Measurement and Analysis of Ergonomic Loads on Mechanical System Installers

by

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ABSTRACT

Construction work is ergonomically hazardous, as it requires numerous awkward postures, heavy lifting and other forceful exertions. Prolonged repetition and overexertion have a cumulative effect on workers often resulting in work related musculoskeletal disorders (WMSDs). The United States spends approximately $850 billion a year on WMSDs. Mechanical installation workers experience serious overexertion injuries at rates exceeding the national average for all industries and all construction workers, and second only to laborers. The main contributing factors of WMSDs are ergonomic loads and extreme stresses due to incorrect postures.

The motivation for this study is to reduce the WMSDs among mechanical system (HVAC system) installation workers. To achieve this goal, it is critical to reduce the ergonomic loads and extreme postures of these installers. This study has the following specific aims: (1) To measure the ergonomic loads on specific body regions (shoulders, back, neck, and legs) for different HVAC installation activities; and (2) To investigate how different activity parameters (material characteristics, equipment, workers, etc.) affect the severity and duration of ergonomic demands. The study focuses on the following activities: (1) layout, (2) ground assembly of ductwork, and (3) installation of duct and equipment at ceiling height using different methods. The researcher observed and analyzed 15 HVAC installation activities among three Arizona mechanical contractors.

Ergonomic analysis of the activities using a postural guide developed from RULA and REBA methods was performed. The simultaneous analysis of the production tasks and the ergonomic loads identified the tasks with the highest postural loads for different body regions and the influence of the different work variables on extreme body postures. Based on this analysis the results support recommendations to mitigate long duration activities and exposure to extreme postures. These recommendations can potentially reduce risk, improve productivity and lower injury costs in the long term.

DEDICATION

To my trailblazer, Ms. Sahar Hussain.

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Thank you to my chair and professor Dr. Panagiotis Mitropoulos for accepting me as his graduate student and allowing me to pursue my interests in the field of construction safety and ergonomics. He was always available for guidance and pushing me to excel. He significantly influenced my career at Arizona State University by supporting me. I would like to thank Dr. Avi Wiezel for his continuous knowledge and encouraging smile. A special thanks to Dr. Linda Guarascio-Howard for her words of support, her vast comprehension in this field and her friendship. Her contribution to my thesis is priceless. Remaining anonymous I would like to thank all the mechanical contractors, safety directors, insurance adjusters and field workers who helped make this thesis what it is. Without their assistance and patience I would not have had any research. My thesis would not have finished without Nadia Pasha's optimistic outlook. I appreciate BSB Design's understanding and patience before, during and after my decision to get a Masters. I wholeheartedly thank Babak Memarian, Neha Malhotra, Claudyne Vilfrant, Aparna Venki and Alpesh Patel for their encouragement throughout the process. Most importantly I would like to thank Allah mia for giving me two wonderful parents Mr. K. Ahmed Hussain and Mrs. Amal Hussain without whom I would not have succeeded.

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Chapter 1

INTRODUCTION

Background: Work-related musculoskeletal disorders

The human body is remarkably adaptable and capable of performing in a wide variety of environments and circumstances. It cannot be said, however, that the body performs equally well under all conditions. In fact, when faced with awkward tasks or environmental demands, the musculoskeletal system may endure substantial performance limitations (Gallagher, 2005). Work-related musculoskeletal disorders are injuries of the muscles, tendons, joints and nerves caused or aggravated by work. Workers are at risk of developing work-related musculoskeletal disorders if they are exposed to a combination of physical force and repetitive motion, awkward or static body postures, heavy lifting of materials, contact stress, vibration, or extreme temperatures (CPWR, 2007).

Work-related musculoskeletal disorders (WMSDs) are recognized as a serious physical problem because of the cost increase associated with wage compensation, medical expenses and reduction in productivity and lower quality of life (Ayoub 1992; Ayoub & Mital 1989; Chaffin & Andersson 1991). Costing about $850 billion annually, 52% of all work-related injuries in the United States are WMSDs (AAOS, 2009). These disorders hinder 5 million workers each year (Chaffin 1994). Indirect costs incurred by an organization are new hire training, worker's compensation, loss of experienced personnel, productivity and quality.

WMSDs are caused by multi-factorial operations of various risk factors, such as working posture, repetitive and forceful activities, and static muscle load (Bernard 1997; Hagberg et al. 1995; Kroemer 1989; Kumar 2001). Physical disability and long term pain are most frequently attributed to muscle and joint disease.

The United States spends approximately $850 billion a year on work related musculoskeletal disorders (WMSDs) (Dougherty 2009). Almost fifty percent of doctor visits for workers over the age of 18 are due to WMSDs. WMSDs are recognized as a major problem in the construction sector. The rate of musculoskeletal injuries and disorders in construction is higher than other industries (Schneider 1997, CPWR 2005). In 2006, there were 1.2 million cases requiring days away from work in the private industry with a rate of 128 per 10,000 workers. Nursing aides, orderlies, and attendants had 49,480 days away from work cases, at a rate of 526 per 10,000 workers, which was more than four times the average rate for all occupations. Table 1 below shows the number of WMSDs per occupation and their incidence rate.

Occupation	Number	Incidence Rate Workers/10,000
Laborers & freight, stock & material movers	28,860	158
Nursing aides, orderlies & attendants	27,590	293
Truck drivers, heavy & tractor trailer	17,400	108
Retail salesperson	11,280	36
Registered nurses	9,200	59
Truck drivers, light & delivery services	8,890	99
Janitors and cleaners, except maids & housekeeping cleaners	8,630	76
Stock clerks & order filler	8,610	69
Construction laborers	8,270	100
Maintenance and repair workers, general	6,870	70

Table 1: Number and incidence rate of WMSDs that required days away from work of selected occupations, 2006

Three other occupations with more than 40,000 cases had rates above 400 per 10,000 workers: construction laborers (488); laborers and freight, stock, and material movers (466); and heavy and tractor-trailer truck drivers (411) (BLS, 2007). Musculoskeletal disorders (MSDs) accounted for 30 percent of injuries and illnesses with days away from work, the same percentage as in 2005.

The construction industry as a whole had the highest incidence rate (220 per 10,000 workers) of all industry sectors but had the fourth highest case count (153,180). The construction industry's rate of 84 per 10,000 workers for contact with objects and equipment was more than twice the rate of the total private industry.

In 2005, the U.S. Bureau of Labor Statistics (BLS) estimated 35,900 construction workers developed a WMSD. The severity of WMSDs is also significant. In 2005, nearly 45% of the days away from work were due to overexertion (CPWR 2008). Due to the significance of the problem, the reduction in the frequency and severity of WMSD among construction workers is a strategic goal of the Construction Sector Council's National Occupational Research Agenda (NORA Construction Sector Council 2008).

Mechanical installation workers experience serious overexertion injuries at rates exceeding the national average for all industries and all construction workers (Albers et al 2005, 2006, CPWR 2008). In 2005, the rate of overexertion injuries with days away from work for HVAC workers was 51.9 (incidents per 10,000 full time workers), second only to laborers (CPWR 2008).

The main factors contributing to WMSDs are ergonomic loads and extreme stresses due to incorrect postures. Risk factors contributing to days away from work included overexertion due to lifting (42%), overexertion other than lifting (34%), bending/twisting (18%) and repetitive motion (6%) (CPWR, 2005). The injury statistics highlight the need to reduce WMSDs in construction and specifically in mechanical trades.

Research motivation

The long-term goal of this study is to reduce the WMSD among mechanical system (HVAC) installation workers. To achieve this goal, it is critical to reduce the ergonomic loads and extreme postural positions of installers.

Mechanical contractors use different methods to organize and perform activities. Such methods may differ in the equipment used (e.g., ladders or scissor lifts), the length of the duct installed, number of workers performing a task or division of work, etc. Crew sizes also vary based on the scheduled work and necessary space requirements. Typically, crews are separated into teams of two to four workers. Teams typically include journeymen and apprentices. Apprentices have on-job experience ranging from zero to five years and journeyman are five years and beyond. Work distribution can have a significant effect on the ergonomic loads of the workers.

Ergonomic loads and postures of an activity are the result of three sets of activity parameters: (1) work requirements created by design—such as type of material, location of installation, fastening requirements, etc.; (2) work methods, characteristics of tools and equipment influencing loads and postures of the workers; and (3) task duration which determines the length of exposure. On the other hand, the total ergonomic load on a worker depends on a fourth factor—the distribution (e.g. rotation) of tasks among crew members. These four factors are interdependent—for example, the height of installation may require different equipment and work rotation may increase the task duration due to reduced specialization. To systematically reduce the physical workloads of installation activities, it is critical to develop an in-depth understanding of the role and significance of the activity parameters of ergonomic loads.

Research objective

The main objective of this research is to understand the effect of activity parameters and work organization on the physical work demands of HVAC installers. Activity parameters that influence the ergonomic demands may include the height of installation, the size of duct, the length of the pre-assembled duct section, the work platform used etc. These factors affect the level and duration of ergonomic demands. The study will also identify different task distributions the crews use and analyze these implications for the worker.

Research Objective: Understand the effects of activity parameters on the exposure (duration) and ergonomic demands for different body areas: back, shoulders, neck, and legs. To this end the research will (1) Quantify the ergonomic load on the body areas caused by various activities, methods and work organization. The primary indicator is the percent of time that a body area is under extreme load. (2) Investigate how different work factors (material, work organization, etc.) affect the ergonomic loads on those body areas.

Research approach

The study focuses on the high risk activities of HVAC installation, specifically:

- Installing duct components at ceiling height
- Assembling ductwork on the ground
- Layout

To investigate the effect of different work parameters on the ergonomic loads, the study observed and analyzed different instances of each activity. The analysis measures and compares ergonomic demands of similar activities under different methods and activity parameters (work platform, duct size, length of duct assembly, etc.). The ergonomic demand is analyzed for different body areas—specifically for the back, shoulders, neck, and legs.

The comparison indicates how different activity parameters contribute to exposure, to injury due to posture and ergonomic loads for different body areas. The findings indicate ways to improve work design and organization of HVAC system installation to reduce the extreme ergonomic loads and postures on HVAC workers. The findings indicate work practices with the greatest potential to mitigate ergonomic demands and reduce exposure to injury. The findings also provide guidelines regarding effective task distribution.

Overview

Chapter 2 reviews the background literature on ergonomic injuries in the construction industry as a whole and more specifically the mechanical trades. It then reviews previous ergonomic studies and interventions for construction and mechanical trades and discusses the points of departure from this study. Chapter 3 presents the research methodology and the research activities. It explains the process of data collection and describes the methods used for production and ergonomic analyses of each activity observed. Chapter 4 provides a summary of the activities analyzed and data collected. The chapter first reviews mechanical installation processes and activities, then discusses different ways that ductwork installation is performed. Next, it presents an overview of the activities observed and analyzed. Chapter 5 expounds on the comparison and analysis of the cases and presents the findings of the analysis. A detailed analysis of each observed activity can be found in Appendix A. Chapter 6 presents the conclusions and recommendations regarding the work organization for reducing ergonomic exposures of HVAC installers.

Chapter 2

LITERATURE REVIEW

Injury statistics show that the U. S. construction industry accounts for the highest number of fatalities, injuries and illnesses of all industries. The cost of these injuries is a financial burden to the industry and the country as a whole. Ergonomic injuries account for a significant portion of the injuries and costs. Mechanical workers contribute a large portion of the ergonomic injuries. The HVAC trades account for 10% of over half the construction industry costs to total fatal and nonfatal injuries (CPWR 2007).

This chapter first reviews the background literature on ergonomic injuries in the construction industry and more specifically, the mechanical trades. Next, it reviews ergonomic studies and interventions for the industry and mechanical trades. Finally, it discussed the points of departure from this study.

Construction industry injury frequency

The construction industry is one of the largest industries in the United States. This industry boasts over 7.2 million wage and salary jobs and 1.8 million self-employed and unpaid family workers in 2008 (BLS 2010). In recent years, the construction sector accounted for 6% of the employment and about 20% of all occupational fatalities (BLS, 2010). In 2008 the construction industry accounted for 11.2% of all reported non-fatal injuries and illnesses.

In 2008 120,240 construction occupational injuries and illnesses with days away from work were reported contributing to the 4.7 incidence rate (BLS 2010), as shown in Table 2 below.

Year	Recordable Incident Rate	Cases with days away from work, job transfer, or restriction	Rate for incidents with days away from work
2009	4.3	2.3	1.6
2008	4.7	2.5	1.7
2007	5.4	2.8	1.9

Table 2: Incidence rates of nonfatal occupational injuries and illnesses (BLS, 2009)

The incidence rates represent the number of injuries and illnesses per 100 full-time workers and were calculated as: (N/EH) x 200,000, where:

- N = number of injuries and illnesses
- EH = total hours worked by all employees during the calendar year
- 200,000 = base for 100 equivalent full-time workers (working 40 hours per week, 50 weeks per year)

Contact with objects and overexertion are the two most common events, followed by fall to lower level and struck by object. In 2009, the incidence rate with days away from work for overexertion incidents was 28.6 according to Figure 1 below.

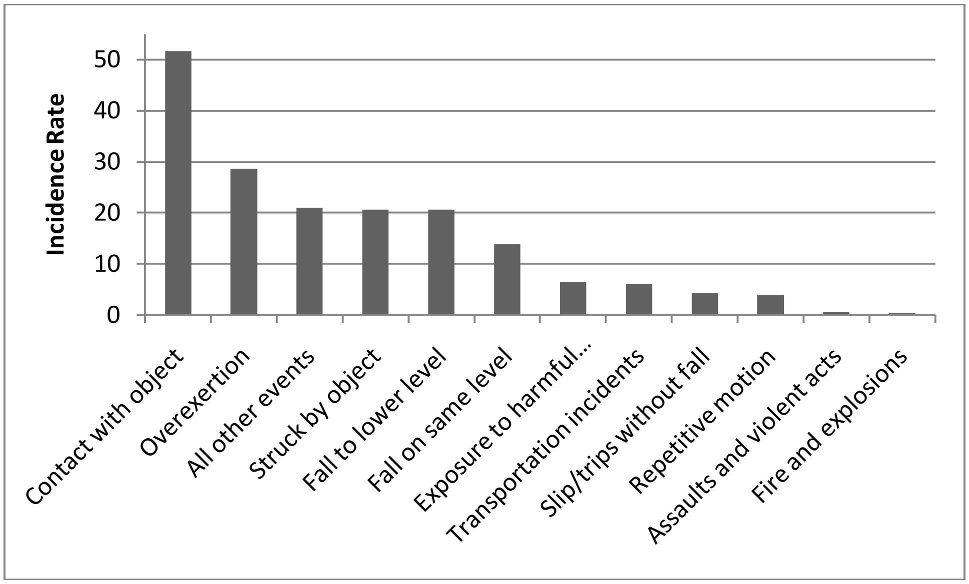


Figure 1: Incidence rate for nonfatal occupational injuries and illnesses involving days away from work for the construction industry and selected event or exposure (BLS, 2009).

The incidence rates represented above are the number of injuries and illnesses per 10,000 full-time workers and was calculated as: (N/EH) x 200,000, where:

- N = number of injuries and illnesses
- EH = total hours worked by all employees during the calendar year
- 200,000 = base for 100 equivalent full-time workers (working 40 hours per week, 50 weeks per year)

Injury costs to the construction industry

The construction industry accounted for only 5.2% of all private industry employment in 2002 (BLS, 2006) but has 15% of all private industry injury costs.

- In 2002 CPWR estimated that nearly $13 billion was spent on fatal and non-fatal injuries for all industries (CPWR 2007). According to Waehrer et al (2007), the cost of construction injuries in 2002 was $11.5 billion, with $4 billion due to fatalities and $7 billion due to nonfatal injuries, primarily driven by cases with days away from work.
- It is estimated that a fatality costs the construction industry $4 million while a non-fatal injury involving days away from work costs $42,000 (Waehrer et al. 2007).
- Of the $13 billion mentioned above the construction industry spends about $1.36 billion a year on medical expenses.

Estimates based on a sample of workers' compensation claims reported to *National Council on Compensation Insurance* (NCCI) fluctuate greatly from year to year due to the varying influence of large claims with significant direct cost amounts. Cumulative trauma injuries cost companies approximately $17,013 on average and strains cost $18,600. Injuries to the hand/finger/wrist are $11,816 and arm/shoulder is $21,120. The lower back and upper back are $21,367 and $15,894 respectively and the neck is $28,239 per injury (National safety council, 2007). In 1998, the construction industry reported the most frequent injuries by body part, as a percentage of total injury and the average direct cost based on incurred medical, compensation and loss expenses depicted in Table 3 below (Cheung, Hight, Hurley, Mc-Koon-Schultz, 2000).

Body Part	Percentage of total injuries	Average direct cost
Back	21%	$33,874
Finger (s)	10%	$10,503
Knee	7%	$26,655
Hand (s)	5%	$14,417

Table 3: Most frequent injuries in construction, 1998 (Cheung et al, 2000)

In 2002 five major trades contributed to over 50% of the total injury costs; miscellaneous special trade contractors, plumbing, heating, and air conditioning; electrical work, heavy construction and residential building as shown in Figure 2 below. These five sectors each had $1.2 billion in cost or more in 2002 (CPWR, 2007).

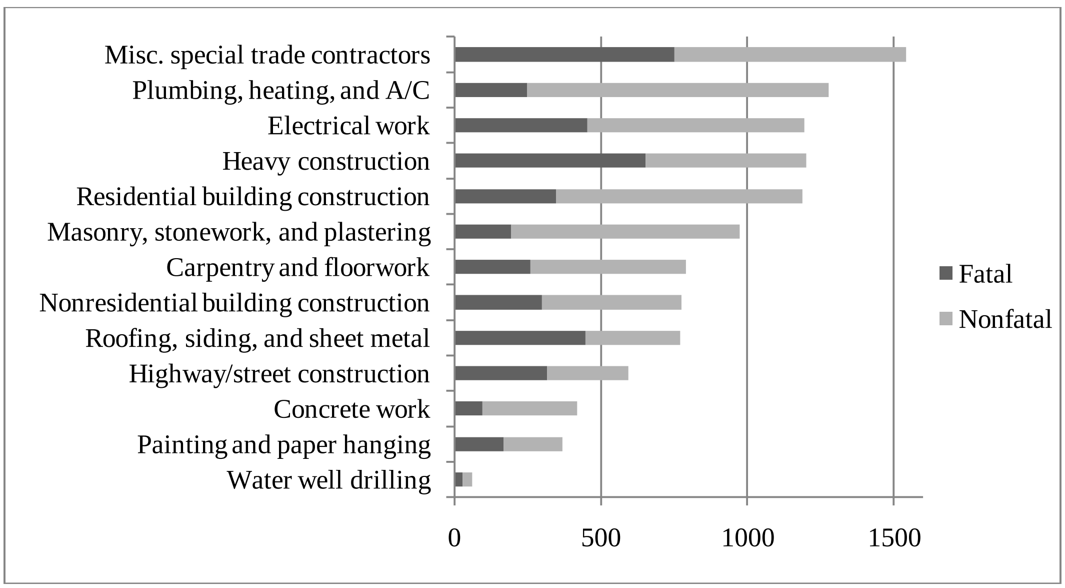


Figure 2: The estimated costs of work related injuries, by construction industry, in millions of dollars. (CPWR, 2002)

Ergonomic injuries in the construction industry

The nature of construction is ergonomically hazardous, commonly requiring numerous awkward postures, heavy lifting and other forceful exertions (Schneider and Susi 1994). For example, installing floors and ceilings requires work at floor and ceiling height which, by definition, is ergonomically hazardous since ceilings have to be above shoulder level and floors below knee height (Schneider and Susi 1996).

Historically, less emphasis has been focused on health issues in the construction industry in favor of the more immediate, high profile (and perhaps more easily solvable) safety issues (Saurin 2008). However, several studies have pointed out high incidence of health problems in this industry (Everett 1999; Gibb et al. 1999).

According to the Bureau of Labor Statistics (BLS), construction workers show significant risk of musculoskeletal disorders (MSDs) with incident rates involving days away from work of 41.4 (per 10,000 workers) compared to 35.4 for all other industries (BLS, 2007).

Ergonomic injuries are a significant portion of construction injuries. In 2007 there were 335,390 reported WMSDs (BLS 2007). WMSDs accounted for 29% of reported workplace injuries. As shown in Table 4 below, in 2009 total cases reported were almost 27,000 with almost two weeks away from work. In comparison in 2006 almost 35,000 reported cases showing a week a half away from work.

In 2006, the United States spent $48.6 billion in direct workers' compensation costs for workplace illnesses and injuries as shown in Figure 3 below (Anderson and Budnick, 2009). Of these, ergonomic injuries comprised of $30.9 billion or 60.3%. Overexertion was recorded as being more than 50% of recorded injuries (Anderson and Budnick 2009).

Year	Total Cases	Incident Rate	Median days away from work
2009	26,690	77.7	13
2008	28,880	53	11
2007	29,420	41.4	12
2006	34,510	49.5	10

Table 4: Cases, incident rates and median days away from work due to WMSDs (BLS 2010)

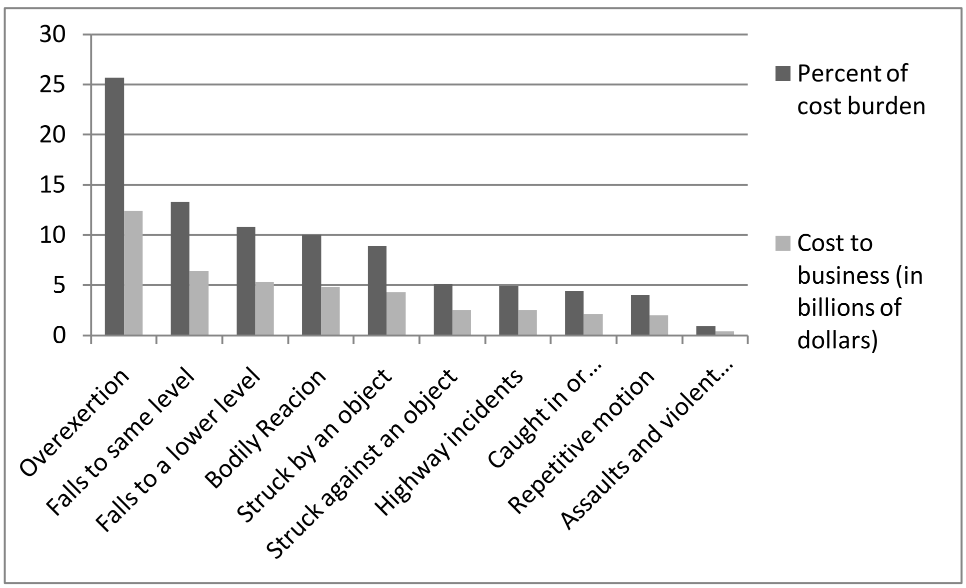


Figure 3: Top ten categories that produced 87.9% of entire cost burden of WMSD injuries in 2006 (Anderson and Budnick, 2009).

Ergonomic risk factors

Everett (1999) identified seven generic risk factors that increase the risk for overexertion: (1) static exertions, (2) repetitive exertions, (3) localized mechanical stress,

(4) posture stress, (5) forceful exertions, (6) vibration and (7) temperature. Static exertions are the maintenance of the same position of body or some part of the body throughout each work cycle or for prolonged periods of time. Repetitive exertions are defined as performing the same acts or motions repeatedly. Localized mechanical stress is mechanical tissue stresses in an area of contact with external objects. Positions of the body that require more effort than others or result in compression or stretching of tissues in or around the joints, nerves or tendons are known as posture stresses. Forceful exertion is the exertion performed to overcome weight, resistance, or inertia of body or work objects. Vibration is the contact of hands with vibrating objects. Lastly, temperature is defined as contact of the hand with air or work objects below 20 degrees Celsius or exposure of workers to low ambient temperature that result in reduced peripheral circulation.

Task performance in non-traditional work postures can also be affected by reduced mobility, stability, and balance (Gallagher, 2005). The physical work or job completed in conjunction with the physical capacity of the worker causes work related musculoskeletal disorders. The seven risk factors mentioned above contribute to these WMSDs, ranging from Carpal tunnel Syndrome (CTS) to Rotator Cuff Syndrome (RCS) from Trigger Finger to Sciatica. Bursitis, Tendonitis, Herniated Spinal discs and Thoracic Outlet Syndrome (TOS) are also common injuries incurred. Symptoms of these disorders can be a decrease in range of motion, decrease in gripping strength, loss of function of a particular limb and even deformity. Symptoms can cause numbness, a burning sensation, stiffness, cramping, tingling and severe pain.

Types of ergonomic injuries

Holstrom et al. (1993) found that the most prevalent overlapping musculoskeletal symptoms during the previous year were located in the; back (72%), knees (52%), neck (37%) and right shoulder (37%). Ergonomic injuries were comprised of Carpal Tunnel Syndrome (CTS), Tendonitis, multiple traumatic injuries and disorders and soreness or pain. These nonfatal occupational injuries and illnesses involved days away from work totaling 46,230 records.

In 2008, construction workers incurred injuries and illnesses with days away from work affecting the neck, shoulders, back and legs totaling 42,460 cases as shown below in Figure 4 (BLS, 2008).

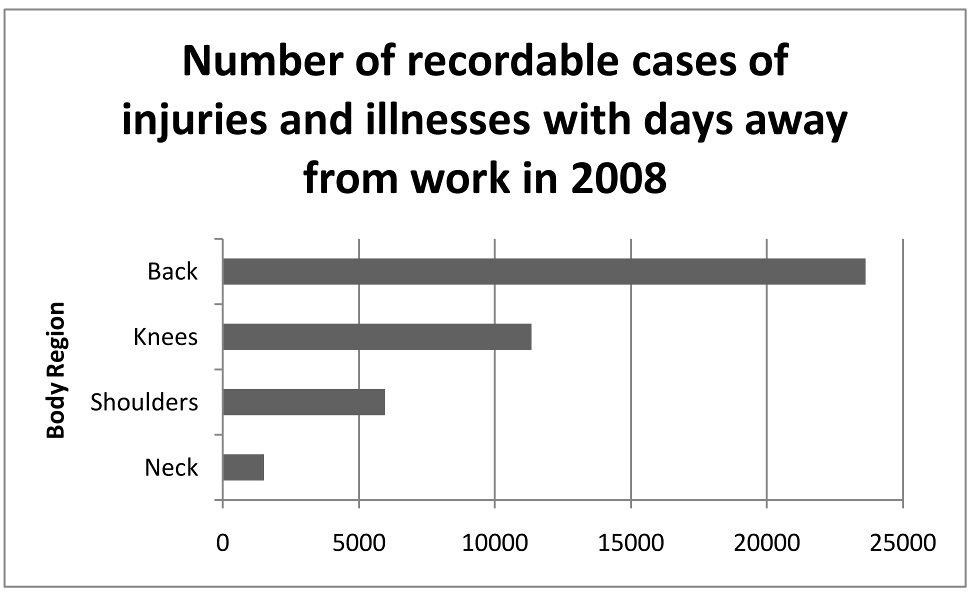


Figure 4: Number of nonfatal occupational injuries and illnesses involving days away from work by part of body affected by the injury or illness, 2008

Injury type in mechanical workers

Mechanical and electrical system installation workers accounted for nearly 15% of 9.3 million building and construction workers in the United States in 2000 (CPWR, 2002). Mechanical installation workers install and service piping and for heating, ventilation, and air conditioning (HVAC) systems for residential, commercial and industrial facilities.

In 2009, plumbing, heating, and air-conditioning contractors had a total recordable rate of 5.3 (BLS, 2009). This incidence rate represents the number of injuries and illnesses per 100 full-time workers as calculated by (N/EH) x 200,000 where N is the number of injuries and illnesses, EH is the total hours worked by all employees during the calendar year and 200,000 represents the base for 100 equivalent full-time workers working 40 hours per week, 50 weeks per year.

According to BLS in 2008 heating, air conditioning and refrigeration mechanics and installers suffered sprains, strains and tears (2,030), fractures (510), cuts or lacerations (620), punctures (50), bruises or contusions (300), heat burns (60), chemical burns (160) and amputations (60) cases with days away from work.

In the same year reported occupational injuries and illnesses involving days away from work for HVAC workers incurred CTS (70), multiple traumatic injuries and disorders with fractures or burns (40), with sprains and bruises (40), back pain or hurt (160) and all other nature of injury or illnesses accounted for 950 cases. Figure 5 depicts the body parts affected by injury or illness involving days away from work in 2008, per the BLS.

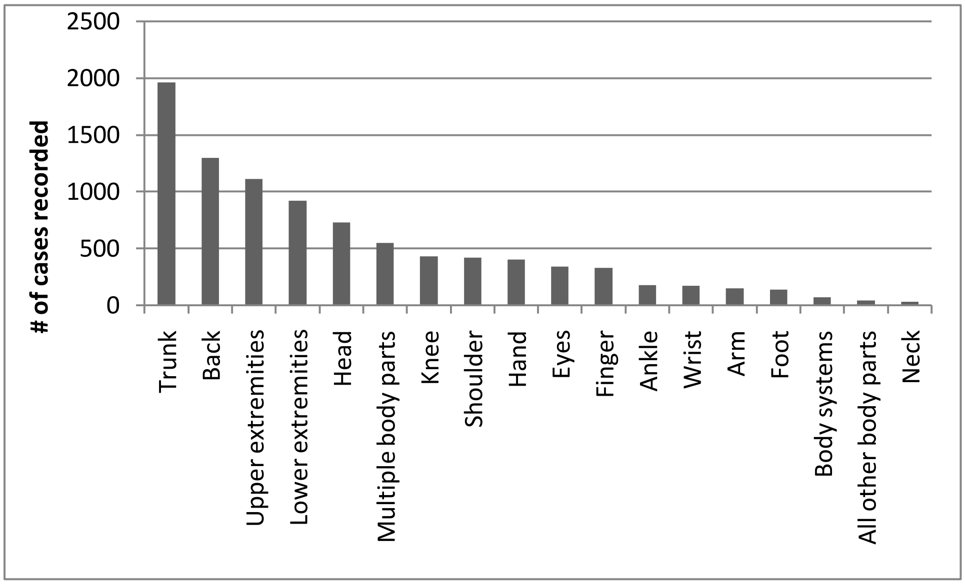


Figure 5: The number of nonfatal occupational injuries and illnesses involving days away from work and selected body parts, 2008

The trunk and upper extremities have the highest number of recorded cases for these workers. Heating, air conditioning and refrigeration mechanics and installers had non-fatal injuries and illnesses involving days away from work due to the following sources of injury; chemicals (220), containers (260), furniture and fixtures (70), machinery (570), parts and material (920), floors, walkways and ground surfaces (950), handheld tools (270), vehicles (260), other persons (1020), worker motion or position (1010) and other sources (860). In 2008 the BLS reported that this occupation had injuries and illnesses involving days away from work due to specific events or exposures leading to injury in the categories shown below in Figure 6.

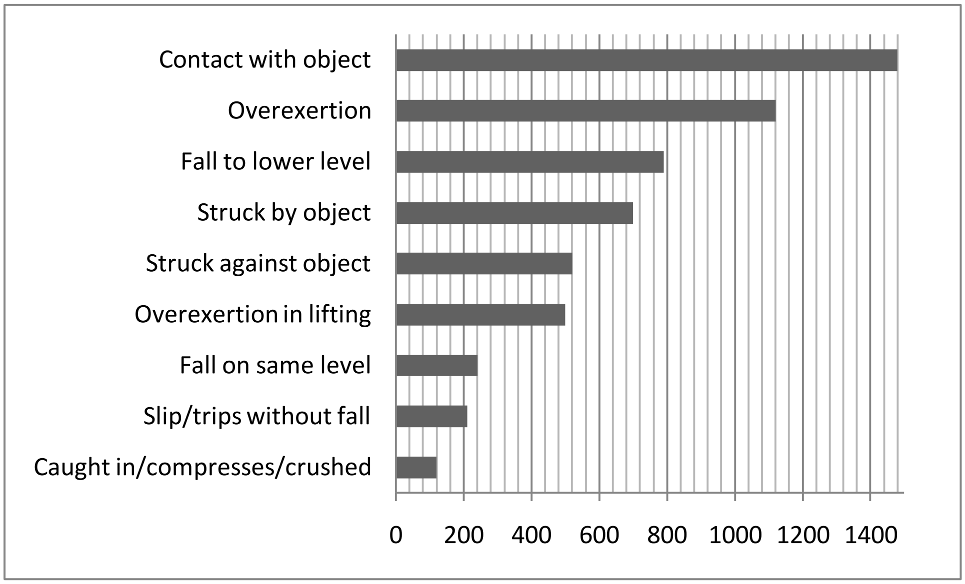


Figure 6: The number of non-fatal occupational injuries and illnesses involving days away from work with selected events or exposures leading to injury or illness, 2008.

