted 12 weeks and was split into four periods of measurement. Results revealed a steady and significant decrease in BMI, body fat percentage, and waist girth during the study period. Survey results revealed the relative successes and failures of the GMCB exercise program; specifically, participants found the educational aspect to be particularly successful.

Lynch et al. (1990) examined the relationship between participation in a corporate exercise program and the number of absences from work due to illness. The study recruited 8,069 participants. Participants were split into two groups, including members of the corporate fitness center (n=2232) and nonmembers (n=5837). All participants were full-time employees of Travelers Insurance, Inc. in the Hartford area during the entirety of the study (3 years) and were given the option to join the corporate fitness center. The study totaled reported absences from work due to illness for each year for each subject, omitting discretionary absences (e.g., funerals, weddings). The study also tracked the frequency of use of the fitness facility by participants. Results of the study showed that membership in the corporate fitness facility appeared to decrease absenteeism, and the magnitude of reduction was affected by the amount of participation of members.

Other studies have also found corporate exercise programs could lead to an increased focus on safety in the workplace. For example, as described above, Smith (2013) evaluated a stretching program intended to increase worker flexibility. Their program was designed to specifically target a group of workers most at risk for musculoskeletal injury. Aside from the study finding that participants in the stretching program increased in flexibility, they also found additional benefits of the stretching program to include an increased focus on worker safety.

McGillis (2015) also reviewed the benefits of stretching programs. The author found that there was no significant evidence to say that stretching programs could reduce frequency and cost of workplace injuries, as some, but not all, programs reported reductions. However, the review did find other benefits to implementing a corporate stretching program, including an increased focus of safety in the workplace or increased employee perceptions of self-worth. These results are consistent with other studies, specifically, Goldenhar & Stafford (2015), which found similar benefits in their study, such as an increased focus on safety and reduction in severity of injuries. Both studies also noted a prevalence of programs that involved a once a day stretching session before a work shift, which may have given the time to bring up relevant safety issues and renew focus on workplace safety.

Bernack & Baun (1984) additionally found that participation in a corporate exercise program was associated with increased job performance. Their study investigated the relationship between levels of adherence in a corporate fitness program and job performance. The study recruited 3,231 workers, and all participants were given access to a corporate fitness center. The workers were classified into four job categories: (1) management (n=561), (2) clerical (n=1,078), (3) professional (n=1,265), and (4) other (n=327). The participants were also split into five exercise adherence groups: (1) nonmember (n=1,090), (2) nonexerciser (n=926), (3) exercise less than one time per week (n=738), (4) exercise 1-2 times per week (n=238), and (5) exercise 2+ times each week (n=239). Job performance was assessed by the company's personnel department on a five point scale, with a score of "1" indicating highest performance and a score of "5" indicating lowest performance. For simplification in analysis, the five categories were condensed to three: above average performance (1,2), average performance (3), and below average performance (4,5). Overall, results revealed a positive association between above average job performance and exercise adherence. Results also showed a negative association between poor job performance and exercise adherence.

The articles reviewed in this section can be found in the literature summary table below (Table 3.2).

Authors	Key Findings
Bernacki & Baun (1984)	1. The study shows an association between exercise adherence and job performance.
Choi & Woletz (2010)	1. Stretching has been shown to reduce the severity of injuries. 2. Stretching programs can also have secondary, non-cost related benefits.
Elberson et al. (2000)	1. Exercise programs can be effective in improving physiological measures.
Goldenhar & Stafford (2015)	1. Little evidence to show effectiveness of reducing occurrence of WMSDs. 2. Stretching may reduce severity of injuries.
Hess & Hecker (2003)	1. Exercise programs could decrease severity and cost of treating MSDs and injuries.
Kabaroff et al. (2013)	1. Exercise programs can be successful with education used to improve implementation.
Kellett et al. (1991)	1. Exercise programs can be beneficial in reducing sick days due to back pain.
Lynch et al. (1990)	1. Effectiveness of stretching programs is influenced by participation and buy-in that the program receives from its participants.
McGillis (2015)	1. Exercise programs can have non-cost benefits of stretching. 2. Exercise programs should target tasks of the specific employee.
Smith (2013)	1. Stretching programs should be designed for the worker to be effective. 2. Stretching programs can have secondary benefits (e.g. safety).

Table 3.2: Exercise Program Benefits Literature Summary Table

3.1.4. Summary

This section reviewed selected articles presenting experiments on corporate exercise or stretching programs or reviews of literature on exercise and stretching programs. All the articles focused on program effectiveness, study conditions and key findings are listed in Table 3.1. Those articles focused on exercise program benefits, study conditions and key findings are listed in Table 3.2. Among the articles reviewed, there was mixed support for corporate stretching programs. Some studies found no significant difference in injury rates when comparing stretching/exercise groups with non-exercise control groups (Hess & Hecker, 2003). However, other studies did find an effect of program implementation (Bertozzi et. al., 2015; da Costa &Vieira, 2008). Some studies examined response measures, extending beyond injury rates, for example McGillis (2015), and found other benefits of structured programs, such as reduced severity of injury or a renewed focus on safety (Choi & Woletz, 2010; Goldenhar & Stafford, 2015).

Among the studies and reviews that recommended stretching programs, some guidelines were provided on program design. All studies recommended tailoring programs to worker needs and specific tasks that workers must perform (McGillis, 2015; Mortensen et. al., 2014). Other recommendations focused on the timing of program delivery, with many studies utilizing one daily stretching session. Recommendations were also made on how long stretches should be held during an exercise program with agreement on 20 to 30 seconds among several papers (Areeudomwong, 2012; O'Sullivan, 2009). Regarding types of stretches, Smith (1994) recommended that stretches be performed bilaterally and repeated at least three times.

The methods and recommendations from the above reviewed articles provide a basis for design of a job-readiness program for the gas cylinder delivery operators and development of a stretching reminder card. Implementation of the recommended methods may also have a benefit for drivers in terms of reducing the potential for upper-extremity and low back MSDs due to overexertion, as revealed by the earlier company OSHA log analysis.

3.2. Exercise cards

Exercise reminder cards are an extension of exercise program design. Although some cards have been developed as part of various programs, their coverage in the literature is less extensive than the exercise program content itself. Having said this, card can have utility in terms of promoting worker adherence to an exercise protocol/regimen as well as the effectiveness of a program.

3.2.1. Adherence & Effectiveness

As mentioned there has been limited study of exercise reminder cards in terms of effectiveness in reminding participants to complete exercises as well as promoting adherence to the proper form of an exercise. Fredrich, Cermak and Maderbacher (1996) examined whether different modes of instruction affected exercise performance, specifically adherence to an identified form. Eighty-seven participants were recruited and were randomly assigned to three different brochures with the same goal. Participants were then further split into two groups; one group was given the brochure and individualized instruction from a physical therapist. The second group was given the brochure but received no instructions. Participants were asked to exercise for 20 minutes every day and training frequency was recorded. The study concluded that verbal and physical exercise instruction can help ensure proper form, which can have positive effects on pain reduction, muscle length, and muscle force capabilities.

Another study looked at whether methods of exercise instruction had an effect on the level of learning and recall of proper form (Reo & Mercer, 2004). Forty participants were included in the study and assigned to one of four groups: (1) live-modeled, (2) videotaped with correct form, (3) videotaped with errors and corrected form, and (4) a handout. Participants were instructed based on their group assignment and then subsequently tested on the proper form of exercises. Approximately 24 hours after the initial assessment, participants were given the list of exercises and were retested to examine how well they retained the instructional information. The study found that the handout group was significantly less accurate in their exercise performance, suggesting instruction beyond a handout may be necessary to achieve results.

Schoo, Morris and Bui (2005) studied the use of written exercise instructions combined with videotaped or audiotaped instructions and whether these instructions increased performance or adherence to a prescribed exercise program. The 115 participants in the study were split into three groups. All groups received written instructions. One group received videotaped instructions along with the written instructions, and the second group received audiotaped instructions in addition to the written instructions. The third group only received the written instructions. Exercises were to be performed for 4 weeks, and at the end of that period, participants were assessed for proper exercise form and they submitted log sheets of home exercises. This process was repeated for a second set of exercises. Results revealed no significant differences between the three groups in terms of adherence to exercise form and performance. Opposite to the Reo & Mercer (2004) study, findings indicated that the videotaped and audiotaped instructions were not necessary for increased performance or adherence.

Schneiders, Zusman and Singer (1998) examined the effect of providing written and illustrated instructions to promote patient compliance in keeping-up with at-home therapy exercises. The study recruited 96 participants and they were split into two groups. One group received only verbal instructions, and the second received written and illustrated instructions along with verbal instructions. All participants were asked to complete a Oswestry Low Back Pain Disability Questionnaire (ODQ) and to complete an exercise log. Results revealed the written and illustrated instructions to have a significant effect on the compliance rate of participants.

3.2.2. Summary

An exhaustive search of the literature identified four studies of the use of written exercise instructions/brochures for promoting proper exercise form as well as adherence to an exercise regimen. The findings of these studies suggest that use of an illustrated exercise brochure can improve adherence to exercise regimens (Schneiders et al., 1998). Additional reminders, however, do not seem to increase adherence, and are likely unnecessary (Schoo, et al., 2005). Furthermore, the findings of this review suggest that a brochure in and of itself may not enough to ensure proper execution of exercises by workers; even if the brochure explains exercise form, technique, and expected frequency (Friedrich, et al., 1996; Reo & Mercer, 2004). Face-to-face or videotaped instructions appear to have a greater impact on correct exercise performance (Friedrich, et al., 1996; Reo & Mercer, 2004).

In general, there is limited evidence of effective forms exercise reminder card design. With this in mind, the present research made use of up-to-date and relevant graphic and human factors design guidelines, techniques, and technology to create a stretching/job-readiness reminder card for the gas cylinder delivery company.

4. Objective and Methods

Beyond the OSHA log analysis and the review of literature on corporate exercise program design, the primary objectives of this research were to conduct an ERA of MMH activities as part of the compressed gas cylinder delivery operations and to make recommendations for design of an exercise card and program as an intervention towards reducing operator risk exposures. In order to address these objectives, the following additional research steps were completed: (1) a detailed hierarchical task analysis (HTA) of typical gas cylinder delivery operations, (2) an ergonomic evaluation of target tasks, and (3) identification at-risk worker muscle groups as a basis for exercise recommendation and reminder card design.

4.1. Hierarchical Task Analysis

The HTA was prepared based on the direct observations of delivery operation tasks as well as the use of the video recordings taken during the ride-alongs, and company safety training videos provided by management. Information on delivery driver daily tasks was also gathered during unstructured interviews conducted with drivers during the ride-alongs.

The HTA identifies the overall objectives of a system and the operations and sub-operations necessary to meet those objectives. Sub-operations are linked by a plan that identifies a flow necessary to achieve an objective. The results of this analysis are represented in hierarchical diagrams that can be used with ergonomic risk analysis methods to identify areas of particular risk factor exposure for workers.

