Reducing Neck And Shoulder Discomfort Associated With The Use Of Portable Leak Detection And Repair (LDAR) Monitors

A Human Factors Engineering project presented to the faculty of California State University – Dominguez Hills in partial fulfillment of the requirements for the degree of Masters in Quality Assurance (MSQA)

by

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Introduction

Impacts of Musculoskeletal Disorders

As repetitive tasks are executed by workers, many factors influence the potential manifestation of musculoskeletal disorders by those workers. According to the Bureau of Labor Statistics (1999), nearly 1 million people each year report taking time away from work to treat and recover from musculoskeletal pain or loss of function either in the low back or upper extremities due to overexertion or repetitive motion. Estimated workers' compensation costs associated with these lost workdays range from $13 to $20 billion annually. This estimate is based only on actual compensation claims. Economic and psychosocial pressures cause many injuries go unreported in industries such as construction, agriculture, and small businesses. Additionally, the numerous factors that may affect reported cases—including work procedures, equipment, and job design; organizational and social factors; physical and psychological characteristics of the individual; and workplace safety culture and reporting practices—has led to questions about causes, nature, severity, and extent of work-relatedness (Kuorinka and Forcier, 1995).

Application of physics to biomechanical systems dictates that loads imposed on a structure must exceed a mechanical tolerance limit for damage to occur. When muscles must remain contracted as more than about 15 to 20% of their maximal capability for extended durations, circulation is impaired which can result in tissue ischemia and delayed dissipation of metabolites, which constitutes a general physiological strain. For shoulder and neck cumulative trauma disorders, repeated muscle contractions and tendon movements are regarded as common causal factors (Chatterjee, 1987).

From a clinical perspective cumulative trauma disorders are varied, sometimes general, and often confusing due to non-specific etiologies and confounding of conditions experienced by affected persons. The usual symptoms are discomfort, pain, tenderness, weakness, swelling, and numbness and manifestation of the symptoms is usually gradual. Many reference materials agree there are generally three stages in the development of cumulative trauma disorders.

Kroemer, Kroemer, and Kroemer-Elbert (2001) summarize these stages as follows:

> Stage 1 is evidenced by complaints of aches or tiredness during the working activities but the quality of work performance goes undiminished. Usually those symptoms are removed overnight by rest and over days off work. Depending upon the frequency and duration of the repetitions of work task(s) that may be causing the musculoskeletal tissue damage, people may experience this condition for weeks or months. Stage 1 physiological conditions are reversible. Stage 2 has symptoms that start early in the work shift, and which do not settle overnight. Sleep may be disturbed and the capacity to perform the repetitive work reduced. This condition usually persists over months. Stage 3 is characterized by symptoms that persist at rest, pain that occurs with non-repetitive movements, and disturbed sleep. The person is

unable to perform even light duties, and experiences difficulties in other tasks. This condition may last for months or years.

Treatment in the first stage, if at all possible, is preferred. Often, the condition causing the symptom can be eliminated or mitigated through ergonomic interventions. It is not uncommon for people to hope a condition is temporary, not recognize the progression, and fail to seek treatment until the condition progresses to the second or third stage. In the third stage, medical attention is necessary.

The Need for Human Factors Engineering (HFE) Countermeasures to Alleviate Human Discomfort While Performing Leak Detection and Repair (LDAR) Monitoring Within a Chemical Manufacturing Plant

This paper evaluates interventions for a work process that requires personnel to lift, transport, stabilize, and manipulate a 13 pound portable organic vapor analyzer for as much as 10 hours per work shift. More specifically the omphalos of this evaluation is the apparent musculoskeletal disorder suffered by one such LDAR technician who has been performing the duty for over 15 years. The analyzer has typically been carried via a shoulder strap the majority of the work shift. Human factors engineering principals will be evaluated and interventions described in an effort to reduce the risk of further injury by the employee who has exhibited symptoms of cumulative trauma in the tissues of the neck and shoulder area.

