Chapter 1

Introduction

1.1 Work place and musculoskeletal disorders (MSDS)

The workplace plays pivotal role in functioning of an organization. The functioning of the organization can be improved by making it conducive and for this it is required to examine the interaction between the worker and the environment at the work place [Coelho et al., 2015; Wang et al., 2009]. This is essential for error free production [Kumar et al., 2015]. Adapting tasks, work stations, tools, and equipment to suit workers can help reduce physical stress on their body and eliminate many potential musculoskeletal disorders (MSDs) [Oborne, 1986]. The basic factors: repetition, excessive force, awkward posture, mechanical stress and use of vibrating tools or machines are responsible for MSDs and related pain [LOSH, 2004; Abdo et al., 2013]. Apart from more comfort and higher productivity, ergonomically designed workplace also improves occupational health and safety in a meaningful way and helps to develop better understanding of employability among the workforce [S. Openshaw, 2006; Thun et. al., 2011]. Work based on poor manual handling leads to work-related stress which reflects pattern of reactions from workers and faced with the lack of knowledge, skills or abilities in work demands. The demand may be related to time pressure or amount of work (quantitative demands), or understanding of the work (cognitive demands) or the empathy required (emotional demands), or even displaying one’s emotions at work. This may also be physical, i.e. high demands in the area of dynamic and static loads [Lamontagne et al., 2013].

When the worker perceives a mismatch between demands and environmental or personal resources, this paves way for a number of possible reactions [Haitao et al., 2007; Chiang et al., 2008; Tao et al., 2014]. These may include physiological responses (e.g. increase in heart beat, blood pressure, hyperventilation), emotional responses (e.g. feeling nervous or irritated), cognitive responses (e.g. reduced attention and perception, forgetfulness), and behavioural reactions (e.g. aggressive, impulsive behaviour, making mistakes).

A dramatic increase in work related stress began in the 1970s when these disorders appeared on company’s injury and illness logs. Occupational safety and
health association (OSHA) revealed hazardous workplace conditions led to problems such as tendinitis, carpal tunnel syndrome and back injuries. The Bureau of Labor Statistics, an agency of the U.S. Department of Labor, recognizes MSDs as a serious workplace health hazard. These injuries now account for more than one third of all lost-workdays.

Musculoskeletal disorders (MSDs), are injuries and disorders of the soft tissues (muscles, tendons, ligaments, joints, and cartilage) and nervous system. These can affect nearly all tissues, including the nerves and tendon sheaths, and most frequently involve the arms and back. Occupational safety and health professionals have called these disorders a variety of names, including cumulative trauma disorders, repeated trauma, repetitive stress injuries, and occupational overexertion syndrome. These painful and often disabling injuries generally develop gradually over weeks, months and years. MSDs usually result from exposure to multiple factors that can cause or exacerbate the disorders, not from a single event or trauma such as a fall, collision, or entanglement. MSDs can cause a number of conditions, including pain, numbness, tingling, stiff joints, muscle loss and even sometimes paralysis. Consequently, workers need to spend time in recovering and not involving and even, some never regain full health. These disorders include carpal tunnel syndrome, tendinitis, sciatica, herniated discs, and low back pain. MSDs do not include injuries resulting from slips, trips, falls, or similar accidents [OSHA, 2000].

1.2 Work-related musculoskeletal disorders (WMSDs)

The workforce of production units has to perform under even adverse physical conditions to achieve higher yields [Silverstein and Hughes, 1996; Zetterberg and Ofverholm, 1999; Meena et al., 2012; Singh et al., 2013]. Under extreme physical conditions at work place Musculoskeletal disorders (MSDs) are developed and are commonly known as Work-Related Musculoskeletal Disorders (WMSDs). WMSDs include back strain, shoulder tendonitis, and carpal tunnel syndrome [Patry et al., 1998; Fagarasanu and Kumar, 2003; Cheng et al., 2013]. Most common sufferers are the workers involved in tasks which require excessively forceful and repetitive motion of neck, shoulders, elbows, wrists, hands, finger extremities and this leads to work related upper extremity disorder (WRUED) [Spies
et al, 2007; Ajimotokan, 2009; Coury et al., 2000; Barnhart et al., 1991; Heiden et al., 2013].

Workers health priorities are now driven by demographics. All of the first world nations are facing the threat of rapidly diminishing work force, an aging population, and growing number of pensioners. So prevention as well as efficient management of work place injuries and disabilities has become a priority. At the same time high performance of industrial sector plays a key role in the development of countries [Barbara and Huges, 1966; Barnhart et al., 1991; David et al., 2008; Kumar et al., 2010; Azadeh et al., 2011].

WMSDs problems are prevalent in many countries and in various occupations especially among industrial workers [Delgrosso and Boillat, 1991; Babasaki and Young, 2002; WHO, 2003; Chiasson, 2012].