The gas cylinder delivery operations were all broken-down to the subtask level based on video analysis and work protocols described by the drivers. The identified tasks and subtasks were subsequently included in development of HTA diagrams. Researchers also took photos of drivers performing the various steps of the delivery tasks under analysis. (The photos are included in the Task section of this document.) A comprehensive HTA, including all tasks involved in a driver delivery of cylinders to a customer site can be found in outline form in Appendix A.

4.2. Ergonomic Risk Assessment

The ERA methodology applied in this study was developed by The Ergonomic Center of North Carolina (ECNC). This section identifies the ergonomic risks considered by the methodology, the method of measurement, and the criteria for body segment risk exposure assessment. Body segments included in the present assessment were the neck, shoulders, arms/elbows, hands/wrists, torso/back, and legs/knees/feet. The risk assessment tool also includes some broader, more general definitions of segments as bases for ratings, which will be presented later. The risk exposure rating scale used in the ECNC method (see Appendix B) ranges from 0-10, spanning three risk levels. The low-risk level includes ratings 0-3; the moderate-risk level includes ratings 4-6; and the high-risk level includes ratings 7-10.

All delivery operation tasks were observed during ride-alongs. Specific tasks were selected for analysis due to ergonomic risks (e.g., high repetition, high force, or awkward posture) observed by researchers during the ride-alongs and video review. In total, three tasks were chosen for assessment, including: pulling dewars, rolling two cylinders, and lifting small cylinders. A HTA was developed for each of these tasks. This section presents descriptions of each task (including pictures of specific steps, as performed by operators), results of the formal HTA, and identification of ergonomic risk factor exposure scores for force, motion and posture.

As part of the ERA, three researchers independently assigned risk ratings for each task, broken-down by body segment and risk factor. Although deviations from company safety procedures and SOPs were observed in ride-alongs, these instances were not considered in risk ratings of the tasks. These ratings were compiled, and average scores were determined for each risk factor for each body segment in each task. In addition, body segment priority levels were determined as a basis for application of ergonomic controls. The sum of all three average factor scores (force, motion and posture) for each body segment was calculated to yield a body segment task rating. The body priority matrix (see Appendix B) was used to determine the priority level for ergonomic controls for each segment. A total body risk score, or "Job Screening Score", was also calculated for each task by weighting the priority levels of each body segment (also see Appendix B). This approach was based on the original ECNC methodology.

4.2.1. Force

The force factor refers to the force required by a worker to perform an identified task. General definitions are provided for force risk levels. For the low risk level, the definition identifies force as requiring no (or minimal) force and requiring <30% of maximum voluntary contraction (MVC). The general definition for the moderate risk level is requiring moderate to strong force, showing obvious effort with unchanged facial expression, or requiring 30-60% of MVC. The high risk level general definition identifies the requirement for very strong force, showing substantial effort with changed facial expression, use of shoulder/trunk for force, or requiring >60% of MVC. The specific definitions for the low, moderate and high risk levels for the body segments can be found in Appendix B.

4.2.2. Posture

The posture factor refers to the posture required of workers in performing delivery operations. Based on relevant literature, the ECNC developed criteria for low, moderate, and high-risk postures for each body segment as part of the ERA methodology. The criterion can be found in Appendix B.

To assess worker posture, a researcher observed an operator during several work cycles and identified the positions assumed as part of tasks to be considered in the risk assessment. Ratings were selected based on the postures held for the longest period during a task or in which the highest load exposure occurred. Both the left and right upper- and lower-extremities were analyzed as part of the ERA. For example, when lifting small cylinders, it was assumed that the right arm would lift the small cylinders while the left arm provided support. In the case that an operator used the left arm for lifting, symmetry was assumed and the results for the right and left sides of the body were reversed.

4.2.3. Motion

The motion risk factor takes into account body part movement repetitions and the time required to perform a specified task. More specifically, this section of the ERA focuses on the number of movement repetitions per minute as well as the number of seconds each risky movement posture needs to be held during task performance. A low risk level indicates that the identified movement is repeated less than one time per minute and the posture is held for under 6 seconds at a time. A medium risk level indicates that the identified movement is repeated between one and five times per minute and the posture is held between 6-20 seconds each time it is performed; whereas, high risk level motions are performed 6 or more times per minute and held for longer than 20 seconds at a time.

It is important to note, however, that the motion risk factor in the ERA was originally intended to rate tasks in a manufacturing environment or factory setting in which motion is continually and regularly occurring during a work shift. During gas delivery work shifts, MMH may be interspersed throughout long periods of driving. The present analysis assumed that each delivery required approximately 15 minutes to complete and all motions assessments were based on averaging observed movements across the defined delivery time. That is, the motion risk exposure during delivery operation considered a continuous work cycle of 15 minutes.

4.3. Facilities

There are several pieces of heavy equipment that are used by drivers in gas delivery operations. Trucks are used for deliveries and can be outfitted with pallets. Pallets are placed securely on trucks with a forklift at gas delivery company facilities (see Figure 4.1 for an example). This allows the drivers to avoid manually moving product over long distances at facilities. Pallets can hold a variety of cylinders or one liquid dewar. Any product is securely attached to a pallet using ratchet straps. At client sites, however, a forklift is usually not available, so drivers move products from the truck into a client's facility by hand or by using material handling equipment, such as a handcart for cylinders. Product is moved on and off of the truck at the client site using either the hydraulic gate, as part of the delivery truck, or a loading ramp, depending on the conditions of the client site.

Figure 4.1: Photograph of a company facility

4.4. Participants

All drivers interviewed as part of this study were trained by the gas delivery company to move all company products safely using the equipment provided. During observations, the drivers performed the tasks according to the SOPs, as defined by the company. However, in some cases drivers were unable to adhere to SOPs due to a lack of equipment at client sites.

4.5. Tasks

The tasks chosen for the ERA included: (1) moving dewars, (2) rolling two cylinders, and (3) lifting small cylinders. These tasks were chosen based on the observations of drivers during the ride-alongs and through the development of the HTA.

4.5.1. Pulling dewars

In moving a dewar, a driver typically pulls the cylinder, which is attached to a wheeled platform, while walking backwards (see Figure 4.2). The dewar is pulled backwards in order for the operator to see any hazards (e.g. cracks in the ground) and to allow for greater stabilization of the heavy load. Figure 4.3 presents an HTA diagram of the steps in pulling the dewar. For the purposes of this analysis, the researchers assumed the left arm grasped the top of the dewar, while the right arm grasped a handle on the side of the dewar, as can be seen in the photograph of driver task performance.

Figure 4.2: A driver pulling a dewar onto a truck. (Note: The driver is walking backwards.)

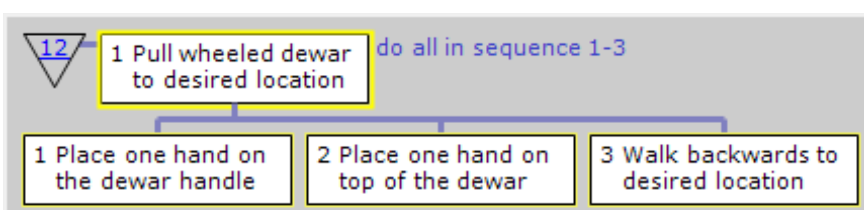

Figure 4.3: HTA for pulling a wheeled dewar

4.5.2. Rolling two cylinders

In moving cylinders short distances, drivers often “roll” the cylinders. Company policy dictates that a handcart must be used for moving cylinders over distances more than 15 feet; however, sometimes space constraints prohibit the use of a handcart, leading the drivers to move cylinders manually (see Figure 4.4). Figure 4.5 presents an HTA of the steps in the cylinder rolling task.

Figure 4.4: A driver rolling two cylinders

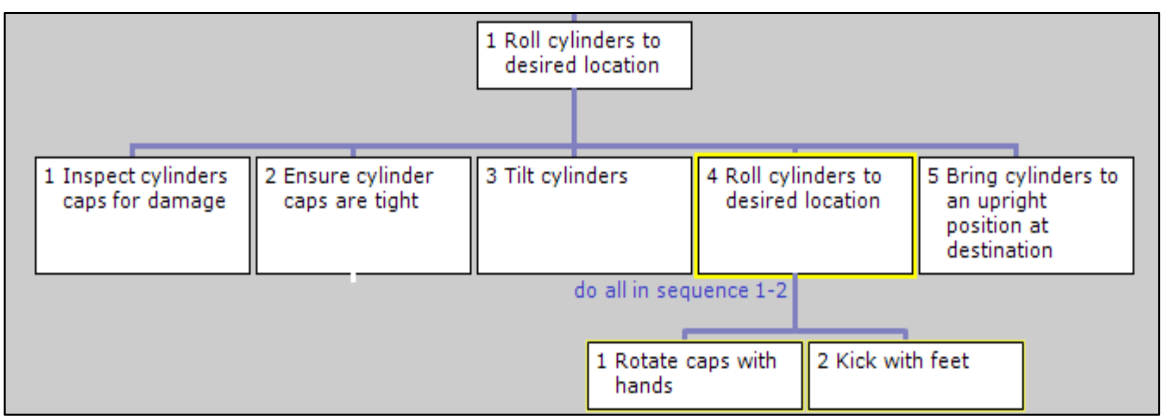

Figure 4.5: HTA for rolling two cylinders

4.5.3. Lifting small cylinders

Some deliveries involve drivers handling different types of small cylinders. Drivers are required to pick up each small cylinder individually with one hand and place them either in a rolling cart (see Figure 4.6) or onto a pallet to be forklifted onto the delivery truck. Some small gas cylinders delivered by the company have been fitted with ergonomically designed handles, while others have not. The focus of the present ERA for the delivery task was on cylinders that do not have ergonomic handles. Furthermore, it is assumed in this analysis that all cylinders are lifted with the right hand. Figure 4.7 shows the HTA of lifting small cylinders.

Figure 4.6: A driver lifting a small cylinder

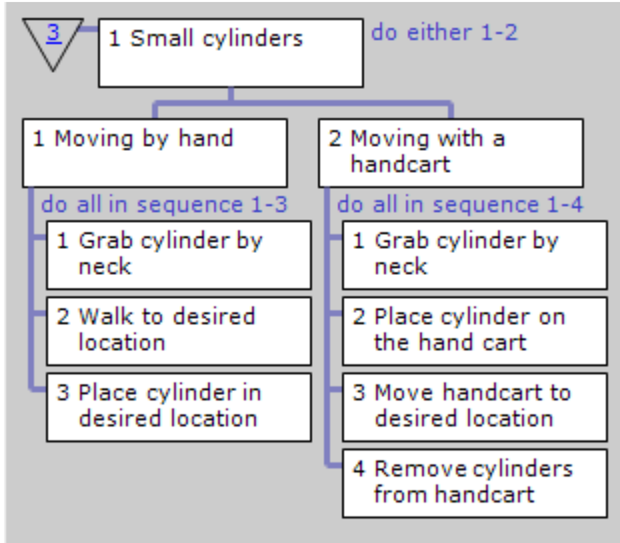

Figure 4.7: HTA for moving small cylinders

4.6. Research Hypotheses

Based on the direct observations of task performance and analysis of the OSHA injury/illness logs for the gas delivery company, three research hypotheses were formulated in relation to the ERA. First, considering the weight of the gas products being delivered, it was hypothesized that moving dewars would result in a high average ergonomic risk rating (H1). Second, it was hypothesized that rolling cylinders would also result in a high average ergonomic risk rating due to repetitive hand movements in awkward posture positions (H2). Researchers noted these particular risk factors during the ride-alongs. Third, it was hypothesized that lifting small cylinders would result in a high average ergonomic risk rating (H3) due to awkward driver posture positions and repetitive motions.