Recent complaints of discomfort and pain in the neck and right shoulder indicate the technician may be experiencing the early stages of a cumulative trauma disorder. Reported symptoms most closely resemble those of neck tension disorder, shoulder tendonitis, or thoracic outlet syndrome. While an exact diagnosis has not been obtained, the majority of the employee's reported symptoms correspond to those commonly attributed to thoracic outlet syndrome.

Thoracic outlet syndrome etiology includes compression of neurovascular bundle(s) at the thoracic outlet (first rib, clavicle, scalenus muscle) owing to various causes: cervical rib, muscular malformation, and ligaments forced hyper abduction with weight load, (Magalini, 1997). The thoracic outlet is the small space between the collar bone and the first rib; which is where the load transferred from a shoulder strap causes compression nerves and blood vessels. Clinical signs and symptoms of thoracic outlet syndrome usually include pain in the neck and shoulder area along with numbness and weakness in the arm or hand. Figure 1 shows an anatomical representation of a normal thoracic outlet, while Figure 2 shows a thoracic outlet representative of thoracic outlet syndrome. The illustrations convey the extent of the enlarged (hypertrophied) scalenus muscles and the resulting compression of neurovascular tissues.

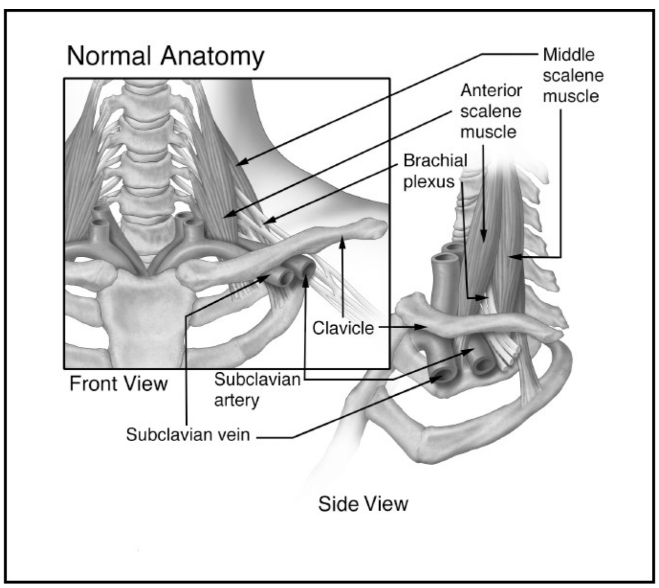

Figure 1. Schematic of a Normal Thoracic Outlet.

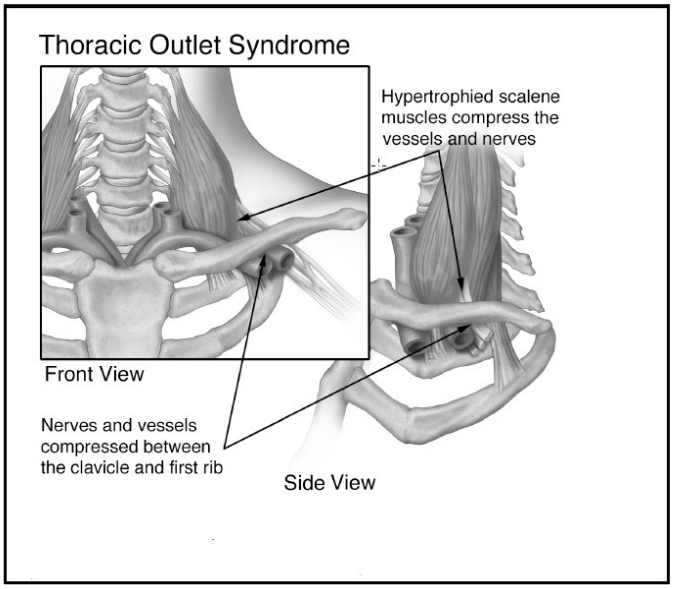

Figure 2. Schematic of a thoracic outlet illustrating the pathologic changes associated with thoracic outlet syndrome.