Current statistics related to injury indicates higher prevalence of WMSDs. In 2001, Bureau of Labor Statistics (BLS) of U.S.A reported over 5.2 million nonfatal occupational injuries and illnesses, of which 2.6 million cases involved lost work days. Of the 5.2 million cases, over 4.9 million were injuries, and over 333,000 were illness cases which involved repeated trauma such as carpal tunnel syndrome [Montgomery, 1995].

In the United Kingdom, 28 February 2002 was declared to be international repetitive strain injury (RSI) awareness day. The trade union council’s figures showed that one in every 50 workers was suffered from the symptoms of RSI. It further claimed that, in 2001, every day 6 workers left their jobs forever because of RSI [Lucire, 2003]. In 1996, the Occupational Safety and Health Administration (OSHA) estimated that workers compensation for WMSDs resulted in approximately $20 billion in direct costs like lost working hours, re-allocation of job, lack of quality and about $80 billion more in indirect costs like compensation and legal costs. Actually, the large numbers of WMSDs and the cost involved therein indicate the urgent need for intervention.

The statistics presented above shows repetitive strain injuries are already at epidemic stages and growing number of people undergoing diagnoses regularly. Consequently the industry can flourish well by keeping an eye on the WMSDs and initiating remedial measures.
### 1.2.1 Causes of work-related MSDs

Prolonged exposure to ergonomic risk factors can cause damage to a worker’s body and lead to MSDs. Exerting excessive force can cause rupture in bones, tendons and ligaments. Excessive repetition of movements can irritate tendons and increase pressure on nerves. Awkward postures, or unsupported positions that stretch physical limits, can compress nerves and irritate tendons. Workers holding static postures or positions for long periods of time, may suffer from restricted blood flow and damaged muscles. Motion at increased speed or accelerated one while bending and twisting, can increase the amount of force exerted on the body. Compression, as reflected in grasping sharp edges like tool handles, can concentrate force on small areas of the body, reduce blood flow and nerve transmission, and damage tendons and tendon sheaths. Less time to recover due to overtime, lack of and/or lesser duration of breaks, and occurrence of failure can leave insufficient time for tissue repair. Excessive vibration, usually from vibrating tools, can decrease blood flow, damage nerves, and contribute to muscle fatigue. The vibration of whole body by driving trucks or operating subways may affect skeletal muscles and cause back pain in lower portion. Working at lower temperature and higher resistance can adversely affect a worker’s coordination and manual dexterity and hence it is required on the part of the worker to apply more force than that needed perform the task. Table 1.1 shows some typical causes of WMSDs.

**Table 1.1:** Activities causing some common work-related musculoskeletal disorders

<table>
<thead>
<tr>
<th>Injury/disorder</th>
<th>Signs and symptoms</th>
<th>Typical causes/ activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carpal tunnel syndrome</strong></td>
<td>Pressure on the median nerve that passes through the carpal tunnel</td>
<td>Repetitive work (e.g. entering data into computer using awkward wrist postures); Work requiring force using awkward wrist postures (e.g., using power tools)</td>
</tr>
<tr>
<td></td>
<td>Tingling, pain and numbness in the thumb and fingers, especially at night.</td>
<td></td>
</tr>
<tr>
<td><strong>Back injuries</strong></td>
<td>Pain in the back or down the leg; Restricted movement of back.</td>
<td>Manual lifting and handling of heavy objects; Awkward back posture; Prolonged static back postures (e.g. computer operator sitting for extended periods of time); Whole body vibration</td>
</tr>
</tbody>
</table>
Continued Table 1.1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Symptoms</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Epicondylitis</strong></td>
<td>Pain and swelling at the site of the disorder while using hand and arm; inability of holding even light weights.</td>
<td>Repetitive extension and flexion of the elbow with rotation of the forearm. Tasks requiring additional force (e.g., folding laundry or preparing and/or serving food)</td>
</tr>
<tr>
<td><strong>Muscle strains</strong></td>
<td>Local pain and swelling; Decreased ability to use muscle</td>
<td>Overuse of muscles (e.g., computer data entry work)</td>
</tr>
<tr>
<td><strong>Rotator cuff</strong></td>
<td>Local pain at the front of the shoulder; deliberate or willingly lesser use of shoulder</td>
<td>Overuse, repetitive outer range, above the head movements</td>
</tr>
</tbody>
</table>

1.2.2 Biomechanical approach to WMSDs

Biomechanics is the study of forces acting on the human body and the effect of these forces on the body’s tissues, fluids, or materials [National Research Council and Institute of Medicine, 2001]. A worker may experience biomechanical loading due to physical as well as psychological body activities, which can exceed internal tolerances of the body mechanism, thereafter may result into various consequences like muscle fatigue, pain and discomfort and whereby a state of work-related musculoskeletal disorder is visibly gained. Biomechanical loading due to working activities and subsequent strain developed beyond internal tolerance limit of body tissues may result into pain, discomfort and WMSD. All individual factors, that depend on the human body metabolic system and vary in effect from person to person depending on individual susceptibility to the biomechanical risk factors like repetitive work and working in a static postures. These factors have been found instrumental in predicting musculoskeletal symptoms in a large variety of occupational groups [Radwin et al., 2002; Hystad, et al.2012].