Ergonomic injuries in mechanical trades

Although the data is limited, WMSDs are a significant problem for the electrical, pipe, and HVAC systems installation trades (Albers et al. 2005). Skilled workers in the mechanical and electrical installation (M/EI) building and construction trades experience high rates of disabling work-related musculoskeletal disorders (WMSDs) (Albers et al, 2005). Workers in the HVAC sector experienced serious overexertion injuries at rates exceeding the national average for all industries and all construction workers (BLS 2004, Welch et al. 1995, Fredericks et al. 2002, Albers et al. 2005).

From 1992 to 1998, 26% of all injuries and illnesses resulting in days away from work were due to overexertion or repetitive motion for mechanical installation workers (Fredericks et al. 2002). A survey of journeyman showed prevalent body region pain, shown in Figure 7.

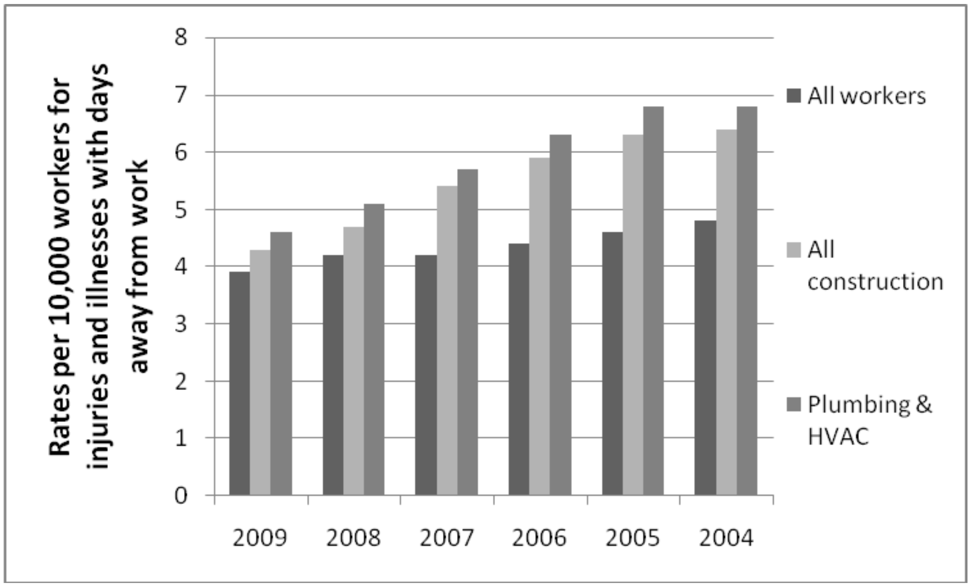


Figure 7: Rates of injuries and illness due to overexertion for the construction industry and mechanical contractors (BLS, 2009)

According to Fredericks this symptom data is self-reported by electricians, plumbers, pipefitters and sheet metal workers. The lower back was reported 33% of all visits whereas the knees were 7%, wrist/hands were 8% and shoulders were 12%. Further studies conducted by Sheet Metal and Air Conditioning Contractors National Association (SMACNA) in conjunction with CNA Insurance Company of 20,000 worker's compensation claims show cumulative trauma disorders as well as ergonomic injuries and illnesses. These claims represent $113 million reported over a 3 year period. Disorders and injuries include carpal tunnel syndrome (CTS), trigger finger, sciatica, tendonitis, carpet layer's knee, white finger syndrome and tension neck syndrome. WMSDs make up 29% of all reported injuries shown below in Figures 8 and 9.

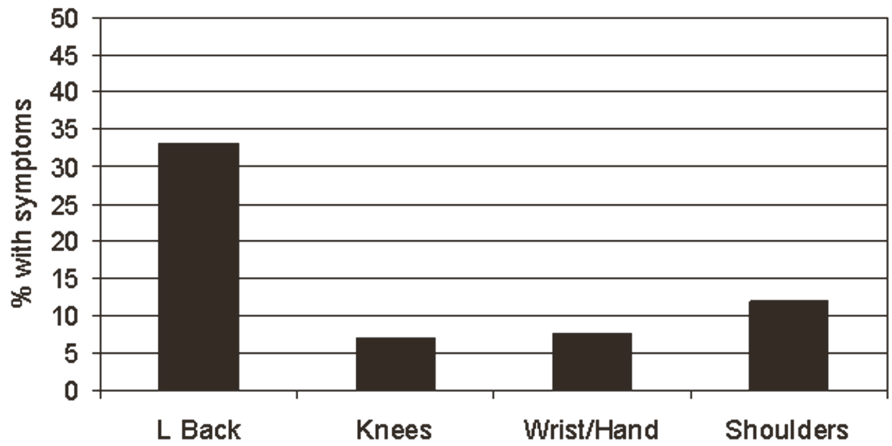


Figure 8: Percent of people seeking medical attention for WMSDs

By body region (Rosecrance, 2006)

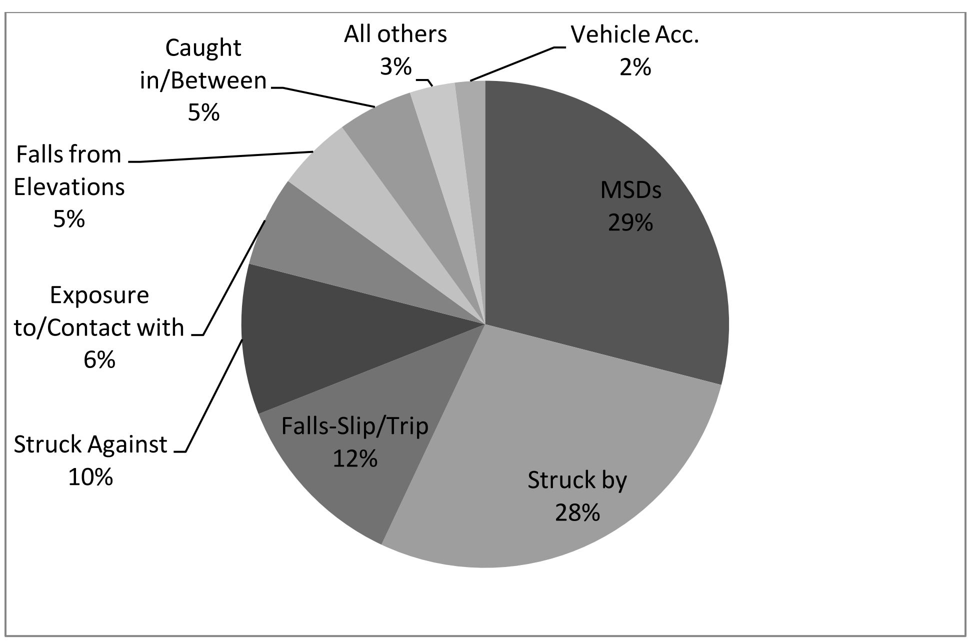


Figure 9: The percent of workman’s compensation claims for mechanical trades

(CNA, 2001)

In 2005, the rate of incidents with days away from work was 51.9 (per 10,000 workers), second only to laborers (CPWR 2005). Part of the reason is that sheet metal work has highly fluctuating postural changes that are held for long durations.

Ergonomic Interventions in the Mechanical & Electrical Construction Trades

Previous research in this area has evaluated interventions for mechanical and electrical installation tasks, including fitting drain pipes (Sillanpaa et al., 1999), overhead use of rotary hammer drills and powder actuated fasteners (Andersson, R.E., 1990; Wos, H., Lindberg, J., Jakus, R., Norlander, S., 1992), and driving screws (Cederqvist, T., Lindberg, M., Magnusson, B., Ortengren, R., 1990; Ortengren, R., Cederqvist, T., Lindberg, M., Magnusson, B., 1991).

National Occupational Research Agenda (NORA) National Construction Agenda

In 2008 the National Occupational Research Agenda (NORA) revised the National Construction Agenda for occupational safety and health research and practice in the U.S. construction sector. In this agenda the six general areas for development to reduce work related musculoskeletal disorders are the following:

1. Conduct a campaign to disseminate information regarding risks, costs and methods to prevent WMSDs
2. Improve the accuracy of surveillance of activities and measurements
3. Improve methods to assess exposure to risk factors
4. Characterize the association between exposure to risk factors and development of WMSDs
5. Expand the number of workplace solutions in prevention of WMSDs
6. Improve the dispersion of information

It was recognized that identification, development and evaluation of interventions were required in further research detail. These interventions could be tools, equipment, programs, training, processes, site coordination and owner requirements. NORA recognizes that factors contributing to WMSDs are awkward postures, forceful exertion and vibration however beyond this are organizational and delivery systems influences. Interventions can range from work environment systems to more focused interventions such as tools used, work methods or training.

Exploring Ergonomic Interventions in the Mechanical & Electrical Construction Trades

Sixty researchers, contractors and trades people representing the piping/plumbing, heating and air conditioning, and electrical sectors of the U.S. Construction industry attended a stakeholder meeting titled ‘‘Exploring Ergonomic Interventions in the Mechanical & Electrical Construction Trades’’ in San Jose, CA, in February, 2002 (Albers et al, 2005). During this meeting the three main mechanical trades were categorized by defining main tasks and activities completed during installation.

Based on contractors’ input, Albers et al (2005) identified the WMSD risk level (insignificant, moderate or high) of different sheet metal activities (Table 5), and identified ergonomic interventions to reduce ergonomic risk to the workers.

A task with an insignificant rating was defined as being free of potentially harmful ergonomic stresses and no corrective actions are necessary. Moderate risk tasks were jobs where stresses that could be problematic (i.e., cause fatigue and/or injury) for some workers. Additional analyses using more precise methods should be used to determine the necessity for intervention. Lastly, activities ranking in the high level were stresses that are likely to cause fatigue and/or injury in some workers.

Activity	Task	Risk
Install duct hangers	Formulate work sequence	Insignificant
	Carry materials to work location	Moderate
	Measure and layout	Insignificant
	Drill holes	High
	Place hangers	High
	Screw/shoot into ceiling	High
	Inspect work	Insignificant
Install ductwork	Formulate work sequence	Insignificant
	Carry materials to work location	Moderate
	Measure and layout	Insignificant
	Position duct section	High
	Connect ductwork to hanger/ceiling	High
	Inspect work	Insignificant
Install equipment	Formulate work sequence	Insignificant
	Carry materials to work location	Moderate
	Measure and layout	Insignificant
	Connect equipment to ceiling/ductwork	High
	Inspect work	Insignificant
Assemble duct pieces in field	Install flange/collar and tap-in/spin-in	High
	Cut and trim duct joints	High
	Assemble duct sections	High
	Weld	High
Demolition	Cut and remove duct sections	High

Table 5: Sheet metal trade activities, tasks and WMSD risk levels (Albers et al, 2005)

Engineering controls are designed and implemented to reduce stress injuries such as WMSDs. These controls are used to change the work flow to lessen the ergonomic risks. Engineering controls used in the field are rolling tables with large casters, anti-vibratory hammers, sheet metal racks, portable ramps, drill extensions, electrical power shears and even knee pads and anti-fatigue mats. Such changes although well thought out can reduce the ergonomic stress on a mechanical worker, however these controls can be used with work organization changes to further lessen the hazard.

Ergonomic interventions were suggested for the high-risk sheet metal activities, such as drilling and shooting fasteners, placing mechanical systems and manually moving material. While shooting fasteners, the use of embedded concrete inserts during material hanging or placing minimum hangers based on engineering standards was recommended. Tool changes were also suggested such as side arm torque drills and low vibratory tools or the use of extension poles and remote triggers. For duct installation, a power lift or scaffolding was suggested to reduce ladder usage and climbing. Another suggestion was the use of powered devices to raise material and equipment to installation height. Lastly, the use of magnets or suction cups was suggested to position duct at height. Material handling interventions include the use of pallet jacks, forklifts and carts. A raised roller conveyor system was proposed to move larger more cumbersome duct lengths. Also, the design of pre-fabricated handles for specific material to improve hand to object coupling was advised. All the suggestions were well thought out and based on previous experience to reduce the worker hazards during the operations.

Attitudes, beliefs and readiness for WMSD injury prevention in construction

Village and Ostry (2010) investigated workers' attitudes regarding actions that can reduce WMSDs. 520 workers were surveyed from five groups: road building laborers, pavers and curb finishers, equipment operators, general laborers and traffic controllers. From these surveys it was ascertained that 36% of workers asked a co-worker to help lift something. Only 10.5% pre-planned an activity while 8.8% used proper lifting techniques. 1.9% of workers were utilizing the proper equipment and 3.8% used the mechanical lifts. There was a significant amount of workers participating in stretching exercises, 22.7%.

It was noticed that 72.3% of the workers were taking personal steps to reduce WMSDs as opposed to their supervisors (Village and Ostry, 2010). These steps were to get assistance while lifting, planning the work beforehand and taking stretch breaks.

Workers who were taking personal action were likely to have experienced pain in the previous work week. Workers in the maintenance or action fields were more likely to experience pain. It was visible that workers who were taking precautions were 2.5 times more likely to be mechanics or traffic control operators. One third of the supervisors admitted to no future intentions of implementing reduction of sprain/strain injuries.

Ergonomic Best Practices for the Residential Construction Framing Contractor

Simonton (2007) investigated ergonomic injuries and best practices for residential framing construction. Based on injury claims for the industry it was found that lifting (29%), strain (26%), repetitive motion (13%) and twisting (13%) were the highest ranking causes for WMSDs. From these claims the lower back (21,678), shoulders (6,975), knees (5,707), wrists (4,628) and abdomen (2,843) were the leading body parts for WMSDs injuries. Claims ranged from $13 million to $188 million per body part. It was shown that for residential carpenters the lower back was affected the most (40% of the injuries) and the highest injury cause was lifting, carrying and holding (46%).

The four main WMSDs risks for these workers were found to be similar to other specialty trades throughout the construction industry. They were frequent lifting of heavy and cumbersome materials, extreme trunk flexion during static postures, working with the hands and wrists above the shoulders and head and carrying heavy, awkward materials over uneven surfaces. A checklist was designed and provided to over 1000 policy holders to use on site. In conjunction with best practices in the field, superintendents provided ergonomic solutions to potentially hazardous postures.

Suggestions made by the superintendent were to pre-plan work design to avoid moving material twice. Also, placing material near the work site of installation reduces the need to search for and move material. The use of mechanized lifting equipment was suggested to reduce manual material handling. Whenever possible mechanized equipment should be utilized as it is safer, faster and requires fewer workers. Recommendations on proper lifting techniques when resorting manually moving material were given with detailed images. It was recommended that two workers help to secure overhead materials to reduce re-work and the possibility of injury. Preassembled pieces are best for speed and accuracy. Wherever work can be completed at waist level is promoted to reduce overhead or extreme back and trunk flexion.

These injuries show an obvious need for ergonomic intervention to reduce the workers' exposure. Such tools were the Ergonomic survival guide for residential carpenters and a review of existing best practices. Best practice guides were given in both English and Spanish as well as having numerous pictures for easily conveying the message. Toolbox talks were suggested and organized building steps for both practice and training. Side by side graphic examples of proper and improper techniques were provided.

Hazard Zone Checklist

A checklist created by the State of Washington gives workers a simple solution for analyzing lifting operations. Lifting is a universal construction operation. A detailed calculation can be done on any job to better understand ergonomic risks during manual material handling. From this equation there are four main areas of focus. These are

1. Hand position
2. Frequency
3. Duration and
4. Twisting

Each has a list of probable solutions to reduce incidents. In hand position the suggestions range from reduction of horizontal distance from the body to removing barriers ad obstacles. The weight of the load being carried should be considered as well as the capacity of the container used for transport. A team lifting situation is the best with two or more workers. Proper handholds and a designed workstation are also advantageous. Both of the considerations reduce trunk flexion. Lastly, it is suggested that storage is no less than 30” from the floor again reducing back flexion.

Frequency of the operation has an impact on the worker as the number of cycles can tire the worker. Recommendations to reduce this are: (1) increase the load so mechanized equipment can be used (2) layout of the work area and site can greatly reduce the number of obstacles encountered. The shortest distance between two points is a straight line. Finally, mobile storage units are suggested so they can be moved closer to the work area, reducing the workers movement.

The third focus is duration. This is related to the length of time spent doing any one activity, such as static postures or awkward positions. This focuses on time and time reduction as the key. It is advised that mechanically assisting equipment be used. This can be overhead hoists, manipulators, vacuum lifts, pneumatic balancers, forklifts or scissor lifts. The second recommendation is job rotation. Rotation spreads the work over many workers, helps eliminate job specialization, boredom or laziness and gives the worker job variety. Not all jobs require lifting and this gives the worker an opportunity for a break.

The last key focus is twisting. Focus is based on reducing the necessity of contorting the body. Suggestions include redesigning the workstation to eradicate twisting. Using slides, gravity and/or chutes to help with manual material handling and reduce lifting while twisting. Location of load is important to lifting and the effect has on the lower back. The closer the material is the trunk to the lower the impact. By keeping the load near the front of the body this can be achieved.

In order to make a job safe the hazard zone checklist can be used. By going through the 6-page list the worker can correctly assess hazards and possible solutions to reduce the risk. To be technologically and economically feasible the hazard level must be reduced and this can be done through use of the risk factors pointed out in the checklist.

Literature limitations and point of departure

Previous studies of HVAC activities and workers do not quantify ergonomic exposures and the effect of different work parameters on ergonomic loads. Work design and organization can affect the worker ergonomically. A continuous analysis of worker time can show these effects.

This study will:

1. Quantify the ergonomic loads on specific body regions caused by different tasks, methods and work organization within an operation. The primary indicator is percent of time that a body area is under extreme load.
2. Investigate how different work factors (material, work organization, method of installation, etc.) affect the ergonomic loads on the body areas.

In order to quantify the ergonomic loads of the different HVAC tasks, it was necessary to better understand the available ergonomic analysis methods, and their suitability for this study. These are reviewed in the next section.

Ergonomic analysis methodologies

The main methods of ergonomic analysis are the following:

1. Rapid Upper Limb Assessment (RULA)

2. Rapid Entire Body Assessment (REBA)

3. Three Dimensional Static Strength Prediction Program (3D SSPP)

4. NIOSH lifting guidelines

5. Quick Exposure Checklist (QEC)

6. Manual Tasks Risk Assessment Tool (Man TRA)

7. Multimedia Video Task Analysis (MVTA)

2.1 Rapid Upper Limb Assessment (RULA)

Sheet metal work is upper extremity intensive; the first method reviewed was Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993). RULA is a relatively simple observational technique that can quickly evaluate targeted areas of the body—upper arms, lower arms, wrists, neck, trunk and legs. RULA establishes a range of flexion and abduction angles for each body part in order to determine an estimate of the body posture, as shown in Figures 1 and 2 below. Once the angle is determined a posture score is given for that body part.

RULA groups body parts into regions—the upper arms, lower arms and wrists are considered the upper body (Figure 10). The neck, trunk and legs are considered the lower body (Figure 11).

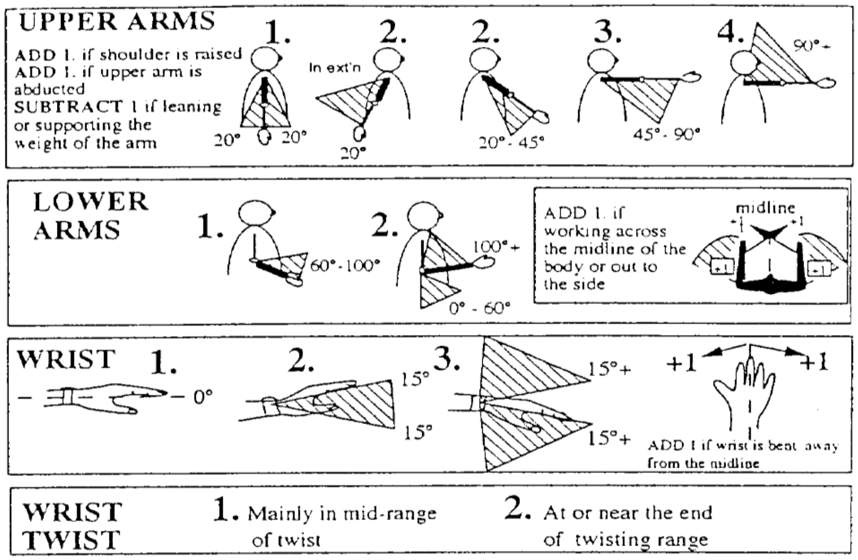


Figure 10: RULA upper body flexion ranges and scores

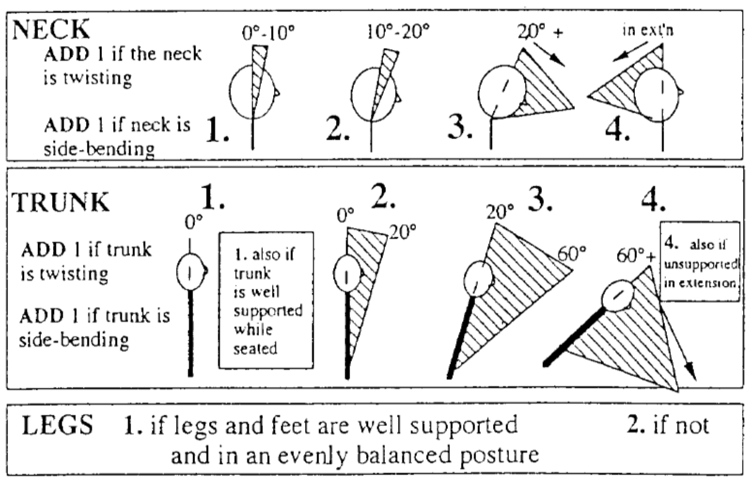


Figure 11: RULA lower body flexion ranges and scores

The RULA posture scores for the upper body and lower body regions are calculated using Table 6 and Table 7 below. The calculations can be completed either by using a program or manually.

		Wrist Posture Score							
		1		2		3		4	
		Twist		Twist		Twist		Twist	
Upper Arm	Lower Arm	1	2	1	2	1	2	1	2
1	1	2	1	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	6	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table 6: RULA Table A for upper body posture scores

	Trunk Posture Score											
	1		2		3		4		5		6	
	Legs		**Legs**		**Legs**		**Legs**		Legs		Legs	
Neck Posture	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	3	4	5	5	6	6	7	7	7	7
3	3	3	3	4	4	5	5	6	5	6	7	7
4	5	5	5	6	5	6	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Table 7: RULA Table B for lower body posture scores

These postural scores are then added to force and muscle loading which then evolve Scores A and B into Scores C and D. These final scores are used in a Grand Score Table to derive a Grand Score depicted in Table 8 shown below.

Score D (Neck, Trunk, Legs)

Score C (Upper Limb)

	1	**2**	**3**	**4**	**5**	**6**	**7+**
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8	5	5	6	7	7	7	7

Table 8: RULA Table C for Grand Scores

RULA develops recommendations for action, based on the assessment of the most extreme ergonomic posture of a task. However, the duration of exposure to extreme demands is factored in. Thus, RULA requires that for a particular task, an assessment is performed for the most extreme task posture. The grand score indicates the action to be taken for the work analyzed to lessen ergonomic loads on the workers. RULA has four action levels.

- Action level 1: Grand scores ranging from 1 to 2 indicate acceptable postures during work. However, if this posture is repeated or maintained for long durations some changes may be needed.
- Action level 2 has grand scores ranging from 3 to 4. These scores indicate that further investigation and a required change may be needed.
- Action level 3 has grand scores ranging from 5 to 6. This level requires that changes and investigation may be needed soon. This timeline is relative and no further information is given as to how long the observer should wait before changing the work parameters to lessen ergonomic loads.
- Action level 4 has grand scores of 7 or higher and indicates the need for immediate investigation and changes.

2.2 Rapid Entire Body Assessment (REBA)

REBA was (Hignett, McAtamney, 2000) was developed to quickly assess the entire body in an instance of the most hazardous posture during work. The goals of the method are to be sensitive to musculoskeletal disorders for different body regions. Similar to RULA, the REBA method divides the body into two segments. Group A includes the trunk, neck and legs. Group B consists of the upper arms, lower arms and wrists. Each part is given a score based on pre-determined flexion and extension degrees, as shown in Figures 12 and 13.

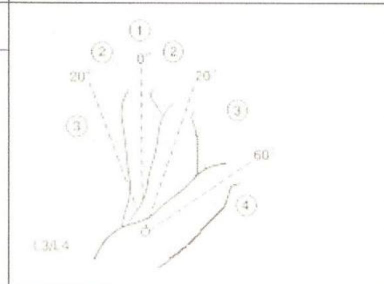
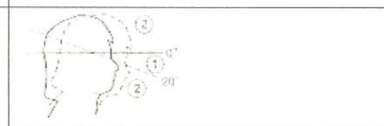
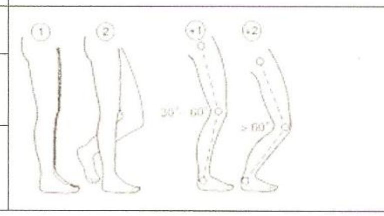
Movement	Score	Change Score	Posture	Score
Trunk				Trunk Score
Upright	1	If back is twisted or tilted to side: +1		
Flexion 0-20° Extension 0-20°	2			
Flexion 20°-60° Extension >20°	3			
Flexion >60°	4			
Neck		If neck is twisted or tilted to side: +1		Neck Score
Flexion 0-20°	1			
Flexion > 20° Extension				
Legs				Leg Score
Bilateral weight bearing, walking, sitting	1	Knees flexion 30°-60° +1		
Unilateral weight bearing, unstable	2	Knees flexion > 60°		

Figure 12: REBA Group A scores

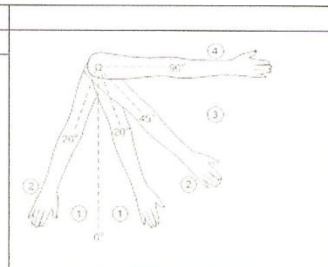
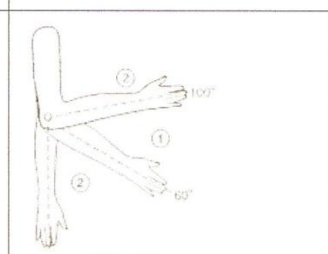
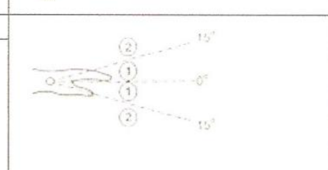
Movement	Score	Change Score		Total Score	
Upper Arms				L	R
20° flexion to 20° extension	1	Arm abducted/rotated + 1 Shoulder raised +1 Arm supported -1			
Flexion 20° – 45° Extension >20°	2				
Flexion 45° - 90°	3				
Flexion >90°	4				
Lower Arms		No Adjustments		L	R
Flexion 60°-100°	1				
Flexion< 60° Flexion > 100°					
Wrists				L	R
Flexion 0-15° Extension 0-15°	1	Wrists deviated/twisted +1			
Flexion >15° Extension >15°	2				

Figure 13: REBA Group B scores

		Trunk				
		1	2	3	4	5
Neck	Legs					
1	1	1	2	2	3	4
	2	2	3	4	5	6
	3	3	4	5	6	7
	4	4	5	6	7	8
2	1	1	3	4	5	6
	2	2	4	5	6	7
	3	3	5	6	7	8
	4	4	6	7	8	9
3	1	3	4	5	6	7
	2	3	5	6	7	8
	3	5	6	7	8	9
	4	6	7	8	9	9

Table 9: REBA Table A for Trunk, Neck and Legs scores

Once the scores for each body segment are determined, Tables A (see Table 9) is used to find a cumulative score for Group A.

This score is then added to a load/force score which accounts for the weight that the worker carries and a Final Score for Group A is calculated. Load/force scores are categorized into 4 segments. The first three segments are weight values per the load carried or the force exerted by the worker. Less than 11 lbs. is a "0" value, 11-22 lbs. is a value of "1" and more than 22 lbs. is a value of "2." In addition to these values a shock or rapid build up of force score adjustment of +1 can be used to modify the three previous values.

The same process is used for Group B. Table 10 gives a cumulative score. This score is then added to a coupling score to give a Final Score B.

Lower Arms	Wrist	Upper Arms 1	2	3	4	5	6
1	1	1	1	3	4	6	7
	2	2	2	4	5	7	8
	3	2	3	5	5	8	8
2	1	1	2	4	5	7	8
	2	2	3	5	6	8	9
	3	3	4	5	7	8	9

Table 10: REBA Table B for Upper arms, Lower arms and Wrist scores

Coupling is the grip a worker has on a tool, machine or material during work. A grip value indicates how easily a worker can hold onto a piece of material or a tool. There are 4 values ranging from 0 to 3. Good coupling or “0” is a well-fitting handle and mid-range, power grip. Value “1” or fair coupling is a hand hold acceptable but not ideal or coupling is acceptable via another part of the body. “2” or poor coupling is hand hold is not acceptable although possible. And lastly, value “3” is unacceptable coupling where awkward, unsafe grip or no handles are available. This coupling score is added to the Table B score and a Final Score B is found.

Once the Final Scores A and B have been calculated, Table C, shown in Table 11 below, calculates the combined score which ranges from 1 to 12.

	Upper Arms											
	1	2	3	4	5	6	7	8	9	10	11	12
Score B												
1	1	1	2	3	4	6	7	8	9	10	11	12
2	1	2	3	4	4	6	7	8	9	10	11	12
3	1	2	3	4	4	6	7	8	9	10	11	12
4	2	3	3	4	5	7	8	9	10	11	11	12
5	3	4	4	5	6	8	9	10	10	11	12	12
6	3	4	5	6	7	8	9	10	10	11	12	12
7	4	5	6	7	8	9	9	10	11	11	12	12
8	5	6	7	8	8	9	10	10	11	12	12	12
9	6	6	7	8	9	10	10	10	11	12	12	12
10	7	7	8	9	9	10	11	11	12	12	12	12
11	7	7	8	9	9	10	11	11	12	12	12	12
12	7	8	8	9	9	10	11	11	12	12	12	12

Table 11: REBA Table C where Final Scores A and B are used

Lastly, an activity score is assessed with regards to repetition and static postures. Activity scores can be given for three types of actions: (1) one or more body parts are static being held for longer than one minute, (2) small range actions which are repeated more than four times per minute (not including walking), and (3) actions causing rapid large range changes in postures or an unstable base. Each factor has a value of 0 or +1 and this number is added to the Score C. Thus, the REBA score can range from 1 to 15.

Based on the REBA score action recommendations are given to the observer for level of change needed. Action levels vary from 0 to 4 and consequent actions are "no action" to "necessary action is needed immediately."

2.3 Three Dimensional Static Strength Prediction Program (3DSSPP)

The 3D SSPP was developed by the Center for Ergonomics at University of Michigan in order to evaluate and design tasks dealing with manual material handling. This program focuses on manual lifting tasks in a singular moment of time. This program works for tasks like lifting, pulling and pushing by approximating posture data, force parameters and anthropometry through job simulation. The researcher manipulates the human model for all positions during a task. The analysis is enhanced by an automatic posture generator and three dimensional graphics of human figures (University of Michigan 2010).

The analysis predicts forces on hand, wrist and arm, predicts spinal compression forces, compares the predictions with the NIOSH lifting guidelines, and calculates percentages of workers based on gender who have the strength to perform certain tasks.

2.4 NIOSH lifting guidelines

As a response to an increase in lower back pain and injuries NIOSH published the work practices guide for manual lifting (Waters, Putz-Anderson, & Garg, 1994). Created in 1981 this summary gave workers related literature, analytical procedures and the lifting equation.