5. Results

This sections details the results of the ERA. Additional tables containing the body priorities for each task can be found in Appendix C.

5.1. Job Screening Score

The total body risk scores for each task are presented in Figure 5.1. All jobs were determined to pose a high (a score >25) or moderate (a score of 17-25) total risk (body priority level) for drivers. The high level indicates a need for job redesign and the moderate level indicates a need for control measures. Rolling two cylinders received the highest total body priority level with a score of 28 (SD=4.65). The other two tasks, pulling a dewar and lifting small cylinders, were considered to pose moderate risk levels with a score of 18 (SD=1.67 and SD=7.08, respectively).

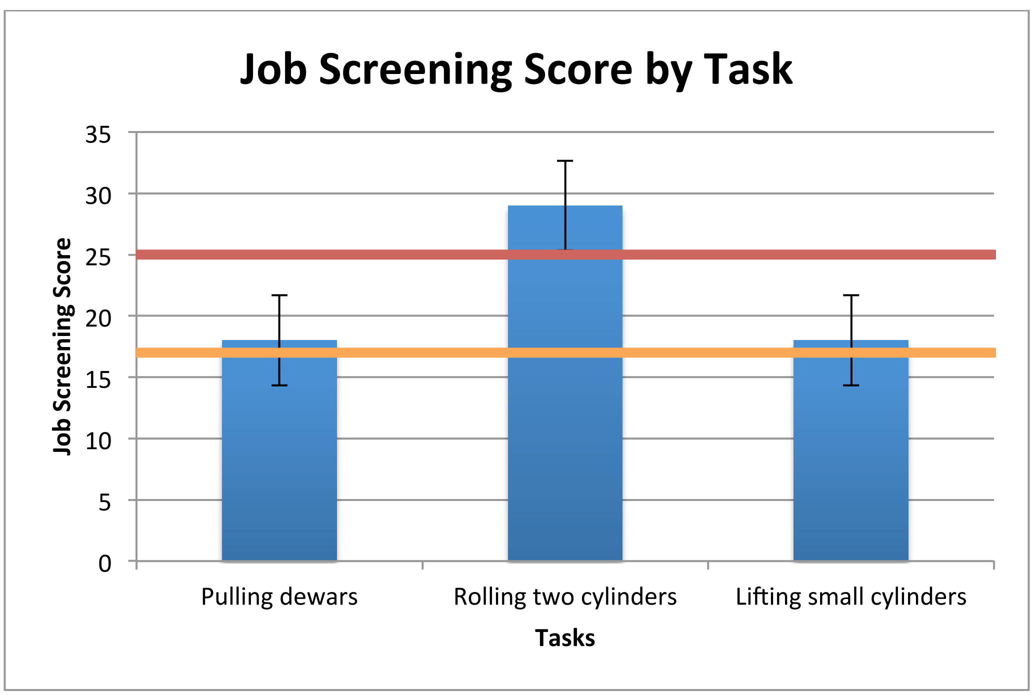

Figure 5.1: Graph of Overall Job Screening Score by Task (Note: The orange line indicates the upper threshold for a moderate risk (a score of 17-25) and the red line indicates the threshold for a high risk (a score >25).)

5.2. Scores by body segment

The ergonomic risk ratings for each task and body segment were averaged across the three raters. The mean ratings for each ergonomic risk (posture, force, motion) were summed to create a risk score specific to each body segment and task. This risk score was then used to identify those body segments at greatest risk during task performance.

Figure 5.2 presents the average researcher risk ratings for each body segment for the task of pulling a dewar. The total body risk score presented in Figure 5.1 was decomposed into scores for each body segment that is primarily affected by the task. Based on this assessment, the most at-risk body segments in pulling a dewar included the shoulders, arms/elbows, back, wrists, and legs. Due to the weight of the dewar and the act of pulling the cylinder, the upper extremities and the back were identified as primary areas of concern. For this task, walking backwards also creates concern for both legs.

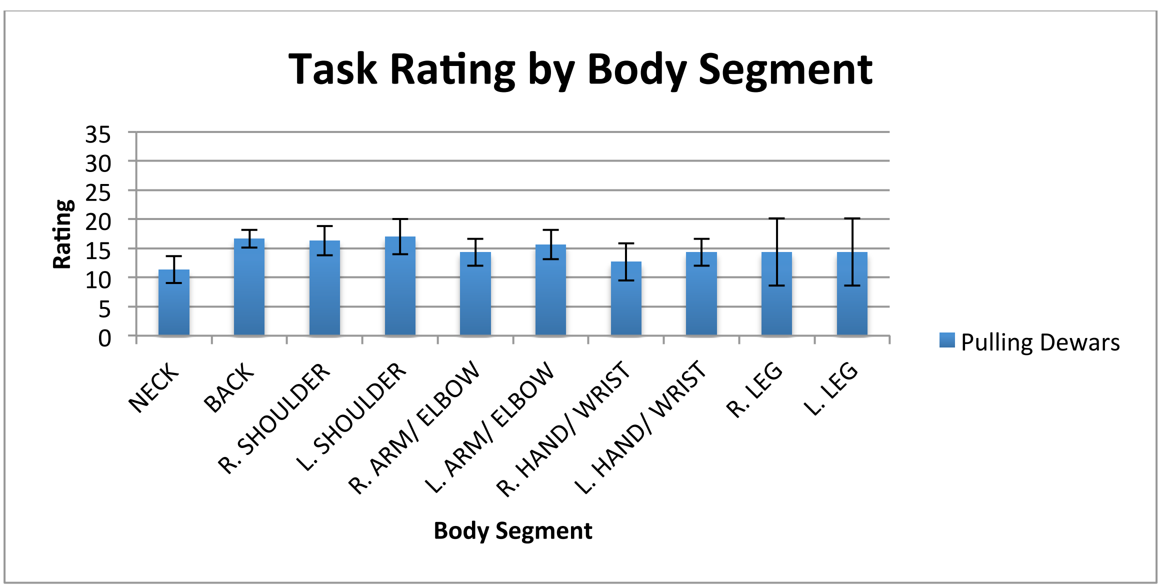

Figure 5.2: Graph of risk ratings for each body segment in pulling dewars

Figure 5.3 presents the average ergonomic risk exposure ratings for each body segment for the task of rolling two cylinders. The total body risk score presented in Figure 5.1 was decomposed into scores for each of the body segments that are primarily affected by the task. Based on this assessment, the most at-risk body segments in rolling two cylinders include the wrists, arms/elbows, shoulders, and back. Again, the upper extremities and the back were identified as areas of concern due to the weight of the cylinders. In addition, the repetition of the rolling motion for the upper extremities led to the wrists being areas of concern.

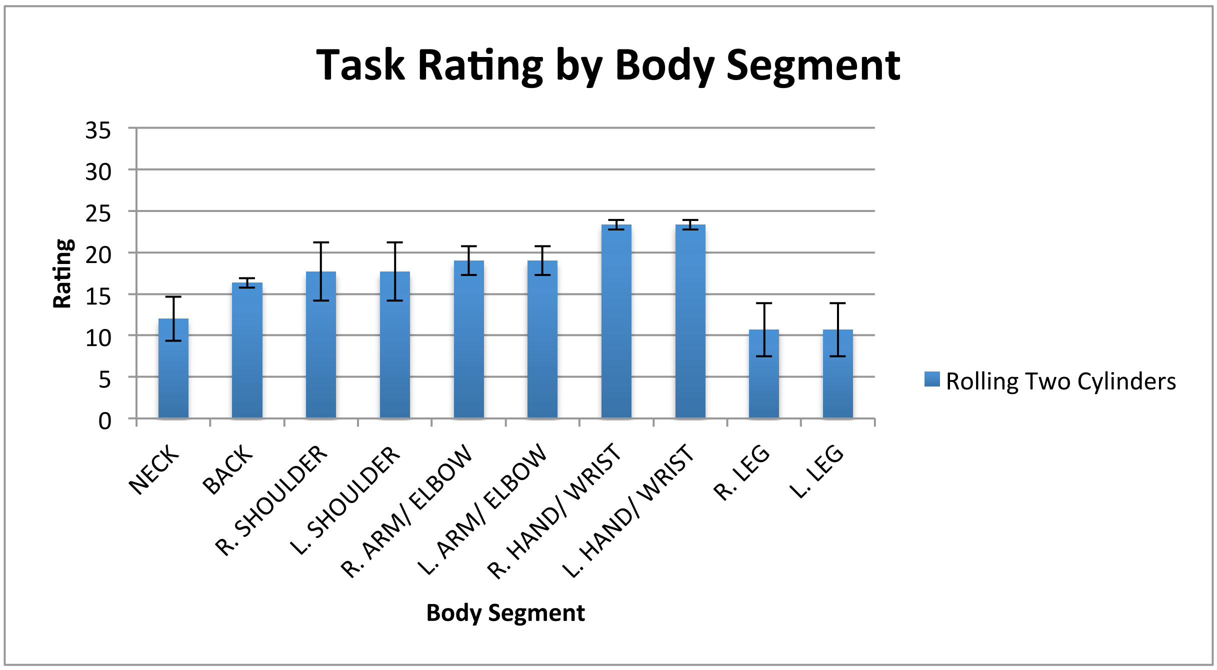

Figure 5.3: Graph of risk ratings for each body segment for the task of rolling two cylinders

Figure 5.4 presents the average risk ratings for each body segment for the task of lifting small cylinders. The total body risk score presented in Figure 5.1 was decomposed into scores for each of the body segments that are primarily affected by the task. Based on this assessment, the most at-risk body segments in lifting small cylinders included the wrists, arms/elbows, shoulders, and the back. The wrists and arms/elbows share the most extreme risk level due to the awkward lifting posture of the arms/elbows, ulnar deviation at the wrists, and the compounding factor of cylinder weight.