Every clinical disorder represents a complex interaction between the affected individual and a set of determinants to respond to injury in a particular individual. In Figure 1.1 the orthogonal axes represent individual risk factors in terms of mechanical, psychological and physiological characteristics and their interaction for development of musculoskeletal disorders. One plane contains the mix of the
individual’s characteristics and social interaction. Second includes physiological characteristics of the individual, including tissue response to load, age, and presence of medical co-morbidities; and the third one includes mechanical exposures, such as physical job demands resulting in external loading.

Figure 1.1: Impact of risk factors for the injury, impairment, and disability attributed to musculoskeletal disorders in the individual [National research council and institute of medicine, 2001]

The importance of each circle, and hence its contribution to the risk of disorder, shows variation among individuals and the work environments they are exposed to. At the centre, the three planes overlap to define a region of risk for disorder, emphasizing the principle that the risk is multi-factorial and reflects the varying contribution of each set of factors, and their tolerance limit. In addition to their specific contributions, the extent to which the planes interact is influenced by social, medical, organizational, and other factors in terms of tolerance and their miscibility. The probability of disorder caused by these factors varies accordingly. The overlap between psychological and physiological characteristics represents the interaction among tissue vulnerability to load, pain, and its effect on the individual. Finally, the overlap between physiological and mechanical planes symbolizes the relationship between physical stressors and response of body tissue to it.
A better understanding of the factors and their interaction is shown in Fig. 1.2. The contributing factors are organized into two broad categories: workplace factors and characteristics of the person and they may affect the development of musculoskeletal disorders. Workplace factors include the external physical loads associated with job performance, as well as organizational factors, and social context variables.

![Conceptual model of factors that may play a role in the development of WMSDs in human body](image)

Fig. 1.2: Conceptual model of factors that may play a role in the development of WMSDs in human body [National research council and institute of medicine, 2001]

The dotted box outline on the right shows mechanisms that vary from one individual to another. The dotted box on the left indicates possible influence of workplace on the sequence of events that can lead to musculoskeletal disorders in the person. Arrows between “Workplace” factors and “Worker” box indicate the
various research disciplines (epidemiology, biomechanics, and physiology). The term ‘load’ describes physical stress acting on the body or on anatomical structures within the body. These stresses include kinetic (force), kinematic (motion), oscillatory (vibration), and thermal (temperature) energy sources. Loads can originate from the external environment such as the force generated by a power hand tool and be reflected upon the individual or they may result from voluntary or involuntary actions of the individuals (in lifting objects). The term ‘tolerance’ is used to describe capacity of physical and physiological responses of the body to loading [Radwin et al., 2002; Jezukeitis et al., 2011]. External loads resulting from work are transmitted through biomechanical forces of the limbs and trunk to create internal loads on the tissues and anatomical structures. Relevant biomechanical factors include body position, exertions, and motions. Biomechanical loading is also affected by individual factors such as anthropometry, strength, agility, dexterity, and other factors mediating the transmission of external loads to internal loads on anatomical structures. When the load exceeds limit of mechanical tolerance or the ability of the structure to withstand the load, damage of tissue occurs.

1.2.3 Upper extremity disorders and the workplace

The pattern of occurrence of upper extremity disorders, supports an important role of physical factors, particularly repetition, force, and vibration. The most dramatic physical exposure occurs in manufacturing, food processing, lumber, transportation, and other heavy industries, and the highest rate of work related upper extremity disorders has been reported in these industries.

A number of characteristics of an individual worker appears to affect vulnerability to work-related musculoskeletal disorders, including increasing age, gender, body mass index, and a number of individual psychosocial factors. These factors are important as contributing and modifying influence on the development of pain and disability and in transition of nature from acute to chronic one. Modification of various physical factors and psychosocial factors could substantially reduce the risk of symptoms for low back and upper extremity disorders. The literature related to basic biology and biomechanics provides an evidence to plausible mechanisms correlating musculoskeletal disorders and workplace physical exposures [Dunning et al., 2010; Nimbarte, 2013].
1.3 Repetitive strain injury (RSI)

WMSD may occur due to repetitive or non-repetitive work. Repetitive strain injury (RSI) occurs due to repetitive work and this forms a major part of WMSD. RSI (also known by several names like: repetitive stress injury, repetitive motion injuries, repetitive motion disorder, cumulative trauma disorder, occupational overuse syndrome, overuse syndrome and regional musculoskeletal disorder) is an injury of musculoskeletal and nervous systems and are caused by repetitive tasks, forceful exertions, vibrations, mechanical compression (pressing against hard surfaces), or sustained or awkward positions [Cho et. al, 2012; Lee et.al., 2015].