Werden (2007) describes the temporal onset of the syndrome as an initial disturbance of intraneural blood flow leading to partial disintegration of the blood-nerve barrier, which is followed by edema within the affected nerve fascicles. Fibrosis and thickening of connective tissue structures within and around the fascicles then develops. With continued compression, segmental demyelination occurs, eventually progressing to diffuse demyelination. Finally, the underlying axons undergo degeneration. The degree and speed of these changes is a function of the frequency and extent of nerve and or vascular compression.

Background

The Regulatory Requirement to Perform Leak Detection and Repair (LDAR) Monitoring.

Manufacturing facilities can be subject to a vast array of regulatory requirements. Facilities in the U.S. which use organic solvents to synthesize new products via chemical reaction are likely to be subject to numerous regulations specified in the Clean Air Act. One such regulation can be found in the code of federal regulations, 40 CFR 63 National Emissions Standards for Hazardous Air Pollutants (NESHAP). A key element of the NESHAP standards, especially for neighbors of the facilities, is the Leak Detection and Repair (LDAR) requirements. These requirements force facilities to have detailed plans describing from both a proactive and a reactive perspective how leaks of organic solvents from storage and processing equipment are identified, repaired, and ultimately minimized. On the proactive side, technicians must conform to schedules defined in the regulations and physically monitor, according to specific test methods, each regulated component of the facility's process equipment to determine whether organic vapors or hazardous air pollutants are escaping into the environment. Each leak must be tracked and repaired within 15 days. Facilities subject to these requirements can have from hundreds to many thousands of components requiring monitoring on recurring schedules.

LDAR Monitoring Body Positions, Physical Demands, Frequency, Durations, and Locations

One key human factor during monitoring becomes apparent as the technicians are required to transport an organic vapor analyzer to each component to be tested. The number of components to be tested on any given day can range from 1 to approximately 1,000. Components are usually pipe flanges (connectors), valve stems and flanges, pump seals, agitator seals, and a few other less common pipe system components. Thus the components are located wherever pipes are located. This requires LDAR technicians to climb and monitor from ladders, scaffolding, and man lifts.

Piping systems can range in surface temperature from -30 ^{o}C to greater than 300 ^{o}C depending upon the design requirements of the chemical process. Even if the technician does not contact the pipes, these temperatures can create uncomfortable working conditions within the chemical processing facility.

Because of the complexity of piping systems, the LDAR technicians are required to assume nearly every possible posture resulting from permutations of rotations of the torso, neck, and arms. The portable analyzer must be with them every step of the way. The effort to carry the load of the analyzer and to stabilize it while climbing, bending, stooping, etc. can lead to mental, physical, and physiological fatigue during a work shift.

Historical LDAR Technician Ergonomic Complaints/Injuries

Historically, most LDAR technicians at the facility involved have performed the tasks described above for up to several years without experiencing musculoskeletal tissue damage and the associated pain, numbness, or tingling sensations. A senior technician has complained of numbness in the shoulder and arm areas, pain in the shoulder and neck, and numbness with a tingling sensation in the right arm. According to the technician, these symptoms are most easily evoked when periods of intense monitoring (greater than 75 components per day) for more than one day in succession follow a week or more of no monitoring.

When asked to point out the exact location of the neck and shoulder pain, the technician indicated the top of the shoulder, where the most downward force exerted by gravity is transferred to the trapezious musculature. The technician also pointed directly to the thoracic outlet from the back. Once inflamed, carrying loads on the shoulder, reaching beyond a reach radius of 2.5 to 3 feet from the center of the shoulder at angles other than a normal resting position (horizontally, vertically, or most combinations thereof) increases pain. Rest reduces pain. Rest of 12 hours or more usually removes the perception of pain and discomfort.

Analysis

Information in Support of an HFE Intervention

The LDAR technician's signs of musculoskeletal damage or inflammation in the neck and shoulder area are brought on by carrying the portable analyzer with a shoulder strap over the shoulder. The technician has alternated shoulders throughout the work shift in order to prevent fatigue in either shoulder and has been doing so for many years. Because the symptoms of a musculoskeletal disorder appear when the monitor is carried over the shoulder, disappear with rest, and do not appear when the monitoring activity is not performed; it is likely the technician is in stage 1 and is amenable to ergonomic and job design interventions.