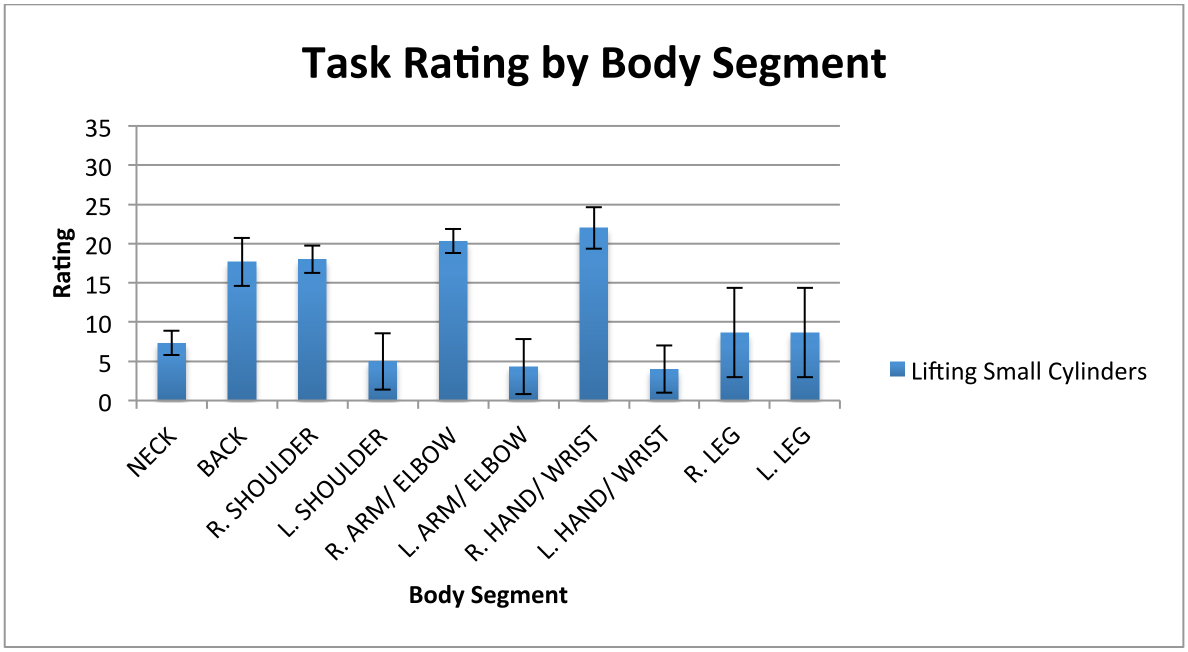

Figure 5.4: Graph of risk ratings for each body segment for the task of lifting small cylinders

6. Discussion

The ERA was conducted on three tasks selected from a set of tasks performed by the drivers on a daily basis by considering imposed ergonomic risks. The tasks selected for analysis included: (1) pulling a dewar, (2) rolling two cylinders, and (3) lifting small cylinders.

6.1. Hypothesis 1

It was hypothesized that moving dewars would result in a high average ergonomic risk rating. This expectation was due to the large size of the dewars and the corresponding force required to move them. Dewars typically weigh approximately 600-800 lbs., resulting in high ergonomic risk for the arms, shoulders, back, and legs when moving the products.

Application of the ERA yielded a job screening score of 18 and a "medium" task risk level. Due to the high force required to move a dewar, it was hypothesized that the rating and risk level would be higher than average. The difference between the hypothesis and the result can be explained by the less risky motion and posture of the task. An assumption was made regarding task frequency as a basis for evaluation of the task. It was assumed that drivers would move a dewar approximately once during a delivery operation, making the task a low frequency task. This assumption was based on observations from the ride-alongs and unstructured driver interviews. Having said this, the moderate risk level does indicate the need for control measures.

6.2. Hypothesis 2

It was hypothesized that the rolling cylinders would result in a high average ergonomic risk rating. This expectation was due to the repetitive motion of the wrist in rolling cylinders, as well as awkward posture positions of the arms and shoulders. The cylinders also pose a significant force on the arms, with each of the two cylinders weighing approximately 70 lbs.

Application of the ERA yielded a job screening score of 28 and a “high” task risk level. These results were consistent with the hypothesis. The task score also indicated a need for job redesign.

6.3. Hypothesis 3

It was hypothesized that lifting small cylinders would result in a high average ergonomic rating. This expectation was due highly repetitive motion involved in moving the cylinders by using the hands/wrists, arms, shoulders, and back. The task also involved awkward postures in which drivers must bend over to grab small cylinders while twisting their back.

Application of the ERA yielded a job screening score of 18 and a “medium” task risk level. However, the task was hypothesized to result in a “high” risk level. The difference between the hypothesis and the results could be explained by the less risky force and motion involved in the task. The small cylinders weigh approximately 10 lbs., which does not pose a high risk to drivers performing this task. The motion ratings were also low as the lifting task only occurs for a brief period of time during the overall delivery process.

6.4. Recommendations

The gas delivery company under study has implemented a number of controls to account for ergonomic risk exposure in driver tasks. For example, a handcart has been provided to move cylinders long distances. However, oftentimes drivers are unable to use the handcart due to space or time restrictions. The company also provides drivers with training on how to perform deliveries (e.g., how to move products). Beyond this, the company has plans to create a mechanized and wheeled cart for dewars in order to reduce the maximum distance for rolling cylinders and they intend to put ergonomic handles on more small cylinders. However, many tasks have an inherent risk, such as high force in pulling dewars. These risks motivate the need for introduction of additional controls. One such control is an exercise program. As covered in the literature review, exercise programs have been implemented successfully in many companies. While a stretching program does not eliminate job risk, evidence of effectiveness in controlling the rate of injury in the workforce has mixed support in the literature, and some studies do report a reduction in the severity of injuries (McGillis, 2015).

Given the autonomous nature of the gas delivery drivers, there is a need for a method to deliver the stretching exercise program to the drivers in the field. A reminder card can be placed in the cab of a driver's truck to allow for easy access and use. Some studies have shown reminder cards to be successful in reminding participants to exercise (Schneiders et al., 1998). However, studies have also shown that these cards are best implemented with an initial training session to familiarize workers with the stretches and protocol (Friedrich, et al., 1996; Reo & Mercer, 2004). For example, the gas delivery company could also incorporate stretches into their existing safety training sessions. A checklist could also be used to ensure that the drivers are completing the program as a part of their delivery safety routine.

Based on the results of the ERA and the OSHA log analysis, stretches were chosen for a driver exercise program to target at-risk body segments from each task. The areas of focus from the tasks included the shoulders, arms, hands, wrists, and back. Muscles moving these body segments were identified. In specific, muscles that are eccentrically contracted (contracting while lengthening) during task movements were targeted for stretching. Stretches were that involve the eccentric movement muscles were selected using a physical therapy text (Kisner & Colby, 2007). A chart detailing this process can be found in Appendix D.

The chosen stretches were described verbally, and pictures depicting each stretch were generated. The verbal stretching descriptions were tested for clarity in pilot study with a sample of college students (n=10) in order to ensure that the correct stretch occurred as a result of the verbal description. If stretches received less than 90% accuracy in execution by students, the descriptions and pictures were edited based on inputs from the participants and researcher observations of posture positions during stretching. Final revisions of stretches were tested again using the same procedure with the students. A list of final stretches and verbal descriptions can be found in Appendix E.

With respect to designing a job-readiness reminder card for the drivers, the gas delivery company's brand identity standards, dictating the color, placement, spacing, font, and other elements of designs for any inter-company products or marketing materials were followed. The details of the design follow the standards and guidelines stated in the company's brand identity documents. Furthermore, general graphic design guidelines from the collaborating gas services company were followed and personal creative elements were added.

The exercise card prototype, excluding stretching information can be seen in Appendix F. Once stretching descriptions were finalized, two prototypes were created to present to the company. The two prototypes contained different stretching programs targeting different body segments. The two options were created due to concerns that the drivers would be reluctant to perform some stretches (e.g., bending over) due to awkward or uncomfortable posture positions. Option A contains no stretches that drivers would be reluctant to perform and concentrates on the upper-extremities and the shoulders (Appendix G, Figure G.1-G.2). Option B contains a more comprehensive set of stretches, which includes one stretch that involves bending over, targeting the back (Appendix G, Figure G.3-G.4).

7. Conclusions

The HTA was used to identify all tasks in a delivery procedure and to provide a structured basis for identification of ergonomic risk factor exposures during delivery performance. The ERA identified body segments exposed to various risks (force, repetition and posture) as well as the levels of exposure. The body segments identified as being vulnerable, according to the ERA, included the back, shoulder, arms/elbows, and hands/wrists. Additionally, the identification of these body segments aided in specification of muscles for stretching and exercises by workers prior to delivery operations. The ERA results also provided a basis for designing a targeted corporate exercise/stretching program and employer reminder technology.

7.1. Limitations

The ERA was limited to consideration of the three riskiest tasks observed during the development of the HTA. However, throughout the course of daily deliveries, drivers may perform other tasks, as identified in the HTA (see Appendix A). In addition, delivery client order and facility layouts can vary greatly. The autonomous nature of the delivery job also means that operators at a client site may not always follow SOPs and safety practices established by the company. All of these conditions can introduce variability in overall ergonomic risk exposure from the levels identified in the present analysis.

The ERA methodology was originally intended for assembly line like tasks. In order to apply the tool to the delivery operation tasks, assumptions were made regarding average frequency and duration of performance as bases for motion ratings. Such assumptions can compromise the accuracy of the risk analysis. Beyond this, the ERA itself is a subjective rating of tasks based on observations. In the present study, three analysts independently rated the delivery tasks for risk exposures and ratings were averaged. The levels of training of analysts and inter-rater reliability can influence this approach. The correlation ratings between raters can be found in Table 7.1 below.

Spearman's Rank Correlation			
Analyst/Analyst	1	2	3
1	1		
2	0.9445	1	
3	0.8838	0.8572	1

Table 7.1: Correlation between analysts

In addition to these issues, in the present study, analysis was limited to a small sample size of drivers from a particular delivery facility, which reduces the generalizability of results to the delivery operator population. The small sample also affects the ratings of the ERA. In addition, it is important to note that individual anthropometry of drivers may influence risk ratings (e.g., taller workers operating in a cramped space might lead to more extreme postures).

With respect to the stretching/job-readiness reminder card, certain stretches were not included in the exercise program due to environmental restrictions. The stretching protocol was designed to be performed at client sites while the driver performs deliveries throughout the day. For this reason stretches involving sitting or lying on the ground were excluded from the protocol. This exclusion involved omitting some exercises aimed at targeting the lower back, as many low back stretches involve either sitting or laying on the ground.

7.2. Future Research

The literature review revealed limited research into the effectiveness of reminder cards and mixed evidence to support corporate stretching programs. The opportunity for research into the effect of using a reminder card to improve adherence to an exercise program exists. As well, research could be conducted to determine both the long-term and short-term effects of a stretching program. Although considerable research has been conducted on stretching programs, there is no consensus regarding program effectiveness. Both short-term physiological effects and long-term benefits, such as a reduced rate of injury, severity of injury and cost of treating injuries, should be studied to determine effectiveness. Beyond this, additional benefits should be identified and quantified. The literature review revealed additional benefits observed by several studies, such as increased focus on safety (Goldenhar & Stafford, 2015; Smith, 2013), increased overall health of the workforce (Elberson, Daniels, & Miller, 2000), and increased job performance (Bernack & Baun, 1984). Research to quantify such benefits could be useful in promoting stretching programs as a part of a company's ergonomic and safety programs. In addition to this study, future work could include verifying that drivers comprehend the stretching descriptions in the field.