Hearing and seeing a virtuoso pianist playing a rapid trill sequence or observing a skilled typist hitting up to seven keys per second gets one realize that the human neuromotor system is capable of achieving extraordinary things. However, on the downside it is also to be noticed that many people have experienced musculoskeletal discomfort and dysfunction of their upper limbs and that by making an effort to display highly developed skills [Barnhart and Rosenstock, 1987; Smith and Savage, 2008].

The disorder caused by RSI is insidious and it creeps up over a varying period in terms of weeks, months, or even years. Often patients recall only the day they could not take the pain anymore or could not continue to work. The process is like that by which a dam gets slowly filled in with water but at a point of time suddenly it overflows [Pascarelli, 2004; Lucire, 2003].

Various symptoms of RSI are fatigue or lack of endurance, weakness in hands or forearms, tingling, numbness or loss of sensation, lost/weakening of hand grip strength, heaviness of hands as feeling like dead weight, clumsiness of hands, lack of control or coordination, chronically cold hands, frequent self-massage (subconsciously) and using non-dominant hand more frequently [Health and safety information sheet, 2010; Wunderlich, 1993; Coury et al., 2000]. The longer it goes unrecognized and untreated, its condition becomes worse.

There are three broad stages in development of RSI:

In the first/early stage of RSI, ache, pain, tingling and feeling of warmth in the hands, arms, neck or shoulder is caused by early inflammation arising from intensive work. These may go away after a night’s rest. Sometimes, nearly
everybody suffers from these but it may remain at this level for months and this sign/ state needs to recognized at the earliest.

In the second stage of RSI, recurrent pains, aching and fatigue occurs initially during working days. These symptoms persist at night, causing sleeplessness, and may go on for months [Handy and Lafreniere, 2006]. People who continue to work despite this by resorting to painkillers or without rest or treatment at this stage may be led to very serious conditions. Painkillers do exactly what its name implies. They aim at killing pain but not curing it.

Third stage of RSI is recognized by irreversible constant pain and weakness, even during the period of rest [Gorsche et al., 1999]. At this stage ability to work and to carry out even light tasks at home gets adversely affected. There is frequent swelling of wrists and hands and they may be unusually cold and may turn almost blue on account of restricted circulation of blood. This stage of RSI may be very dramatic one and may lead hands to suddenly “seizing up” [Manu, 1998].

1.3.1 Types of RSI

There are two types of RSI viz. Symptomatic and Idiopathic.

a) Symptomatic: Symptomatic RSI (Type I) includes well defined syndromes such as carpal tunnel syndrome (pain and compression in the wrist), tendonitis (inflammation of a tendon), tenosynovitis (inflammation of a tendon sheath), frozen shoulder, etc. These conditions may arise or get worsened due to repetitive tasks. However, these syndromes are also common in people who are not exposed to repetitive tasks. These syndromes may have other symptoms such as swelling, inflammation and nerve compression problems [Babaski and Young, 2002]. This may range from ordinary daily stress to truly bad work setups and work conditions.

b) Idiopathic: Idiopathic RSI (Type II) gets recognized by symptoms which do not fit into a well-defined syndrome. Also, there are no 'objective' or 'measurable' signs such as inflammation, swelling or problems with nerve function. Hence, it is sometimes called 'diffuse RSI' or 'non-specific pain syndrome' [Pope, 1997; Kemp et al., 2009; Finneran and Sullivan, 2010].

1.3.2 Findings of positive RSI

Typically several findings have been reported on observation of patients with complaints related to RSI. Most common of them are discussed as follows:
a) Poor posture

The more frequent physical finding in RSI is a characteristic postural misalignment. The head controls glands, blood vessels, and smooth muscles. The sympathetic nervous system is a part of the autonomic nervous system and therefore, it is not under conscious control. The patient’s hands are cold and sometimes sweaty, and his perception of pain is usually very high [Fredriksson et al., 2001]. This state is called reflex sympathetic dysfunction. In this case, rapid intervention is important, because such patients are approaching more serious complication known as reflex sympathetic dystrophy/complex regional pain syndrome (RSD/CRPS).

b) Loss of shoulder range of motion

The restricted shoulder movement becomes painful when extreme movements are attempted. Correcting these conditions is a tedious task because performing activities with limited shoulder movement shifts the workload to more delicate forearm and hand muscles. Bicipital tendinitis occurs when the tendons of the biceps muscle become irritated in a groove at the shoulder. Postural misalignment is usually associated with such conditions [Okada et al., 2000].