This material aided in teaching workers about two handed symmetrical lifting and gave controls for reducing lower back injuries. Since this initial edition a revised equation was derived reflecting asymmetrical lifting and less than optimal coupling of the workers hands with the object being lifted. The equation given below is a tool that can be used to verify if a job is hazardous to the workers.

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$$

Where: RWL = the recommended weight limit,

LC = the load weight, HM = the horizontal location, VM = the vertical location, DM = the vertical travel distance, AM = the asymmetry angle, FM = the lifting frequency and CM the coupling classification. M = a value given after all parts of the equation to signify multiplier.

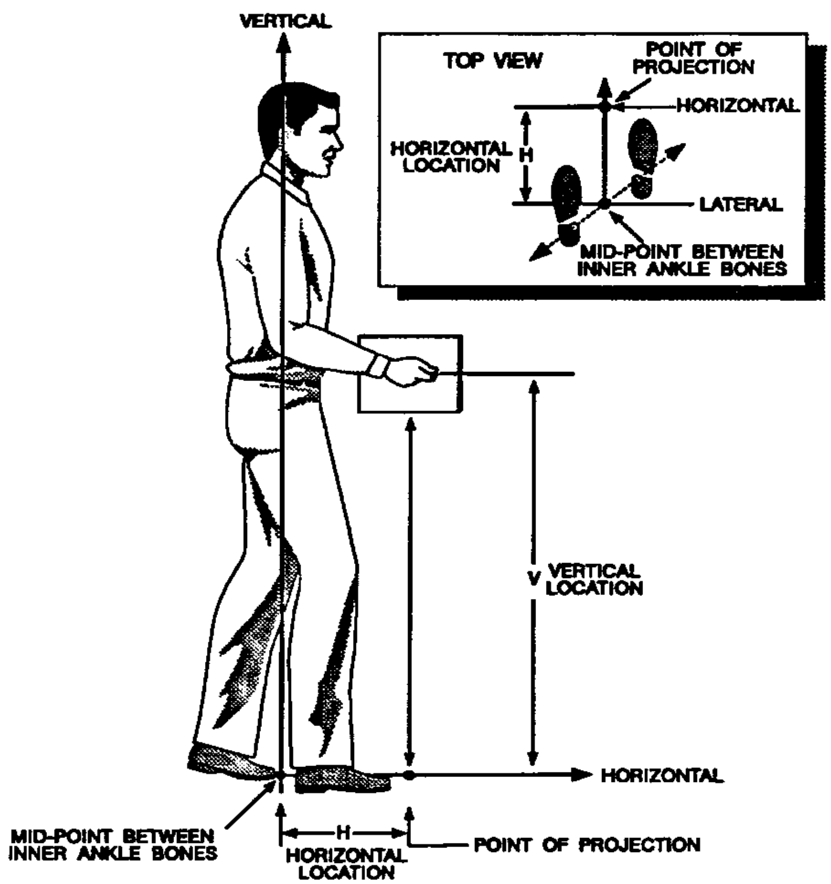


Image 1: NIOSH graphical representation of lifting equation values

Image 1 above graphically displays all the values in the equation to give the summation value for recommendations. This equation being only one part of an analysis was used to create the postural guide. Values for lifting as well as pushing and pulling were given in the ergonomic analysis based on the NIOSH lifting guide (Waters et al., 1994).

2.5 Quick Exposure Checklist (QEC)

QEC is an ergonomic assessment tool developed for Occupational Safety and Health practitioners (Woods et al. 2008). QEC assessments include (1) observations of the task by an observer, and (2) self-assessment by the workers. Both the assessor and worker can complete their checklist in less than five minutes and scores can be evaluated in the same time. QEC focuses on four body regions. These are mainly the back, wrist/hand, shoulder/arm and neck.

The assessor and worker assessments are comprised of seven multiple choice questions. The assessor answers questions on their portion of the questionnaire about performance, lifting, push/pull and body region specific questions. The worker answers questions on their portion about maximum weights carried, average time spent, visual demands and levels of difficulty. Both checklists can be seen in Figures 14 and 15 below.

Worker's name ______________________ Date ____________

Observer's Assessment

Back

A **When performing the task, is the back**
(select worse case situation)

- A1 ☐ Almost neutral?
- A2 ☐ Moderately flexed or twisted or side bent?
- A3 ☐ Excessively flexed or twisted or side bent?

B **Select <u>ONLY ONE</u> of the two following task options:**

EITHER

For seated or standing stationary tasks. Does the back remain in a <u>static</u> position most of the time?

- B1 ☐ No
- B2 ☐ Yes

OR

For lifting, pushing/pulling and carrying tasks (i.e. moving a load). Is the <u>movement</u> of the back

- B3 ☐ Infrequent (around 3 times per minute or less)?
- B4 ☐ Frequent (around 8 times per minute)?
- B5 ☐ Very frequent (around 12 times per minute or more)?

Shoulder/Arm

C **When the task is performed, are the hands**
(select worse case situation)

- C1 ☐ At or below waist height?
- C2 ☐ At about chest height?
- C3 ☐ At or above shoulder height?

D **Is the shoulder/arm movement**

- D1 ☐ Infrequent (some intermittent movement)?
- D2 ☐ Frequent (regular movement with some pauses)?
- D3 ☐ Very frequent (almost continuous movement)?

Wrist/Hand

E **Is the task performed with**
(select worse case situation)

- E1 ☐ An almost straight wrist?
- E2 ☐ A deviated or bent wrist?

F **Are similar motion patterns repeated**

- F1 ☐ 10 times per minute or less?
- F2 ☐ 11 to 20 times per minute?
- F3 ☐ More than 20 times per minute?

Neck

G **When performing the task, is the head/neck bent or twisted?**

- G1 ☐ No
- G2 ☐ Yes, occasionally
- G3 ☐ Yes, continuously

Worker's Assessment

Workers

H **Is the maximum weight handled MANUALLY BY YOU in this task?**

- H1 ☐ Light (5 kg or less)
- H2 ☐ Moderate (6 to 10 kg)
- H3 ☐ Heavy (11 to 20kg)
- H4 ☐ Very heavy (more than 20 kg)

J **On average, how much time do you spend per day on this task?**

- J1 ☐ Less than 2 hours
- J2 ☐ 2 to 4 hours
- J3 ☐ More than 4 hours

K **When performing this task, is the maximum force level exerted by one hand?**

- K1 ☐ Low (e.g. less than 1 kg)
- K2 ☐ Medium (e.g. 1 to 4 kg)
- K3 ☐ High (e.g. more than 4 kg)

L **Is the visual demand of this task**

- L1 ☐ Low (almost no need to view fine details)?
- *L2 ☐ High (need to view some fine details)?

* *<u>If High, please give details in the box below</u>*

M **At work do you drive a vehicle for**

- M1 ☐ Less than one hour per day or Never?
- M2 ☐ Between 1 and 4 hours per day?
- M3 ☐ More than 4 hours per day?

N **At work do you use vibrating tools for**

- N1 ☐ Less than one hour per day or Never?
- N2 ☐ Between 1 and 4 hours per day?
- N3 ☐ More than 4 hours per day?

P **Do you have difficulty keeping up with this work?**

- P1 ☐ Never
- P2 ☐ Sometimes
- *P3 ☐ Often

* *<u>If Often, please give details in the box below</u>*

Q **In general, how do you find this job**

- Q1 ☐ Not at all stressful?
- Q2 ☐ Mildly stressful?
- *Q3 ☐ Moderately stressful?
- *Q4 ☐ Very stressful?

* *<u>If Moderately or Very, please give details in the box below</u>*

* *Additional details for L, P and Q if appropriate*

*** L**

*** P**

*** Q**

Figure 14: Both observer and worker checklists, QEC

Exposure Scores Worker's name ______________________ Date __________

Back

Back Posture (A) & Weight (H)

	A1	A2	A3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 1

Back Posture (A) & Duration (J)

	A1	A2	A3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 2

Duration (J) & Weight (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 3

Now do **ONLY** 4 if static
OR 5 and 6 if manual handling

Static Posture (B) & Duration (J)

	B1	B2
J1	2	4
J2	4	6
J3	6	8

☐ Score 4

Frequency (B) & Weight (H)

	B3	B4	B5
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 5

Frequency (B) & Duration (J)

	B3	B4	B5
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 6

Total score for Back
Sum of scores 1 to 4 **OR**
Scores 1 to 3 plus 5 and 6 __________

Shoulder/Arm

Height (C) & Weight (H)

	C1	C2	C3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 1

Height (C) & Duration (J)

	C1	C2	C3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 2

Duration (J) & Weight (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 3

Frequency (D) & Weight (H)

	D1	D2	D3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 4

Frequency (D) & Duration (J)

	D1	D2	D3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 5

Total score for Shoulder/Arm
Sum of Scores 1 to 5 __________

Wrist/Hand

Repeated Motion (F) & Force (K)

	F1	F2	F3
K1	2	4	6
K2	4	6	8
K3	6	8	10

☐ Score 1

Repeated Motion (F) & Duration (J)

	F1	F2	F3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 2

Duration (J) & Force (K)

	J1	J2	J3
K1	2	4	6
K2	4	6	8
K3	6	8	10

☐ Score 3

Wrist Posture (E) & Force (K)

	E1	E2
K1	2	4
K2	4	6
K3	6	8

☐ Score 4

Wrist Posture (E) & Duration (J)

	E1	E2
J1	2	4
J2	4	6
J3	6	8

☐ Score 5

Total score for Wrist/Hand
Sum of Scores 1 to 5 __________

Neck

Neck Posture (G) & Duration (J)

	G1	G2	G3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 1

Visual Demand (L) & Duration (J)

	L1	L2
J1	2	4
J2	4	6
J3	6	8

☐ Score 2

Total score for Neck
Sum of Scores 1 to 2 __________

Driving

M1	M2	M3
1	4	9

Total for Driving __________

Vibration

N1	N2	N3
1	4	9

Total for Vibration __________

Work pace

P1	P2	P3
1	4	9

Total for Work pace __________

Stress

Q1	Q2	Q3	Q4
1	4	9	16

Total for Stress __________

Figure 15: Combining assessor and worker answers to give cumulative scores, QEC

When both checklists are completed the observer calculates the cumulative values for the four body regions as well as driving, vibration, work pace and stress. The scores indicate the levels of change necessary and where an intervention is needed as depicted in Table 12 below.

Exposure factor	Exposure level			
	Low	Moderate	High	Very high
Back static	8-14	16-22	24-28	30-40
Back moving	10-20	22-30	32-40	42-56
Shoulder/arm	10-20	22-30	32-40	42-56
Wrist/hand	10-20	22-30	32-40	42-56
Neck	4-6	8-10	12-14	16-18
Driving	1	4	9	-
Vibration	1	4	9	-
Work pace	1	4	9	-
Stress	1	4	9	16

Table 12: Proposed priority levels for Quick Exposure Check scores (David et al.,2005) QEC for assessing exposure to risk factors for WMSDs

This checklist offers a number of features including being quick and easy to utilize, can be used in numerous industries, quickly completed, comprehensive, reliable, it involves the workforce and gives basic instructions on how to use it. Information gathered from this combined checklists gives direction on intervention usage but is limited in delving further into causes of the problem. The causation of stress or management's mentality on policy and procedures are some of the limits of this method.

2.6 Manual Tasks Risk Assessment Tool (Man TRA)

Cornell University developed the Man TRA to aid the Division of Workplace Health and Safety force (DWHS) during workplace audits. The tool was developed in accordance with the Queensland Manual Tasks Advisory Standard with an aim to assess musculoskeletal exposure of risk during manual tasks (Burgess-Limerick et al. 2004).

This method accounts for both ergonomic loads and duration of task. The program analyzes four main body regions; back, lower limbs, neck/shoulder and arm/wrist/hand. Five main task characteristics are reviewed: (1) time, (2) force, (3) speed, (4) awkwardness and (5) vibration. An overall score evaluates the task severity for the complete task of each individual. The program gives thresholds to better aid the researcher in deciding the action to be taken.

2.7 Multimedia Video Task Analysis (MVTA)

A development from the University of Wisconsin Madison, this program automates time and motion studies while providing ergonomic analysis (University of Wisconsin-Madison, 2003). The user uploads a video of an activity, observes the video and sets point breaks in the video to identify the start and stop of ergonomic "events". For example, when a worker's back is bent more than a specific angle, this can indicate the start of the event. The events are determined by the user.

The program produces time study reports, computes frequency of occurrence and gives postural analyses (Jorgensen et al. 2007). There are additional features which include activity sampling, event analysis, detailed job analysis, postural analysis, risk factor identification, task analysis, quantification of repetition and duration, work sampling, micro-motion analysis, left hand/right hand analysis, behavior observation and elemental analysis. Some of the calculations provided by MVTA are force/load and posture reports and posture and task elements. The main reports given are a time study, frequency report, raw time report and duration report. MVTA was a very useful tool during the process of selecting the right ergonomic program as it was the first to show continuous time analysis reports. Many of the features were advantageous to this research however the main setback was it is not compatible with windows 7. As a result, the study performed video analysis but without using this software.

Chapter 3

METHODOLOGY

Research approach

The objective of this study is to investigate the effects of activity parameters and work organization on the ergonomic exposures and work demands of HVAC installation workers. To accomplish this goal, this research uses a comparative analysis of HVAC installation activities. The researchers selected specific HVAC installation activities for analysis, as discussed below. Variations in the methods used for each activity were identified, and each activity was observed multiple times as it was performed with different materials or methods.

The analysis measures and compares ergonomic demands of similar activities under different methods and activity parameters (work platform, duct size, length of duct assembly, etc.). The ergonomic demand analyzes different body areas—specifically for back, shoulders, neck, and knees. The comparison indicates how different activity parameters contribute to ergonomic exposures, postures and loads for different body areas.

Research activities

Research involved the following activities:

1. Identification HVAC installation activities for analysis

    During this step, the researcher observed field operations to familiarize herself with the HVAC activities and selected activities to analyze.

2. Selection method for ergonomic analysis of activities

    During this step, the researcher developed a postural guide based on existing RULA and REBA ergonomic assessment methods and the NIOSH lifting guide.

3. Collection of field data

For each activity observed, the researcher performed the following tasks:

- Discussed the activity with the supervisors and workers. In addition to understanding the steps, hazards and difficulties the discussion also addressed issues related to manpower, productivity, planning, work area preparation, and work distribution.
- Observed and videotaped the operation.

4. Performing production and ergonomic analysis as follows:

- Developed the Crew Balance Chart (CBC) indicating tasks that the worker was performing and their durations, and measured productivity.
- Performed a continuous time ergonomic analysis of the operation per body region, using the postural guide. The analysis shows what percentage of the cycle time the workers are in extreme ergonomic postures and the tasks where this occurs.
- In parallel to the ergonomic analysis, the analysis of the production tasks examined the task variables that affected the intensity and duration of the ergonomic risk factors. The element of task duration is critical for both productivity and ergonomic exposure.

1. Identification of HVAC installation activities for analysis

The first research activity was to get familiar with Heating, Venting and Air Conditioning (HVAC) installation activities through site observations and interviews with four mechanical contractors. Identification of the main activities of sheet metal duct installation, are given as the following:

1. Movement of material to and within the jobsite
2. Drawing the layout
3. Installation of hangers or struts
4. Location of material
5. Creation of assemblies on the ground
6. Installation of ductwork, and
7. Installation of equipment (air handling units, etc.)

Depending on the project, other activities may also be required, such as demolition and removal of existing ductwork. Mechanical contractors use different methods to organize and perform the activities. Such methods may differ in the number of workers performing the task, division of the work, length of the duct installed and equipment used (e.g., ladders or scissor lifts).

The size of duct installation crews varies, depending on the workload and schedule requirements. Typically, crews are separated into teams of two to four workers. Each team of two typically includes a journeyman working with one apprentice. Apprentices have on-job experience ranging from zero to five years and journeyman have five years or more.

1.1 Movement of material to and within the jobsite

Material is handled numerous times from the delivery on site to the final installation. Material consists primarily of sheet metal duct and more complicated mechanical parts such as VAV and CAV boxes, diffusers, registers, thermostats, etc. Other material includes flex duct, hangers or struts, all thread and drives. These auxiliary parts are used to hang and connect duct runs.

Image 2: Forklift moving air handling unit

Sheet metal parts are either pre-assembled off site and shipped in crates to the site or assembled on site. Sheet metal workers unload crates, duct runs and material from the bed of the truck using mobile equipment as seen in Image 2 above. It is typically seen as faster and safer to use mobile equipment however workers can unload smaller materials by hand.

Image 3: An Apprentice using an upright lift to move air handler to the storage area

If the material is being shipped by truck a drop down area is located on site outside the building. The crates are stored in a designated area inside the structure. This area is then stocked with all material for the floor or site as depicted in Image 3 above. Storage areas are organized based on arrival on site or by the sequence of installation. This is a supervisor specific detail.

1.2 Drawing the layout

Before any other duct work can begin the layout drawings must be prepared. These drawings are done on the ground directly under the future duct locations. This work can be done in a team of two or by a single sheet metal worker seen in Image 4 below.

Image 4: A Journeyman drawing the layout on the concrete floor using a permanent marker, metal square and clear spray.

The work involves (1) checking drawings, (2) measuring on the floor and (3) marking the floor. Depending on the floor conditions and finished floor product the markings are done either in pencil/chalk covered with clear spray paint or permanent marker. The workers must be able to correctly measure off the drawings and accurately mark the points on the concrete floor; their work dictates the precision of future installation.

Layout workers typically use a cart where they carry the drawings and material. Their tools and material include a tape measure, pencil/permanent marker, clear spray paint, metal square and chalk line.

Work is fast paced and cycle times are short, ranging from one to four minutes in duration. If two workers are simultaneously drawing the layout, more floor space is covered in a shorter cycle time.

The task starts by reviewing drawings. This is followed by locating the floor area where the layout will be drawn. Using a ¼" scale the worker measures directly from the engineered drawings and walks to the work (layout) area.

The journeyman works by himself. In order to snap a chalk line he used a chalk dust bucket in to hold the far end of the line and while holding the other end he was able to mark the center line for the duct run above. The first marks are located while bending down on the floor and using a tape measure and metal square. Once a number of marks are made, the worker uses a clear spray to highlight and protect the pencil markings and chalk lines drawn. Finally, after completing these steps the drawing cart is rolled to the next layout area.

1.3 Installation of hangers

Hangers and struts are the metal attachments used to hang duct from the ceiling or roof. Metal hangers are used for round duct regardless of size and for smaller rectangular duct ranging in size from 8" to 48" wide. Struts are heavy duty and are used for larger more cumbersome rectangular duct runs. The size of the duct dictates whether a uni-strut or double strut will be installed. A uni-strut is a single metal welded U-shaped piece that holds up the duct. A double strut is simply two uni-struts welded together to create an H-shape. The connection is completed with a long threaded rod known as an all thread, this is connected to the strut supporting the duct and goes up to attach at the ceiling thus completing the hanger assembly.

A mechanical engineer calculates the length of duct needed and this dictates how many straps are required. One strap is located on each side of the duct requiring the worker to place two straps per designated duct length. One sheet metal worker can do this task for a full shift using a powder actuated tool (PAT) gun, a laser light, the metal straps and a ladder.

This task shown in Image 5 below it requires the worker to (1) verify the floor drawn layout, (2) place the laser according to the layout, (3) position and climb the ladder, (4) place hanger using a laser light beam and (5) attach the hanger into place using powder actuated fasteners.

Image 5: Journeyman using a PAT gun to shoot a hanger into place

However, if the duct being installed is rectangular and larger than 48” in width a strut is used. The strut is placed below the duct and all threads are attached to the strut on either side of the duct and taken vertically to the ceiling for attachment with embedded anchors. This process requires two workers in a scissor lift to complete the task. Workers will; (1) verify the floor layout, (2) position and ascend the scissor lift (3) pre-drill holes for all thread are embedded with anchors (4) install all threads in ceiling (5) place uni-strut or double strut (as required) below the duct to be suspended (6) thread and tighten nuts and bolts to hold strut in place.

These workers use different tools and equipment to do primarily the same task. The tools for round and smaller rectangular ducts are a PAT. 18 volt cordless drill, tape measure and a ladder (a scissor lift may be necessary for higher ceiling heights). While the use of a mechanical scissor lift and rotary hammer drill are necessary for the larger rectangular duct installation.

1.4 Location of material

During installation various lengths of duct may be required and the worker must locate and retrieve them from the storage area. This requires the worker to move outside of his work space to reach the storage area. These storage areas house all materials, shown in Image 6 below, that will be needed for installation and may be in areas far from the work area.

Image 6: Worker locating duct in storage area

Any member of the team can obtain the material list and locate the next piece of material needed. To locate a specific item the worker must (1) walk to the storage area, (2) retrieve the docket, (3) find the duct piece and (4) transport the duct back to their work area. Locating the needed piece can become tedious as the storage area becomes disorganized due to unlimited worker access and material being moved while workers are locating parts. A packing list is used to identify pieces within an unopened crate. A worker must first search for the required piece by viewing the duct labels located on the side of all assembled pieces. This label informs the worker of duct size, in length, width parameters, manufacturer, date of assembly and the sheet metal thickness.

The location of the material dictates how the workers will retrieve the pieces they need; including if necessary additional workers, forklifts, upright jacks or making numerous trips to the storage area while transporting material by hand. Once the correct duct has been located and retrieved, the worker can return to his work area to complete installation.

1.5 Creation of assemblies on the ground

Sometimes locating the correct item may require the worker to combine numerous pieces, making an assembly. A duct run can be manipulated to create a more intricate configuration. Such work is seldom done on site as most companies try to reduce the level of cognitive overload by creating and providing complex assemblies off site. However, due to the constantly evolving job site conditions a pre-assembled run may be inadvertently dismantled and used for another assembly without knowing how or why it was originally created. This type of miscommunication requires subsequent work to use readily available parts on site to create complex assemblies. Thus breaking down the site organization and pre-planning process of material handling.

For many operations of duct installation, pre-planning is used as a means of increasing productivity and work specialization. One such task is creating assemblies on the ground. This is done with a team of two, a journeyman and an apprentice. These tasks are performed to build an inventory of assemblies for other installation teams. Based on skill and knowledge of the task both workers can create a stockpile of various assemblies for other installing teams. This task involves;

- Familiarity with the manufacturing of duct
- The delivery of material
- On-site organization of material
- Manual handling of material.

An understanding of dimensions, sizes and drawings is needed in order to work efficiently. Tools used during this task are a permanent marker, a tape measure, a reciprocating saw, 18V screw drill and a utility knife. The workers consider the concrete ground their work table and wear knee pads for protection.

Creating duct assemblies starts by (1) reviewing the drawings, (locate ducts for connection, (3) measure and mark, seen in Image 7 below, (4) cut duct, (5) slide duct pieces together and (6) fasten screws for connection.

Image 7: An Apprentice measuring and marking a duct run for reference during cutting.

The layout tell the worker what area the duct will be installed and where to locate the pieces. Once the required pieces have been located the drawings are used to verify duct sizing. Once cut, excess pieces are placed under a tarp so as to reduce construction dust within the duct. Preassembled units are attached by sliding the flange into the cut piece and attaching with sheet metal screws. These steps are repeated until the assembly is complete. There is virtually no limit to how big an assembly can be as super lifts are used during installation. The only limiting factors when creating assemblies are the floor and roof areas that may cause obstruction.

1.6 Installation of ductwork

Installation at a height can be tackled in two ways. Each method utilizes different equipment but has the same outcome. The first method involves workers using ladders. These ladders can be varying heights depending on the height of the ceiling. The second method uses scissor lifts. Scissor lifts can hold two workers comfortably and can soar to heights that far exceed a ladder. Scissor lifts are considered to be the safer of the two methods, however; space requirements for maneuverability and height restrictions determine which method is used. Regardless of the method selected, once the worker is at installation height the process is the same. Connection consists of (1) adjusting the duct so metal flanges align, (2) use horse nippers or a duct puller to clamp the two pieces together, (3) insert an s-drive to connect the two ducts, (4) hammer the drive above and below the duct (5) drill four screws for connection (6) screw drill the hangers to the duct and (7) seat the entire joint with putty.

Whether the method of equipment used is a ladder or a scissor lift the tools used are similar.

Image 8: An Apprentice completing duct installation by drilling the connection in a scissor lift.

Duct installation tools required are a flathead screwdriver, a hammer, a tape measure, an 18 volt cordless drill, horse nipper/duct puller and a paint brush to apply "sealing putty," at all joints to reduce air leakage.

As stated earlier, elevating a worker from the floor to work height is achieved with either a ladder or scissor lift, however moving the duct from the floor to ceiling involves other processes. A worker will manually place the duct on a super lift and secure it in place with drywall pieces and C-clamps so it would not roll off. Depending on the length of duct one or two super lifts may be used. Cranking the duct up to installation height by both super lifts must occur simultaneously. If the duct installed is small or only one super lift is available the workers may resort to other options. These options are to carry the duct up to height manually or to place the material in the scissor lift and carry it up to height. These options are determined based on the availability of equipment.

1.7 Installation of equipment

Ductwork and mechanical equipment are both installed in a similar fashion. The connection of mechanical equipment to the duct run is similar. However, the main difference between equipment and duct installation is the weight of the material being installed. Equipment typically, controlled air volume systems (CAV), variable air volume systems (VAV) and motors are manufactured off site and shipped to the site as required per the plans. These pieces can either be (1) connected to duct on the floor and then lifted to installation height using a super lift or (2) carried manually by one or both workers to the height of installation, (Image 9 below).

Image 9: An Apprentice (Left) and Journeyman (Right) install a VAV box.

The first method is not only safer but provides an easier work surface for the team. The second option forces the workers to use a single hand to carry the equipment up the ladder while not having three points of contact with the ladder at all times. Once the equipment has been carried to installation height one worker must hold the equipment up while the other completes the connection to existing duct. This connection is done in exactly the same manner as described above in section 1.6.

2. Selection of activities

Long duration activities with multiple tasks during the operation were studied further. Of the seven activities above mentioned five were chosen for showing high ergonomic hazard. The following activities and variations were selected for productivity and ergonomic analysis:

- Install duct on ladders with super lifts. This activity was selected as workers were continuously climbing up and down and using a ladder rung as the work platform while completing installation above head.
- Installing equipment on ladders with super lifts. This similar activity was chosen as it introduced new work factors. Equipment may be smaller than the width of the super lift arms therefore requiring workers to carry it up the ladder. Workers are required to hold the equipment up while completing installation. Installation is done overhead.
- Installing duct in scissor lifts with super lifts. Again, similar to the first selection this activity introduces mechanical, worker operated, equipment. Thus, eliminating the work platform hazard while giving the worker a larger range of movement. Work is completed both at shoulder and above head levels.
- Creating assemblies on the ground. This activity was selected because the workers utilize the concrete floor as a work surface. Kneeling, squatting,

bending at the waist and hunching over material were all observed during initial selections.

- Drawing the layout on the ground. This activity was selected as the worker must draw the ceiling layout on the ground for the installation crew. In this activity the ground is the work surface and similar body movements to creating assemblies were noticed in these workers.

3. Selection method for ergonomic analysis

The research objective is to evaluate the effect of task parameters on ergonomic loads for HVAC installers. The ergonomic analysis method needed to address the following:

- Focus on body regions that showed significant extreme postures during HVAC installation. This includes the following body areas; (1) Neck, (2) Shoulders, (3) Back and (4) Legs.
- Calculate the durations (exposure) and severity of ergonomic postures, seen in Appendix A. A key indicator for the ergonomic risk was the time in an extreme posture of a particular activity as a percentage of the overall task for each body part.
- Relate production tasks performed to ergonomic loads during extreme ergonomic postures.

For these reasons the researchers performed the following:

1. Developed a postural guide to identify extreme postures for the four above mentioned body regions

2. Performed a continuous time analysis using the postural guide and video observations.
3. Performed a productivity analysis of the tasks performed, this was captured with the Crew Balance Chart.

Postural Guide development

This guide was developed using RULA, REBA and the NIOSH lifting guide. These three existing ergonomic methods aided in creating the correct angles of flexion and extension for specific body regions. The body regions were then chosen based on the work done and regions at highest risk.

The postural guide seen in Tables 13 and 14 below was created to distinguish each body region; neck, shoulders, back and legs.

Body Part	Criterion	Neutral	Minimal	Moderate	Extreme	Comment
Neck	Flexion	-	0-20°	> 20°	-	RULA/REBA
	Extension	-	0-20°	> 20°	-	
	Twisted	-	-	-	All movement	
Shoulders	Flexion	-	0-45°	45°-90°	> 90°	RULA/REBA
Back	Flexion	-	0-20°	20°-60°	> 60°	REBA
	Extension	-	-	0-20°	> 20°	
	Twisting	-	-	45°-60°	> 60°	
Legs	Standing, walking, sitting	< 30°	30°-60°	-	-	REBA
	Unstable	-	-	30°-60°	> 60°	
	Squatting	-	-	Stable	Unstable	

Table 13: Postural guide showing body regions

Force	Light	Moderate	Heavy	Source
Push/Pull	0-14 lbs.	15-50 lbs.	-	NIOSH
Lifting	0-14 lbs.	15-50 lbs.	< 50 lbs.	

Table 14: Postural guide showing forces

The angles of flexion and extension range from 0° to 90° depending on the region in question. Each angle was then related to levels of grading giving more significance to higher risk movements. These grades ranged from neutral to extreme. Lastly, forces were included to take into account loads of material and tools used during installation. Two forces were accounted for pushing/pulling and lifting. Both forces were valued in pounds of the object lifted or moved ranging from 0 lbs. to 50 lbs. grades were also given to these values ranging from light to heavy.

4. Collection of field data

For each of the fifteen activities observed, the researcher discussed the activity with the supervisors and workers while taking notes and pictures. Discussions included questions regarding tools used, equipment utilized, specific worker experiences, history, and details of the job. The researcher then observed and videotaped the operation for future analysis and reference.

During review of the operations, reliability issues of the video recording were noticed. These were:

- One camera was used and it was primarily focused on the worker performing the installation. Thus, analysis could only be completed on this worker and not the team.

- Occasionally, a worker left the work area and was thus not in video. Ergonomic and productivity analysis were not completed during this time.
- Numerous cameras should have been employed to read all body angles. Body angles may be considered inaccurate due to the difference in elevation between the worker at work height and the observer at ground level.
- During analysis only one side of the workers' body was studied. Fluctuations from left to right sides varied on the more extreme posture between the two.
- Video recordings are not continuous from start to finish of the cycle. Breaks were taken, operations were halted and workers walked away from work area to do unrelated work.
- Weight of tools and equipment is approximate. Workers guessed tool belt, tool, material and equipment weights. Particularly, the weight of tool belts on the back and legs was not considered during ergonomic analysis.
- RULA and REBA designed Postural guide shows a wide range of body movement. However, there are combined body postures and extreme movements that did not fall into one category.
- Lastly, the observer was talking to the workers during activities. Talking was considered a distraction and this prolonged activity duration.

5. *Perform production and ergonomic analysis*

The analysis involved the following steps:

- Developed the Crew Balance Chart (CBC) and performed productivity analysis.

- Developed the Postural Analysis Chart (PAC) and performed ergonomic analysis.
- Examined the task factors that affected the exposure to extreme postures.

Productivity analysis

The CBC indicates the tasks performed and their durations by a worker. A full description of tasks for each worker analyzed per operation can be found in Appendix B. The productivity analysis indicated what percent of time was used for productive work, support work or idle time. Productive work was considered as any task that involved the final installation of material. Table 15 below indicates the productive & support tasks for different activities.