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APPENDICES

Appendix A: Hierarchical Task Analysis

No.	Task	Plan
	Making daily deliveries	do all in sequence 1-8
1	Paperwork	
2	Drive to and park at client site	
3	Unload product from truck	Do 1-2, then do either 3-4
3.1	Prepare for moving materials	do all in any order
3.1.1	Put on appropriate PPE	
3.1.2	Check for hazards at site	
3.1.3	Ensure clear path for moving through client site	
3.2	Remove ratchet strap from desired materials	
3.3	Use ramp	do 1-4 according to customer order
3.3.1	Move small cylinders off of the truck	Do either 1-2
3.3.1.1	Move by hand	do all in sequence 1-3
3.3.1.1.1	Grab cylinder by neck	
3.3.1.1.2	Walk to desired location	
3.3.1.1.3	Place cylinder in desired location	
3.3.1.2	Moving with a handcart	do all in sequence 1-4
3.3.1.2.1	Grab cylinder by neck	
3.3.1.2.2	Place cylinder on the hand cart	
3.3.1.2.3	Move handcart to desired location	
3.3.1.2.4	Remove cylinders from handcart	

No.	Task	Plan
3.3.2	Roll cylinders off of the truck	do all in sequence 1-5
3.3.2.1	Inspect cylinder caps for damage	
3.3.2.2	Ensure cylinder caps are tight	do 1 if necessary
3.3.2.2.1	Tighten caps with hands	
3.3.2.3	Tilt cylinders	
3.3.2.4	Roll cylinders to desired location	do all in sequence 1-2
3.3.2.4.1	Rotate caps with hands	
3.3.2.4.2	Kick with feet	
3.3.2.5	Bring cylinders to an upright position at destination	
3.3.3	Liquid containers (dewars)	do either 1-2, depending on product type
3.3.3.1	Pull dewar with wheeled base to desired location	
3.3.3.2	Dewar without wheeled base	do all in sequence 1-6
3.3.3.2.1	Hook the dewar to the hand cart	
3.3.3.2.2	Tilt the dewar back	
3.3.3.2.3	Move hand cart forks under the dewar	
3.3.3.2.4	Pull the cart to the destination	
3.3.3.2.5	Tilt the dewar	
3.3.3.2.6	Unhook the dewar from the hand cart	
3.3.4	Clusters	do either 1-2, depending on product type
3.3.4.1	Pull six pack cluster off of truck	

No.	Task	Plan
3.3.4.2	Remove twelve pack cluster using forklift	
3.4	Use lift	do 1-4 according to customer order
3.4.1	Move product to lift area	do 1-4, according to customer order
3.4.1.1	Moving small cylinders	do all in sequence 1-3
3.4.1.1.1	Grab cylinder by neck	
3.4.1.1.2	Walk to desired location	
3.4.1.1.3	Place cylinder in desired location	
3.4.1.2	Roll cylinders to lift area	do all in sequence 1-5
3.4.1.2.1	Inspect cylinder caps for damage	
3.4.1.2.2	Ensure cylinder caps are tight	do 1 if necessary
3.4.1.2.2.1	Tighten caps with hands	
3.4.1.2.3	Tilt cylinders	
3.4.1.2.4	Roll cylinders to desired location	do all in sequence 1-2
3.4.1.2.4.1	Rotate caps with hands	
3.4.1.2.4.2	Kick with feet	
3.4.1.2.5	Bring cylinders to an upright position at destination	
3.4.1.3	Liquid containers (dewars)	do either 1-2, depending on product
3.4.1.3.1	Pull dewar with wheeled base to desired location	
3.4.1.3.2	Dewar without wheeled base	do all in sequence 1-6
3.4.1.3.2.1	Hook the dewar to the hand cart	

No.	Task	Plan
3.4.1.3.2.2	Tilt the dewar back	
3.4.1.3.2.3	Move hand cart forks under the dewar	
3.4.1.3.2.4	Pull the cart to the destination	
3.4.1.3.2.5	Tilt the dewar	
3.4.1.3.2.6	Unhook the dewar from the hand cart	
3.4.1.4	Clusters	do either 1-2, depending on product
3.4.1.4.1	Pull six pack cluster to lift area	
3.4.1.4.2	Move twelve pack cluster with forklift	
3.4.2	Secure product with two chains	
3.4.3	Operate lift	
3.4.4	Remove chains from product	
4	Deliver product to client	do 1-4 according to customer order
4.1	Small cylinders	do either 1-2
4.1.1	Moving by hand	do all in sequence 1-3
4.1.1.1	Grab cylinder by neck	
4.1.1.2	Walk to desired location	
4.1.1.3	Place cylinder in desired location	
4.1.2	Moving with a handcart	do all in sequence 1-4
4.1.2.1	Grab cylinder by neck	
4.1.2.2	Place cylinder on the hand cart	

No.	Task	Plan
4.1.2.3	Move handcart to desired location	
4.1.2.4	Remove cylinders from handcart	
4.2	Cylinders	if distance to travel is <15 ft., do 1, else do 2
4.2.1	Rolling cylinders	do all in sequence 1-5
4.2.1.1	Inspect cylinders caps for damage	
4.2.1.2	Ensure cylinder caps are tight	do 1 if necessary
4.2.1.2.1	Tighten caps with hands	
4.2.1.3	Tilt cylinders	
4.2.1.4	Roll cylinders to desired location	do all in sequence 1-2
4.2.1.4.1	Rotate caps with hands	
4.2.1.4.2	Kick with feet	
4.2.1.5	Bring cylinders to an upright position at destination	
4.2.2	Move cylinders with hand cart	do all in sequence 1-4
4.2.2.1	Check cart for damage/wear and tear	do all in any order
4.2.2.1.1	Check the bearings	
4.2.2.1.2	Check the handles	
4.2.2.1.3	Check the base	
4.2.2.1.4	Check that the wheel pressure is at 30 PSI	
4.2.2.2	Put cylinder into cart	do all in sequence 1-4
4.2.2.2.1	Tilt cylinder forward with hand	

No.	Task	Plan
4.2.2.2.2	Move cart under cylinder	
4.2.2.2.3	Pull back on cylinders	
4.2.2.2.4	Move hands to cart grips	
4.2.2.3	Push cart to destination	
4.2.2.4	Remove cylinders	do all in sequence 1-5
4.2.2.4.1	Move hands from cart handles to cylinder caps	
4.2.2.4.2	Place foot on bottom on cart to stabilize	
4.2.2.4.3	Lean cylinders forward until cart is flat on ground	
4.2.2.4.4	Rotate cylinders off the cart	
4.2.2.4.5	Remove cart	
4.3	Liquid Containers (dewar)	do either 1-2, depending on product type
4.3.1	Pull wheeled dewar to desired location	do all in sequence 1-3
4.3.1.1	Place one hand on the dewar handle	
4.3.1.2	Place one hand on top of the dewar	
4.3.1.3	Walk backwards to desired location	
4.3.2	Pull dewar without wheeled base to desired location	do all in sequence 1-6
4.3.2.1	Hook the dewar to the handcart	
4.3.2.2	Tilt the dewar back	
4.3.2.3	Move hand cart forks under the dewar	
4.3.2.4	Pull the cart to the destination	

No.	Task	Plan
4.3.2.5	Tilt the dewar	
4.3.2.6	Unhook the dewar from the hand cart	
4.4	Cluster	do either 1-2, depending on product type
4.4.1	Pull six pack cluster(s) to desired location	
4.4.2	Move twelve pack clusters with a forklift	
5	Load empties into truck	do 1, then do either 2-3
5.1	Prepare truck	do all in sequence 1-3
5.1.1	Check truck for damage	
5.1.2	Check for hazards in truck bed	
5.1.3	Check truck equipment for damage	
5.2	Use ramp	do 1-4 according to customer order
5.2.1	Small cylinders	do all in sequence 1-3
5.2.1.1	Grab cylinder by the neck	
5.2.1.2	Walk to desired location	
5.2.1.3	Place cylinder in desired location	
5.2.2	Cylinders	Do 1 if distance to travel is < 15 ft., else do 2
5.2.2.1	Roll cylinders to desired location	do all in sequence 1-5
5.2.2.1.1	Inspect cylinders caps for damage	
5.2.2.1.2	Ensure cylinder caps are tight	do 1 if necessary
5.2.2.1.2.1	Tighten caps with hands	

No.	Task	Plan
5.2.2.1.3	Tilt cylinders	
5.2.2.1.4	Roll cylinders to desired location	do all in sequence 1-2
5.2.2.1.4.1	Rotate caps with hands	
5.2.2.1.4.2	Kick with feet	
5.2.2.1.5	Bring cylinders to an upright position at destination	
5.2.2.2	Move cylinders with hand cart	do all in sequence 1-4
5.2.2.2.1	Check cart for damage/wear and tear	do 1-4, in any order
5.2.2.2.1.1	Check the bearings	
5.2.2.2.1.2	Check the handles	
5.2.2.2.1.3	Check the base	
5.2.2.2.1.4	Check that the wheel pressure is at 30 PSI	
5.2.2.2.2	Put cylinder into cart	do all in sequence 1-4
5.2.2.2.2.1	Tilt cylinder forward with hand	
5.2.2.2.2.2	Move cart under cylinder	
5.2.2.2.2.3	Pull back on cylinders	
5.2.2.2.2.4	Move hands to cart grips	
5.2.2.2.3	Push cart to destination	
5.2.2.2.4	Remove cylinders	do all in sequence 1-5
5.2.2.2.4.1	Move hands from cart handles to cylinder caps	
5.2.2.2.4.2	Place foot on bottom on cart to stabilize	

No.	Task	Plan
5.2.2.2.4.3	Lean cylinders forward until cart is flat on ground	
5.2.2.2.4.4	Rotate cylinders off the cart	
5.2.2.2.4.5	Remove cart	
5.2.3	Liquid containers	do either 1-2, depending on product
5.2.3.1	Pull dewar with wheeled base to desired location	
5.2.3.2	Pull dewar without a wheeled base	do all in sequence 1-5
5.2.3.2.1	Hook the dewar to the handcart	
5.2.3.2.2	Tilt the dewar back	
5.2.3.2.3	Move hand cart forks under the dewar	
5.2.3.2.4	Pull the cart to the destination	
5.2.3.2.5	Tilt the dewar	
5.2.3.2.6	Unhook the dewar from the hand cart	
5.2.4	Clusters	do 1-2, depending on product
5.2.4.1	Pull six pack cluster to desired location	
5.2.4.2	Move twelve pack cluster using forklift	
5.3	Use lift	do all in sequence 1-6
5.3.1	Move product to lift area	do 1-4, depending on customer order
5.3.1.1	Move small cylinders	do all in sequence 1-3
5.3.1.1.1	Grab cylinder by neck	
5.3.1.1.2	Walk to desired location	