c) Cubital tunnel syndrome

Cubital tunnel syndrome is more common as compared to carpal tunnel syndrome. As the ulnar nerve comes down the arm to the elbow from the neck, it comes to an area where the ulnar nerve must pass over a notch at the elbow, and which is covered by an arched ligament, creating a tunnel (the cubital tunnel). If the compression at the elbow persists even just for a few months, it can cause a painful condition known as tardy ulnar nerve palsy.

d) Thoracic outlet syndrome

Thoracic outlet syndrome is marked by compression of blood vessels between neck and shoulder caused by carrying heavy objects above shoulder height.

e) Radial tunnel syndrome

Radial tunnel syndrome, also known as supinator syndrome, results from traction and compression of the radial nerve as it enters the tight canal near the elbow. Basically, the nerve gets caught between two layers of supinator muscles on its way to hand. This may result into deep forearm pain followed by gradual fist weakness. This same area may also be affected in tennis elbow.
f) **Raynaud’s syndrome**

This is also known as Vibration White Finger. The blood vessels of the hand are damaged (narrowed) by repeated exposure to vibration for long time.

**g) Myofascial pain syndrome**

When muscles get injured, they release chemicals that stimulate nerve fibers, causing pain, soreness, and contraction in the hands, forearms, neck, and upper back. With more severe injury, swelling and inflammation occur. Myofascial pain syndrome is common condition observed in people with RSI.

**h) Bursitis**

Every person has hundreds of bursa (small sacs) scattered throughout the body and lying between tendon and bone or skin. The function of a bursa is to decrease friction between two surfaces that move in different directions [Mogk and Keir, 2008; Dogan et al., 2009]. A problem arises when a bursa becomes inflamed. The bursa loses its gliding capabilities, and becomes more and more irritated when it is moved. When the condition called bursitis arises, the normally slippery bursa becomes swollen and inflamed. The added bulk of the swollen bursa causes more friction within the space already confined [Pascarelli, 2004]. Bursitis usually results from repetitive movement or due to prolonged and excessive pressure. Patients who rest on their elbows for long periods or those who bend their elbows frequently and repetitively (such as an assembly line worker performing long hours of work) can develop elbow bursitis. Similarly in other parts of the body, repetitive use or frequent pressure can irritate a bursa and cause inflammation. Traumatic injury is a cause of bursitis.

**i) Dupuytren’s contracture**

It involves thickening of deep tissues that are passing from the palm of hand into fingers. The ring finger and the little finger get most commonly affected. The middle finger may be affected in advanced stages, but the index finger and the thumb are almost always spared. In patients with this condition, the tissues under the skin on the palm of hand thicken and shorten so that the tendons connected to the fingers cannot move freely. Rock climbers or manual labourers involved in manual work and associated with constant stress and micro-traumas of the tendons while climbing or absorbing shock of heavy blows of sledgehammers, jackhammers, spud bars, etc. are generally found suffering from this condition. It generally develops in both the hands and finds no connection to dominance of hands. Dupuytren's contracture
decreases ability to grip objects. Dupuytren contracture may initially develop a
minor painless lump in the palm of hand and near the base of fingers. As Dupuytren
contracture progresses, it may lead to an inability to fully extend the affected finger
from the flexed position. This may result into a loss of normal grasping [Patry, 1998].

j) Epicondylitis

It is a common term for a condition caused by overuse of arm and forearm
muscles and this results into elbow pain. Though the injury can happen to almost
anyone, it is commonly associated with playing tennis and other racquet sports and
hence it is called tennis elbow. It is caused by sudden injury to muscle and tendon
area around the outside of the elbow. Tennis elbow specifically involves the area
where muscles and tendons of the forearm attach to outside bony area (called the
lateral epicondyle) of the elbow. Tennis elbow is an overuse injury occurring in
lateral side of the elbow region, but more specifically, occurs at common extensor
tendon and it originates from the lateral epicondyle. Sportspersons as well as those
who used to take repetitive motion for many years, especially in their profession,
suffered from tennis elbow. Majority of patients suffer from tennis elbow in their
right arms. During early experiments, it was thought that tennis elbow was primarily
caused by overexertion. The study has shown that trauma such as direct blows to
epicondyle, a sudden forceful pull, or forceful extension have caused more than half
of these injuries. Radial nerve injury was also significantly involved in developing
tennis elbow. Disorders such as the rotator cuff and carpal tunnel syndrome may
also increase chances of tennis elbow [Lucire, 2003].