	Productive work	Support work
Installation activities	Install S drive, attach duct hanger, hammering, fastening, attaching gasket	Moving material, ascend/descend the ladder, reach for tool, adjust material, measuring, moving ladder, adjusting tool, cranking super lift, putting tool away, moving super lift, material preparation, removing object from lift, moving up/down in scissor lift, moving toolbox, moving scissor lift, removing plastic wrap, unscrewing strut, talking cutting, cutting strap.
Ground assembly activities	Putting two pieces together, fastening	Positioning duct, cutting material, moving cut piece to storage, straightening edges, putting tool away, searching for next duct piece, getting a tool, measuring duct, drawing cut line on material, checking alignment, wrapping duct with plastic, getting plastic wrap
Layout activities	Measuring and marking slab	Reviewing drawings, spraying slab, walking to and from cart, moving within work area, placing bucket, placing chalk line, replacing line, moving cart, smearing chalk line

Table 15: Work activities and productive and support work tasks

Ergonomic analysis

Next, the researchers performed a continuous time ergonomic analysis using the postural guide and video recordings. The result was the PAC which indicates the severity of posture over the duration of the activity. This analysis shows what percentage of the cycle time the worker was in an extreme ergonomic posture. A detailed analysis of all operations can be found in Appendix A.

Work factor analysis

The element of task duration is critical for both productivity and ergonomic exposure. Using the CBC and PAC the analysis examined the task variables that affected the intensity and duration of the ergonomic risk factors.

Chapter 4

CASES

This chapter provides an overview of the cases analyzed. Case profiles show the contractor used, how the work was performed and number of cases per activity.

The study focused on three activities:

1. Layout
2. Duct assembly on the ground
3. Duct and equipment installation

The study analyzed a total of 15 operations by three contractors (Contractors A, B and C) as shown in Table 16. Based on the activities outlined in previous chapters the activity distribution is based on by work availability the three contractors.

Activity	Method	Cases	Contractor		
			A	B	C
Layout	At ground level	3		3	
Ground Assembly	At ground level	3		3	
Duct Installation	In a scissor lift	3		3	
Duct Installation	On a ladder	3	2		1
Equipment Installation	On a ladder	3	1		2

Table 16: A breakdown of operations in this research showing the distribution of cases between companies.

Contractor Descriptions

As seen in Table 16 above there were three main contractors who had available work for this study. These national contractors are all located in the Phoenix metropolitan area. All projects observed were commercial buildings either as tenant improvements or new construction.

Due to work availability in the phoenix area limited sources were used for this study. This is evidenced by Table 16 above. Some contractors had more work than others and were able to provide numerous job sites for observation whereas other companies were restricted not only by jobs but corporate privacy rules of video recording.

Contractor A

Contractor A was founded in 1973. This contractor provides process and mechanical system installations in the electronics, biopharmaceutical, healthcare, data centers, and general industries. Contractor A designs and installs gas, chemical, water and waste systems for photovoltaic manufacturing lines with an unparalleled combination of experience, quality, capacity and versatility. Contractor A services include pre-construction services, Building Information Modeling, state-of-the-art fabrication, chemical delivery solutions, field operations and project management.

Contractor A has a safety policy called, "The Beyond Zero" program. This philosophy is intended to increase the focus on improving physical and environmental risk factors, and processes that control or eliminate defects. This philosophy is a corporate identity that nurtures personal safety, responsibility, inspires continuous improvement, and focuses on creating an environment where safety happens by choice.

Contractor A utilizes a union workforce. This ensures quality assurance, knowledgeable and respected workers and available help when needed. Union workers belong to Sheet Metal Workers Local 359. Union workers have apprentices and journeyman based on years of service and implemented training. This distinction in experience is reflected in their pay scale.

It can be noticed that contractor A had no scissor lift operations. This contractor primarily had projects with low ceiling heights. This gave way to ladder installations. Another reason is the space availability for lifts and the cost of renting such equipment. The jobs observed for this contractor had ceiling heights under 10’-0”. Workers are given aluminum A-frame ladders ranging in size from 6’ to 12’.

Contractor B

Contractor B is an EMCOR company, that does start to finish projects. Contractor B has the expertise to apply a range of specialized techniques and procedures that can help end-users, owners, general contractors, and architects achieve substantial benefits before construction begins.

Contractor B is affiliated with a number of associations including the Sheet metal Workers International Association, (SMWIA), the Mechanical Contractors Association of America (MCAA), the Sheet metal and Air Conditioning Contractors National Association (SMACNA), and the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE).

This contractor has a three pronged approach to each project, known as Safety, Quality and Productivity (SQP). Their safety program known as the, “Be There for Life! – Zero Accident Program” which has led to safety performance that's 5-to-10 times better than the national average with accident rates. Many of their operations go months, even years without any injuries. This contractor has a Quality Assurance Program that ensures that all customers, statutory and regulatory requirements, support the zero accident values, manage costs and risks, and continuously improve their processes and methods for consistent, measurable and repeatable quality on every project. These programs also play a significant role in their ongoing efforts to improve productivity. Through careful planning and sound set up, they have created a safe working environment. This reduces risk. Reduced risk means fewer accidents. An accident-free project is more productive.

Contractor B, similar to Contractor A, uses union workers from the same local union. Many Arizona mechanical contractors use union workers. Using this knowledgeable and safety driven work force has its disadvantageous as well. When work is slow there are workers on hand however, when the state is busy and many projects are going at once the work force is limited and it may force some contractors to use non-union help.

From table 16 above its evident that contractor B had all the scissor lift operations. This contractor primarily had projects with high ceilings. This contractor has teams two or four workers. For each apprentice there is a journeyman so the on job training is constant. Each team is also given scissor lifts known as mobile elevating work platforms (MEWP). These ensure a safer work area for the workers at height with waist high cages, tie-off bars and easy maneuverability.

This contractor also provides layout and ground assembly operations. This was the only contractor who had enough jobs at varying stages of completion to offer for study. Both these operations are done on the ground and thus no equipment, I.E. ladders or scissor lifts, were needed. Workers use the concrete floor as their work area.

Contractor C

Contractor C is a Comfort Systems company that began serving Arizona in 1962. This contractor changed its focus from residential to commercial mechanical contracting and service in 1976. This contractor is a premier national provider in the installation and service of heating, ventilating, air conditioning, plumbing, piping and related services.

This contractor also boasts the following standards:

1. Safety record that outperforms the national average
2. Technical proficiency working with all major manufacturers
3. National footprint/local presence
4. An Energy-Star® partner
5. A member of the United Green Building Council
6. LEED© Accredited Professionals in each of their operating companies

Contractor C conducts continuous training and monitoring programs to assure full awareness of safety issues, policies, and best practices by all employees in safety sensitive positions. Every employee along with a 10 hour OSHA certification is trained in the following:

- Mine safety and health administration (MSHA)
- Aerial lifts
- Confined space entry
- Trenching and excavation
- Hazard communication
- Lockout tag-out
- Personal Protective Equipment (PPE)
- Blood borne pathogens
- Electrical safety
- Fall protection
- Ladder safety
- Manual material handling (MMH)
- Portable fire extinguishers

Contractor C is the only contractor in this study that did not use union workers. This was a corporate choice to avoid low work force availability during busy times. These workers are not apprentices or journeymen but called sheet metal workers regardless of experience or years of field experience. These workers self perform all tasks from the layout to the installation. This can add to the cycle times as worker does more than one task during the work day.

Similar to contractor A this contractor uses ladders during installation. The project observed had low ceilings and thus ladder work was appropriate and economical. Contractor C only formed teams when larger ductwork was installed or cognitive decisions needed to be made, to resolve design issues.

Operation grouping

Contractors A, B and C were used in this study because they were companies with current mechanical projects using sheet metal workers and they were willing to participate in this research. As stated above the availability of projects for study was based on workload, privacy policies and completion of work.

Below in tables 17-21 the case profiles are shown. Each table is grouped into operations of similar tasks, I.E. layout, ground assembly. Operations 1-3 are duct installation operations using a ladder, operations 4-6 are equipment installation on ladders, operations 7-9 are scissor lift operations of duct installation, operations 10-12 are ground assemblies and operations 13-15 are layout tasks.

Each operation has its own profile. There are 15 profiles. The profile gives detailed information regarding the specific categories of each operation. Categories shown are; (1) Company, (2) Task, (3) Height of installation, (4) Workers, (5) Equipment, (6) Method, (7) Tools, (8) Time, (9)Worker observed.

The operation specific information is given for each category per operation.

Duct installation using ladder(s)

Shown below in Table 17 is the case profile of ladder installation of duct.

	Operation 1	Operation 2	Operation 3
Company	A	A	C
Task	Install 12”x12”x12’ rectangular duct ≈15 lbs.	Install 12"x12"x12' rectangular duct ≈15 lbs.	Install 24"x18" round vent & 48" of flex duct
Height of installation	9’-6” to bottom of duct	9’-6” to bottom of duct	10'-4" to bottom of duct
Workers	1 Journeyman & 1 Apprentice	1 Journeyman & 1 Apprentice	1 Sheet metal worker
Equipment	One 8’ aluminum ladder & one super lift	One 8’ aluminum ladder, one 12' aluminum ladder & one super lift	One 8' aluminum ladder
Method	Journeyman on ladder installing, apprentice on the ground operating super lift.	Apprentice on ladder installing. Journeyman on the ground operating super lift & on ladder installing.	Sheet metal worker assembling, cutting duct & installing
Tools	Flathead screwdriver, one 18V (≈5 lbs.) cordless drill, a pair of horse nippers, a hammer and a pair of metal shears	Two pairs of horse nippers, a hammer and a pair of metal shears	Metal shears, tension gun, zip tie, hammer, reciprocating saw, power cord, hand seamer, 18V cordless drill (≈5 lbs.), flathead screwdriver
Time	3 minute 45 seconds	4 minute 47 seconds	13 minute 30 seconds
Workers observed	Journeyman	Journeyman & Apprentice	Sheet metal worker

Table 17: Case Profile for Operations 1 through 3

Equipment installation using ladder

Shown below in Table 18 is the case profile of ladder installation of equipment.

	Operation 4: Ladder (Equip)	Operation 5: Ladder (Equip)	Operation 6: Ladder (Equip)
Company	A	C	C
Task	Install12"x12"x2' rectangular VAV box ≈10 lbs.	Install 11"x23"x10' duct with motor ≈45 lbs.	Install 11"x23"x10' duct with motor ≈45 lbs.
Height of installation	9'-6" to bottom of box	9'-8" to bottom of motor	9'-8" to bottom of motor
Workers	1 Journeyman	1 Sheet metal superintendent	1 Sheet metal superintendent
	1 Apprentice	1 Sheet metal worker	1 Sheet metal worker
Equipment	One 8' and one 10' aluminum ladders	Two 10' aluminum ladders & one super lift	Two 10' aluminum ladders & one super lift
Method	Both Journeyman and Apprentice on ladders. One holding the VAV, the other installing.	Both sheet metal workers operating super lift & installing on ladders	Both sheet metal workers operating super lift & installing on ladders
Tools	Flathead screwdriver, two 18V (≈5 lbs.) cordless drills, a pair of horse nippers, two hammers and one pair of metal shears	Pliers, two hammers, flathead screwdriver, vise grip, measuring tape, metal shears, reciprocating saw, extension cord, duct puller, flashlight, hand seamer, two 18V (≈5 lbs.) cordless drills	Duct puller, flathead screwdriver, two hammers, two 18V (≈5 lbs.) cordless drills
Time	4 minutes 2 seconds	15 minutes 52 seconds	15 minutes 13 seconds
Workers observed	Journeyman & Apprentice	Sheet metal worker	Sheet metal worker

Table 18: Case profiles for Operations 4 through 6

Duct installation using Scissor lift

Shown below in Table 19 is the case profile of scissor lift installation of duct.

	Operation 7: Scissor lift	Operation 8: Scissor lift	Operation 9: Scissor Lift
Company	B	B	B
Task	Install 16’ long x 12” diameter round duct ≈20 lbs.	Install 16’ long x 12” diameter round duct ≈20 lbs.	Install 46"x18"4' curved rectangular duct ≈15 lbs.
Height of installation	18’-0” to bottom of duct	18’-0” to bottom of duct	12'-0" to bottom of duct
Workers	1 Apprentice	1 Journeyman 1 Apprentice	1 Foreman 1 Journeyman 2 Apprentices
Equipment	One scissor lift & one super lift	One scissor lift & one super lift	Two scissor lifts & one super lift
Method	Apprentice operated super lift Journeyman operated super lift and installed in scissor lift.	Journeyman operated super lift and apprentice installed in scissor lift	Apprentice 1 prepping for install, supplying material. Apprentice 2 installing. Journeyman installing. Foreman coordinating
Tools	18V (≈5 lbs.) cordless drill, one level and three C clamps, pliers	18V (≈5 lbs.) cordless drill, two levels and three C clamps	two 18V (≈5 lbs.) cordless drills, two vise grips, two hammers, one 2x4 and plastic wrap
Time	13 minutes	4 minutes 28 seconds	22 minutes 50 seconds
Workers observed	Journeyman	Journeyman & Apprentice	Journeyman & Apprentice

Table 19: Case profiles for Operations 7 through 9

Ground Assembly Operations

Shown below in Table 20 is the case profile of ground assembly operations.

	Operation 10: Ground Assembly	Operation 11: Ground Assembly	Operation 12: Ground Assembly
Company	B	B	B
Task	Assemble 12' long, 12" diameter round duct ≈10 lbs.	Assemble 12' long, 12" diameter round duct ≈10 lbs.	Assemble 8' long, 12" diameter round duct ≈10 lbs.
Height of installation	0'-0", created on concrete floor	0'-0", created on concrete floor	0'-0", created on concrete floor
Workers	1 Journeyman	1 Apprentice	1 Journeyman
Equipment	N/A	N/A	N/A
Method	Journeyman cuts duct on ground, locates other duct to assemble with, reference drawings for size and type	Apprentice cuts duct on ground, locates other duct to assemble with, reference drawings for size and type	Journeyman cuts duct on ground, locates other duct to assemble with, reference drawings for size and type
Tools	18V (≈5 lbs.) cordless reciprocating saw, 18V cordless drill, plastic wrap, utility knife	18V (≈5 lbs.) cordless reciprocating saw, 18V cordless drill, plastic wrap, utility knife	18V (≈5 lbs.) cordless reciprocating saw, 18V cordless drill, plastic wrap, utility knife
Time	5 minutes 55 seconds	9 minutes 8 seconds	5 minutes 17 seconds
Workers observed	Journeyman	Apprentice	Journeyman

Table 20: Case profiles for operations 10 through 12

Layout Operations

Shown below in Table 21 is the case profile of layout drawing operations.

	Operation 13: Layout	Operation 14: Layout	Operation 15: Layout
Company	B	B	B
Task	Draw installation layout per drawings on floor	Draw installation layout per drawings on floor	Draw installation layout per drawings on floor
Height of installation	0'-0", created on concrete floor	0'-0", created on concrete floor	0'-0", created on concrete floor
Workers	1 Journeyman	1 Journeyman	1 Journeyman
Equipment	N/A	N/A	N/A
Method	Journeyman reviews drawings to verify location, dimension, size and type of duct to be installed, draws this information on ground	Journeyman reviews drawings to verify location, dimension, size and type of duct to be installed, draws this information on ground	Journeyman reviews drawings to verify location, dimension, size and type of duct to be installed, draws this information on ground
Tools	Industrial broom, pencil, utility knife, permanent marker, chalk line, bucket, clear spray, measuring tape	Pencil, permanent marker, chalk line, bucket, clear spray, measuring tape	Pencil, permanent marker, chalk line, bucket, clear spray, measuring tape, T square
Time	1 minutes 56 seconds	2 minutes 44 seconds	4 minutes 16 seconds
Workers observed	Journeyman	Journeyman	Journeyman

Table 21: Case profiles for operations 13 through 15

Chapter 5

DATA ANALYSIS

This chapter presents the findings from the analysis of 15 operations. The detailed chart showing complete percentages of each operation is presented in Appendix A. As described in the Methodology section, the analysis of each case involved the following:

1. Development of the Crew Balance Chart (CBC) that shows the tasks workers performed and task durations.
2. Ergonomic analysis based on the postural guide for the body regions and calculation of the percentage of time in extreme postures.
3. An examination of extreme body postures in combination with tasks to understand when the workers were in extreme postures, tasks performed and what work factors generated the extreme postures.

The analysis is organized as follows:

- Review of each case profile
- Analysis of each worker observed, focusing on specific tasks that contribute to extreme postures
- Discussion of reasons for extreme postures and task factors
- Summary of key findings and observations

Operation 1: Installing duct on ladders

Company:	A, union workers
Task:	Install 12”x12”x16’ rectangular duct ≈15 lbs.
Work height:	9’-6” to bottom of duct
Workers:	1 Journeyman (8 years experience) & 1 Apprentice (4 years experience)

Equipment: One 8’ aluminum ladder & one super lift

Method: Journeyman on ladder installing, apprentice on the ground operating super lift.

Tools: Flathead screwdriver, one 18V (≈5 lbs.) cordless drill, a pair of horse nippers, a hammer and a pair of metal shears

Duration: 3 minute 45 seconds

Workers observed: Journeyman

The building had a ceiling height of 12’-0”. The company did not provide lifts for its workers due to the height and space confines of the job.

Journeyman

Installation of 16 LF of duct took two workers 3.75 minutes to install. This worker performed productive work 7% of the time, support work 88% of the time, and was idle for 5% of the time. During this operation the journeyman had extreme postures in the neck (11% of the time), shoulders (0%), back (7% of the time), and legs (11% of the time). The cumulative exposure to extreme postures was 29%. Pushing/pulling and lifting were both light, (87% of the time) and moderate (13%), respectively. Table 22 below shows the main tasks that the workers performed and the extreme postures that occurred during those tasks.

Moving material took 4% of the time. The material was lying on the arms of the super lift which was below waist height, while the journeyman was moving it. The height of the duct at this time caused the 2% extreme neck value. Looking down at the material on the lift and twisting his neck to the left to give instructions to the apprentice, contributed to this posture.

Positioning the ladder took 16% of the time. The journeyman positioned and re-positioned his ladder twice during the operation to align it at an approximate 30° angle to the duct length. The worker made connections on both sides of the duct hence the ladder movement. This provided better position and effectually reduced ergonomic loads on the back and shoulders. However, extreme neck twisting was evident 2% of the time. While on the ground this worker was gauging the best ladder placement thus causing him to look up.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Moving material [S]	4%	2%				Looking down at material
Positioning the ladder [S]	16%	2%				Looking up while moving equipment
Ascending/ Descending ladder [S]	7%				7%	Moving on 4" rung, maintaining balance
Aligning the duct [S]	45%	5%			4%	Looking around material to verify alignment. Moving up/down ladder while making adjustments
Putting horse nippers on [S]	8%			7%		Too close to duct. Creating work space by moving body
Idle time	5%	2%				Looking up at duct
TOTAL		**11%**	**0%**	**7%**	**11%**	

Table 22: Task durations and extreme postures for operation 1 Journeyman

Ascending/Descending the ladder was 7% of the time. This worker climbed up and down his ladder twice which is closely linked to positioning the ladder. Climbing up and down the ladder caused leg exposure in the extreme (bilateral weight bearing, unstable leg flexion greater than 60º) for 7% of this task time.

Aligning the duct took 45% of the time. Adjustments to the duct were hindered for two reasons: (1) the duct was long and (2) the journeyman was moving the duct alone on a single ladder while his apprentice was on the ground moving the super lift. Super lift adjustments are generally large, movements to get material to an approximate desired location, whereas the actual alignment requires small precise movements at the connection point. The ducts could have been aligned faster with less extreme neck and leg exposure, if the apprentice was on a ladder and both workers were handling the material.

Putting the horse nipper on took 8% of the time. Back posture in the extreme position (extension greater than 20 degrees) was observed 7% of the time when the journeyman was putting the horse nippers on the duct to pull the two runs together for alignment. His ladder position being such as to limit range of motion thus contributing to this exposure.

Idle time was 5% of the time. The journeyman in this operation was waiting while the apprentice moved the super lift. The journeyman was looking up at the duct from the ground, mentally measuring where he should place his ladder. A 2% extreme neck value was observed during this time.

Key findings/observations - Journeyman

- For one worker a small amount of productive work (7%) was completed. The majority of tasks performed were support work as can be seen in Table 22. Support tasks were the only tasks contributing to extreme postures.

- Aligning the duct took 45% of the time. Better methods are needed to align the duct during installation. Possible re-design of duct flanges needed to reduce operation time thus reducing worker exposure.
- No extreme postures for shoulders were observed. The position of the ladder was such that the worker did not have to overextend his arms. Ladder positioning appears to be critical. However, ladder position was too close to the duct and caused back twisting. Ladders provide very little movement flexibility. Thus, requiring more turning (twisting) and overextending (flexion/extension).

Operation 2: Duct installation on ladders

Company:	A, union workers
Task:	Install 12”x12”x12’ rectangular duct ≈15 lbs.
Work height:	9’-6” to bottom of duct
Workers:	1 Journeyman (27 years experience) & 1 Apprentice (1 year experience)
Equipment:	One 8’ aluminum ladder, one 12' aluminum ladder & one super lift
Method:	Apprentice on ladder installing. Journeyman on the ground operating super lift and on ladder installing
Tools:	Two pairs of horse nippers, a hammer and a pair of metal shears
Duration:	4 minute 47 seconds
Workers observed:	Journeyman and apprentice

Operation 2 took place at the same site as operation 1. It involved the same contractor but different workers—a very experienced journeyman who was on the ground giving instructions to a new apprentice who was on the ladder performing the operation.

Journeyman

The installation of 12 LF of duct took two workers 4.78 minutes. The journeyman in this operation was on the ground while the apprentice was on the ladder performing the installation. The journeyman performed no productive work and had 0% idle time while having support work for 100% of the time. During this operation the journeyman had extreme postures values for the neck (27%), shoulders (3% of the time), back (0%), and legs (5%). The cumulative exposure to extreme postures was 35%. Pushing/pulling was light (76% of the time) and moderate (24%). Lifting was light (100% of the time). Table 23 below shows the main tasks that the workers performed and the extreme postures that occurred during those tasks.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Instructing apprentice [S]	29%	22%				Looking up at apprentice on ladder
Cranking super lift [S]	15%	5%				Looking up at material to verify correct height
Ascending/ Descending ladder [S]	3%		3%		5%	Moving on 4" rung maintaining balance
Total		**27%**	**3%**	**0%**	**5%**	

Table 23: Task durations and extreme postures for operation 2 Journeyman

Instructing the apprentice took 29% of the time. The journeyman on the ground was giving verbal directions to the apprentice on the ladder during installation. The height difference caused this worker to look up while talking. A 22% extreme neck value was observed for this worker. This was due to the constant conversation during installation as one worker was on the ground while the other was at height.

Cranking the super lift was 15% of the time. Cranking involves both arms moving in a forward circular movement, similar to rowing. This lifts the material, on the arms of the crank, up to installation height. During this task it is the worker's job to verify the height of installation and correctly maneuver the duct as accurately as possible. More refined adjustments to the duct take place at height. During this task the journeyman raised his head beyond a 20° angle to view the duct at height causing the 5% extreme neck posture.

Ascending and descending the ladder took 3% of the time. The journeyman climbed his ladder once during the end of the operation to assist the apprentice. This was done to help put the horse nippers on the duct. During this task the worker used his arms for balance while he climbed up or down the ladder thus the simultaneous extreme shoulder (3%) and legs (5%) values. If the apprentice had been able to swiftly place the horse nippers on the duct the journeyman would not have had to climb his ladder. This in effect would have negated both extreme postures.

Apprentice

The apprentice had 35% productive work, 65% support work and 0% idle time. The apprentice in operation 2 showed extreme postures values in the neck (40%), shoulders (4% of the total time), back (4%) and legs (6%). The cumulative exposure to extreme postures was 54%. Pushing/pulling and lifting were both light, (100% of the time). Seen in Table 24 below are the main tasks that the apprentice performed and the extreme postures that occurred during those tasks.

Inserting the S drive was 17% of the time. This task connects two duct runs together along with the S drive. The drive is placed under/above or on the right/left sides of the duct by sliding over the two flanges securing the connection. It is then hammered into place at the duct ends. Two concurrent extreme body postures were recorded during this task; (1) shoulders, 4% and (2) neck, 4%. To avoid being hit in the head with his own hammer the apprentice moved his neck, while his shoulders were hammering the drive into place causing these postures.

Apprentice Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Inserting the S drive [P]	17%	4%	4%			Move head to avoid being hit and using tool above head
Aligning the duct [S]	12%	12%		2%		Ladder too close to material, moved to create work space
Ascending/ Descending ladder [S]	6%				6%	Unsafe work platform, moving on 4" rung
Measuring the drive [S]	6%	4%				Looking around material for better sight lines
Cutting the S drive [P]	16%	7%				Looking down at material
Adjusting the horse nippers on duct [S]	13%	13%		2%		Ladder too close to material moved to create work space. Looking around material for better sight lines
TOTAL		**40%**	**4%**	**4%**	**6%**	

Table 24: Task durations and extreme postures for operation 2 Apprentice

Aligning the duct took 12% of the time. Duct alignment is a task that involves making slight adjustments to the material while on a ladder at height. This is done to properly align the existing installed duct with the new run. The perpendicular position of the worker's ladder to the duct caused higher neck values to be recorded. For this worker there were two extreme body postures; (1) back, 2% and (2) neck, 12%. Working on a ladder greatly limited this workers' range of motion. Due to inexperience on the apprentices' part his ladder placement was too close to the duct. Rather than climb down and re-position he moved his body to create a work space.

Ascending and descending the ladder was 6% of the time. The apprentice climbed his ladder once to perform his work. During the operation he climbed up one more rung to be closer to the duct and to get better visibility. Similarly, while descending he stopped after one rung and finished hammering, then descended to the floor. Extreme leg postures were evident in this operation, 6% of the time. This worker was climbing up one rung to work on the top of the duct, while stepping down one rung to work on the bottom of the duct.

Measuring the S drive was 6% of the time. During this task the apprentice was guessing the measurement of the drive while cutting it with metal shears. His estimation involved looking up at the duct and back down at the material in his hands. While standing on the ground, this movement recorded an extreme neck posture of 4%. This neck posture could have been reduced had the worker measured the length of the drive while the material was still at waist height on the super lift.

Cutting the S drive took 16% of the time. This task is closely related to the previous description and could have been reduced if done when the material was at waist height. While using metal shears and talking with the journeyman the apprentice cut the drive. This task observed a 7% extreme neck value.

Adjusting the horse nippers was 13% of the time. While standing on a ladder the apprentice was adjusting the placement of the horse nippers on the bottom flanges of the duct runs for closer alignment. This action pulls the existing and new duct together, making for a cleaner connection with the S drive. A (1) 2% extreme back value and (2) 13% neck twisting value were recorded during this task. This worker was struggling with the task due to incorrect duct alignment. These body postures occurred because of limited movement on the ladder.

Key findings/observations - Journeyman

- The worker on the ground had high extreme neck postures (27%). This was due to looking up at the duct and the apprentice on the ladder while standing on the ground.
- 100% support time in this worker registered extreme body postures. These were attributed to cranking the super lift, looking up at the apprentice and having to climb his ladder to assist the apprentice.

Key findings/observations - Apprentice

- High extreme neck values (40%) were recorded for the apprentice. This was observed during several tasks and mainly when adjusting the horse nippers. This posture was largely due to the angle and position of the ladder.
- The position of the ladder was a significant factor. The ladder was positioned perpendicular to the duct, not parallel. The ladder was positioned this way due to its height (12') in relation to the bottom of the duct (9'-6"). As a result, this worker moved his body to reach the duct.

- Working on a ladder limits the workers' range of motion. With the least amount of effort the worker moves accordingly to create work space for his head, arms and trunk causing extreme postures in the neck, shoulders and back.

Operation 3: Installing duct on ladders

Company:	C, non-union worker
Task:	Install 24"x18" round vent & 48" of flex duct
Work height:	10'-4" to bottom of duct
Workers:	1 Sheet metal worker (14 years experience)
Equipment:	One 8' aluminum ladder
Method:	Sheet metal worker assembling, cutting duct & installing
Tools:	A pair of metal shears, tension gun, zip tie, hammer, reciprocating saw, power cord, hand seamer, 18V cordless drill (≈5 lbs.), and flathead screwdriver
Duration:	12 minute 40 seconds
Workers observed:	Sheet metal worker

This cycle was considerably longer than the previous operations as this worker was working by himself and completing numerous types of operations. As a non-union worker this sheet metal worker is required to understand and perform all sheet metal duct installation tasks. Retrieving tools, getting power, and locating material were all in separate locations and took time find.

Sheet metal worker

The installation of 1 round vent and 4 LF of flex duct took one worker 12.66 minutes to install. The sheet metal worker performed productive work 49% of the time, support work for 47% of the time and had 5% idle time. During this last operation the sheet metal worker had extreme postures values for the neck (16%), shoulders (22% of the time), back (4%), and legs (11%). The cumulative exposure to extreme postures was 53%. Pushing/pulling and lifting were both light, (100% of the time). Table 25 below shows the main tasks that the workers performed and the extreme postures that occurred during those tasks.

Sheet metal worker Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Aligning the duct [S]	11%	4%	3%	1%		Space was confined, restricted visibility and movement
Searching for tool [S]	16%	5%		1%		Bending at waist and knees to reach tools on floor
Ascending/ Descending ladder [S]	13%		13%		8%	Moving on 4" rung, maintaining balance
Cutting [S]	13%	5%	2%	1%	3%	Above head while on ladder
Idle	5%			1%		Bending at waist while waiting
Talking [S]	6%	1%				Twisting head around ladder
Fastening [P]	7%	1%	4%			Above head while on ladder
Total		**16%**	**22%**	**4%**	**16%**	

Table 25: Task durations and extreme postures for operation 3 Sheet metal worker

Aligning the duct took 11% of the time. Precision movement of the new duct is done to properly align with existing duct so the connection can be made. Existing sprinkler pipe lines and waste vents caused a problem for the sheet metal worker as he needed to position himself on the ladder in between these lines. Positioning is important during installation. Adjustments were difficult as the worker had limited space to work and needed to accommodate his body, tools and materials in the space available. These adjustments showed extreme postures in the shoulders (3% of the time), back (1%) and neck (4%).

Searching for a tool was 16% of the time. The varied tools used during this operation caused the worker to walk outside his work area to retrieve tools. Back extreme postures (1%) were evident while the worker bent to pick tool up from the floor and neck twisting (5%) were recorded when the worker was looking around the site for specific tools. Pre-task planning may have reduced the amount of travel time needed to retrieve specific tools. This may have also shortened the cycle time.

Ascending and descending the ladder took 13% of the time. The worker moved up and down his ladder five times to get materials or tools. Extreme shoulder postures (13%) were seen when the worker was climbing up or down as he was using his arms for balance. Movement in either direction on the ladder caused extreme leg postures (8%). Some pre-task planning and better site organization could have lessened his time on the ground, thus reducing his need to ascend and descend. This worker could have worn a tool belt to keep necessary tools close by and within reach.

Cutting was 13% of the time. This sheet metal worker was using metal shears to cut straps. This task had extreme postures in all four body regions. Extreme shoulders (2%), back (5%) and neck (1%) were all due to accommodating the work space while on the ladder. Existing lines hindered his movement. Extreme leg postures (3%) were while the worker was on the ground cutting the straps in a kneeling position. The worker used his leg as a bench and cut the strap as he did not have a work table.

Idle time was 10% of the time. This worker was idle while waiting for a power strip from another worker in the area. While waiting, this worker was bending at the waist moving the cord. This caused an extreme back posture (1%) to occur. This site was relatively disorganized. Other job sites hung power strips from the ceiling for communal use or had designated poles for use which effectively reduced the need for a worker to bend at the waist to move cords.

Talking took 6% of the time. While this worker was installing, the observer was talking to him. This took up a significant amount of time as the worker could not continue work while talking. This added to the length of the cycle. The observers' position was such that the worker was twisting his upper body to talk. An extreme back posture (1%) was evident during this time. The observer should have waited till after the installation to ask questions or have a discussion with the worker thus reducing extreme back exposure and the operation time.

Fastening took 7% of the time. Fastening was done on the ladder at height while making the connection. Extreme postures for shoulders (4%) and neck (1%) were seen during this task. The worker was working around existing pipes to make room for both his arm and the drill, while being able to see what he was doing.

Key findings/observations – Sheet metal worker

- This project was a tenant improvement and the site had pre-existing pipes and lines. This is an important factor for the extreme shoulder, back and neck percentages. The space constraints dictated the worker's body movements during installation.
- Searching for tools was a main factor that added to this worker's cycle time. A reciprocating saw, power cord and metal shears were all searched for during this

operation as the worker did not have these tools handy. Visually searching for the tools, he borrowed other worker's tools from their work areas.