Portable Organic Vapor Analyzer Instrument Attributes

The analyzer weighs 13 pounds and is bulky with physical dimensions of 4 in. x 10 in. x 14 in. The manufacturer provides a shoulder strap for the unit at no charge and offers a back pack separately for an additional cost of just over $200. The analyzers are bulky and heavy due to the user requirement that they be portable and operational for a normal 8 to 12 hour work shift. The nickel cadmium battery contributes the majority of the weight of the unit. Additionally, the analyzer must be able to pull vapors from a source into the analyzer for detection and quantification. Thus each analyzer has a small vacuum pump that operates continuously once the unit has been turned on. The continuous noise, approximately 40 db at a distance of two feet from the ear, generated by the vacuum pump can be considered an annoyance and; therefore, contribute to worker fatigue. Additionally, the vacuum pump and the electronic components within the analyzer generate heat continuously. The heat source is not severe enough to pose an acute exposure concern, but it does contribute to worker fatigue when the analyzer is held proximal to the body.

Instrument Transport

The primary transport method historically employed by LDAR technicians has been the shoulder strap. Ease of use and flexibility have been cited as the primary drivers for the decision to use the shoulder strap. A number of years ago the straps were supplemented with additional padding which made them wider and more comfortable. The padding has since deteriorated. The 13 pound instrument exerts a force of approximately 3.2 pounds per square inch on the shoulder. Figure 3 shows the analyzer, the analyzer transported via shoulder strap, and the analyzer transported via back pack. The arrow in Figure 4 points to the region of the shoulder where the compressive force posed by the strap touches the shoulder musculature.

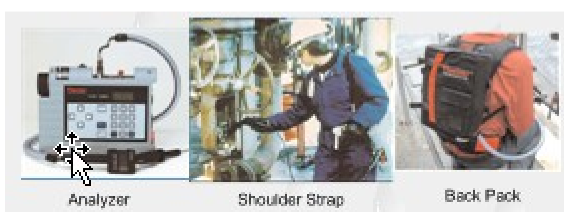

Figure 3. Analyzer, Shoulder Strap, and Back Pack.

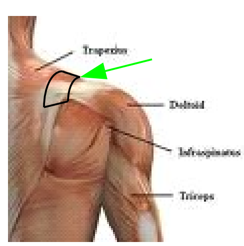

Figure 3. Location of Compressive Forces Posed by Use of Shoulder Strap.

Work Factors

When questioned about possible ergonomic interventions, the technicians consistently rate the need for comfort, mobility, and flexibility as the determining factors in their decisions to transport the monitors over other options. Working from ladders and in extremely narrow passages ultimately determines the ultimate acceptance of new approaches to transporting the analyzers throughout the facility.

HFE Countermeasures

Fine (2000) succinctly summarizes countermeasure development as the intent to provide specific engineering controls to address specific factors or conditions of the physical workplace and job characteristics; administrative controls to address characteristics of the organization thought to be relevant; and to mitigate individual modifiers such as age, gender, body mass index, comorbidity, smoking habits, and reaction to the psychosocial environment at home and at work.

Optimization of Method by which the Instrument is Carried on the Body

An initial attempt to provide an ergonomic solution was to purchase a back pack designed by the manufacturer specifically for the portable monitors. Within two weeks of continued use, the technician with neck and shoulder pain complained of excessive loading of the musculature in the lower lumbar region of the back accompanied by irritation of the sciatic nerve. Subsequently, a custom fabricated front pack similar to the typical baby carrier was evaluated by the LDAR technician. Use of the front pack was quickly discontinued due to the heat generated by the unit being concentrated on the chest and facial surfaces. Additionally, the noise of the vacuum pump was deemed as an annoyance.

After three failed attempts to provide an ergonomic solution seeking comfortable placement on the body for optimal, sustained usage, a combination of benchmarking, technician interviews, and research led to revisiting the standard back pack; but with a slight modification. It was determined that the original manufacturer supplied back pack was missing a crucial human factors engineering design element. It was not constructed with a frame that rested on the hips. Recently a new version with hip supports has been created by the manufacturer. An off the shelf hiking back pack with such a design was purchased and described as much more comfortable by the technician.