k) Rotator cuff syndrome

Rotator cuff tear is the most common conditions which affect shoulders. It
involves inflammation of muscles and tendons in the shoulder [Garg et al., 2006].
Rotator cuff impingement syndrome is divided into three stages of severity. In stage
I, swelling and/or bleeding occurs. Stage I is frequently associated with an overuse
injury. At this stage, the syndrome can either be reversed or it can progress. In stage
II, there is inflammation of the tendon (tendinitis) and development of scar tissue
(fibrosis). Stage III generally involves a tendon rupture or muscle tear and often
represents fibrosis and tendinitis for years. Workers at risk of rotator cuff syndrome
are those who repeatedly move heavy weights over their heads, such as painters,
welders, plate workers, and slaughterhouse workers. This syndrome also has been reported in sewing machine operators. It can occur in athletes who engage in sports such as swimming, tennis, weightlifting, and baseball in which the arm is repeatedly raised over the head [Kelly et al., 1995]. Younger individuals are more likely to experience rotator cuff syndrome as a result of trauma, overuse, shoulder joint instability, or muscle imbalance. In older individuals, the syndrome is more commonly related to chronic wear and shoulder degeneration. Rotator cuff syndrome generally occurs in the dominant arm.

1) Carpal tunnel syndrome

Carpal Tunnel Syndrome is a repetitive strain injury (RSI) and it involves swelling of the tendons located inside the tunnel space. The tendons of hands are wrapped with a lining that produces a lubricant/slippery fluid (synovium) which lubricates tendons. But with repetitive movement of the hand, the lubrication system may be deficient. This reduction in lubrication results in inflammation and rubbing of tendon area. Repeated episode of swelling causes thick tissue to form and prevent tendon movement. This causes the medium nerve entrapment [Zetterberg and Ofverholm, 1999].

Out of various syndromes related to RSI conditions, carpal tunnel syndrome is the area of interest in this study which has been explained further in detail.

1.4 Carpal Tunnel Syndrome

Carpal Tunnel Syndrome (CTS) is a symptomatic compression neuropathy of the median nerve at the level of the wrist/hand and characterized physiologically evidence with increased pressure within the carpal tunnel and decreased function of the nerve at that level. It is characterized by patients reporting numbness, tingling, hand and arm pain and muscle dysfunction. [Kouyoumdjian et al., 2002, Werner et al., 1994, Simon and Tenkku, 2011].

The relentless stress combined with a sedentary life style and sub-optimal diet has resulted into a dysfunction of epidemic proportions: Carpal Tunnel Syndrome [Wunderlich, 1993]. CTS involves swelling of the tendons located inside the tunnel space, resulting in pressure on the median nerve and that causes pain in wrist and hand [Coury et al., 2000; Lopes et al. 2011; Martin et al. 2013]. The carpal tunnel consists of tissues (transverse carpal ligament and 9 flexor tendons) that surround the median nerve as it passes through wrist and palm area. If this median
nerve gets compressed CTS disorder occurs, and it is marked by weakness and pain in hand and wrist [Carpal tunnel syndrome, Technical Learning College, 2008].

Carpal tunnel syndrome (CTS) originates from over-worked, over-strained muscles of arms and hands, and it results into a loss of nerve conductivity and it leads to muscle strength problems [Jones, T., Kumar, S., 2004; Montgomery, K., 1995; Kostopoulos, D., 2004; Nordstrom, DL, et al. 1997; Kumar et al., 2010].

A neuroorthosis control system in patients with CTS may be good to limit wrist movements with better degree of freedom. [Giersiepen, K. et al., 2000; Üğurlu, U. et al., 2008]. Wrist deviation occurs in almost all industrial and office jobs and it appears to be hazardous for carpal tunnel syndrome. Proper wrist position is likely to decrease hazard of carpal tunnel pressure [Fagarasanu, 2004]. Providing higher quality medical care to workers occupationally having carpal tunnel syndrome (CTS) may reduce disability, facilitate return to work, and lower the cost involved therein [Nuckols, T., 2011]. Median nerve mobility is observed in carpal tunnel dynamically and with ultrasound during wrist and finger flexion and extension and defines difference between normal people and patients with CTS [Yi-Ho, 2010].

1.4.1 Anatomy of human hand and CTS

Anatomy of hand is shown in Figure 1.3 to display the better understanding of CTS. Movement in the body parts is caused by muscles. Muscles must be well supplied with nutrients and must be connected to functioning nerves. Good performance requires that muscle attachment to tendons, ligaments, and bones remain intact and that the joints are in good condition. Muscles that are not in good tune with other muscles can instigate events leading to damage of soft tissues. The cascading factors of postural deterioration damage nerves, other soft tissues, and ultimately many other muscles of the body [Pascarelli, 2004]. Nerves play an important role in CTS because it is the nerves that get trapped or pulled in the injured soft tissues and cause pain - the most common symptom of CTS. Nerves carry pain messages from the site of tissue damage to the brain.

In most serious injuries of reflex sympathetic dystrophy/complex regional pain syndrome (RSD/CRPS), the sympathetic branch of the involuntary nervous system, regulates basic body functions, triggers severe symptoms of pain, temperature and skin color change, swelling, and sweating. And, of course, all these affect motor function [Kogosowski, 2010]. The main nerve controls the last two
fingers of hand and which passes outside the carpal tunnel is called Ulnar nerve and the nerve which controls the thumb, index and middle fingers of hand is called Median nerve.