- Climbing up and down the ladder had a significant impact on this worker's exposure percentages. Numerous times this worker ascended and descended the ladder to get materials and tools. This worker was not wearing a tool belt and he collected the tools he knew he would need on the top of the ladder.

Comparative Analysis

Table 26 and Figure 16 below show the extreme values of each of the four body regions for ladder installation, operations 1 through 3.

	Operation 1	**Operation 2**		**Operation 3**
Body Regions	Journeyman Ladder	Journeyman Ground	Apprentice Ladder	Sheet metal worker Ground and Ladder
Neck	11%	27%	40%	16%
Shoulders	0%	3%	4%	22%
Back	7%	0%	4%	4%
Legs	11%	5%	6%	11%
Cumulative	**29%**	**35%**	**54%**	**53%**

Table 26: Extreme postures for Operations 1-3

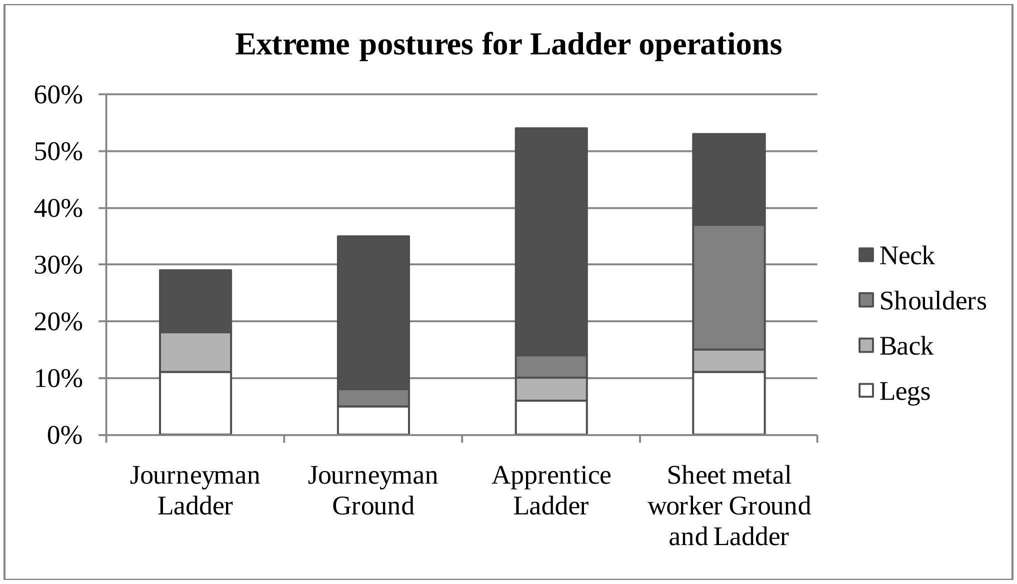


Figure 16: Extreme postures for ladder duct installation, Operations 1-3

Cumulative extreme postures range from 29% to 54% for the four workers analyzed. The journeyman in operation 1 and the apprentice in operation 2 were both working on ladders with another person on the ground operating the super lift, while the sheet metal worker in operation 3 was working alone and did not have a super lift. Significant differences were ladder positioning during installation.

In operation 1 the journeyman was the only one on a ladder and he moved his ladder twice to be on either side of the duct to complete the installation. This journeyman was positioned at a 30° angle to the duct in both instances.

While in operation 2 the journeyman had no intention of climbing his ladder as he felt the apprentice was capable of completing the operation alone. This journeyman was on the ground performing support work - as expected he has significant extreme neck posture while looking up. However, as the apprentice was struggling with the material alignment and the journeyman quickly climbed his ladder to assist. The apprentice was positioned perpendicular to the material whereas the journeyman was positioned at an approximate 15° angle.

In operation 3 the sheet metal worker had no one to rely on and although he climbed his ladder numerous times he did not have to move it. However, his ladder positioning was dictated by the existing pipes and lines in his immediate work area. His positioning was at a 20° angle to the duct.

Neck

Extreme neck postures (twisting) were present in all cases and ranged from (11% to 40%). Extreme neck postures occurred during:

- Operation 1 while aligning the duct with the existing run. Also, while on the ladder the worker was looking down across his body into his saddlebags on his tool belt.
- In operation 2 the journeyman was on the ground working the super lift and giving direction to the apprentice. He was looking up at the apprentice and the duct. The apprentice in this operation positioned his ladder so it affected body postures—he used a tall ladder (12') positioned parallel to the duct run, instead of perpendicular.
- Ladder positioning was a key factor in dictating neck movement. Looking at the duct from the side caused workers to have extreme neck postures. In operation 3 this occurred while talking to the observer who was standing on the ground and at an angle to the worker and when searching for tools in the vicinity of his work area.

Extreme neck postures (twisting) can be reduced with better ladder positioning. Positioning as described above can greatly reduce neck twisting.

Shoulders

Extreme shoulder postures (shoulder flexion greater than 90°) for workers doing the installation were low in operations 1 and 2 from (4% to 11%) and significant in operation 3 (22%). The position of the ladder was such that the workers in operation 1 and 2 did not have to overextend and the worker in operation 3 was twisting. The main reason for the high values in operation 3 was the existing installed pipes and vents on the ceiling that created an obstacle.

Back

Extreme back postures were low, ranging from (4%-7%) for the workers on the ladder and (0%) for the journeyman in operation 2, working on the ground. They varied in the different back grades from extension to flexion and twisting.

Extreme back postures occurred while:

- The journeyman in operation 1 was extended his body during one task (aligning the duct) in the cycle. This was attributed to being too close to the duct and having to move his upper body to create a work space for his arms.
- The apprentice in operation 2 had back twisting values. This was a small percent which was due to ladder positioning. The worker moved his body to get better visibility of the duct during connection.
- The sheet metal worker in operation 3 had a 4% flexion in this body region. This was due to the existing pipes and vent lines in his way during installation.

Extreme back postures can be reduced with better ladder positioning. Positioning the ladder perpendicular to the duct reduce twisting in the back and neck while reducing overextension in the shoulders. Preferred placement would be with 12” of the duct.

Legs

Extreme leg postures were moderately low in all cases ranging from (0-11%) of the time.

- The journeyman in operation 1 climbed up and down to reposition the ladder twice.
- In operation 2 both the journeyman and apprentice climbed their ladders once thus limiting leg exposure.
- In operation 3, the worker was working alone and performed several tasks (installed two smaller duct components) and had no one to give support. As a result, he went up and down the ladder numerous times.

Extreme postures for legs can be reduced if the worker does not have to go up and down the ladder for material and tools. This would also increase productive time. On the other hand, repositioning the ladder can provide better orientation and reduce the extreme postures for other body regions.

Overall

- Only a small portion of the time is attributed to actual connection work. A majority of work done is support work in preparation of installation. Long duration tasks that could possibly reduce operation duration and worker exposure are; (1) duct alignment by re-designing the flange connection, (2) cranking the super lift by using hydraulic lifts, (3) inserting the S drive by possibly re-designing the flange connection, (4) adjusting the horse nippers would not be needed if flanges were re-designed and (5) ascending/descending the ladder by either using scissor lifts or wearing a tool belt. Some ladder movement is understandable but excessive climbing puts the worker at risk.

- There is a wide range of movement required to complete installation. Ladders provided limited movement causing extreme postures in all body regions
- Aligning the duct is a task that takes significant portions of time to complete and contributes to extreme postures. Better methods for alignment are needed to reduce cycle duration and worker exposure. Possible re-designs to the duct flanges may be one solution.
- As seen in operation 1 the position of the ladder (orientation and distance) related to the duct, significantly affects posture and can mitigate extreme postures. However, although this worker had 0% shoulder exposure he did have extreme back and neck exposures. Ideally, the ladder should not be placed underneath the duct as this restricts how high the worker can reach thus causing extreme shoulder postures. Ladder positions when possible should be placed within 12" and perpendicular to the duct. This will negate extreme shoulder and back postures.
- Duct manufacturing creates sheet metal duct with flanges on two out of the four sides. It is at these flanges where the S drive is inserted and connections are made. Engineering parameters based on ceiling height, duct size and plenum requirements dictate which side the flanges will be whether it is top and bottom or on the sides. If the drive is to be installed on the top/bottom this causes extreme shoulder and neck postures in regards to reaching. However, if the drive is to be installed on the sides this can potentially cause extreme back postures depending on ladder positioning.

Operation 4: Installing equipment on ladders

Company:	A, union workers
Task:	Install 12”x12”x2’ rectangular VAV box ≈10 lbs.
Work height:	9’-6” to bottom of duct
Workers:	1 Journeyman (8 years experience) & 1 Apprentice (4 years experience)
Equipment:	One 8’ aluminum ladder & one 10’ aluminum ladder
Method:	Both journeyman and apprentice on ladders. One holding the VAV box while the other completes installation
Tools:	Flathead screwdriver, two 18V (≈5 lbs.) cordless drills, a pair of horse nippers, two hammers and a pair of metal shears
Duration:	4 minute 2 seconds
Worker Observed:	Journeyman and Apprentice

The building had a ceiling at 12’-0”. The company did not provide lifts for its workers due to the height and space confines of the job.

Journeyman

The installation of one VAV box took two workers 4.03 minutes. The journeyman performed productive work 24% of the time, support work 76% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (35% of the time), shoulders (25% of the time), back (27%), and legs (19% of the time). The cumulative exposure for this worker to extreme postures was 106%. Many of the postures occurred simultaneously thus causing the cumulative percentage to be greater than 100%. Pushing/pulling was light, (75% of the time) and moderate (25%).

Lifting was light (88%) and moderate (13%). Shown below in Table 27 are the main tasks that the worker performed and the extreme postures that occurred during those tasks.

Aligning the duct took 23% of the time. The VAV box was a cumbersome load for these workers as they tried to align the flanges to make the connection. The journeyman was holding the material with one hand while using his other hand for balance. The ladder was parallel and placed to the right of the duct to give the apprentice enough room for similar ladder placement on the other side of the duct. Both the journeyman and apprentice, worked side by side. The journeyman had to twist his body to see the flanges while holding the duct. This caused extreme postures in the neck (23%), shoulders (17%), and back (22%).

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Aligning the duct [S]	23%	23%	17%	22%		Ladder positioning, twisting body for visibility
Insert S drive [P]	4%	4%		4%		Holding material, working with one hand
Ascending/ Descending ladder [S]	16%	8%	2%		15%	Moving on 4" rung while managing balance
Fastening [P]	15%		6%		4%	Above head, bottom of duct
Total		**35%**	**25%**	**27%**	**19%**	

Table 27: Task durations and extreme postures for operation 4 Journeyman.

Inserting the S drive was 4% of the time. This task involved the worker slipping the right side drive on the VAV box. During this task the journeyman was holding the VAV box for balance while putting the drive in. His ladder position caused his body to twist so he could view the alignment properly. This movement caused extreme postures in the back (5%) and neck (4%).

Ascending and descending the ladder took 16% of the time. The journeyman climbed and descended his ladder twice during the operation; (1) to take the material up to installation height and (2) to bring the correct tool for use. Extreme postures were for the shoulders (2%), neck (8%) and legs (15%). While climbing, this worker held onto higher rungs for balance while looking up at the duct.

Fastening took 15% of the time. After attaching the VAV box to the existing run with an S drive the journeyman fastened the hanger to the box. A shoulder value of 6% and neck value of 4% were seen during this operation due to the worker not climbing high enough on the ladder. He was below the material when fastening.

Apprentice

The apprentice performed productive work 40% of the time, support work 60% of the time and had no idle time. This worker had extreme postures during the operations in all four body regions; Neck (29%), shoulders (31%), back - twisting greater than 60° (23%), and legs (4%). His cumulative exposure to extreme body postures was 87%. Pushing/pulling and lifting were both light, (94% of the time) and moderate (6%). Table 28 summarizes the extreme postures and tasks where they occurred.

Getting a tool was 16% of the time. During the operation the apprentice used numerous tools, all of which were in his tool belt. Two low slung saddlebags hung on either side of his waist. Retrieving tools meant crossing his body to reach what he needed or dipping to one side to reach into a bag. This movement caused extreme postures to occur in the shoulders (4%) and neck (2%).

Aligning the material took 29% of the time. The apprentice was holding the left side of the duct while making adjustments. Holding the existing duct with one hand and holding the VAV box with the other caused extreme postures in the shoulders (13%), back (13%) and neck (13%). These extreme postures were caused by the ten foot ladder being placed too close to the installation area. This caused the worker to (1) to turn his body to view the duct and (2) overextend his reach.

Apprentice Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Reach for tool [S]	16%	2%	4%			Cross body movement, looking down into tool belt
Aligning the duct [S]	29%	13%	13%	13%		Holding material, working with one hand
Ascending/ Descending ladder [S]	4%				4%	Moving on 4" rung while managing balance
Inserting the S drive [P]	29%	14%	14%	10%		Cross body, above head, stretching to reach
Total		**29%**	**31%**	**23%**	**4%**	

Table 28: Task durations and extreme postures for operation 4 Apprentice.

Ascending and descending took 4% of the time. The apprentice climbed up and down his ladder once. This task took 10 seconds of the worker's time, giving way to the low extreme leg posture (4%).

Inserting the S drive was 29% of the time. The drives were located on the sides of the duct. Being right handed while working on the left side of the duct with his ladder too close to the work area caused extreme postures to occur. Had the worker placed his ladder perpendicular to the installation area the extreme back (14%) and neck (10%) postures may have been reduced. As he was working above his head and to the right side of his body a shoulder value of 14% was observed.

Ke*y findings/observations - Journeyman*

- The most significant extreme body region was the neck. This was mainly contributed to ladder placement in relation to the duct.
- Ladder position was an important factor as the worker was parallel and in front of the duct being installed. However, working on the right caused this worker to reach, twist and turn his body to view, connect and work on the duct.
- Multiple extreme postures occurred at the same time as a combination of the cumbersome box being lifted and aligned and the position of his ladder.

Key findings/observations – Apprentice

- Ladder positioning is crucial. This worker's position was too close to the duct and caused extreme postures in the shoulder, back and neck. Ladders provide very little movement flexibility, which causes more turning and reaching. Placing the ladder perpendicular and approximately 12" away from the duct can help reduce exposure.

- Having all tools and material for installation in the immediate work area reduces the need to ascend and descend numerous times, thus reducing extreme leg posture.
- The VAV box was too small to fit on the arms of a super lift and these two workers decided the most time efficient solution would be to carry it up to height together. Had the workers placed a flat sheet of metal/plywood across the arms of the lift they could have placed the VAV box on top and used the lift to carry the box to height.
- The box was connected to a duct run at height instead of being connected to a duct on the ground and then raised to height on a super lift because it was the last piece in the length. To cut out an additional step, the length of duct previously installed could have had the VAV box assembled with it so one continuous length is hung once instead of two separate operations.

Operation 5: Installing equipment on ladders

Company:	C, non-union workers
Task:	Install 11"x23"x10' rectangular duct with motor ≈45 lbs.
Work height:	9'-8" to bottom of motor
Workers:	1 Sheet metal worker (27 years experience) & 1 Superintendent (9 years experience)
Equipment:	Two 10' aluminum ladders & one super lift
Method:	Both sheet metal workers operating super lift and installing on ladders

Tools: A pair of pliers, two hammers, flathead screwdriver, a vise grip, measuring tape, a pair of metal shears, reciprocating saw, extension cord, duct puller, flashlight, hand seamer, two 18V (≈5 lbs.) cordless drills

Duration: 15 minute 52 seconds

Worker Observed: Sheet metal worker and superintendent

The building had a ceiling at 11'-8". The company did not provide lifts for its workers due to the height and space confines of the job.

Superintendent

The installation of 10 LF of duct with a motor took two workers 15.87 minutes. The Superintendent performed productive work 24% of the time, support work 73% of the time and was idle for 3% of the time. During the operation, the superintendent had extreme postures for neck (16% of the time), shoulders (18% of the time), back (5%), and legs (11% of the time). The cumulative exposure for this worker for extreme postures was 50%. Pushing/pulling was light, (97% of the time) and moderate (3%). Lifting was light (94%) and moderate (6%). Summarized below in Table 29 are the main tasks that the worker performed and the extreme postures that occurred during those tasks.

Measuring took 8% of the time. Using a measuring tape while standing on the ladder, the superintendent measured the distance from the ceiling to the connection point. This was done to confirm that the duct size was correct. The tape was used above the worker's head at the ceiling through the open web of the floor trusses, which caused extreme values in the shoulders (5%) and neck (3%) to occur. This worker thoughtlessly placed his ladder near the duct and climbed it to confirm measurements quickly. Extreme postures were present due to his haphazard ladder placement.

Superintendent Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Measuring [S]	8%	3%	5%			Top of duct, ladder position
Ascending/ Descending ladder [S]	11%	1%	2%	<1%	11%	Moving on 4" rung maintaining balance
Moving ladder [S]	5%	1%	<1%			Hand placement, looking at duct
Aligning the duct [S]	8%	2%	2%			Ladder placement, existing lines and pipes hindering movement
Idle	3%	<1%	3%			Waiting for sheet metal worker to complete task
Inserting the S drive [P]	12%		3%	2%		Floor truss at ceiling hindering movement
Bending material [S]	5%	2%	2%	2%		Ladder placement
Reaching for a tool [S]	12%	5%	1%			On tool belt
Moving material [S]	9%			1%		Lifting material from ground to super lift
Talking [S]	10%	2%				Looking up at duct and worker
Total		**16%**	**18%**	**5%**	**11%**	

Table 29: Task durations and extreme postures for operation 5 Superintendent.

Ascending and descending was 11% of the time. This worker climbed up and down his ladder seven times throughout the duration of the cycle. Moving the super lift, retrieving tools and moving his ladder were all reasons that caused movement on the ladder. While climbing the worker would hold onto higher rungs thus causing extreme shoulder postures (2%) to occur. The extreme neck postures happened while the worker was climbing and looking at the duct or at the other worker. Moving the ladder took 5% of the time. The superintendent moved his ladder for better placement four times during the operation. During this task he either (1) folded the ladder and moved it or (2) dragged it across the floor. Both of these actions caused extreme body postures in the shoulders and neck.

Aligning the material was 8% of the time. The open web floor trusses were in place and the duct was being installed in-between them. While on the ladder this worker had limited work space. The superintendent was working on the left side which gave him less than 6” between the duct and the metal truss to work. Extreme postures were seen in the shoulders (2%) and neck (2%) due to a confined work space.

Idle time was 3% of the cycle. This worker had extreme postures during this 35 seconds of idle time in the shoulders (3%) and neck (<1%). The superintendent was on the ladder waiting for the sheet metal worker to make the proper adjustments on the right side of the duct in order to complete his task. While waiting he was leaning with his hand on the ceiling.

Inserting the S drive took 12% of the time. This worker’s hands were working in a confined space trying to hammer the drive into place, through the open web of the metal floor trusses. To see what he was doing beyond the truss he moved his body causing the extreme back posture (2%). The drive was at the top of the duct thus causing the extreme shoulder posture (3%). Based on engineering specifications the duct installation dictates where drives will be installed.

Bending the material was 5% of the time. While on the ladder and using a pair of metal seamers, the superintendent bent the straps before fastening them. As the hangers were already attached to the ceiling this work had to be completed at height. With the truss and ladder in the way the worker moved his body to create a work space.

Consequently, the extreme postures that occurred were in the shoulders (2%), back (2%) and neck (2%).

Reaching for a tool took 12% of the time. This worker was wearing a three saddlebag tool belt. He had one saddlebag on each hip and one resting behind the right side bag. He had a number of tools ready for his immediate use however he had to search for them. Reaching caused extreme postures in the (1) shoulders (1%) when reaching for something behind and (2) neck postures (5%) when looking down into either side bag.

Talking was 10% of the time. The superintendent was giving verbal direction to and taking advice from the sheet metal worker during the operation. This caused a (2%) extreme neck value to occur. Either on the ground or on the ladder the superintendent was looking up or down at the other worker while discussing operation decisions.

Sheet metal worker

The sheet metal worker performed productive work 12% of the time, support work 88% of the time and had no idle time. During the operation, the sheet metal worker had extreme postures for neck (14% of the time), shoulders (12% of the time), back (33%), and legs (8% of the time). The cumulative exposure for this worker for extreme postures was 67%. Pushing/pulling was light, (98% of the time) and moderate (2%). Lifting was light (97%) and moderate (3%). Shown below in Table 30 are the main tasks that the worker performed and the extreme postures that occurred during those tasks.

Talking was 9% of the time. The sheet metal worker had extreme postures in the shoulders (1%) and neck (2%) during this task. These were due to his explanation of attachment solutions to the superintendent while motioning at the duct and looking at the other worker.

Moving the material took 7% of the time. Extreme postures were evident in the shoulders (<1%), back (2%) and neck (1%). Lifting the material from the ground onto the super lift and placing it properly so it would not fall off caused these postures.

Sheet metal worker Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Talking [S]	9%	2%	1%			Gesticulating at duct
Moving material [S]	7%	1%	<1%	2%		Lifting and moving duct on super lift
Aligning the duct [S]	30%	6%	5%	30%		Ladder position, height on ladder
Reaching for a tool [S]	9%	3%	4%	1%		On tool belt
Ascending/ Descending ladder [S]	8%	<1%	<1%		8%	Moving on 4" rung maintaining balance
Total		**13%**	**12%**	**33%**	**8%**	

Table 30: Task durations and extreme postures for operation 5 Sheet metal worker.

Aligning the duct took 30% of the time. Throughout the operation the sheet metal worker was making adjustments to the duct to align the flanges while on the ladder. His ladder position was at an approximate 30° angle to the duct causing him to turn his body to face the duct. The ladder placement and consequent movements were the reasons for the extreme shoulder (5%), back (30%) and neck (6%) postures to occur.

Reaching for a tool was 9% of the time. Similarly, to the superintendent this worker had to reach into his side saddlebags to retrieve tools. Tools were also searched for in a five gallon bucket on the floor in the work area. Extreme postures were in the shoulders (4%), back (1%) and neck (3%). Cross body motions and looking down to reach tools contributed to these values.

Ascending and descending the ladder took 8% of the time. This worker climbed his ladder four times during the operation. Tool retrieval and moving the super lift were reasons for descending. During the operation one step up or down was taken to ensure better reach or visibility depending on what area the worker was working on. An 8% extreme leg value was recorded during this task.

Key findings/observations - Superintendent

- Existing open web floor trusses caused extreme postures in the shoulders, back and neck. Tenant improvement projects create restricted work areas for duct installers as pipes, vents and trusses hinder mobility.
- Aligning the duct had extreme postures, even with the metal trusses in the way, had a considerably shorter duration than all other operations. This was due mainly to work organization. The superintendent relied upon the sheet metal worker to align the duct.
- Ladder movement and ascending/descending the ladder were excessive for this worker; (1) Verification and confirmation were need as both sides of duct were measured; he was concerned about a tight duct fit against the ceiling. (2) He prepared the flange on the existing duct with a screwdriver for quicker alignment. (3) The super lift was not cranked high enough and a larger movement was needed for the duct before making precise alignments. (4) He moved the new duct run to align with the existing length. (5) He had to get a tool, left in the work area absent-mindedly that should have been in his tool belt. (6) Not enough cranking was done and he made a small crank to better align the material. (7) He

moved his ladder to the other side of the duct to fasten the hanger while the sheet metal worker was prepping a new duct install.

Key findings/observations – Sheet metal worker

- The worker with more years in the field did less productive work (12%). The work distribution was such that the superintendent did double the percent of productive work. The team organization was such that the sheet metal worker was relied upon to do support tasks.
- The most significant extreme body posture was the back (twisting greater than 60°). This was due to ladder position and was observed during duct alignment. If this worker had positioned his ladder perpendicular to the ladder this may have lessened his back exposure.
- Working on the right side of duct and having plenty of room to hammer, align and connect as the open web, metal trusses were approximately three feet away. Truss spacing and duct layout contributed to one worker working through the truss and the other having enough space to move more freely.

Operation 6: Installing equipment on ladders

Company:	C, non-union workers
Task:	Install 11”x23”x10’ rectangular duct with motor ≈45 lbs.
Work height:	9’-8” to bottom of motor
Workers:	1 Sheet metal worker (27 years experience) & 1 Superintendent (9 years experience)
Equipment:	Two 10’ aluminum ladders & one super lift

Method:	Both sheet metal workers operating super lift and installing on ladders
Tools:	Two hammers, flathead screwdriver, extension cord, duct puller, two 18V (≈5 lbs.) cordless drills
Duration:	8 minute 21 seconds
Worker Observed:	Sheet metal worker and superintendent

The building had a ceiling at 11'-8". The company did not provide lifts for its workers due to the height and space confines of the job.

Superintendent

The installation of 10 LF of duct with a motor took two workers 8.35 minutes. The Superintendent performed productive work 8% of the time, support work 60% of the time and was idle for 32% of the time. During the operation, the superintendent had extreme postures for neck (27% of the time), shoulders (11% of the time), back (0%), and legs (14% of the time). The cumulative exposure for this worker for extreme postures was 52%. Pushing/pulling was light, (73% of the time) and moderate (27%). Lifting was light (97%) and moderate (3%). Table 31 below shows the main tasks that the worker performed and the extreme postures that occurred during those tasks.

Moving the ladder took 3% of the time. This worker moved his ladder six times throughout the operation. Slight adjustments were made for better positioning. Extreme postures recorded during this task were; shoulders (1%) and neck (2%) due to looking at the duct while moving the equipment.

Aligning the duct took 21% of the time. Material alignment involved both workers. Using both ladders, the super lift and while making slight adjustments this worker had extreme body postures in the shoulders (9%) and neck (21%). Ladder placement, an approximate 25° angle, and the height the worker climbed to on the ladder dictated body postures and caused exposure. This alignment was done above his head.

Superintendent Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Move ladder [S]	3%	2%	1%			Looking at duct
Aligning the duct [S]	21%	21%	9%			Ladder position, height on ladder
Inserting the S drive [P]	6%		1%			Above head
Cranking [S]	13%	2%				Looking at duct
Walking [S]	7%	2%				Looking at duct
Ascending/ Descending Ladder [S]	7%				14%	Moving on 4" rung maintaining balance
Total		**27%**	**11%**	**0%**	**14%**	

Table 31: Task durations and extreme postures for operation 6 Superintendent.

Inserting the S drive took 6% of the time. This task had extreme shoulder postures (1%) as work was done above his head to hammer the drive at the top of the duct. Similarly, in operation 5 this worker was again working through the open web floor trusses hindering his movements and causing him to adjust his body posture accordingly.

Cranking the super lift was 13% of the time. During this task the superintendent was looking up at the duct to verify when to stop cranking the super lift and to make general alignment modifications. This action caused an extreme neck posture (2%).

Walking was 7% of the time. While moving around the work area the superintendent was looking up at the duct trying to decide the best way to continue with installation. This upward looking body posture caused an extreme exposure in the neck (2%).

Ascending and descending the ladder took 7% of the time. This worker climbed up and down his ladder four times. He did this; (1) to move the super lift twice, (2) retrieve a tool and (3) talk on the phone. Vertical ladder movement causes extreme leg exposure. Extreme postures recorded during this task were in the legs (14%).

Sheet metal worker

The sheet metal worker performed productive work 8% of the time, support work 92% of the time and had no idle time. During the operation, the sheet metal worker had extreme postures for neck (13% of the time), shoulders (47% of the time), back (8%), and legs (13% of the time). The cumulative exposure for this worker for extreme postures was 81%. Pushing/pulling was light, (88% of the time) and moderate (12%). Lifting was light (91%) and moderate (9%). Table 32 below depicts the main tasks that the worker performed and the extreme postures that occurred during those tasks.

Moving the ladder was 4% of the time. Similar to the superintendent this worker made slight ladder movements for better placement. This task was done four times and involved dragging the ladder a few inches. Ladder positioning ended up being an approximate 20° angle to the duct. Extreme postures recorded during this task were shoulders (1%).

Aligning the duct took 57% of the time. Adjustments to the material involved; (1) standing on the ladder while holding up the duct, (2) cranking and moving the super lift and (3) slightly moving the duct while on the ladder. Extreme postures observed were in the; shoulders (40%), back (8%) and neck (12%). Postures were due to the approximate 20° angle ladder placement and while standing on the ground looking up.

Reaching for a tool took 7% of the time. Extreme postures recorded during this task were shoulders (4%) and neck (1%). This worker was wearing a tool belt with two side saddlebags. Reaching down into them to get a tool caused both posture occurrences. Wearing his tool belt higher on the hips may have reduced the extreme shoulder postures.

Sheet metal worker Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Move ladder [S]	4%		1%			Looking at duct
Aligning the duct [S]	57%	12%	40%	8%		Ladder position, height on ladder
Reaching for a tool [S]	7%	1%	4%			In saddlebag on tool belt
Fastening [P]	4%		2%			Height on ladder
Ascending/ Descending ladder [S]	13%				13%	Moving on 4" rung maintaining balance
Total		**13%**	**47%**	**8%**	**13%**	

Table 32: Task durations and extreme postures for operation 6 Sheet metal worker.

Fastening was 4% of the time. During this task the worker was fastening the hangers to the duct. This was done both at the top of the duct and underneath it. The extreme posture visible during this task was in the shoulders (2%) as the worker was working above his head. The worker descended one or two rungs on the ladder and worked beneath the duct for better visibility and reach.

Ascending and descending the ladder took 13% of the time. The sheet metal worker climbed up and down his ladder five times during the course of the operation. This caused a 13% extreme leg value to occur. Climbing up and down his ladder was done; (1) to move the ladder for better placement, (2) to move the super lift for closer alignment, (3) to retrieve a tool needed for installation and (4) to move to the other side of the duct to finish installation.

Key findings/observations - Superintendent

- No extreme back postures were recorded this was due to his ladder position. Many times the reduction of one extreme posture causes higher percentages to be present in other body regions, i.e. the neck.
- Aligning the material was the longest duration task with the most significant cumulative extreme posture percentages. Working through the open web floor trusses and around existing pipes running perpendicular to the duct, caused a hindrance in body movement which was already limited due to working on a ladder.
- Ascending/descending the ladder was excessive for this worker. Material alignment, tool organization and staying focused all could have reduced this workers' exposure.

Key findings/observations – Sheet metal worker

- Cumulative extreme posture was more than 30% higher than superintendent. Extreme shoulder postures had the most significant impact (47%) for this worker. This was contributed to aligning the duct and ladder positioning.

Comparative Analysis

Table 33 and Figure 17 below show the extreme values of each of the four body regions for ladder installation of equipment - operations 4 through 6.

	Operation 4		Operation 5		Operation 6	
Body Regions	Journeyman Ladder	Apprentice Ladder	Super Ground and Ladder	SWM Ground and Ladder	Super Ground and Ladder	SMW Ground and Ladder
Neck	35%	29%	16%	13%	27%	13%
Shoulders	25%	31%	18%	12%	11%	47%
Back	27%	23%	5%	33%	0%	8%
Legs	19%	4%	11%	8%	14%	13%
Cumulative	**106%**	**87%**	**50%**	**66%**	**52%**	**81%**

Table 33: Extreme postures for Operations 4-6

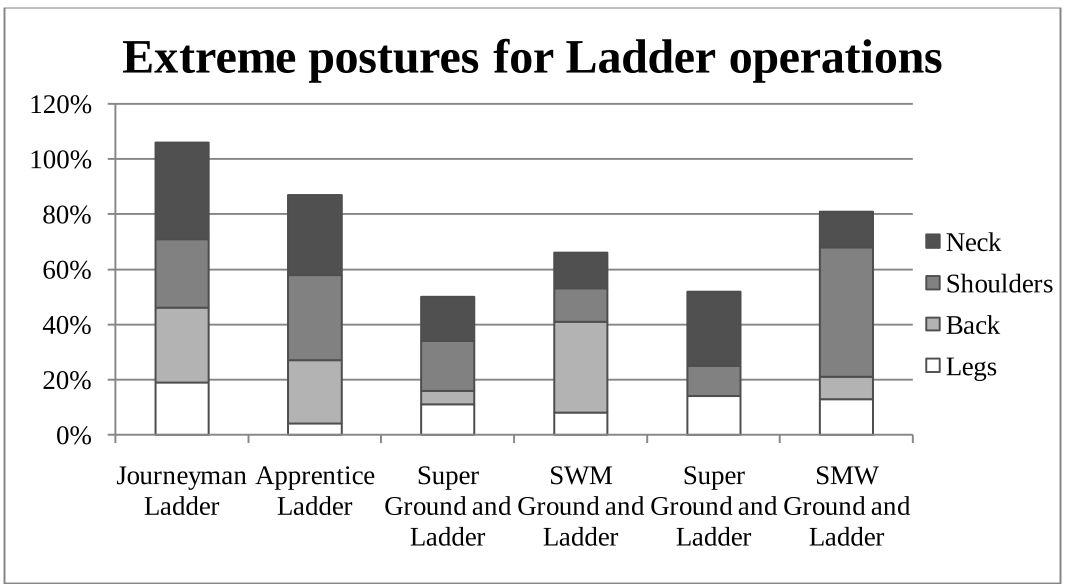


Figure 17: Extreme postures for ladder equipment installation, Operations 4-6

Cumulative extreme postures ranging from 50% to 106% were present during these operations. The journeyman and apprentice in operation 4 were both working on ladders while in operations 5 and 6 both workers were on the ground using the super lift and on the ladders installing. Significant differences were team and company practices.