No.	Task	Plan
5.3.1.1.3	Place cylinder in desired location	
5.3.1.2	Move cylinders	Do 1 if distance to travel is <15 ft., else do 2
5.3.1.2.1	Roll cylinders to desired location	do all in sequence 1-5
5.3.1.2.1.1	Inspect cylinders caps for damage	
5.3.1.2.1.2	Ensure cylinder caps are tight	
5.3.1.2.1.2.1	Tighten caps with hands	
5.3.1.2.1.3	Tilt cylinders	
5.3.1.2.1.4	Roll cylinders to desired location	
5.3.1.2.1.4.1	Rotate caps with hands	
5.3.1.2.1.4.2	Kick with feet	
5.3.1.2.1.5	Bring cylinders to an upright position at destination	
5.3.1.2.2	Move cylinders with hand cart	do all in sequence 1-4
5.3.1.2.2.1	Check cart for damage/wear and tear	
5.3.1.2.2.1.1	Check the bearings	
5.3.1.2.2.1.2	Check the handles	
5.3.1.2.2.1.3	Check the base	
5.3.1.2.2.1.4	Check that the wheel pressure is at 30 PSI	
5.3.1.2.2.2	Put cylinder into cart	
5.3.1.2.2.2.1	Tilt cylinder forward with hand	
5.3.1.2.2.2.2	Move cart under cylinder	

No.	Task	Plan
5.3.1.2.2.2.3	Pull back on cylinders	
5.3.1.2.2.2.4	Move hands to cart grips	
5.3.1.2.2.3	Push cart to destination	
5.3.1.2.2.4	Remove cylinders	
5.3.1.2.2.4.1	Move hands from cart handles to cylinder caps	
5.3.1.2.2.4.2	Place foot on bottom on cart to stabilize	
5.3.1.2.2.4.3	Lean cylinders forward until cart is flat on ground	
5.3.1.2.2.4.4	Rotate cylinders off the cart	
5.3.1.2.2.4.5	Remove cart	
5.3.1.3	Liquid containers (dewars)	do either 1-2, depending on product
5.3.1.3.1	Push dewar with wheels to desired location	
5.3.1.3.2	Dewar without wheels	do all in sequence 1-6
5.3.1.3.2.1	Hook the dewar to the hand cart	
5.3.1.3.2.2	Tilt the dewar back	
5.3.1.3.2.3	Move hand cart forks under the dewar	
5.3.1.3.2.4	Pull the cart to the destination	
5.3.1.3.2.5	Tilt the dewar	
5.3.1.3.2.6	Unhook the dewar from the hand cart	
5.3.1.4	Clusters	do either 1-2, depending on product
5.3.1.4.1	Pull six pack cluster onto lift	

No.	Task	Plan
5.3.1.4.2	Move twelve pack cluster with a fork lift	
5.3.2	Secure product with chain	
5.3.3	Operate lift	
5.3.4	Remove chains from product	
5.3.5	Move product to pallets	do 1-4, depending on customer order
5.3.5.1	Moving small cylinders	do all in sequence 1-3
5.3.5.1.1	Grab cylinder by neck	
5.3.5.1.2	Walk to desired location	
5.3.5.1.3	Place cylinder in desired location	
5.3.5.2	Roll cylinders to lift area	do all in sequence 1-5
5.3.5.2.1	Inspect cylinder caps for damage	
5.3.5.2.2	Ensure cylinder caps are tight	
5.3.5.2.2.1	Tighten caps with hands	
5.3.5.2.3	Tilt cylinders	
5.3.5.2.4	Roll cylinders to desired location	
5.3.5.2.4.1	Rotate caps with hands	
5.3.5.2.4.2	Kick with feet	
5.3.5.2.5	Bring cylinders to an upright position at destination	
5.3.5.3	Liquid containers (dewars)	do either 1-2, depending on product
5.3.5.3.1	Pull dewar with wheeled base to desired location	

No.	Task	Plan
5.3.5.3.2	Dewar without wheeled base	
5.3.5.3.2.1	Hook the dewar to the hand cart	
5.3.5.3.2.2	Tilt the dewar back	
5.3.5.3.2.3	Move hand cart forks under the dewar	
5.3.5.3.2.4	Pull the cart to the destination	
5.3.5.3.2.5	Tilt the dewar	
5.3.5.3.2.6	Unhook the dewar from the hand cart	
5.3.5.4	Clusters	do 1-2, depending on product
5.3.5.4.1	Pull six pack cluster to lift area	
5.3.5.4.2	Move twelve pack cluster with forklift	
5.3.6	Secure products with ratchet strap	
6	Return to facilities	
7	Unload empties from truck	do all in sequence 1-3
7.1	Prepare for moving materials	do all in sequence 1-3
7.1.1	Put on appropriate PPE	
7.1.2	Check for hazards at site	
7.1.3	Ensure clear path for moving through client site	
7.2	Remove pallets using forklift	
7.3	Move pallets to desired location using forklift	
8	Load truck with next day's deliveries	do all in sequence 1-3

No.	Task	Plan
8.1	Prepare truck	do all in any order
8.1.1	Check for truck damage	
8.1.2	Check for hazards in the truck bed	
8.1.3	Check truck equipment for damage	
8.2	Prepare pallets with customer orders	
8.3	Use forklift to place loaded pallets onto truck	

Appendix B: ERA Metrics

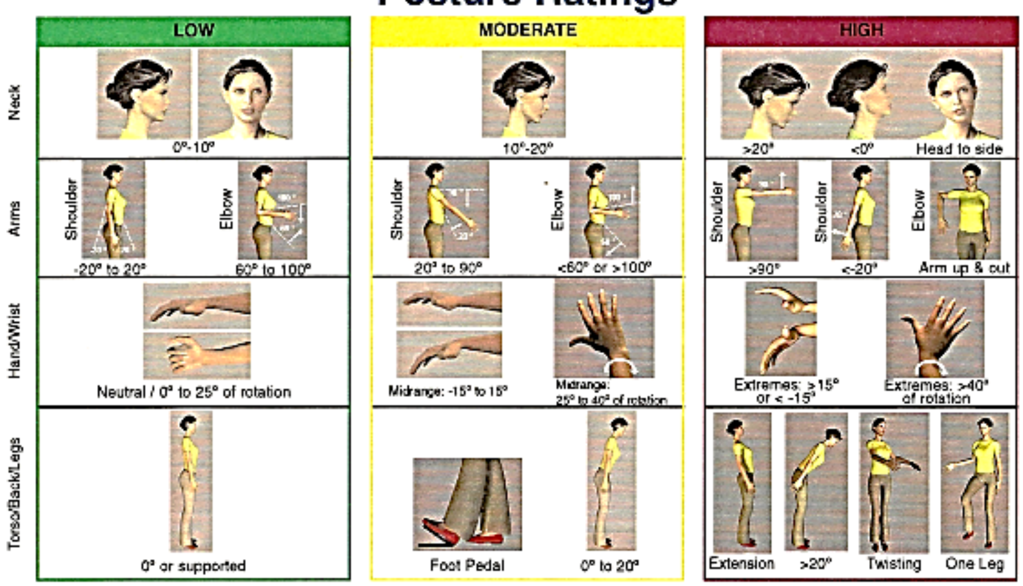
Motion Ratings

	LOW	MODERATE	HIGH
Hand Activity Level	0 1 2 3	4 5 6	7 8 9 10
General Definition	Hands idle most of the time; no regular exertions; consistent, conspicuous, long pauses; OR very slow motions	Slow steady motion/exertion; frequent brief pauses; steady motion/exertion; infrequent pauses	Rapid steady motion/exertion; no regular breaks or pauses; difficulty keeping up
Static	Posture held < 6 seconds	Posture held 6-20 seconds	Posture held > 20 seconds
Repetitive	< 1 / minute	1-5 per minute	> 5 per minute

Force Ratings

	LOW	MODERATE	HIGH
CR10 Borg	0 1 2 3	4 5 6	7 8 9 10+
General Definitions	No or minimal force; noticeable effort; < 30% MVC	Moderate to strong force; obvious effort, but unchanged facial expression; 30-60% MVC	Very strong force; substantial effort with changed facial expression; use of shoulder or trunk for force; >60% MVC
Neck	Neutral neck; head turned partly to side; back or forward slightly; back leaning forward 0-20 degrees	Head turned to side; head fully back; forward about 20 degrees; back leaning forward 20-45 degrees	Same as moderate but with force or weight; head stretched forward; back leaning forward >45 degrees
Shoulders	Neutral arms; arms slightly away from sides; arms extended with some support	Arms away from body, no support; working overhead or behind	Exerting forces or holding weight with arms away from body or overhead
Arms/Elbows	Neutral; arms away from body, no load; light forces lifting near body; no twisting	Rotating arm while exerting force; arm motion or reach	High forces exerted with rotation; lifting with arms extended; forceful exertion
Hands/Wrists	Neutral; light forces or weights handled close to body; straight wrists; comfortable power grips	Grips with wide or narrow span; moderate wrist angles, especially flexion; use of gloves with moderate forces; using hand tools; static grip	Pinch grips; extreme wrist angles; holding slippery surfaces; lift or carry with hands; precision task; heavy tools; high torque
Torso/Back	Standing; sitting with lumbar support; Leaning to side or bending slightly; arching back	Bending forward, no load; lifting moderately heavy loads near body; working overhead	Lifting or exerting force while twisting; high force or load while bending; Heavy lifting, lowering, carrying, pushing/pulling
Legs/Knees/Feet	Standing, walking without bending or leaning; weight on both feet; sitting with supported legs; sit/stand stool	Bending forward, leaning on table; weight on one side; pivoting while exerting force; foot pedal; kneeling, squatting; static stand	Exerting high forces while pulling or lifting; crouching or squatting while exerting force; walking with heavy load; standing on one foot

Posture Ratings



Appendix C: ERA Tables of Results

JOB TASKS/PROCESS	
TASK 1	PULLING DEWERS
TASK 2	ROLLING 2 CYLINDERS
TASK 3	LIFTING SMALL CYLINDERS

Table C.1.: List of Tasks

BODY PART			
TASK / BODY PART	1	2	3
NECK	11.33	12	7.33
BACK	16.66	17.33	17.66
R. SHOULDER	16.33	17.66	18
L. SHOULDER	17	17.66	5
R. ARM/ ELBOW	14.33	19	20.33
L. ARM/ ELBOW	15.67	19	4.33
R. HAND/ WRIST	14	23.33	22
L. HAND/ WRIST	14.33	23.33	4
R. LEG	14.33	10.66	8.66
L. LEG	14.33	10.66	8.66

Table C.2.: Risk Score by Task and Body Part

TASKS	TOTAL BODY PRIORITY					
	L	M	H			
	Low x 1	Moderate x 2	High x 4	JOB TOTAL	JOB Pr. LEVEL	
1	6	2	2			
	6	4	8	18	MODERATE	PULLING DEWER
2	3	1	6			
	3	2	24	29	**HIGH**	ROLLING 2 CYLINDERS
3	6	2	2			
	6	4	8	18	MODERATE	LIFTING SMALL CYLINDERS