Figure 1.3: Anatomy of human hand
[http://en.wikipedia.org/wiki/Carpal_tunnel_syndrome]

Tendons are collagenous tissues that form the links between muscles and bones. The orientation of collagen fiber in tendons is in the form of parallel bundles. This arrangement of fibers minimizes the stretch or creep in these tissues when subjected to tensile loading. Tendons are surrounded by synovial tissues, which serve to lubricate tendons. With repeated loading these synovial tissues can become inflamed, resulting in reduction of lubrication and may cause damage to tendons [Radwin et al., 2002]. In human body, carpal tunnel or carpal canal is the passageway on palmar side of the wrist that connects forearm to middle compartment of deep plane of the palm. In carpal tunnel, the tendons of fingers surround the median nerve. Swelling of tendons reduces the space in tunnel and squeezes median nerve which is softer than the tendons. The pressure on this nerve can injure it. Such injury results in sensation of numbness, tingling, pain, and clumsiness of the hand. This combination of symptoms is called carpal tunnel syndrome. People with carpal tunnel syndrome experience difficulty in performing
tasks such as unscrewing bottle tops, fastening buttons, or turning keys [Carpal tunnel syndrome, Technical Learning College, 2008]. Transverse Carpal Ligament (TCL) encompasses ligaments tied together, and ligaments tying muscle to bone, bone to bone, and bone to other soft tissue. But ligaments are also dynamic structures that play an active role in maintaining joint stability and sending signals to the brain regarding their status. Ligaments control the limits of joint movement and prohibit exaggerated ones [Pascarelli, 2004]. Abductor Pollicis Brevis (APB) is a flat, and thin muscle located just under the skin. It is a thenar muscle, and therefore contributes to the bulk of the palm's thenar eminence. Abduction of thumb is defined as the movement of thumb and is controlled by Abductor Pollicis Brevis. The abductor pollicis brevis (APB) is a member of the thenar muscles and is often affected by muscle atrophy associated with carpal tunnel syndrome (CTS) [Wunderlich, 1993; MacDermid and Wessel, 2004].

1.4.2 Symptoms and causes of CTS

The typical symptoms of carpal tunnel syndrome are tingling of thumb, and that of index, middle, and ring fingers, and pain at night. The pain finds the patient sleepless, but he is often relieved of the pain by shaking, hanging, or massaging hands. Pain may involve not only hands, but also arms and shoulders. Numbness and loss of manual dexterity occur in more advanced cases. Weakness of hand also occurs, causing difficulty in grasp and pinch. The victim may drop objects or be unable to use keys or count by using affected hands. The skin may become dry because of reduced sweating [OSHA, 2000]

Most cases of CTS are idiopathic and without a known cause. A common factor considered in developing carpal tunnel symptoms is increased use of hand activity but it is yet to be investigated for clear understanding. Physiology and family history may play a significant role in individual's susceptibility to CTS. Further, more stress, trauma and several other diseases are also possible causes of CTS. Like many musculoskeletal disorders, CTS also has variety of causes. It is more often the result of a combination of factors viz. genetic predisposition, health and lifestyle, work place factors, anatomic factors, and alterations in balance of body fluids [Pascarelli, 2004; Mogk and Keir 2009].
a) Genetic predisposition

Certain people are more likely than others to develop CTS. The amount of natural lubrication for flexor tendons varies from person to person. The less lubrication paves way for more likelihood of CTS. One study has revealed a relation between cross-sectional shape of the wrist, geometry of carpal tunnel, and occurrence of CTS [Mogk and Keir, 2008].

b) Health and lifestyle

People with diabetes, gout, and rheumatoid arthritis are more prone to develop CTS. The hormonal changes related to pregnancy, menopause, and use of birth control pills are also found responsible for CTS. Job stress has also been linked to an increased likelihood of CTS. It is seems to have more vulnerability among alcoholics [Montgomery, 1995].

c) Work place factors

It's possible that working with vibrating tools or on an assembly line that requires prolonged or repetitive flexing of the wrist may develop harmful pressure on median nerve, or worsen existing nerve damage. While flexing hands or fingers, flexor tendons rub against walls of the carpal tunnel. If the hand is allowed time to recover, this rubbing is not likely to lead to irritation. The amount of recovery time required varies from fraction of a second to minutes, depending on nature of circumstances, including genetic and health factors, intensity of flexing, weight of any objects in hand, and extent of bending wrist.

d) Anatomic factors

A wrist fracture or dislocation that alters space within carpal tunnel may develop extraneous pressure on median nerve. Also, carpal tunnel syndrome is generally more prevalent in women. This may be due to their smaller carpal tunnel area as compared to that in men. Women having carpal tunnel syndrome have been found to have smaller carpal tunnels as compared to healthy women.