Company A (operation 4) used the mentor-student team dynamic while Company C (operations 5 and 6) had more flexible work roles.

The sheet metal worker in operation 6 had the highest extreme shoulder posture due to his ladder position, which was at an approximate 20° angle to the duct. The sheet metal worker in operation 5 had the most significant back percentage (33%) due to ladder placement. Back twisting greater than 60° was also present during this operation for this worker. The journeyman in operation 4 had the most noticeable extreme neck and leg postures, 35% and 19% respectively. These were due to ladder placement and frequent ladder climbing.

Neck

Extreme neck postures were present in all cases and ranged from (13% to 35%). This range is very close to those seen in operations 1-3 due to the similarity in the operations, ladder installation of duct or equipment done at height.

Extreme neck postures occurred during:

- Operations 4 and 6 when both workers were aligning the duct. The highest percentages were observed during this task. Ladder positioning again dictated the workers movement.
- In operation 5 the superintendent had high neck values while reaching for a tool and the sheet metal worker had extreme values while making material adjustments.

Extreme neck postures (twisting) can be reduced with better ladder positioning, better tool retrieval and with improved alignment solutions.

Shoulders

Extreme shoulder postures (shoulder flexion greater than 90°) for workers doing the installation were higher in all operations (31%, 18% and 47%). The position of the ladder in relation to the duct is a significant indicator for all body regions. The central reason for the high values was aligning the duct for connection. Work is done on the ladder, overhead. Extreme shoulder postures can be reduced with better ladder positioning, particularly when the ladder is perpendicular to the duct. This reduces back and neck twisting while possibly lessening extreme shoulder postures. A better solution to duct alignment may also reduce exposure.

Back

Extreme back postures varied ranging from (0%-33%) for all workers in these operations. Back twisting in operation 4 for both workers was severely impacted by the placement of ladders in relation to the installation area. Ladders were parallel and side by side which forced both the journeyman and apprentice to twist their bodies. Considerably lower percentages were noticed in operations 5 and 6 for both workers involved. Ladder placement overall was generally in a perpendicular angle to the duct.

Extreme back postures occurred when:

- The journeyman and apprentice in operation 4 had back twisting during this operation. This was attributed to the position of their ladders to the equipment being installed.
- The superintendent and sheet metal worker in operation 5 had back twisting values. However, the sheet metal worker also had back flexion greater than 60°. Twisting was due to ladder positioning but the flexion in the sheet metal worker was due to reach and the height he climbed to on the ladder.

- The superintendent in operation 6 had no extreme back values. This was due to very little time on the ladder installing. The sheet metal worker in this operation had relatively low back twisting values. Due mainly to ladder placement and ladder movement.

Extreme back postures can be reduced with better ladder positioning. Climbing higher on the ladder reduces shoulder exposure while being perpendicular to the duct reduces extreme back and neck postures. However, working on a ladder not only limits movement but exposes the worker to extreme leg postures.

Legs

Extreme leg postures were moderate in all cases ranging from (4%-19%) of the time.

- The journeyman in operation 4 climbed up and down to reposition twice. The only worker to climb his ladder once and stay there for the duration of the operation was the apprentice in operation 4.
- In operation 5 the superintendent climbed his ladder seven times to reposition the ladder and get tools while the sheet metal worker climbed his four times to reposition and get tools.
- During operation 6 the superintendent climbed his ladder four times and the sheet metal worker five times both for similar reasons as observed in operation 5.

Extreme postures for legs can be reduced if the worker does not have to climb up and down the ladder for material and tools. This would also increase productive time. On the other hand, repositioning the ladder can provide better orientation and reduce the extreme postures for other body regions.

Overall

- Only a small portion of the time is attributed to actual connection work. Most work done is support work due to material preparation. The largest contributing factor is duct alignment. Precision work done at height takes time to properly align as connection quality is important.
- Working on a ladder limits movement which results in extreme postures for all body regions. The range of motion needed to complete the operation is hindered by the work platform. A larger work platform, like a scissor lift would reduce extreme leg exposure as the worker would not have to climb. Dependent on placement a scissor lift work platform can reduce extreme postures in the shoulders and back and the worker does not have to reach or twist as far.
- The position of the ladder (orientation and distance from duct) has an affect on postures. The further away a worker is, the more reaching and twisting is done. The closer the ladder is to a perpendicular angle (90°) the less the twisting in the neck and back regions. However, ladder positioning may not always be ideal as there could be existing trusses, pipes and lines that stop the worker from climbing to the appropriate height or the ladder may not fit in the space available. Another hindrance that prevents the ideal placement may be how close the ladder is to the duct. If the ladder is underneath the duct this may cause extreme postures in the shoulders and neck whereas if the ladder is too far away this will causes extremes in the back and shoulders.
- Tenant improvement projects and sites produce hindered work spaces. Existing pipes and trusses negatively impact extreme body postures. Workers struggle to

find space enough to fasten, hammer and connect. This causes extreme postures in the back, neck and shoulders.

- Aligning the duct is a task that takes significant portions of time and has considerable extreme postures. Better methods for alignment are needed to reduce cycle duration and extreme postures.

Operation 7: Installing duct in scissor lift

Company:	B, union workers
Task:	Install 16' long x 12" diameter round duct ≈20 lbs.
Work height:	18'-0" to bottom of duct
Workers:	1 Journeyman (17 years experience) & 1 Apprentice (2 years experience)
Equipment:	One scissor lift and two super lifts
Method:	Journeyman and apprentice operate one super lift and journeyman went up in scissor lift to complete installation
Tools:	One 18V (≈5 lbs.) cordless drill, level, three C clamps, flathead screwdriver and a pair of metal shears
Duration:	13 minutes
Worker Observed:	Journeyman

The building had a ceiling at 21'-0". The company provided lifts for its workers due to the height of installation required. Teams were given two super lifts and two scissor lifts depending on availability and scheduling.

Journeyman

The installation of 16 LF of round duct took two workers 13 minutes. The journeyman performed productive work 10% of the time, support work 90% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (21% of the time), shoulders (43% of the time), back (14%), and legs (2% of the time). The cumulative exposure for this worker for extreme postures was 80%. Pushing/pulling was light, (81% of the time) and moderate (19%). Lifting was light (96%) and moderate (4%). Seen below in Table 34 are the main tasks the worker performed and the extreme postures that occurred during those tasks.

Walking was 9% of the time. As the journeyman was walking around the work area getting tools, checking the material and explaining installation to the apprentice he was gesturing above his head with his arms. This caused a 4% shoulder value to occur. While looking up at the duct and moving from one end of the work area to the other he tripped on a leg of the super lift causing an extreme leg exposure. If he was paying closer attention to his surroundings he would not have tripped thus negating this exposure.

Talking took 13% of the time. Most talking was done while leaning over the top rail of the scissor lift at height, looking down at the apprentice on the ground. This caused extreme postures in the shoulders (5%), back (2%) and neck to occur. The journeyman was asking for tools and reaching for them as the apprentice supplied them. Although, he was wearing a tool belt the journeyman did not have a screwdriver or a level with him when he was at installation height.

Material preparation was 12% of the time. This task included pulling the plastic wrap off the duct and verifying that the duct would not roll off the arms of the super lift before raising it to installation height. Both these tasks caused extreme postures to occur in the shoulders (2%) and neck (3%). The super lift in the full down position is just below waist height. In order to reach it the journeyman bent at the waist.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Walking [S]	9%		4%		<1%	Explanation to apprentice, tripping on super lift
Talking [S]	13%	<1%	5%	2%		Looking down over the rail of scissor lift
Material preparation [S]	12%	3%	2%			Pulling off plastic wrap, pushing and pulling material
Cranking [S]	19%	5%	12%			Ill maintained equipment, looking up
Aligning the duct [S]	16%	3%	10%	5%	<1%	Done on the ground and at height
Moving scissor lift [S]	8%	2%	3%	3%		Maneuvering equipment in congested work space
Get tool [S]	6%	3%	4%			Toolbox on floor of scissor lift
Fastening [P]	7%	3%	1%	2%		Above head, on top of duct
Cutting [S]	3%	2%	2%	2%		Above head, on top of duct
Total		**21%**	**43%**	**14%**	**2%**	

Table 34: Task durations and extreme postures for operation 7 Journeyman.

Cranking the super lift was 19% of the time. This task was approximately 150 seconds of the cycle as the equipment used needed maintenance. The journeyman was complaining about the amount of force he had to exert during cranking and took frequent breaks to rest his arms. Extreme postures were in the shoulders (12%) and neck (5%). Contributing factors were; (1) the approximate verification of installation height by watching the duct rise up and (2) the difficult to use equipment.

Aligning the duct took 16% of the time. This task was done while the material was just below waist height on both the super lifts as well as when it was raised to height. Extreme postures were observed in all four body regions during this task. In the shoulders (10%) while moving the duct slightly for proper alignment, back (5%) while leaning closer to the duct, neck (3%) in order to see above the duct for confirmation of alignment and legs (<1%) while adjusting the material. These postures occurred while; (1) moving the duct, (2) moving to work around the duct and (3) for visibility.

Moving the scissor lift was 8% of the time. This worker used the mechanical hand toggle while moving the scissor lift causing extreme postures to occur. These were seen in the; shoulders (3%) as the worker was standing away from the toggle to see around the lift, back (3%) while leaning over the railing to watch the ground and neck (2%) looking both up for positioning and down to avoid hitting someone or something.

Getting a tool took 6% of the time. Tools are kept either in a tool belt on the worker or on the floor of the scissor lift. During tool retrieval, the worker was either twisting his body to get the tool or picking it up from the work platform. Extreme body postures were evident in the shoulders (4%) while reaching into the tool belt or picking it up from the floor and neck (3%) when looking into saddlebags.

Fastening was 7% of the time. This connection was done at the top of the duct and underneath it. While using an 18V cordless drill the journeyman was attaching the belly bands (metal strap hangers) to the round duct. Extreme postures were seen in the shoulders (1%) while reaching above the duct, back (2%) while leaning to reach due to MEWP placement and neck (3%) for visibility. Properly positioning the scissor lift is essential during duct connection. When the scissor lift is perpendicular to the duct the distance away from the duct can restrict worker postures while being parallel to the duct limits the workers' access to the other side of the duct.

Cutting took 3% of the time. Extreme postures during this task were seen in the shoulders (2%) done above his head, back (2%) leaning against the railing and neck (2%) for proper sight lines. Estimated measurements were taken from the duct before cutting was done. The journeyman was using metal shears to cut the belly bands to the approximate lengths before connecting them.

It should be noted that operations 1, 2, 4, 5 and 6 are rectangular duct installations. Operation 9 was a rectangular duct installation however the size of the duct (46" width) required gasket installation and fastening the connection, a uni-strut was used instead of hangers. In operation 3 flex duct was installed. Operations 4, 7 and 8 were round duct installs. One of the differences between rectangular and round duct installation is that rectangular duct requires the insertion of an S drive at the flanges to complete the connection, whereas round duct does not. Round duct is slipped into each other and the flanges are fastened together thus completing the connection. Hammering and inserting the drive are tasks specific to rectangular duct only.

Key findings/observations – Journeyman

- Scissor lift placement is important. The height of the scissor lift can be restricted if the lift is underneath the duct, this causes the worker to have extreme postures in the back, neck and shoulder when overextending. Similarly, if the scissor lift is positioned parallel to the duct the distance from the duct can effect extreme shoulder, neck and back postures. Ideal positioning would be running parallel to the duct being a maximum of 12" away. The railing of the lift should be at the approximately center of the duct. This scissor lift placement results in reducing extreme postures in the shoulder, back and neck.

- Shoulders had the highest extreme posture value (43%) due to the scissor lift railing being under the duct. While legs were under 2% total due to the extended work platform and the decreased need to climb.
- Work distribution was heavily weighted on the journeyman. This worker did both cranking a super lift and completing the installation at height.
- Well maintained equipment could have lessened the strain on this worker reducing extreme shoulder exposure and shortened the cycle time.

Operation 8: Installing duct in scissor lift

Company:	B, union workers
Task:	Install 16’ long x 12” diameter round duct ≈20 lbs.
Work height:	18’-0” to bottom of duct
Workers:	1 Journeyman (17 years experience) & 1 Apprentice (2 years experience)
Equipment:	One scissor lift and one super lift
Method:	Journeyman operated super lift and apprentice completed installation in scissor lift
Tools:	One 18V (≈5 lbs.) cordless drills, two levels and three C clamps
Duration:	4 minutes 28 seconds
Worker Observed:	Journeyman and Apprentice

The building had a ceiling at 21’-0”. The company did provide lifts for its workers due to the height of installation required. Teams were given two super lifts and two scissor lifts depending on availability, scheduling and necessity.

Journeyman

The installation of 16 LF of round duct took two workers 4.47 minutes to complete. The journeyman performed productive work 0% of the time, support work 100% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (11% of the time), shoulders (35% of the time), back (15%), and legs (0% of the time). The cumulative exposure for this worker for extreme postures was 61%. Pushing/pulling was light, (70% of the time) and moderate (30%). Lifting was light (96%) and moderate (4%). Shown below in Table 35 are the main tasks the worker performed and the extreme postures that occurred during those tasks.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Spotting [S]	23%	2%	13%	7%		Explanation to apprentice
Placing C clamps [S]	17%	7%	7%	2%		Work done lower than waist height
Walking [S]	23%	2%	4%	6%		Explanation to apprentice
Cranking [S]	16%		11%			Ill maintained equipment, looking up
Total		**11%**	**35%**	**15**	**0%**	

Table 35: Task durations and extreme postures for operation 8 Journeyman.

Spotting took 23% of the time. This task had the worker watching the movement of the apprentice operated scissor lift. The journeyman was giving directions on how to best place the lift for installation. Extreme postures observed during this task were in the shoulders (13%) while pointing to locations, back (7%) while lifting cords off the ground to avoid damage and neck (2%) while looking and watching the lift movements.

Placing the C clamps was 17% of the time. During this task the journeyman was placing the clamps on the super lift to prevent the round duct from rolling during cranking. Extreme postures seen during this task were in the shoulders (7%) as he was placing the clamps, back (2%) while bending down to secure clamps on the lift that was below waist height and neck (7%) while looking down at the duct. These were caused by the worker having to position himself between the super lift and the second floor temporary railing.

Walking was 23% of the time. Extreme postures were seen in the shoulders (4%), back (6%) and neck (2%). These postures were caused by animatedly talking to the apprentice. Hand gestures towards the duct while looking up at the apprentice in the raised lift were contributing factors.

Cranking the super lift took 16% of the time. Similarly, to operation 7 the super lift during this operation was badly maintained, thus causing the journeyman to strain while cranking. Cranking forced this worker to have extreme postures in the shoulders (11%) because of the force he exerted to turn the handles.

Apprentice

The apprentice had 28% productive work, 72% support work and 0% idle time. The apprentice in operation 8 showed extreme postures values in the neck (26%), shoulders (30% of the total time), back (11%), and legs (0%). The cumulative exposure to extreme postures was 67%. Pushing/pulling was light, (93% of the time) and moderate (7%). Lifting was light (100%). As seen in Table 36 below are the main tasks that the apprentice performed and the extreme postures that occurred during those tasks.

Apprentice Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Ascend/ Descend in scissor lift [S]	14%	4%	4%	7%		Looking down over railing
Place strap [S]	16%	4%	15%			Above head, on top of duct
Aligning material [S]	10%	4%	4%	4%		Above head, scissor lift placement
Fastening [P]	13%	4%	7%			Above head, on top of duct
Moving scissor lift [S]	27%	6%				Looking down over railing, standing away from controls
Pushing out extension [S]	5%	4%				Looking down at lever
Total		**26%**	**30%**	**11%**	**0%**	

Table 36: Task durations and extreme postures for operation 8 Apprentice.

Ascending and descending in the scissor lift took 14% of the time. Scissor lift movement in the up/down direction is controlled by hand toggles inside the MEWP. This worker was standing away from the toggles while maneuvering the vehicle and checking his surroundings over the railing. These body movements caused extreme postures in the shoulders (4%) to reach the toggle, back (7%) while looking over the railing and neck (4%) while looking down at the ground and up at the duct.

Placing the belly band around the duct was 16% of the time. A metal strap attached at ceiling height is placed around the body of the round duct is then secured with screws on top of the duct to hold it aloft. The apprentice was working above his head at the top of the duct with little visibility. Extreme postures observed during this task were in the shoulders (15%) and neck (4%) both due to scissor lift placement. The apprentice had positioned his MEWP at a 30° angle to the duct while part of the railing was underneath the duct. Being approximately 18” away from the duct also caused reaching and twisting to occur.

Aligning the material was 10% of the time. This task had extreme postures in the shoulders (4%) due to being too far away from the material, back (4%) because of reaching and neck (4%) for visibility. These were caused by the 30° angle (perpendicular) placement of the scissor lift underneath the duct. The railing of the duct limited the height of the scissor lift so the worker accommodated these restrictions with his body posture.

Fastening took 13% of the time. Extreme body postures were in the shoulders (7%) working above head and neck (4%) in order to get visibility. These were attributed to the scissor lift placement. The height and angle of the scissor lift in relation to the duct caused extreme postures to occur in most tasks and body regions.

Moving the scissor lift was 27% of the time. Similar to ascending and descending in the scissor lift this is done when the lift is in the full down position. Movement had extreme body postures in the neck (6%) as this was due to looking over the railing of the lift to verify safe movement of the vehicle. During this task the worker was standing next to the toggles and was not straining to see.

Pushing the extension out took 5% of the time. This task involves the worker pushing a lever on the bottom of the scissor lift bed while pushing forward to extend the work platform an additional 24”. A 4% extreme neck posture was observed as the worker was looking down to confirm full extension.

Key findings/observations – Journeyman

- Well maintained equipment could have lessened the strain on this worker's shoulders, his highest contributing body region. The operation duration could have been shortened with maintained equipment.

Key findings/observations – Apprentice

- Scissor lift placement (30° angle) caused extreme postures for this worker twisting and reaching over the railing. The position of the lift was under the duct, this restricted how high the lift could go causing extreme shoulder and neck postures. This may be due to the worker trying to save time by refusing to lower his lift to the ground and maneuvering it into a better position.
- Super lift placement dictates scissor lift movement. The legs of the super lift restrict where the scissor lift can move and how close the worker can be to the duct.
- This operation showed close cumulative percentages (61% and 67%) for both workers regardless of their productive work contributions. This is due mainly to the journeyman using his arms above his head while talking and the apprentice's scissor lift placement.

Operation 9: Installing duct in scissor lift

Company: B, union workers

Task: Install 46"x 18"x 4' Rectangular curved duct ≈15 lbs.

Work height: 12'-0" to bottom of duct

Workers:	1 Journeyman (18 years experience), 1 Apprentice A (3 years experience), 1 Foreman (18 years experience) & 1 Apprentice B (1.5 years experience)
Equipment:	Two scissor lifts and one super lift
Method:	Journeyman and apprentice A completed installation in scissor lifts while foreman operated super lift on ground and apprentice B supplied tools and materials as necessary
Tools:	Two 18V (≈5 lbs.) cordless drills, two vise grips, two hammers, one 2x4 and plastic wrap
Duration:	22 minutes 50 seconds
Worker Observed:	Journeyman and Apprentice A

The building had a ceiling at 18’-0”. The company did provide lifts for its workers due to the height of installation required. Teams were given two super lifts and two scissor lifts depending on availability, scheduling and necessity.

Journeyman

The installation of one curved duct took two workers 22.83 minutes to install. The journeyman performed productive work 15% of the time, support work for 79% of the time and had 6% idle time. During the operation, the journeyman had extreme postures for neck (22% of the time), shoulders (30% of the time), back (13%), and legs (2% of the time). The cumulative exposure for this worker for extreme postures was 67%. Pushing/pulling and lifting were both light, (99% of the time) and moderate (1%). Below in Table 37 are the main tasks the worker performed and the extreme postures that occurred during those tasks.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Attaching gasket [P]	7%	3%	7%	1%	<1%	Above head, on top of and around duct
Unscrewing strut [S]	4%	1%	4%	<1%	<1%	Restricted height from existing trusses
Moving scissor lift [S]	5%	2%	1%	<1%		Looking up/down for clearance
Talking [S]	18%	9%	4%	4%	1%	Looking down over the rail of scissor lift
Aligning the duct [S]	17%	5%	15%	<1%		Existing pipes hindered smooth connection
Putting tool away [S]	3%		<1%	3%		No tool belt, tools kept on floor of scissor lift
Get tool [S]	7%	2%	<1%	2%		No tool belt, tools kept on floor of scissor lift
Total		**22%**	**30%**	**13%**	**2%**	

Table 37: Task durations and extreme postures for operation 9 Journeyman.

Attaching the gasket took 7% of the time. A gasket is a white plastic adhesive that is pressed against the duct flange before another duct is connected to it. This is done to prevent air leakage on larger duct pieces. The journeyman had extreme postures in the shoulders (7%) while reaching above and around the duct, back (1%) while leaning to reach the top of the duct, neck (3%) as he was looking up at the duct and legs. These postures were due to the scissor lift placement. Similar to operation 3 these workers had limited space to work within as there were existing lines, trusses and pipes cluttering the work area.

Unscrewing the strut was 4% of the time. This task involves unscrewing the nut and bolt holding the uni-strut together; allowing the duct to be placed within and the uni-strut to be re-attached. Extreme body postures were seen in the shoulders (4%) working above his head under the duct, back (<1%) while leaning back to see the duct as he was tall, neck (1%) looking up at the duct and legs (<1%) while bending to see. Existing pipes and floor trusses in the immediate installation area restricted the height the scissor lift could raise to, thus causing the worker to overextend.

Moving the scissor lift took 5% of the time. For safety reasons, company policy requires the scissor lift to be fully down when the operator moves the vehicle. This work area was congested with power cords, equipment and people below with existing pipes, duct and floor trusses above. This journeyman moved his scissor lift nine times during the operation, vying for better placement. Extreme postures include shoulders (1%) while standing away from the toggles to get better visibility, back (<1%) and neck (2%) while looking up at overhead lines and down at the ground.

Talking was 18% of the time. Existing lines and conflicts with a seamless installation caused the journeyman in the raised scissor lift to discuss options with the foreman on the ground. The worker was looking over the railing of the scissor lift down to the foreman while twisting his body to avoid the pipes and duct. This movement caused extreme postures to occur in the shoulders (4%) which were resting on the railing, back (4%) which was bent to lean on the railing, neck (9%) while looking down and legs (1%) which were bent to avoid his head from hitting anything.

Aligning the material was 17% of the time. The duct being installed was a cumbersome piece that was hitting the ceiling. It was a half macaroni shaped piece that was designed to avoid an existing sprinkler line. Much adjusting was done on both the journeyman and apprentice's parts to align the material properly. Extreme postures were observed in the shoulders (15%) while holding the top of the duct, back (<1%) while leaning backwards to accommodate the duct size and neck (5%) while looking up.

Putting a tool away took 3% of the time. This worker did not wear a tool belt as a preference. Instead he used the floor of the scissor lift to store his tools. This caused extreme postures in the shoulders (<1%) while reaching down and back (3%) while bending to retrieve tools from the floor. The worker had to turn his body and bend at the waist to avoid being hit by the existing duct and pipes.

Getting a tool took 7% of the time. Similarly, to the above task the worker had to search for tools on the floor of the scissor lift. This task had extreme postures in the shoulders (<1%), back (2%) and neck (2%).

Apprentice

The apprentice had 19% productive work, 75% support work and 6% idle time. The apprentice in operation 9 showed extreme postures values in the neck (20%), shoulders (12% of the total time), back (32%), and legs (0%). The cumulative exposure to extreme postures was 64%. Pushing/pulling was light, (100% of the time). Lifting was light (99%) and moderate (1%). As seen in Table 38 below are the main tasks that the apprentice performed and the occurring extreme postures.

Carrying the material took 2% of the time. During this task the apprentice had the awkwardly shaped duct piece on the railing of his scissor lift while holding it and ascending up to installation height. Once there he maneuvered the piece into place for connection. Extreme postures were in the shoulders (<1%) while holding both sides of the duct and back (<1%) while leaning back to make room for the duct piece. Much of the lifting work was done by the scissor lift.

Apprentice Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Carrying the duct [S]	2%		<1%	<1%		Large, awkwardly shaped duct
Connecting duct [P]	17%	9%	9%	13%		Restricted height from existing trusses
Get tool [S]	14%	3%	1%	12%		No tool belt, tools kept on floor of scissor lift
Ascend/ Descend in scissor lift [S]	3%		2%	3%		Looking up/down for clearance
Fastening [S]	2%	<1%		2%		Scissor lift placement, existing pipes hindering movement
Measuring [S]	2%	1%		2%		Restricted height from existing trusses, working under duct
Talking [S]	2%	2%				Looking across at journeyman
Moving scissor lift [S]	9%	3%				Looking up/down for clearance
Total		**20%**	**12%**	**32%**	**0%**	

Table 38: Task durations and extreme postures for operation 9 Apprentice.

Connecting the duct was 17% of the time. This task involved moving the scissor lift numerous times into position by avoiding existing pipes and trusses to fasten the flanges. Extreme postures observed during this task were in the shoulders (9%) working above his head, back (13%) while extending backwards to have a work space and neck (9%) while looking up. The connections were made on the right side of the duct where this worker was working as well as along the bottom of the duct.

Getting a tool took 14% of the time. Similarly, to the journeyman in this operation this apprentice did not wear a tool belt. His tools were kept on the floor of the scissor lift. Extreme postures were seen in the shoulders (1%) while reaching down to get tools, back (12%) while twisting and bending to avoid overhead lines and reach the floor and neck (3%) while looking down. The right side of the duct installation had many more pipes, trusses and lines in the area that hindered body movement.

Ascending and descending in the scissor lift took 3% of the time. Extreme postures were seen in the shoulders (2%) and back (3%). These postures were caused because of handling the toggles while watching the movement of the vehicle.

Fastening took 2% of the time. The extreme postures during this task were in the back (3%) while twisting to reach duct and neck (<1%) while looking up. These were caused by the placement of the scissor lift underneath the duct. The worker was too close to the duct and had to bend backwards over the railing to get his arm and sight line clearances.

Measuring was 2% of the time. Similar, to fastening, the placement of the scissor lift was not moved and measurement was done in the same way. The extreme postures were in the back (1%) while bending backwards to create a work space and neck (1%) while looking up at the duct due to height restrictions.

Talking took 2% of the time. During the task the worker was asking questions and getting instructions from the journeyman. Talking was done primarily with the journeyman to the left of the worker. Neck twisting was seen during this task (2%) according to the journeyman’s location.

Moving the scissor lift took 9% of the time. The apprentice moved his scissor lift four times throughout the operation. Movement was done to better align himself with the duct but due to inexperience and limited work spaces movement also caused extreme body postures. Extreme postures were seen in the neck (3%) while looking at the ground.

Key findings/observations – Journeyman

- Scissor lift placement was parallel to duct. However, the height of the scissor lift was restricted as the railing of the lift was underneath the duct. This worker needed to be close in order to reach the top of the duct and going any higher was restricted by existing pipes and trusses.
- The scissor lift had restricted movement due to being placed between the duct and a sprinkler line. Each worker was working on right or left side of the duct and the journeyman could only go as far as the existing lines would permit. The apprentice had to manage the rest of the install from the right side.
- Wearing a tool belt may reduce extreme back bending as the worker will not have to bend to retrieve tools from the floor of the scissor lift. However, as seen in previous operations wearing a tool belt causes extreme postures in the neck and shoulders.

Key findings/observations – Apprentice

- Connecting the duct was the longest duration task with the highest percent of extreme body postures. This was attributed to the existing trusses and pipes hindering the movement of both the scissor lift and the worker. The duct piece being connected was cumbersome and tight fitting and required additional solutions for proper connection.
- Wearing a tool belt may reduce extreme back bending as the worker will not have to bend to retrieve tools from the bed of the scissor lift. However, as seen in previous operations wearing a tool belt causes extreme postures in the neck and shoulders.

- This worker was positioned at an approximate 45° angle to the duct. This was due to working on the right side of the duct where the majority of trusses, lines and pipes were.

Comparative Analysis

Table 39 and Figure 18 below show the extreme values of each of the four body regions for ladder installation of equipment - operations 7 through 9.

	Operation 7	**Operation 8**		**Operation 9**	
Body Regions	Journeyman Scissor lift	Journeyman Ground	Apprentice Scissor lift	Journeyman Scissor lift	Apprentice Scissor lift
Neck	21%	11%	26%	22%	20%
Shoulders	43%	35%	30%	30%	12%
Back	14%	15%	11%	13%	32%
Legs	2%	0%	0%	2%	0%
Cumulative	**80%**	**61%**	**67%**	**67%**	**64%**

Table 39: Extreme postures for Operations 7-9

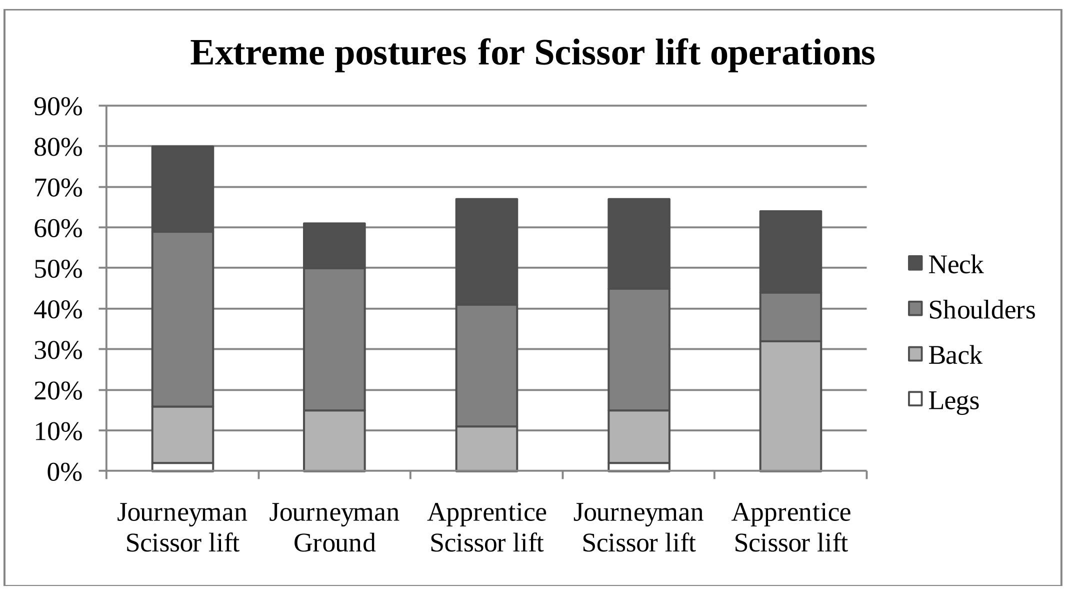


Figure 18: Extreme postures for ladder equipment installation, Operations 7-9

Cumulative extreme postures range from 61% to 80% for these operations. The journeyman in operation 8 was working on the ground while in all other instances the workers were in scissor lifts installing. Significant differences were in; (1) operations 7 and 8 the super lift was operated by the worker observed whereas in operation 9 it was handled by the foreman, (2) the number of workers in operation 9 was twice that in operations 7 and 8, (3) operations 7 and 8 did not have any hindering pipes, lines or trusses obstructing the movement of scissor lifts and workers.