Additional Methods of Transporting the Portable Instrument

The optimal HFE intervention would allow the technician to transport the monitor without compressive loads on musculoskeletal tissues or awkward postures. Two types of carts, two wheel and four wheel, were evaluated. The carts purchased for this HFE intervention were standard rectangular laboratory carts. The first four wheeled cart was constructed of light weight high density polypropylene but could not be used by the technician experiencing neck and shoulder pain because the wheels were too small to traverse the various types of grating prevalent in chemical processing areas. The wheels (4.5 in. tall and 1 in. wide) became lodged in the grating nearly every time the cart traveled over a grate. A second four wheeled cart was purchased with much larger wheels (8 in. tall and 3.5 in. wide) and that cart can traverse grating without incident.

A small aluminum frame hand cart similar in appearance to what is commonly referred to as a dolly or hand truck was also purchased. The unit weighs less than 5 pounds and is easily folded for storage.

Perceived advantages and disadvantages of each proposed countermeasure

Clearly the original manufacturer supplied back pack was successful in redistributing the weight of the monitor from one shoulder to two; however, it did not provide enough padding to prevent a deleterious compressive load of the musculoskeletal tissues of the lower back. The manufacturer's first generation back pack was purchased and rejected by the technician due to lower back discomfort. Since then, the manufacturer redesigned the pack and added hip support to the lower frame as can be seen in Figure 3. From and HFE perspective, if the back pack must be used, hip supports must be provided in order to redistribute the load across more surface area of the body; thereby relieving the shoulders. While much improved over the first back pack, the second pack did not have enough padding around the frame or the monitor to be comfortable for the technician to use. Ultimately a pack with hip supports purchased at an upscale sporting goods store was deemed comfortable; however, the neck and shoulder pain returned after just a few days of use.

The two wheel and four wheel carts provide the most relief from an HFE perspective because they remove the condition responsible for the damage to musculoskeletal tissues. The primary disadvantage of carts is that the postures required to push or pull them are not optimal, especially when the carts must be transported through doors. The carts are wide enough relative to the door openings that there is some risk of injury as the technician manages the heavy doors in order to pass through.

Recurring Monitoring Necessary to Determine the Effectiveness of the HFE Interventions

The analyzer must be carried on the body (shoulder strap, back pack, front pack) whenever components to be monitored can only be accessed via ladders or scaffolding, or when the carts are too wide to pass through poorly designed piping passages. In order to convey the long term need to minimize carrying the analyzer on the body, the number of instances where this must be done will be tracked. Any viable corrections to facilities that can be implemented will be identified through recurring review of this “metric”.

Over time, new injuries could develop if actions are not taken to correct the situation such that the technician can stand erect (i.e. no stooping) while moving the cart. An effort to modify (raise) the handles is currently under development.

Conclusion

No clear, irrefutable diagnosis has been provided describing any actual damage in the musculoskeletal tissues of the LDAR technician. Given the early stage of the ailment, no clinical diagnostic test exists to positively conclude whether the technician suffers from neck tension disorder, shoulder tendonitis, or thoracic outlet syndrome. What is known; however, is that the following factors that must be sustained in order to prevent (further) musculoskeletal damage or inflammation in the neck and shoulders of LDAR technician: (1) The use of carts over packs or shoulder straps must be adopted whenever feasible in order to keep compressive loads from support straps off the shoulders. (2) Whenever ladder work is required, choose a back pack with hip supports rather than the shoulder strap as the method of transporting the analyzer. (3) Whenever carrying the analyzer on the body, perform simple stretches of the arms, neck, and shoulders to increase blood flow to the muscles. (An athletic trainer has been contracted to assist in identifying the proper pre-work warm up.) (4) Encourage the LDAR technician, an employee of nearly 30 years, to enlist in a yoga class and to pursue other opportunities to exercise (Free access to multiple exercise facilities is a company provided benefit).

In the two months since providing the carts for transport of the analyzer, the technician has not had a recurrence of sharp neck and shoulder pain accompanied by numbness in the right arm.

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