Table C.3.: Total Body Priority by Task

OVERALL BODY PRIORITIES					
BODY PARTS	**MOTION RATING**	**FORCE RATING**	**POSTURE RATING**	**PRIORITY**	**WORST TASK#**
NECK	L	L	H	L	2
BACK	L	H	H	H	3
R. SHOULDER	L	H	M	M	3
L. SHOULDER	L	H	M	M	2
R. ARM/ ELBOW	M	M	H	H	3
L. ARM/ ELBOW	L	M	H	M	2
R. HAND/ WRIST	M	H	H	H	2
L. HAND/ WRIST	L	M	M	L	2
R. LEG	L	M	L	L	1
L. LEG	L	M	L	L	1

Table C.4.: Overall Body Priorities

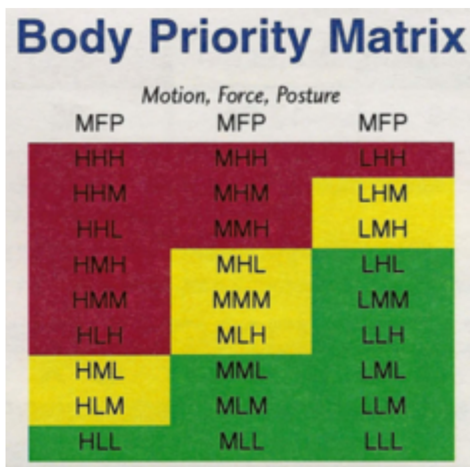


Figure C.13.: Body Priority Matrix

TASK 1 BODY PRIORITIES				
BODY PARTS	MOTION RATING	FORCE RATING	POSTURE RATING	PRIORITY
NECK	L	L	H	L
BACK	L	H	H	H
R. SHOULDER	L	H	M	M
L. SHOULDER	L	H	M	M
R. ARM/ ELBOW	L	M	M	L
L. ARM/ ELBOW	L	H	H	H
R. HAND/ WRIST	L	M	M	L
L. HAND/ WRIST	L	M	M	L
R. LEG	L	H	L	L
L. LEG	L	H	L	L

Table C.5.: Body segment priorities for pulling dewars

TASK 2 BODY PRIORITIES				
BODY PARTS	MOTION RATING	FORCE RATING	POSTURE RATING	PRIORITY
NECK	L	L	H	L
BACK	L	H	M	M
R. SHOULDER	M	H	M	H
L. SHOULDER	M	H	M	H
R. ARM/ ELBOW	M	M	H	H
L. ARM/ ELBOW	M	M	H	M
R. HAND/ WRIST	H	H	H	H
L. HAND/ WRIST	H	H	H	H
R. LEG	L	M	M	L
L. LEG	L	M	M	L

Table C.6.: Body segment priorities for rolling two cylinders

TASK BODY PRIORITIES				
BODY PARTS	**MOTION RATING**	**FORCE RATING**	**POSTURE RATING**	**PRIORITY**
NECK	L	L	M	L
BACK	L	H	H	H
R. SHOULDER	L	H	M	M
L. SHOULDER	L	L	L	L
R. ARM/ ELBOW	M	H	H	H
L. ARM/ ELBOW	L	L	L	L
R. HAND/ WRIST	M	H	H	H
L. HAND/ WRIST	L	L	L	L
R. LEG	L	M	L	L
L. LEG	L	M	L	L

Table C.7.: Body segment priorities for lifting small cylinders

Appendix D: Task to Exercise Breakdown

Task	Body Segment	Muscles	Eccentric Movement Muscles	Stretches that Yield Eccentric Contractions	Duration	Repetition
Moving dewars	Back	Trapezius, latimus dorsi, rhomboids, teres minor, teres major, obliques	*Trapezius, latimus dorsi*, rhomboids	1. Parallel Arm Shoulder Stretch, 2. Hamstring and Low Back Stretch	20 seconds	3 times for each arm
	Shoulder/ Upper Arm	Biceps brachii, triceps brachii, brachialis, deltoids, trapezius, rhomboids	*Posterior deltoid, biceps brachii, triceps brachii*, rhomboids, *trapezius*	1. Upper Arm Shoulder Stretch 2. Chest and Bicep Stretch	20 seconds	3 times for each arm
	Lower arm/Elbow	Brachio radialis, flexors, extensors, pronators, supernators	Flexor carpi ulnarus	1. Finger Flexor Stretch	20 seconds	3 times for each arm
Rolling two cylinders	Hand/wrist	Flexors, opponens, adductors, abductors, lumbricalis	Opponens pollicis, flexor digiti minimi, flexor pollicis brevis, abductor pollicis brevis, oppenens digiti minimi	1. Finger Flexor Stretch 2. Finger Extensor Stretch	20 seconds	3 times for each arm
	Lower arm/Elbow	Brachio radialis, flexors, extensors, pronators, supernators	Brachio radialis, flexor carpi radialis, flexor digitorum superficialis, palmaris longus	1. Finger Flexor Stretch	20 seconds	3 times for each arm
	Shoulder/ Upper Arm	Biceps brachii, triceps brachii, brachialis, deltoids, trapezius, rhomboids	Brachio radialis, trapezius, posterior deltoid, biceps brachii	1. Upper Arm Shoulder Stretch 2. Chest and Bicep Stretch 3. Parallel Arm Shoulder Stretch	20 seconds	3 times for each arm
	Back	Trapezius, latimus dorsi, rhomboids, teres minor, teres major, obliques	Trapezius	1. Chest and Bicep Stretch	20 seconds	3 times for each arm
Lifting small cylinders	Hand/wrist	Flexors, opponens, adductors, abductors, lumbricalis	N/A	1. Finger Flexor Stretch 2. Finger Extensor Stretch	20 seconds	3 times for each arm
	Lower arm/Elbow	Brachio radialis, flexors, extensors, pronators, supernators	Brachio radialis	1. Finger Flexor Stretch	20 seconds	3 times for each arm
	Shoulder/ Upper Arm	Biceps brachii, triceps brachii, brachialis, deltoids, trapezius, rhomboids	Reach: Biceps brachii, posterior deltoid, trapezius, rhomboids, brachialis Lift: Triceps brachii, anterior deltoid	1. Upper Arm Shoulder Stretch, 2. Parallel Arm Shoulder Stretch, 3. Chest and Bicep Stretch	20 seconds	3 times for each arm
	Back	Trapezius, latimus dorsi, rhomboids, teres major, obliques	Reach: Latimus dorsi, teres major, rhomboids, trapezius Lift: n/a	1. Parallel Arm Shoulder Stretch, 2. Chest and Bicep Stretch, 3. Upper Arm Shoulder Stretch	20 seconds	3 times for each arm

Appendix E: Stretch Descriptions

Parallel Arm Shoulder Stretch
Bring one arm straight across chest at shoulder height and grab truck for support. Twist torso toward the arm. Repeat on opposite side.

Chest and Bicep Stretch
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.

Upper Arm Shoulder Stretch
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 sideways at waist, leaning torso in direction of stretch. Repeat on opposite side.

Reverse Shoulder Stretch
Interlock hands behind back. Slowly raise hands upwards. Keep back straight.

Finger Extensor Stretch
Stretch arm in front of body. Bend hand at wrist with fingers pointing down, palm facing body. Use opposite hand to pull fingers towards body. Repeat on opposite side.

Finger Flexor Stretch
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.

Quad Stretch
Standing on left foot while holding truck for support, bend right leg at knee. Use right hand to grab right foot, pull towards buttocks. Repeat on opposite side.

Hamstring and Low Back Stretch
Bend at hips. Touch toes, if possible.

Appendix F: Card Prototype

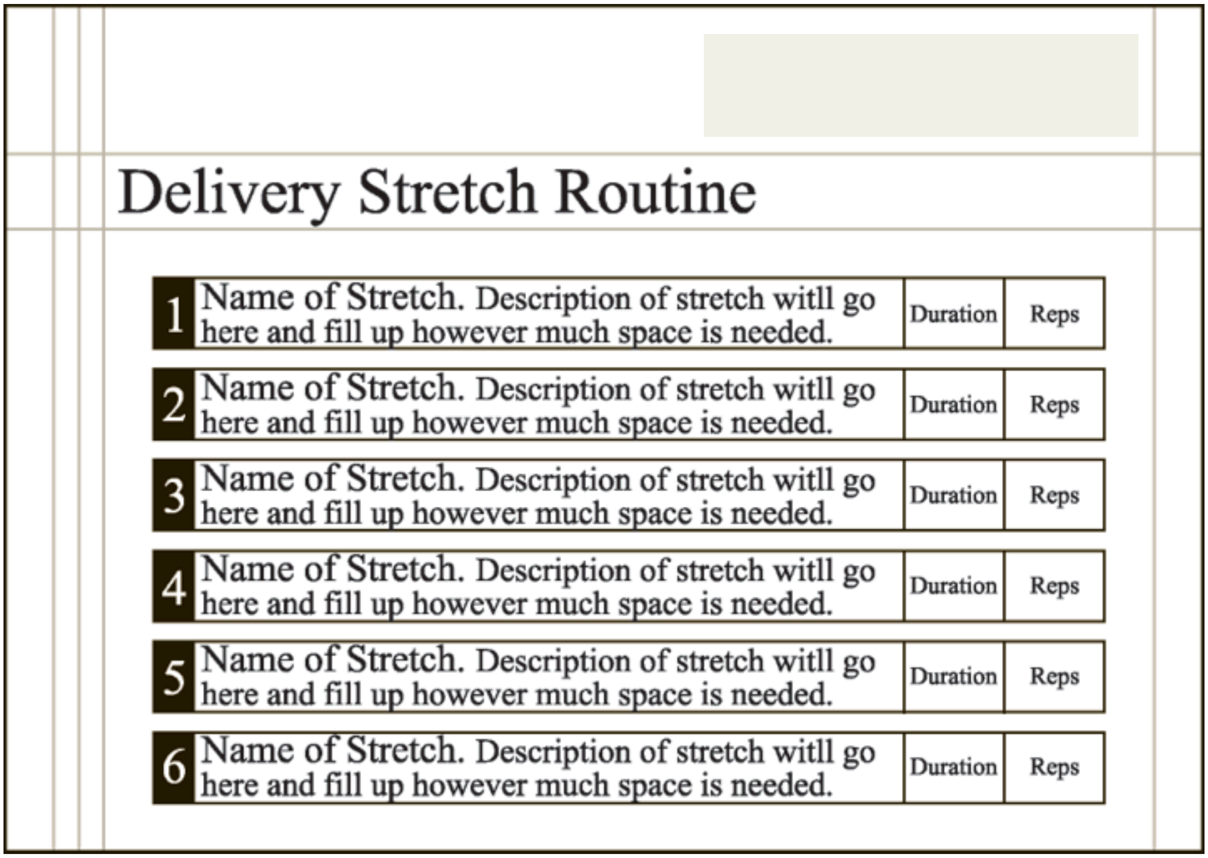


Figure E.1: Card Prototype (front of card)