The journeyman in operation 7 had the highest extreme shoulder posture due to cranking the super lift and aligning the material. While the apprentice in operation 9 had the most significant back percentage (32%) due to scissor lift placement in direct relation to existing pipes. The apprentice in operation 8 had the most noticeable extreme neck posture, 26%. This was due to his scissor lift placement. Lastly, extreme leg postures were very low across all operations.

Neck

Extreme neck postures (twisting) were present in all cases and ranged from (11% to 26%). The apprentice in operation 9 had the highest percentage which was double that of the other workers. This was due mainly to scissor lift positioning.

Extreme neck postures occurred when:

- The material, equipment or tool was either above or below the neutral or moderate range of head motion. When this was evident the worker was either looking above their head or below their shoulders for better visibility.

Extreme neck postures can be reduced with parallel scissor lift positioning within 12” of the duct and better tool retrieval by use of tool belts.

Shoulders

Extreme shoulder postures (shoulder flexion greater than 90°) were seen in a variegated number of tasks. In these operations workers doing the installation were not the only ones with high percentages. Work is done in the scissor lift, overhead. Three main factors contributed to significant shoulder postures; (1) existing pipes and trusses in the immediate work area, (2) the position of the scissor lift in relation to the duct and (3) badly maintained super lifts. Probable solutions to these contributing factors are; (1) BIM drawings can greatly reduce conflicts in the field by designing duct to work around existing pipes, (2) extreme shoulder postures can be reduced with better scissor lift positioning, (3) maintenance of equipment can lessen force exerted and cycle times.

Back

Extreme back postures varied, ranging from (11%-32%) for all workers in these operations. The predominant extreme back postures were flexion greater than 60° and back extension greater than 20°. Both these postures were evident during talking and when physically handling the duct. Due to the scissor lift placement and existing pipes and trusses in his immediate work area the apprentice in operation 9 had twice the percentage of the other workers.

Extreme back postures occurred:

- When leaning over the railing of the scissor lift to talk to the other workers on the ground or to get a tool.
- In operation 9 where both workers did not wear tool belts and used the floor of the scissor lift to store tools. This caused each worker to bend down to retrieve tools and in some instances twisting before bending.

Extreme back postures can be reduced with better scissor lift positioning and if the workers wear tool belts. Preferred scissor lift positioning should be parallel to the duct and within 12” of it. The railing of the lift should be placed approximately at the center of the duct giving the worker the ability to reach the top of the duct without overextending. When possible the railing of the lift should not be underneath the duct at this limits how high the lift can go as well as causing the worker to reach above.

Legs

Extreme leg postures were low in all cases ranging from (0%-2%) of the time.

- All workers except the journeyman in operation 7 were in scissor lifts. During these operations extreme leg exposure was greatly reduced as climbing was done mechanically.

Overall

- Only a moderate portion of the time is attributed to actual connection work. Most of the work done is support work in preparation of installation. Tasks that could possibly be reduced in duration thus reducing exposure are; (1) cranking by having well maintained equipment, (2) material alignment by re-designing the duct flanges, (3) moving the scissor lift with more accurate placement and positioning, (4) ascending/descending in the scissor lift which is closely linked to moving the scissor lift and (5) getting a tool by wearing a well placed tool belt.
- Increased movement (up/down) in the scissor lift greatly reduces extreme leg postures however; the position of the scissor lift (orientation and distance from duct) has an affect on extreme body. The position of the scissor lift is dictated in many cases by the position of the super lift and existing truss and pipes.

Operation 10: Ground Assembly of duct lengths

Company:	B, union worker
Task:	Assemble 12' long, 12" diameter round duct ≈10 lbs.
Work height:	0'-0" created on concrete floor
Workers:	1 Journeyman (22 years experience)
Equipment:	Not applicable
Method:	Journeyman cuts duct on ground, references drawings for size and type and locates next duct piece to assemble with
Tools:	One 18V (≈5 lbs.) cordless drill, reciprocating saw, plastic wrap, utility knife
Duration:	5 minutes 55 seconds
Worker Observed:	Journeyman

The company did not provide waist high work tables for its workers, so the concrete floor was used extensively. After recommendations were made by the researcher portable tables were supplied. Analysis was done prior to tables being provided.

Journeyman

The assembly of 12 LF of round duct took one worker 5.92 minutes. The journeyman performed productive work 31% of the time, support work 69% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (14% of the time), shoulders (4% of the time), back (28%), and legs (14% of the time). The cumulative exposure for this worker for extreme postures was 60%. Pushing/pulling and lifting were both light, (100% of the time). Seen below in Table 40 are the main tasks the worker performed and the extreme postures that occurred during those tasks.

Getting a tool took 18% of the time. For this operation tools were considered as either the tools mentions above in the profile or screws used for fastening. This journeyman was working on the ground and left his tools on the floor. Reaching into his low, deep saddlebags and picking up tools from the ground caused extreme postures to occur during this task. These extreme postures were in the; shoulders (3%) while getting tools from the his tool belt, back (8%) when picking tools up from the floor, neck (4%) while looking into his saddlebags and legs, unstable balance, bending greater than 60° (6%) when bending to retrieve from the floor.

Searching for the next duct piece was 8% of the time. To limit time waste and walking around the site, this task was done in a central location closest to duct storage. Duct pieces were kept under a plastic tarp in the vicinity of the work area. The worker in this operation had to bend at the waist while lifting the tarp to look for the correct piece. This motion caused extreme body postures in the shoulders (1%) while lifting the tarp, back (3%) during bending and neck (1%) while searching for a piece.

Cutting the duct took 9% of the time. This activity is done on the floor while the worker is standing with one foot on the ground and the other foot resting on the duct. A reciprocating saw was used to cut the duct. Extreme postures observed during this task were seen in the back (1%) while being bent to hold the duct with one foot and legs (7%) while unstably balancing on one foot. Unbalanced, hopping movements were made repeatedly during this task.

Positioning the duct was 19% of the time. The worker was in two different positions during this task, (1) squatting on the ground and (2) standing beside the duct. Both these body postures showed extreme postures in the back (11%) when bending to lift the duct from the floor, neck (4) while looking around the duct and legs (1%) while squatting next to the duct. Material alignment is necessary for both quality assurance and accuracy. The assemblies created by these workers are used by the installation teams who depend on accuracy for speed efficiency.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Get tool [S]	18%	4%	3%	8%	6%	Low slung, deep saddlebags, tool left on the ground
Search for next duct [S]	8%	1%	1%	3%		Under tarp on the floor
Cutting duct [S]	9%			1%	7%	Using the floor as work table, using foot to steady duct
Positioning duct [S]	19%	4%		11%	1%	While kneeling on the ground
Connecting two ducts [P]	13%	1%		4%		Using the floor as work table
Fastening [P]	17%	4%		1%		Looking at and around duct
Total		**14%**	**4%**	**28%**	**14%**	

Table 40: Task durations and extreme postures for operation 10 Journeyman.

Connecting two pieces together was 13% of the time. The worker was on the ground putting duct pieces together to create assemblies. Extreme postures seen during this task were in the back (4%) while bending next to the duct and neck (1%) while looking down at the duct. These were caused by the lack of a work table. If a work table had been provided the extreme back postures would have been reduced.

Fastening took 17% of the time. This task was closely related to getting a tool. Fastening is done both on the ground and while standing next to the duct depending on the length of the duct. A personal preference is made by the worker to kneel beside the duct or stand it upright. Extreme body postures were seen in the back (1%) and neck (4%) as the worker was looking around the duct to assure a quality connection.

Key findings/observations – Journeyman

- This journeyman to prevent cuts and to make the work as painless as possible wore full length Kevlar sleeves and rubber knee pads. Having to kneel on the concrete floor for hours can become painful after some time.
- Two differing extreme leg postures were observed during this operation, (1) unilateral weight bearing, unstable knee flexion greater than 60º while cutting the duct and (2) unstable squatting seen during material alignment. This worker used the concrete floor as a work table. If a waist high table had been provided this would have mitigated both extreme leg and back postures.
- These operations are fast paced with short durations. However, long duration tasks show high extreme posture values; getting a tool, positioning the duct and fastening. Assemblies are made for other installation teams. Quality control and accurate connections are dependent on worker competency for the company to efficiently meet time schedules while maintaining assured work.
- This worker used his foot to steady the material rather than his hand thus reducing higher extreme back percentages but causing extreme leg postures.
- Working in the duct storage area reduced travel time around the work site. This could be one reason (task planning) why cycle times are short and work is fast paced.

Operation 11: Ground Assembly of duct lengths

Company: B, union worker

Task: Assemble 12’ long, 12” diameter round duct ≈10 lbs.

Work height: 0’-0” created on concrete floor

Workers: 1 Apprentice (2 years experience)

Equipment: Not applicable

Method: Apprentice cuts duct on ground, references drawings for size and type and locates next duct piece to assemble with

Tools: One 18V (≈5 lbs.) cordless drill, reciprocating saw, plastic wrap, utility knife

Duration: 9 minutes 8 seconds

Worker Observed: Apprentice

The company did not provide waist high work tables for its workers, so the concrete floor was used extensively. After recommendations were made by researchers portable tables were supplied. This study was conducted before tables were provided.

Apprentice

The assembly of 12 LF of round duct took one worker 9.17 minutes. The apprentice performed productive work 5% of the time, support work 95% of the time and had no idle time. During the operation, the apprentice had extreme postures for neck (11% of the time), shoulders (0% of the time), back (70%), and legs (0% of the time). The cumulative exposure for this worker for extreme postures was 81%. Pushing/pulling and lifting were both light, (100% of the time). Below is Table 41 showing the main tasks the worker performed and the extreme postures that occurred during those tasks.

Apprentice Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Measuring [S]	20%	5%		20%		Kneeling and bent over duct
Drawing line [S]	14%	6%		14%		Kneeling and bent over duct
Cutting duct [S]	28%			28%		Legs straight, bent back, using hand to roll/steady duct
Search for next duct [S]	8%			8%		Under tarp on the floor
Total		**11%**	**0%**	**70%**	**0%**	

Table 41: Task durations and extreme postures for operation 11 Apprentice

Measuring the duct took 20% of the time. The apprentice measured the duct while on the ground beside the material. Extreme postures caused during his task were in the back (16%) while leaning over the duct and neck (11%) while looking down at duct to confirm measurements. A waist high work table would have negated extreme back postures during this task.

Drawing the line was 14% of the time. The apprentice drew a line with a permanent marker on the duct as a guide for cutting. The extreme posture observed was in the back (15%). This task was done in a similar position as measuring.

Cutting the duct took 27% of the time. After measuring and drawing the line, this worker then cut the material to length. This posture was different from the journeyman in operation 10. The extreme posture during this task was in the back (28%) while bent over the duct. This worker was standing with both feet on the ground and while bending at the waist he used his left hand to steady the material. He cut the duct with his right hand using a reciprocating saw.

Searching for the next duct piece was 8% of the time. Duct kept under the tarp in the work area was searched. The extreme posture for this task was in the back (11%). Bending at the waist this worker lifted the plastic tarp and looked for the piece he needed.

Key findings/observations – Apprentice

- This operation was twice the duration of both operations 10 and 12 which were equal or shorter length assemblies. This was due to the time it took this worker to measure the duct. His measurement and line drawing tasks were significant time consumers. This was because the worker was inexperienced and concerned with the quality of his work. Measurements lines do not have to be continuous lines nor does the measurement have to be precise as the connection can compensate for the excess.
- The apprentice used his hand to steady the material rather than his foot. This reduced extreme leg percentages but caused extreme back postures. Each worker had their own technique which resulted in one severe posture or the other. A waist high work table would have reduced both extreme leg and back postures.

Operation 12: Ground Assembly of duct lengths

Company:	B, union worker
Task:	Assemble 8' long, 12" diameter round duct ≈10 lbs.
Work height:	0'-0" created on concrete floor
Workers:	1 Journeyman (22 years experience)
Equipment:	Not applicable
Method:	Journeyman cuts duct on ground, references drawings for size and type and locates next duct piece to assemble with

Tools: One 18V (≈5 lbs.) cordless drill, reciprocating saw, plastic wrap, utility knife, level

Duration: 5 minutes 17 seconds

Worker Observed: Journeyman

The company did not provide waist high work tables for its workers, so the concrete floor was used extensively. After recommendations were made by researchers portable tables were supplied.

Journeyman

The assembly of 8 LF of round duct took one worker 5.28 minutes. The journeyman performed productive work 21% of the time, support work 79% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (5% of the time), shoulders (11% of the time), back (27%), and legs (16% of the time). The cumulative exposure for this worker for extreme postures was 59%. Pushing/pulling and lifting were both light, (100% of the time). As seen in Table 42 below are the main tasks the worker performed and the extreme postures that occurred during those tasks.

Getting a tool took 13% of the time. Extreme body postures observed during this task were in the shoulders (3%). This was caused by the journeyman reaching down to the ground to pick up a tool or reaching deep into his saddlebags on his tool belt. If this worker was at a table he would not have had to reach down to the ground nor into his tool belt as tools could be left on the work surface.

Searching for the next duct piece was 5% of the time. While lifting the plastic tarp off the ground that was protecting unused duct from construction dust, the journeyman had recordable extreme postures. These were in the shoulders (2%) while lifting and back (4%) while bending to lift.

Connecting two duct pieces took 9% of the time. The worker was on the floor and working in front of his duct. Connecting a three foot, T-shaped piece to the end of the duct caused extreme body postures to be observed. These were seen in the shoulders (2%) while reaching across the duct and back (5%) while bending over the connection, as the journeyman connected the flanges.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Get tool [S]	13%		3%			Low slung, deep saddlebags, tool left on the ground
Search for next duct [S]	5%		2%	4%		Under tarp on the floor
Connecting two ducts [P]	9%		2%	5%		Using the floor as work table
Positioning duct [S]	14%		2%	3%		While squatting on the ground
Get plastic wrap [S]	5%	2%	2%	2%		Standing near cart
Assist apprentice [S]	15%	3%		3%	14%	While squatting on the ground
Fastening [S]	12%			2%	2%	Using the floor as work table
Wrap duct [S]	7%			8%		Bending at waist to reach duct
Total		**5%**	**11%**	**27%**	**16%**	

Table 42: Task durations and extreme postures for operation 12 Journeyman

Positioning the duct took 14% of the time. Duct alignment is a crucial factor in quality control. The journeyman in this operation was adjusting the material to fit together correctly. This task had extreme postures in the shoulders (2%) during slight adjustments to the duct and back (3%) while bending forward over the connection. This worker was reaching over a three foot piece to make these adjustments.

Getting the plastic wrap was 5% of the time. Sticky, blue, plastic wrap is used on-site to prevent dust entering the duct thus complicating air flow tests and calculations. The wrap was kept on a cart in the work area. The journeyman walked to the cart, pulled the roll of wrap, laying it flat against a tool box, also on the cart, and cut the wrap using a utility knife. This task had extreme body postures in the shoulders (2%) while pulling the wrap, back (2%) bending over the wrap and neck (2%) while looking down at the plastic wrap.

Assisting the apprentice took 15% of the time. During this task the apprentice required help from the journeyman. The journeyman stopped working on his duct and assisted the apprentice with his assembly, then requested that the apprentice help him on his duct. While squatting on the ground in front of the apprentice's duct the journeyman had extreme postures in the back (3%) while leaning over the duct, neck (3%) while looking down at the material and legs (14%) while squatting in front of the assembly. These extreme postures would have been the same had the journeyman been working on his assembly. An ideal way to mitigate these postures would be to provide these workers with a table to elevate their work surface.

Fastening was 12% of the time. Extreme postures during this task were seen in the back (2%) while bending down to secure the screw and legs (2%) while bending to the level of the connection.

Wrapping the duct took 7% of the time. Once plastic wrap was cut from the roll at the cart it was carried back to the duct and placed on the openings. The duct was standing on the ground at approximately two feet in height. When the journeyman placed the wrap on the duct he bent at the waist and placed it on the duct. This caused an extreme back percentage to be recorded (8%).

Key findings/observations – Journeyman

- When the duct is in front of the worker all extreme body postures are recorded. When the worker is beside the duct, percentages are lower but still present. Having to lean across and over duct had more severe postures. Extreme shoulder, back and leg postures can be greatly reduced with a waist high portable work table.
- The journeyman in operations 10 and 12 had very close cumulative percentages. This worker's extreme back percentages were almost identical and his extreme legs postures were within 2 percent. This worker has high productive work percents while the apprentice in operation 11 has very low productive work. This could be due to experience and confidence in work quality.
- This is the only operation where both workers (journeyman and apprentice) were working together to finish the assembly. This was only due to the apprentice needing help and then the journeyman requesting his assistance in return.

Comparative Analysis

Table 43 and Figure 19 below show the extreme values of each of the four body regions for ladder installation of equipment – operations 10 through 12.

	Operation 10	Operation 11	Operation 12
Body Regions	Journeyman On ground	Apprentice On ground	Journeyman On Ground
Neck	14%	11%	5%
Shoulders	4%	0%	11%
Back	28%	70%	27%
Legs	14%	0%	16%
Cumulative	**60%**	**81%**	**59%**

Table 43: Extreme postures for operations 10 through 12

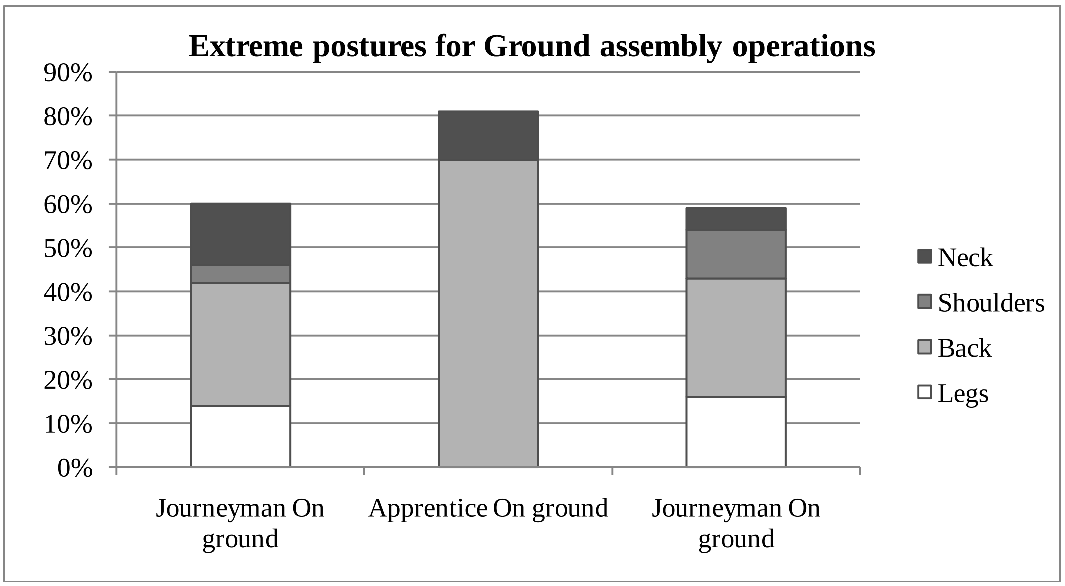


Figure 19: Extreme postures for ground assembly, Operations 10-12

Cumulative extreme postures range from 59% to 81% for these three operations. All three workers were working on the ground, connecting and creating duct assemblies. Workers worked individually only asking for help when more hands were needed, as seen in operation 12. Significant differences were in operations 10 and 12 where the journeyman had cumulative percentages in the sixties range where in operation 11 the apprentice was in the eighties. However, in operation 11 the apprentice had no recordable shoulder or leg extreme postures whereas the journeyman in both operations 10 and 12 had extreme postures in all four body regions.

The journeyman in operation 11 had the highest extreme shoulder posture due to his position in relation to the duct he was working on. The apprentice in operation 11 had the most significant back percentage (70%) due to his duct cutting technique. The journeyman in operation 10 also had the highest extreme neck posture (14%) due to a number of tasks. Lastly, the journeyman in operation 12 had the most significant extreme leg postures due to squatting (16%). This was due to his position beside the duct.

Neck

Extreme neck postures were present in all cases and ranged from (5% to 14%). The journeyman in operation 10 had the highest percentage which was almost three times that of the other worker in operation 12. This was due mainly to the varied positions this worker was in during the operation. At times the duct was lying on the ground or standing up; this difference caused extreme postures to occur.

Extreme neck postures occurred when:

- The worker was looking down at the material.

Extreme neck postures similar to extreme back and shoulders can be greatly reduced with the use of a work table provided for workers.

Shoulders

Extreme shoulder postures (shoulder flexion greater than 90°) were seen in a variegated number of tasks. In these operations the only worker with recordable shoulder percentages was the journeyman. This worker had two main contributing tasks to shoulder postures; (1) getting a tool and (2) searching for the next duct piece. Tool belts worn by both workers in these operations had low slung, deep pocketed saddlebags in order to carry a greater amount of tools. This caused the worker to have extreme back and shoulder percentages. Another large contributing factor was these workers were working on the ground instead of at waist height. Having a table to work on may have greatly reduced extreme shoulder, back and leg postures.

The apprentice in operation 11 had a 0% extreme shoulder reading. This is due to his positioning when working on the duct. He was always close to his tools and material and never reached far for anything.

Back

Extreme back postures varied ranging from (27%-70%) for the workers in these operations. The predominant extreme back posture was flexion greater than 60°. This posture was evident during talking and when physically working on the duct. Due to working on the ground and inexperience the apprentice in operation 11 had two and half times the percentage of the other workers analyzed. A number of tasks showed back percentages. However, extreme back postures occurred mainly during:

- The preferred position for cutting the duct was on the ground. Either your hand or foot was holding the duct in place while your other hand cut the material with a reciprocating saw.

Extreme back postures can be reduced with waist high portable work tables and anti-fatigue mats. The position of the worker in relation to the duct is also a significant factor for reaching. The journeyman in operation 12 was working in front of the duct causing higher percentages as opposed to the apprentice in operation 11 kneeling beside the duct.

Legs

Extreme leg postures were moderate ranging from (0%-16%) of the time. In operation 11 the apprentice had a 0% extreme leg postures due to his stable kneeling position by the duct. Workers in all three operations wore rubber knee pads as working on the concrete floor for 8-10 hours a day will take its toll on your knees and back.

- The journeyman in operations 10 and 12 had relatively close percentages of extreme leg postures. This was due to the worker squatting during assembly. This caused leg percentages to be visible.

The extreme leg postures can be greatly reduced if the worker is kneeling beside the duct as seen in operation 11. However, this position causes other extreme body postures in the back and neck. Standing is considered to be a neutral leg posture and by working at a table these percentages are mitigated.

Overall

- Productive work varied from journeyman (21% and 31%) to apprentice (5%). Due to speed, accuracy and job knowledge.
- If a worker had 0% extreme postures it resulted in extraordinarily high percentages for other body regions as seen in the apprentice in operation 11.
- Working on the ground had a great impact on extreme body postures. Working on the floor leaning over the material caused extreme body postures to occur in all four body regions. Waist high portable work tables with anti-fatigue mats can reduce these percentages immensely.
- Working in the same area as the material reduced job site travel time. Having all the necessary material and tools in the immediate work area aided in speeding up

the assembly process. Speed is a necessity for these workers as they are supplying up to six teams with pre-assembled duct ready for installation.

Operation 13: Drawing Layouts

Company:	B, union worker
Task:	Draw installation layout per engineering drawings on floor
Work height:	0’-0” created on concrete floor
Workers:	1 Journeyman (12 years experience)
Equipment:	Not applicable
Method:	Journeyman reviews drawings to verify location, dimension, size and type of duct to be installed, draws this information on the ground.
Tools:	Industrial broom, pencil, utility knife, permanent marker, chalk line, bucket, clear spray, measuring tape, T square
Duration:	1 minutes 56 seconds
Worker Observed:	Journeyman

Journeyman

The drawing of approximately 18 LF of layout took one worker 5.93 minutes. The journeyman performed productive work 18% of the time, support work 82% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (8% of the time), shoulders (4% of the time), back (58%), and legs (34% of the time). The cumulative extreme posture exposure for this worker was 104%. Pushing/pulling and lifting were both light, (100% of the time). Many of the postures occurred simultaneously thus causing the cumulative percentage to be greater than 100%.

As shown below in Table 44 are the main tasks the worker performed and the extreme postures that occurred.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Review drawings [S]	43%		4%	28%		From behind cart, leaning on front of cart
Measure/ mark slab [P]	20%	8%		17%	20%	On ground, combined, complex postures
Spray [S]	14%			13%	14%	Bent over while moving
Total		**8%**	**4%**	**58%**	**34%**	

Table 44: Task durations and extreme postures for operation 13 Journeyman.

Reviewing the drawings took 43% of the time. The cart that had the engineering drawings lying on it was a metal cart standing approximately four feet in the front and five feet in the back, thus angling the table top. The journeyman often reviewed the drawings to get measurements, verify duct sizes and type as well as confirm locations. Extreme postures were seen in the shoulders (4%) while leaning on the cart and back (28%) due to leaning over either the front or the back of the cart to view drawings. An adjustable height cart could have lessened these exposures.

Measuring and marking the slab was 18% of the time. This task involved two simultaneous actions; (1) measuring with a tape and (2) marking the measurement on the slab with a pencil. Extreme postures seen during this task were in the back (17%) while leaning over the drawing, neck (8%) while looking at the floor and legs (17%) bent severely to get close to the work. These postures were due to the worker working very close to the ground in complex positions. Being able to see what he was doing while accurately marking the floor were key factors in dictating his movements.

Spraying took 14% of the time. The last task in this operation was spraying a clear paint over the pencil markings to ensure they do not rub away. A spray can was kept in the back pocket of the journeyman's jeans. Extreme postures were observed in the back (13%) while bending at the waist to confirm the markings and legs (17%) while bent and moving forward.

Key findings/observations – Journeyman

- Two extreme leg postures were evident; (1) unilateral weight bearing, unstable knee flexion greater than 60º while kneeling on one leg with the other out stretched and (2) unstable squatting while getting close to the ground to make accurate marks.
- This work can be done with one worker however; two workers would have been faster as they could be working simultaneously to draw the layout.
- This is a fast paced, short duration task that still had high extreme body postures due to the worker working on the ground. To lessen the impact this worker was wearing rubber knee pads as he was constantly kneeling on the ground.

Operation 14: Drawing Layouts

Company:	B, union worker
Task:	Draw installation layout per engineering drawings on floor
Work height:	0'-0" created on concrete floor
Workers:	1 Journeyman (12 years experience)
Equipment:	Not applicable

Method:	Journeyman reviews drawings to verify location, dimension, size and type of duct to be installed, draws this information on the ground.
Tools:	Pencil, permanent marker, chalk line, bucket, clear spray, measuring tape
Duration:	2 minutes 44 seconds
Worker Observed:	Journeyman

Journeyman

The drawing of approximately 9 LF of layout took one worker 2.73 minutes. The journeyman performed productive work 28% of the time, support work 72% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (18% of the time), shoulders (9% of the time), back (52%), and legs (36% of the time). The cumulative exposure for this worker for extreme postures was 115%. Pushing/pulling was light, (94% of the time) and moderate (6%). Lifting was light (100% of the time). Many of the postures occurred simultaneously thus causing the cumulative percentage to be greater than 100%. Seen below in Table 45 are the main tasks the worker performed and the extreme postures that occurred during those tasks.

Placing the bucket took 4% of the time. This journeyman was working alone and in order to draw a chalk line he improvised with what he had. Using the replacement chalk dust bucket he placed one end on the tab and pulled the string of the chalk line taut. Extreme postures observed during this task were 6% as seen in the shoulders, back and legs and 3% for the neck. If there had been two workers this task would not have happened thus shortening the cycle time however, these body postures would have been present in both workers.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Place bucket [S]	6%	3%	6%	6%	6%	On the ground
Drawing chalk line [S]	3%		3%	3%	3%	Pulling string taut to strike line
Moving cart [S]	4%	3%		4%		Pulling wheeled cart to new location
Measure/ mark slab [P]	27%	6%		27%	27%	On ground, combined, complex postures
Review drawings [S]	27%	6%		12%		Leaning on front of cart
Total		**18%**	**9%**	**52%**	**36%**	

Table 45: Task durations and extreme postures for operation 14 Journeyman.

Drawing the chalk line was 1% of the time. After pulling the chalk line taut the worker pinched the string and pulled up approximately four inches and let go to strike a line. The worker was squatting on the ground and bent over while reaching for the string. Extreme postures were seen in the shoulders (3%) during reaching for the line, back (3%) while bent over the chalk line and legs (3%) during squatting.

Moving the cart took 4% of the time. This is a highly dynamic operation and the worker was able to move quickly through cycles. Moving progressively to the left side of the building he pulled and rolled his cart closer to his lay down area. This caused extreme postures in the back (3%) twisting as he pulled the cart and neck (3%) twisting to see the next area.

Measuring and marking the slab was 27% of the time. Extreme postures were seen in the back (34%) while leaning over the layout drawings, neck (6%) while looking down at the ground and legs (27%) during squatting. Extreme postures were due to the way the worker was moving along the ground. These percentages were due to the journeyman moving from being in a crouching position to shifting to a squatting position then into a kneeling position all while looking down.

Reviewing the drawings took 27% of the time. Leaning on the angled table top of the cart the journeyman had 6% extreme body postures in the back and neck.

Key findings/observations – Journeyman

- Two extreme leg postures were evident; (1) unilateral weight bearing, unstable knee flexion greater than 60º while crouching down next to his ground drawings and (2) unstable squatting while drawing on the floor. Extreme leg, back and shoulder postures can be greatly reduced if the worker used a telescopic extension arm to draw the layout while standing.
- This work can be done with one worker however; two workers would have been more efficient. This cycle time was longer as the worker was using a bucket to draw the chalk line. If he had been working with someone this may have been a shorter duration operation.

Operation 15: Drawing Layouts

Company:	B, union worker
Task:	Draw installation layout per engineering drawings on floor
Work height:	0’-0” created on concrete floor
Workers:	1 Journeyman (12 years experience)
Equipment:	Not applicable

Method:	Journeyman reviews drawings to verify location, dimension, size and type of duct to be installed, draws this information on the ground.
Tools:	Pencil, permanent marker, chalk line, bucket, clear spray, measuring tape, T square
Duration:	4 minutes 16 seconds
Worker Observed:	Journeyman

Journeyman

The drawing of approximately 15 LF of layout took one worker 4.27 minutes. The journeyman performed productive work 46% of the time, support work 53% of the time and had no idle time. During the operation, the journeyman had extreme postures for neck (8% of the time), shoulders (0% of the time), back (59%), and legs (43% of the time). The cumulative exposure for this worker for extreme postures was 110%. Pushing/pulling and lifting were both light, (100% of the time). Many of the postures occurred simultaneously thus causing the cumulative percentage to be greater than 100%. Table 46 below shows the main tasks the worker performed and the extreme postures that occurred during those tasks.

Measuring and marking the slab was 44% of the time. Extreme postures observed during this task were in the back (34%) while bent over drawings, neck (2%) while looking down at the floor and legs (39%) while being in a crouched position. This worker was in complex postures that caused multiple body posture exposures to occur.

Reviewing the drawings took 12% of the time. Extreme postures seen during this task were in the back (9%) while leaning over the back of the cart, neck (2%) while looking down at the drawings and legs (2%). The cart was facing away from the work area. If the worker turned the cart around he could view the drawing without having to walk around the cart saving time. Viewing the drawings while standing upright would reduce all extreme postures except for the neck, which was very low for this task.

Journeyman Tasks	Duration Percent	Extreme postures				Comments
		Neck	Shoulders	Back	Legs	
Measure/ mark slab [P]	44%	2%		34%	39%	On ground, combined, complex postures
Review drawings [S]	12%	2%		9%	2%	From behind cart, leaning on front of cart
Place bucket [S]	6%			6%		On ground
Replace chalk line [S]	8%	4%		8%		Untangle line and reel in
Smear chalk line [S]	8%			2%	2%	Rework
Total		**8%**	**0%**	**59%**	**43%**	

Table 46: Task durations and extreme postures for operation 15 Journeyman.

Placing the bucket was 4% of the time. This task would not have occurred had the journeyman had a second worker. However, improvisation was used in its place. This caused extreme posture in the back (6%) while putting the bucket in place. This was registered when the journeyman picked up and placed the bucket in the work area. Another worker would have helped to strike the chalk line however this journeyman's postures would have been the same.

Replacing the chalk took 8% of the time. While reeling in the chalk laden string back into its housing the worker bent to untangle the line. This motion caused extreme body postures in the back (8%) and neck (4%).

Smearing the chalk line was 8% of the time. This is the only operation in the series that had rework. A slight miscalculation was drawn on the slab only to be erased with the sole of a rubber boot and then a gloved hand before being redrawn. This not only caused extreme body postures but extended the duration of the cycle. Extreme postures seen during this task were in the back (2%) while leaning over the line as the worker was crawling and legs (2%) when he was squatting.

Key findings/observations – Journeyman

- No extreme shoulder postures were recorded yet unlike previous operations the other body regions have comparable and consistent percentages. This worker did not overextend nor did he reach during this operation.
- This cycle time was longer as the worker was using the bucket to draw the chalk line. If he had been working with someone this may have been a shorter operation. He also, misread the drawings and placed the chalk line incorrectly which caused (1) rework, (2) longer duration cycle and (3) extreme postures.

Comparative Analysis

Table 47 and Figure 20 below show the extreme values of each of the four body regions for ladder installation of equipment – operations 13 through 15.

	Operation 13	Operation 14	Operation 15
Body Regions	Journeyman on ground	Journeyman on ground	Journeyman on ground
Neck	8%	18%	8%
Shoulders	4%	9%	0%
Back	58%	52%	59%
Legs	34%	36%	43%
Cumulative	**104%**	**115%**	**110%**

Table 47: Extreme postures for operations 13-15

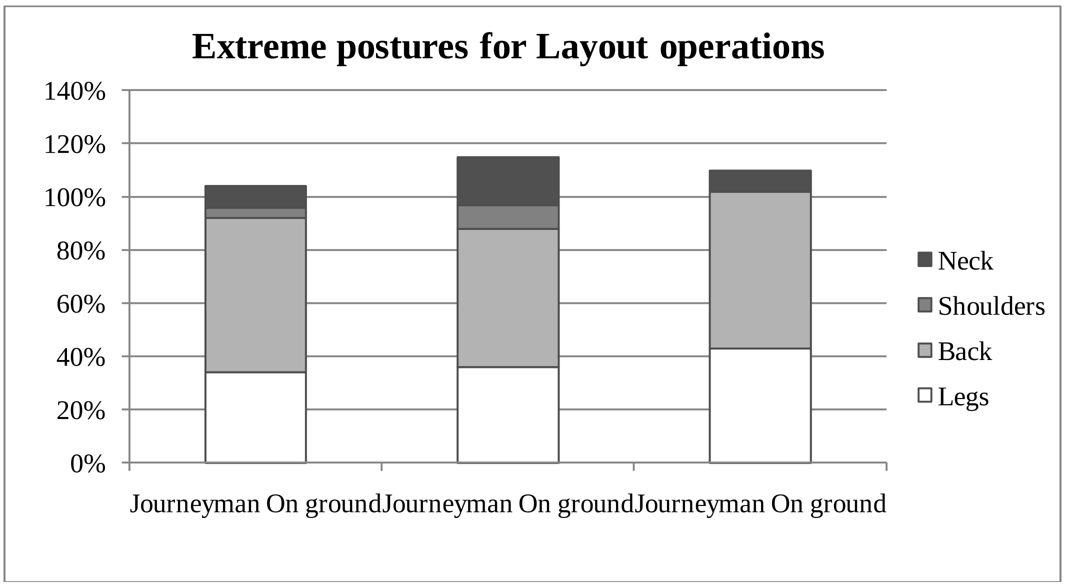


Figure 20: Extreme postures for ladder equipment installation, Operations 13-15

Cumulative extreme postures range from 104% to 115% for layout operations. This is by far the highest range of cumulative percentages and the closest from one operation to the next. All workers were working on the ground, drawing layouts. Workers worked individually, managing to create a second pair of helping hands when necessary, as seen by use of the chalk dust bucket. A significant difference was in operation 15 when the journeyman had no extreme shoulder exposure but had rework.

The journeyman in operation 14 had the highest extreme shoulder posture due to placing the bucket. The journeyman in operation 15 had the most significant back percentage (59%) mainly due to measuring and marking the slab. The journeyman in operation 14 also had the highest extreme neck posture (18%) as measuring and marking was the main contributing task. Lastly, the journeyman in operation 15 had the most significant extreme leg postures due to squatting (43%).

Neck

Extreme neck postures (twisting) were present in all cases and ranged from (8% to 18%). The journeyman in operation 14 had the highest percentage which was more than double that of the workers in operations 13 and 15. This was due mainly to moving the cart.

Extreme neck postures occurred when the journeyman was measuring and marking the slab. These postures can be reduced with the use of a higher work table however; in these operations looking down at the ground is inevitable.

Shoulders

Extreme shoulder postures (shoulder flexion greater than 90°) were seen in a limited number of tasks. In operations 13 and 14 the journeyman had recordable shoulder percentages while (1) reviewing the drawings, (2) placing the bucket and (3) drawing the line. Leaning on the cart while verifying drawings, caused extreme postures to occur. If the worker had a higher work table therefore standing up straight to view the drawings these percentages could have been reduced. Also, if the worker had a second pair of hands to assist while drawing the chalk line this could have reduced shoulder exposure.

The journeyman in operation 15 had a 0% extreme shoulder reading. Although, the same tasks were repeated in this operation the worker only had moderately recorded percentages. This could be because of extreme back percentages increasing.

Back

Extreme back postures varied ranging from (52%-59%) for the workers in these operations. The principal extreme back posture was flexion greater than 60°. A number of tasks showed back percentages. However, extreme back postures occurred mainly during measuring and marking the slab. It was during this task that the worker was bent close to the ground to view his work.

Extreme back postures can be reduced if the worker was using a hand held, telescopic extension pole. This pole would also reduce extreme shoulder and leg postures.

Legs

Extreme leg postures were high ranging from (34%-43%) of the time. All operations had two extreme leg postures visible; (1) unilateral weight bearing, unstable knee flexion greater than 60º and (2) unstable squatting. Workers in all three operations wore rubber knee pads as working on the concrete floor for 8-10 hours a day will take its toll on your knees and back. Significant extreme leg postures occurred when the journeyman was measuring and marking the slab. Crouching, kneeling and squatting positions were recorded in both extremes postures.

The extreme leg postures can be greatly reduced if the worker had a hand held, telescopic extension pole. Similarly to extreme back exposure, the need to bend down to the floor would be negated.

Overall

- As cycle times increased so did the percentages of productive work. Reviewing the drawings is a support task closely linked to measuring and marking the slab which is a productive task. The more time the worker had to review the drawings the more layout he drew on the slab thus increasing productive percentages.
- Working on the ground had a great impact on extreme body postures. Measuring and marking the slab and reviewing the drawings were closely linked tasks that had considerable extreme postures in the back and legs. To get the worker off the ground and working in an upright, neutral position a hand held extension should be provided for drawing.
- Extreme back percentages were recorded consistently in the 50's while extreme leg percentages were in the 30's for all operations. This operational series had the highest cumulative extreme postures. This was mainly because of back and leg exposure during measuring and marking the slab.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research was to better understand the effect of activity parameters and work organization on the physical work demands of HVAC installation workers. To investigate the effect of different work parameters on the ergonomic loads, the study observed and analyzed physical movements and body postures for each activity. The analysis measured and compared ergonomic loads of similar activities for various methods and activity parameters (work platform, duct size, length of duct assembly, etc.). The ergonomic demand was analyzed for four body regions. This analysis indicates how differing activity factors can contribute to undesirable ergonomic exposure and postural loads for different body areas.

The analysis of each activity identified specific tasks that contributed to extreme postures. Hazardous tasks were based on duration (time) and exposure (ergonomic load). Support tasks take up a significant portion of the entire activity time and involve extreme postures. These tasks are the focus for improvement based on recommendations.

Duct and equipment installation using ladders (Operations 1-6)

- Aligning the duct
- Inserting the S drive
- Reaching for a tool

Recommendations

Ladder position is a key contributing factor for extreme body postures. The distance and orientation of the ladder can negatively impact how the worker moves. Placing the ladder perpendicular and within 12” of the duct can reduce extreme postures in the shoulders, back and neck. This will effectively reduce turning and overextending in those body regions.

Climbing up and down a ladder has a significant impact on extreme postures. By reducing the frequency of times the worker moves up and down a ladder, extreme postures may be reduced in the legs, shoulder and neck. Wearing a tool belt and working in close proximity of the material being installed can both decrease exposure to extreme postures.

Ladders limit the workers' mobility. When possible and feasible scissor lifts should be used, the immediate impact of additional costs for equipment may be offset in the long term, by a safer work environment and reduced injury costs. The increased work platform aids in giving the worker freedom to move along the duct during installation. The bed of the lift can also be used to store both tools and material, reducing the frequency of ascent and descent by the worker. The worker can reach higher ducts while working within the security of the lift's cage.

When working on tenant improvement projects, schedule duct installation prior to sprinkler, waste vent and water piping installation. Existing pipes, lines and vents hinder worker accessibility, causing the worker to move according to the limited space available. These movements cause extreme body postures seen in the shoulder, back and neck.

Duct installation using scissor lift (Operations 7-9)

- Cranking the super lift
- Spotting
- Walking
- Moving the scissor lift

- Talking
- Connecting duct

Recommendations

In installation operations 1 through 9 for rectangular ducts, material alignment is a significant contributing task for extreme postures and task duration. If duct manufacturers re-design the duct flanges by creating flanges to slip into one another similar to round duct this would have a considerable impact. This will remove the insertion of the S drive all together. However, duct alignment will still be required as new lengths are installed to existing duct.

Using a scissor lift rather than a ladder increases work platform areas, reducing knee flexion and back extreme postures involving twisting. With scissor lift usage comes super lift cranking. Cranking may cause increased shoulder and neck postures.

Scissor lift position is paramount in reducing extreme body postures. The direction the equipment is facing in relation to the duct; parallel or perpendicular, front or side, can significantly impact the workers body posture. Extreme shoulders, back and neck postures are evident when the worker is improperly located next to the duct. It is recommended to never place the railing of the scissor under the duct as this causes extreme postures and limits the height of the lift. Suggested positioning to reduce these postures would be; 12" away with the railing of the scissor lift cage at the mid height of the duct, if the ceiling height permits. Placement should run parallel to the duct so the worker has the maximum range of movement along the duct length.

Super lifts are needed to raise the duct up to installation height. However, this equipment can hinder the mobility of the scissor lift. Position super lifts as far as possible from straps and hangers already installed. The scissor lift operator needs to complete installation by fastening these hangers and the legs of the super lift may obstruct the worker from positioning the scissor lift in the optimum position, thus causing extreme postures from reaching and twisting.

Super lift cranking contributes to extreme shoulder, back and neck postures. Provide hydraulic super lifts to reduce exposure during cranking and reduce pushing/pulling actions. If hydraulic lifts are not available, well maintained equipment can lessen the strain on workers by reducing extreme shoulder exposure and shortened cycle times.

Wearing a tool belt may reduce extreme back bending as the worker will not have to bend to retrieve tools from the floor. However, wearing a tool belt causes extreme postures in the neck and shoulders. Suggest shallower saddlebags for tool belts. If a worker has a deeper saddlebag, the more extreme his shoulder exposure can be. Request workers use tool belts in lieu of the scissor lift platform to keep tools within reach reducing extreme back and leg postures.

Ground Assembly (Operations 10-12)

- Positioning the duct
- Cutting the duct

Recommendations

Fabricate duct assemblies at waist height by providing metal frame work stands to elevate the work surface off the floor. This will reduce extreme shoulder, neck and back postures as seen during material alignment and insertion of the S drive. However, it should be noted that new duct to existing duct connections will still be made at height and inserting the S drive will be a contributing factor. This recommendation reduces the number of time workers will have to either climb a ladder or use a scissor lift.

Provide workers with portable, waist-high work tables with anti-fatigue mats to reduce extreme leg postures; (1) unilateral weight bearing, unstable knee flexion greater than 60º and (2) unstable squatting.   This in effect can reduce extreme back, shoulder and leg postures in these workers while impacting extreme neck percentages. All assembly tasks, measuring, cutting, aligning duct and fastening, can be done at a table as opposed to working on the concrete floor. Workers will no longer need to wear rubber knee pads as; bending, kneeling and squatting will be mitigated. These tables can also reduce the need to over-extend, reach, twist and turn while making connections.

Layout (Operations 13-15)

- Reviewing the drawings
- Measuring and marking the slab

Recommendations

For layout workers provide an adjustable-height and tilting top work cart. While reviewing the drawings the worker will not have to bend down to the table. Being able to clearly read the drawings can reduce extreme shoulder, back and neck postures.

Providing hand held telescoping extension tools can greatly reduce the extreme body postures during layout. Hand extension tools can reduce extreme back and leg exposures by making the worker stand while drawing thus keeping his body in a neutral position.

Limitations

The study had the following limitations that could have created some errors:

a. Use of one video camera.
b. Position of the camera on the ground.
c. Analyst bias.

The use of one camera, in some cases videotaped only one worker. In other cases, a portion of the cycle time of a worker was not recorded because the worker walked away from the work area. The main priority in videotaping was the worker performing the installation, the support worker(s) were a secondary consideration.

The position of the video camera on the ground created some difficulty in accurately assessing flexion/extension angles when workers were at significant height. However, in many instances, the researcher was able to move the video camera around and videotape from a better position on the ground.

To minimize the researcher's error during postural analysis, a sample of the ergonomic analysis was tested for validity by an industry professional. An experienced ergonomist independently conducted an ergonomic analysis of selected operations. The ergonomist's angles of flexion and extension were compared with the researcher's analysis. The comparison found agreement in over 95% of the operations.

The postThe postural guide used for ergonomic analysis was based on RULA and REBA methods. Although, comprehensive in their compilation of possible body movements there are some gaps. During ergonomic analysis it was found that several body positions did not fit neatly within the guidelines set by RULA/REBA. These combined positions are in regards to the limbs, arms or legs. Combined posture examples happened during:

- The layout while the worker was in a squatting position, while leaning on one knee the other leg was out stretched for balance. One leg was severely bent and the other was in a neutral position.

- In the installation operations during duct alignment a worker would hold the duct up with one hand while inserting the S drive. One arm is in a moderate position while the other is in an extreme position.

Combined postures were analyzed based on the most hazardous or extreme posture seen in that limb.

Study Contributions

Despite these limitations, this study makes important contributions towards reducing WMSDs for HVAC installers:

1. The continuous time analysis developed in this study provides detailed information in regards to extreme body postures and duration for different operations and tasks.
2. The comparison of similar activities identified several task factors that influence extreme postures. It found that significant variability in postures is caused by small changes in the operation.
3. It identifies specific opportunities for reducing extreme postures.

This study has the prospective opportunity for continued research. Future studies in this direction could branch off into a number of different areas while studying ergonomics in construction. The following suggestions are studies that could focus further on;

- Combined postures for mechanical duct installers. Analyzing both sides of the body for a more accurate reading on the hazards inflicted on these workers during HVAC work.
- More operations for a comprehensive data base of postures, workers and tasks. Broadening the field of scope to the entire state of Arizona or beyond to a

national level. Company specific practices could be further analyzed to distinguish safety culture compared with actual hazards.

- Researching changes the above recommendations have on ergonomic loads in these workers. Observing the differences in work practices that were changed by ergonomic hazard reducing interventions.
- Expand this study to other trades, (framers, concrete pourers, drywall hangers, etc.) to compile a compendium of hazards and recommendations in the construction industry.
- Researching the effects that combined body postures have the workers. Considering how cumulative percentages relate to WMSDs of more than one body part, I.E. back and shoulders or back, shoulders and neck during mechanical installation activities.
- Investigate increased productivity through activity sequence changes. If the closely linked activities are reordered, can this reduce ergonomic hazards while increasing production?

The above research prospects can expand the reliability of results shown in this study.

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APPENDIX A

WORKER EXPOSURE AND TASK DURATION TABLES PER OPERATION

Body Regions & Degrees	Operation 1 - Ladder	Operation 2 - Ladder		Operation 3 - Ladder
Neck	Journeyman	Journeyman	Apprentice	Sheet metal worker
Flex./Ext. 0-20°	0.59	0.46	0.23	0.24
Flex./Ext. > 20°	0.30	0.27	0.38	0.61
Twisted	0.11	0.27	0.40	0.16
Shoulder				
Flexion 0-45°	0.63	0.49	0.38	0.49
Flexion 45°-90°	0.37	0.49	0.58	0.29
Flexion 90° >	0.00	0.03	0.04	0.22
Back				
Flexion 0-20°	0.61	0.86	0.46	0.66
Flexion 20°-60°	0.00	0.03	0.04	0.22
Extension 0-20°	0.02	0.00	0.00	0.01
Flexion > 60°	0.00	0.00	0.00	0.04
Extension > 20°	0.07	0.00	0.00	0.00
Twisting < 45°	0.30	0.11	0.46	0.08
Twisting > 60°	0.00	0.00	0.04	0.00
Legs				
Stand, Walk, Sit < 30°	0.24	0.81	0.38	0.20
Stand, Walk, Sit 30°-60°	0.00	0.03	0.00	0.03
Unstable 30°-60°	0.65	0.11	0.00	0.66
Unstable > 60°	0.11	0.05	0.06	0.11
Squatting (Stable)	0.00	0.00	0.56	0.00
Squatting (Unstable)	0.00	0.00	0.00	0.00
Push/Pull				
0-14 Lbs.	0.87	0.76	1.00	1.00
15-50 Lbs.	0.13	0.24	0.00	0.00
Lifting				
0-14 Lbs.	0.87	1.00	1.00	1.00
15-50 Lbs.	0.13	0.00	0.00	0.00
> 50 Lbs.	0.00	0.00	0.00	0.00

Table 48: All body postures percentages for Ladder Operations 1-3

Body Regions & Degrees	Operation 4 - Ladder Eq.		Operation 5 - Ladder Eq.		Operation 6 - Ladder Eq.	
Neck	Journeyman	Apprentice	Sheet metal worker	Superintendent	Sheet metal worker	Superintendent
Flex./Ext. 0-20°	0.40	0.40	0.27	0.55	0.38	0.52
Flex./Ext. > 20°	0.25	0.31	0.59	0.28	0.49	0.21
Twisted	0.35	0.29	0.14	0.16	0.13	0.27
Shoulder						
Flexion 0-45°	0.54	0.50	0.49	0.44	0.26	0.36
Flexion 45°-90°	0.21	0.19	0.39	0.38	0.27	0.53
Flexion 90° >	0.25	0.31	0.12	0.18	0.47	0.11
Back						
Flexion 0-20°	0.65	0.15	0.57	0.88	0.33	0.65
Flexion 20°-60°	0.00	0.00	0.09	0.06	0.08	0.11
Extension 0-20°	0.00	0.06	0.00	0.00	0.00	0.00
Flexion > 60°	0.00	0.00	0.04	0.05	0.00	0.00
Extension > 20°	0.00	0.00	0.00	0.00	0.00	0.00
Twisting < 45°	0.08	0.56	0.01	0.00	0.52	0.24
Twisting > 60°	0.27	0.23	0.29	0.00	0.08	0.00
Legs						
Stand, Walk, Sit < 30°	0.40	0.06	0.49	0.30	0.16	0.35
Stand, Walk, Sit 30°-60°	0.00	0.00	0.01	0.04	0.00	0.00
Unstable 30°-60°	0.42	0.90	0.42	0.56	0.71	0.52
Unstable > 60°	0.19	0.04	0.08	0.11	0.13	0.14
Squatting (Stable)	0.00	0.00	0.01	0.00	0.00	0.00
Squatting (Unstable)	0.00	0.00	0.00	0.00	0.00	0.00
Push/Pull						
0-14 Lbs.	0.75	0.94	0.98	0.97	0.88	0.73
15-50 Lbs.	0.25	0.06	0.02	0.03	0.12	0.27
Lifting						
0-14 Lbs.	0.88	0.94	0.97	0.94	0.91	0.97
15-50 Lbs.	0.13	0.06	0.03	0.06	0.09	0.03
> 50 Lbs.	0.00	0.00	0.00	0.00	0.00	0.00

Table 49: All body postures percentages for Ladder Equipment Operations 4-6

Body Regions & Degrees	Operation 7 - Scissor lift	Operation 8 - Scissor lift		Operation 9 - Scissor lift	
Neck	Journeyman	Journeyman	Apprentice	Journeyman	Apprentice
Flex./Ext. 0-20°	0.40	0.35	0.26	0.27	0.60
Flex./Ext. > 20°	0.39	0.54	0.48	0.51	0.21
Twisted	0.21	0.11	0.26	0.22	0.20
Shoulder					
Flexion 0-45°	0.22	0.22	0.07	0.36	0.67
Flexion 45°-90°	0.35	0.43	0.63	0.35	0.21
Flexion 90° >	0.43	0.35	0.30	0.30	0.12
Back					
Flexion 0-20°	0.61	0.56	0.67	0.55	0.43
Flexion 20°-60°	0.11	0.20	0.22	0.15	0.08
Extension 0-20°	0.01	0.02	0.00	0.00	0.06
Flexion > 60°	0.13	0.15	0.07	0.08	0.14
Extension > 20°	0.00	0.00	0.04	0.04	0.18
Twisting < 45°	0.12	0.07	0.00	0.15	0.10
Twisting > 60°	0.01	0.00	0.00	0.01	0.00
Legs					
Stand, Walk, Sit < 30°	0.83	0.78	0.93	0.86	0.90
Stand, Walk, Sit 30°-60°	0.13	0.22	0.07	0.06	0.01
Unstable 30°-60°	0.03	0.00	0.00	0.05	0.09
Unstable > 60°	0.01	0.00	0.00	0.02	0.00
Squatting (Stable)	0.00	0.00	0.00	0.02	0.00
Squatting (Unstable)	0.01	0.00	0.00	0.00	0.00
Push/Pull					
0-14 Lbs.	0.81	0.70	0.93	0.99	1.00
15-50 Lbs.	0.19	0.30	0.07	0.01	0.00
Lifting					
0-14 Lbs.	0.96	0.96	1.00	0.99	0.99
15-50 Lbs.	0.04	0.04	0.00	0.01	0.01
> 50 Lbs.	0.00	0.00	0.00	0.00	0.00

Table 50: All body postures percentages for Scissor lift Operations 7-9

Body Regions & Degrees	Operation 10 - Ground assembly	Operation 11 - Ground assembly	Operation 12 - Ground assembly
Neck	Journeyman	Apprentice	Journeyman
Flex./Ext. 0-20°	0.44	0.19	0.34
Flex./Ext. > 20°	0.42	0.70	0.61
Twisted	0.14	0.11	0.05
Shoulder			
Flexion 0-45°	0.53	0.59	0.31
Flexion 45°-90°	0.43	0.41	0.58
Flexion 90° >	0.04	0.00	0.11
Back			
Flexion 0-20°	0.50	0.29	0.36
Flexion 20°-60°	0.18	0.01	0.23
Extension 0-20°	0.00	0.00	0.02
Flexion > 60°	0.28	0.70	0.25
Extension > 20°	0.00	0.00	0.00
Twisting < 45°	0.04	0.00	0.13
Twisting > 60°	0.00	0.00	0.02
Legs			
Stand, Walk, Sit < 30°	0.47	0.28	0.45
Stand, Walk, Sit 30°-60°	0.21	0.35	0.16
Unstable 30°-60°	0.00	0.00	0.00
Unstable > 60°	0.07	0.00	0.00
Squatting (Stable)	0.18	0.36	0.23
Squatting (Unstable)	0.07	0.00	0.16
Push/Pull			
0-14 Lbs.	1.00	1.00	1.00
15-50 Lbs.	0.00	0.00	0.00
Lifting			
0-14 Lbs.	1.00	1.00	1.00
15-50 Lbs.	0.00	0.00	0.00
> 50 Lbs.	0.00	0.00	0.00

Table 51: All body postures percentages for Ground assembly Operations 10-12

Body Regions & Degrees	Operation 13 - Layout	Operation 14 - Layout	Operation 15 - Layout
Neck	Journeyman	Journeyman	Journeyman
Flex./Ext. 0-20°	0.29	0.39	0.24
Flex./Ext. > 20°	0.63	0.42	0.69
Twisted	0.08	0.18	0.08
Shoulder			
Flexion 0-45°	0.29	0.48	0.31
Flexion 45°-90°	0.67	0.42	0.69
Flexion 90° >	0.04	0.09	0.00
Back			
Flexion 0-20°	0.33	0.27	0.25
Flexion 20°-60°	0.08	0.21	0.12
Extension 0-20°	0.00	0.00	0.00
Flexion > 60°	0.58	0.52	0.59
Extension > 20°	0.00	0.00	0.00
Twisting < 45°	0.00	0.00	0.04
Twisting > 60°	0.00	0.00	0.00
Legs			
Stand, Walk, Sit < 30°	0.67	0.39	0.27
Stand, Walk, Sit 30°-60°	0.00	0.24	0.18
Unstable 30°-60°	0.00	0.00	0.12
Unstable > 60°	0.21	0.12	0.41
Squatting (Stable)	0.00	0.00	0.00
Squatting (Unstable)	0.13	0.24	0.02
Push/Pull			
0-14 Lbs.	1.00	0.94	1.00
15-50 Lbs.	0.00	0.06	0.00
Lifting			
0-14 Lbs.	1.00	1.00	1.00
15-50 Lbs.	0.00	0.00	0.00
> 50 Lbs.	0.00	0.00	0.00

Table 52: All body postures percentages for Layout Operations 13-15

Operation 1 Journeyman	
Task	Duration (in seconds)
Move material	5
Idle	10
Move ladder	40
Ascend/Descend	20
Reach for tool	20
Align material	100
Place tool	15
Putting Horse nippers on	20

Table 53: Task description and duration for operation 1 journeyman

Operation 2 Journeyman	
Task	Duration (in seconds)
Moving around work area	10
Place tool	65
Use Tool	100
Talking	10
Move ladder	10
Ascend/Descend	15
Not in video	45
Align material	35

Table 54: Task description and duration for operation 2 journeyman

Operation 2 Apprentice	
Task	Duration (in seconds)
Moving around work area	10
Place tool	65
Measure drive	18
Talking	10
Move ladder	10
Ascend/Descend	15
Not in video	45
Align material	35
Adjusting horse nippers	36
Cutting S drive	46

Table 55: Task description and duration for operation 2 apprentice

Operation 3 Sheet metal worker	
Task	Duration (in seconds)
Align material	100
Search for tool	125
Ascend/Descend	105
Use Tool	97
Get material	20
Talking	90
Moving around work area	60
Idle	45
Prepping material	30
Making connection	20
Cutting	76
Fastening	57

Table 56: Task description and duration for operation 3 sheet metal worker

Operation 4 Journeyman	
Task	Duration (in seconds)
Carry material	5
Ascend/Descend	40
Adjust material	55
Reach for tool	5
Place tool	10
Fastening	40
Talking	15
Move ladder	5
Moving around work area	55
Inserting S drive	10

Table 57: Task description and duration for operation 4 journeyman

Operation 4 Apprentice	
Task	Duration (in seconds)
Move ladder	10
Place tool	75
Ascend/Descend	15
Reach for tool	45
Adjust material	70
Use tool	25

Table 58: Task description and duration for operation 4 apprentice

Operation 5 Superintendent	
Task	Duration (in seconds)
Move material	45
Search for tool	210
Use tool	60
Talking	95
Move ladder	50
Moving around work area	65
Move equipment	15
Ascend/Descend	105
Carry material	5
Idle time	35
Adjust material	75
Measuring	76
Inserting S drive	114

Table 59: Task description and duration for operation 5 superintendent

Operation 5 Sheet metal worker	
Task	Duration (in seconds)
Not in video	210
Moving around work area	60
Talking	70
Move material	40
Use tool	210
Search for tool	70
Adjust material	250
Ascend/Descend	40

Table 60: Task description and duration for operation 5 sheet metal worker

Operation 6 Superintendent	
Task	Duration (in seconds)
Adjust material	95
Ascend/Descend	50
Use tool	90
Moving around work area	30
Move ladder	10
Not in video	180
Search for tool	20
Inserting S drive	30

Table 61: Task description and duration for operation 6 superintendent

Operation 6 Sheet metal worker	
Task	Duration (in seconds)
Not in video	35
Move equipment	15
Walking around work area	15
Move ladder	20
Ascend/Descend	50
Adjust material	290
Use tool	35
Place tool	5
Search for tool	20
Fastening	20

Table 62: Task description and duration for operation 6 sheet metal worker

Operation 7 Journeyman	
Task	Duration (in seconds)
Material preparation	80
Moving around work area	70
Talking	105
Use equipment	165
Adjust material	125
Use tool	25
Move equipment	60
Ascend/Descend	35
Get tool	45
Fastening	55
Cutting	15

Table 63: Task description and duration for operation 7 journeyman

Operation 8 Journeyman	
Task	Duration (in seconds)
Moving around work area	65
Move material	20
Talking	75
Use tool	10
Use equipment	45
Idle time	15
Placing C clamps	40

Table 64: Task description and duration for operation 8 journeyman

Operation 8 Apprentice	
Task	Duration (in seconds)
Fastening	13
Get tool	25
Ascend/Descend	20
Move equipment	40
Adjust material	15
Place strap	22

Table 65: Task description and duration for operation 8 apprentice

Operation 9 Journeyman	
Task	Duration (in seconds)
Ascend/Descend	95
Move equipment	75
Idle time	70
Material preparation	215
Get tool	110
Moving around work area	30
Talking	260
Not in video	145
Adjust material	235
Use tool	115
Use equipment	15
Move material	5

Table 66: Task description and duration for operation 9 journeyman

Operation 9 Apprentice	
Task	Duration (in seconds)
Not in video	505
Move equipment	120
Talking	30
Move material	85
Ascend/Descend	55
Get tool	190
Use tool	246
Idle time	85
Fastening	27
Measuring	27

Table 67: Task description and duration for operation 9 apprentice

Operation 10 Journeyman	
Task	Duration (in seconds)
Looking at material	5
Moving around work area	20
Adjust material	70
Fastening	58
Move material	5
Prepare material	10
Search for material	30
Connect	45
Get tool	75
Talking	10
Cutting	32

Table 68: Task description and duration for operation 10 journeyman

Operation 11 Apprentice	
Task	Duration (in seconds)
Prepare material	17
Moving around work area	95
Cutting	153
Move material	15
Get tool	5
Adjust material	5
Search for material	45
Connect	30
Drawing line	75
Measuring	110

Table 69: Task description and duration for operation 11 apprentice

Operation 12 Journeyman	
Task	Duration (in seconds)
Move material	45
Get tool	65
Adjust material	50
Fastening	30
Talking	50
Prepare material	45
Moving around work area	35

Table 70: Task description and duration for operation 12 journeyman

Operation 13 Journeyman	
Task	Duration (in seconds)
Moving around work area	27
Reviewing drawings	52
Spray	17
Measure/mark slab	24

Table 71: Task description and duration for operation 13 journeyman

Operation 14 Journeyman	
Task	Duration (in seconds)
Measure/mark slab	50
Moving around work area	55
Move cart	5
Reviewing drawings	40
Placing bucket	10
Drawing chalk line	5

Table 72: Task description and duration for operation 14 journeyman

Operation 15 Journeyman	
Task	Duration (in seconds)
Reviewing drawings	35
Moving around work area	55
Rework	25
Measure/mark slab	100
Place bucket	20
Replace chalk line	20

Table 73: Task description and duration for operation 15 journeyman

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