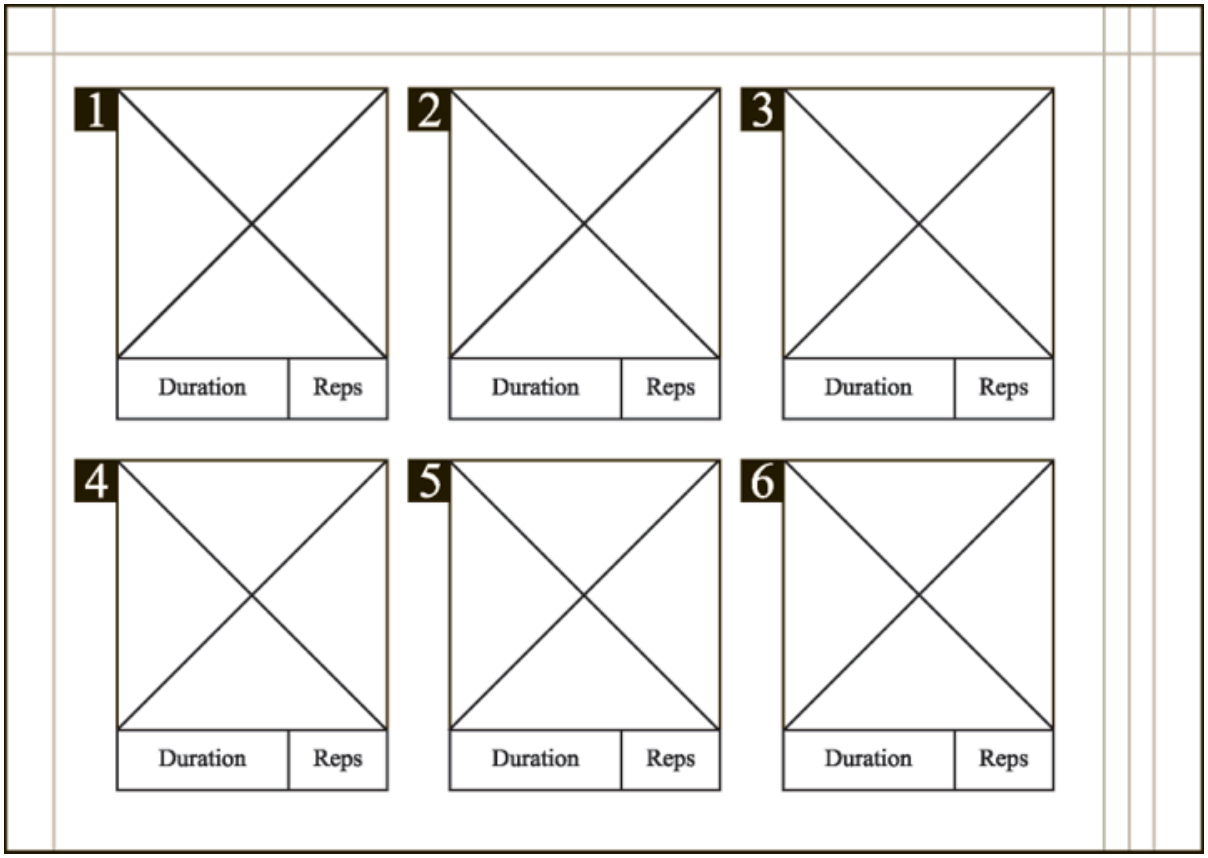


Figure E.2: Card Prototype (back of card)

Appendix G: Final Card Designs

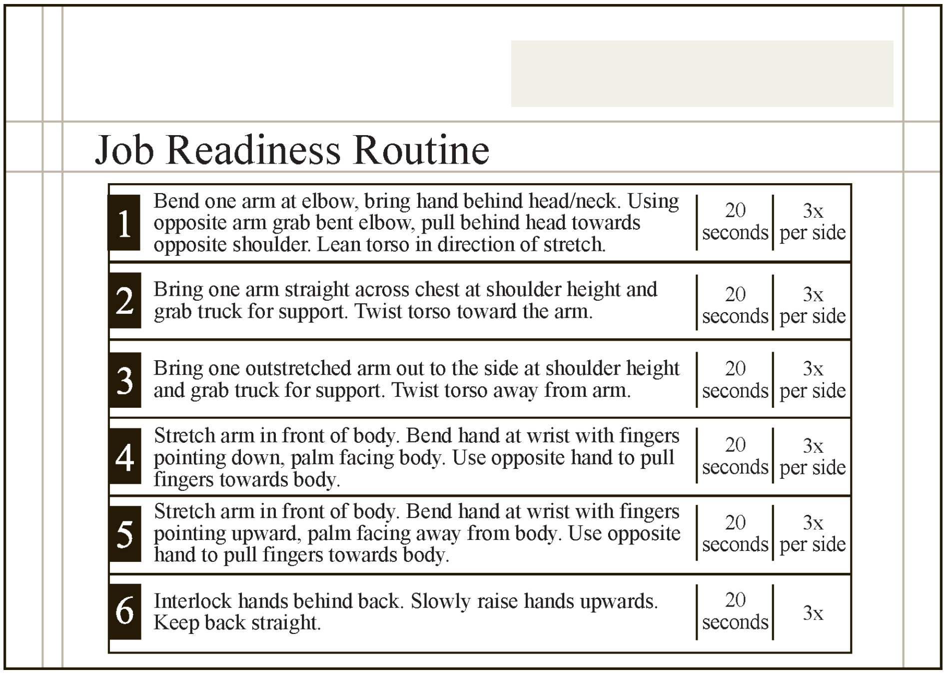


Figure G.1: Card Design Option A (front of card)

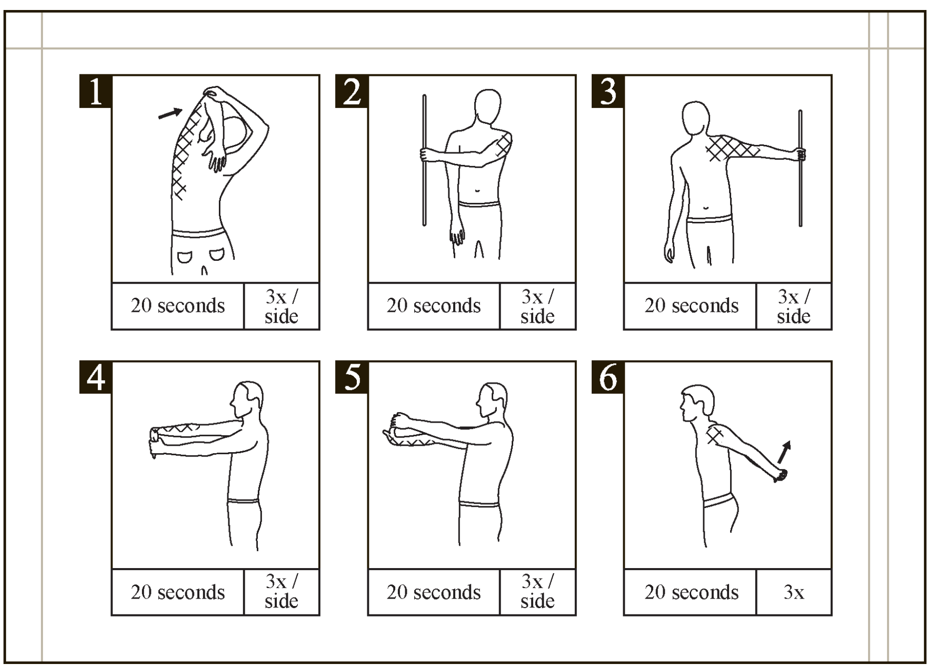


Figure G.2.: Final Card Design Option A (back of card)

Job Readiness Routine

1	Bend one arm at elbow, bring hand behind head/neck. Using opposite arm grab bent elbow, pull behind head towards opposite shoulder. Lean torso in direction of stretch.	20 seconds	3x per side
2	Interlock hands behind back. Slowly raise hands upwards. Keep back straight.	20 seconds	3x
3	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.	20 seconds	3x per side
4	Stretch arm in front of body. Bend hand at wrist with fingers pointing down, palm facing body. Use opposite hand to pull fingers towards body.	20 seconds	3x per side
5	Standing on left foot while holding truck for support, bend right leg at knee. Use right hand to grab right foot, pull towards buttocks.	20 seconds	3x per side
6	Bend at hips. Touch toes, if possible.	20 seconds	3x

Figure G.3: Card Design Option B (front of card)

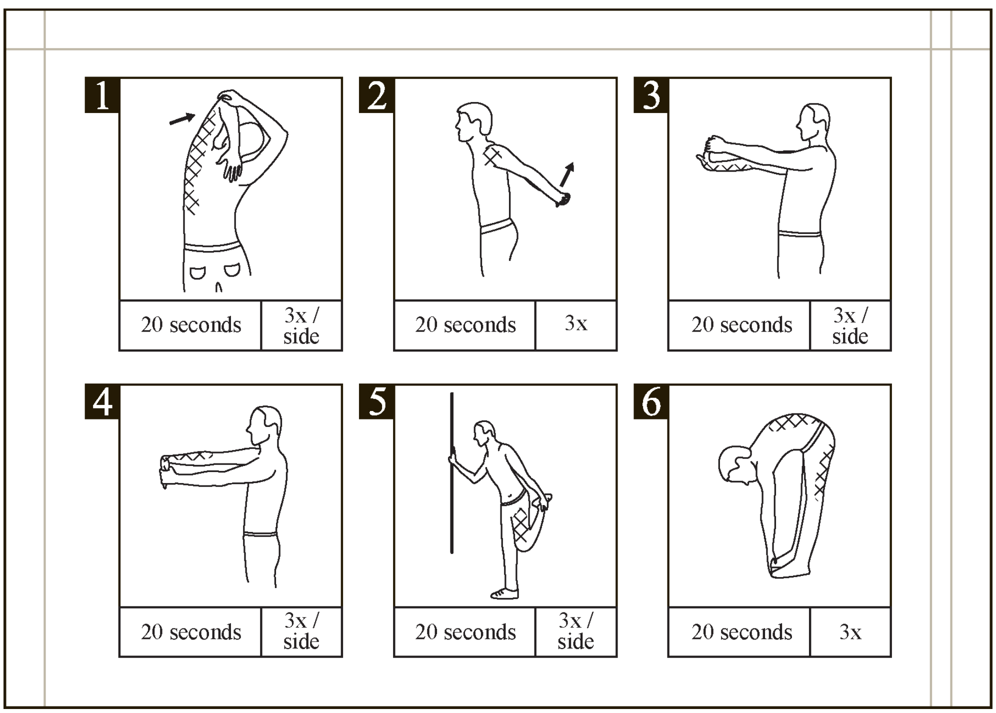


Figure G.4.: Final Card Design Option B (back of card)