e) Alterations in the balance of body fluids

Certain conditions such as pregnancy, menopause, obesity, thyroid disorders and kidney failure affect level of fluids in the body and thereby pressure within the carpal tunnel also gets affected. Excessive pressure can constrict blood flow and cause nerve damage. The symptoms of compression are pain, loss of sensation, and decreased function of hand.
1.4.3 CTS risk factors

A risk factor is any attribute, experience or exposure that increases the probability of occurrence of a disease or disorder. It is very difficult to identify specific risk factors of CTS because many risk factors may interact simultaneously. Moreover, the interaction between risk factors may have a synergistic effect rather than an additive effect in developing CTS. It is also difficult to isolate occupational stressors from other risk factors including personal and psychosocial factors. Individual susceptibility further compounds the problems. These risk factors are classified largely into two groups: occupational (physical) factors consisting of task and environmental conditions, and personal factors including age, gender, anthropometric factors and medical history [Armstrong, 1986].

a) Occupational risk factors

CTS may arise from ordinary movements that include repetitive activities such as gripping. These movements may become hazardous if they are repeated in a forceful manner and on awkward posture without sufficient time for rest i.e. recovery time. The major risk factors in this group are forceful exertion, repetitive motions, awkward postures, localized contact stresses, vibration, and cold temperature [Armstrong, 1986; Hagberg et al., 2008; Murgia et al., 2011; Vanti et. al. 2012].

(i) Forceful exertion: Most jobs require some degree of force to move loads, resist gravity, and stabilize the body. Manual tasks in manufacturing and production industries often involve exertion of high pinch or grip forces on hand tools or workplaces, and that also often within very small cycle times i.e. amounting to thousands of forceful pinches per day. The research in line reported reveals that the risk of CTS increases with an increase in forceful exertions. Tasks requiring forceful exertions place higher loads the muscles, tendons, ligaments and joints. As muscle force increases in response to static and dynamic task loads, circulation within the muscle decreases, and which in turn accelerates development of localized fatigue [Silverstein et al., 1987; Kroemer, 1989; Bussieres 2008; Herin et al. 2006; Murgia et al. 2011].

(ii) Repetitive motions: A number of study identified repetitive motion as a risk factor associated with development of CTS. Many workers perform same task involving similar motion time and again, sometimes thousands
or tens of thousands time each day. Repetitive motion at higher frequency requires fast muscle contractions, and thereby muscles become less efficient and require larger recovery time as muscle capacity to produce force diminishes with increase in contraction speed [Silverstein et al. 1987; Roquelaure et al., 1997; Herold et al. 2008].

The repetitive and forceful movement of hand and wrist during work or leisure activity can cause carpal tunnel syndrome. Repeated motion performed during the course of normal work or other daily activities can result into repetitive motion disorder called: Bursitis. It is inflammation of bursa sacs. Bursa are fluid-filled sacs located in the areas thereby it where muscles and tendons glide over the bones. The bursa can become inflamed and makes movement stiff and painful. Tendinitis (tendonitis) is inflammation of tendon. Tendons connect muscles to bones. When tendons become inflamed, the movement becomes stiff and painful. Tendinitis is inflammation of tendon. Inflammation of tendon sheath is called tenosynovitis.

(iii) Awkward posture: Awkward posture is one of the most commonly cited risk factors for CTS. Common examples of awkward wrist postures include excessive flexion, extension, radial and ulnar deviation, and pinch grips. Awkward postures overload muscles and tendons, loads joints in an asymmetric manner, thereby blood flow gets inhibited. The median nerve may be under considerable risk during awkward hand postures places and this extreme pressure on the flexor tendon. In fact, larger compressive forces have been found in median nerve when hand movement involve simultaneous pinching and extreme wrist flexion [Kair et al., 2007; Armstrong, 1986; Hagberg et al., 2008; Mogk and Keir 2009].

b) Personal risk factors

Musculoskeletal disorders including CTS are not always work-related. These disorders may occur due to recreational activities and may even occur with unknown cause [Nathan et al., 2002; Westgaard and Jansen, 1992; Kaplan et al. 2008]. Risk of CTS increases with aging year. Categorically, active workers over 40 years old are 20 percent more at risk than younger workers [Tanaka et al., 1989; Phalen, 1951, 1966].
The development of CTS has also been related to previous medical history. Several diseases or trauma such as chronic trauma, bone fracture, rheumatoid arthritis, bone disease, and hypertension have been found in medical history of CTS patients [Putz-Anderson, 1988; Phalen, 1951, 1966; Tanaka, et al., 1989; Lo, et al., 2009]. Anthropometric consideration showing a small wrist or hand size is a potential risk factor as the force per unit surface area on median nerve during wrist deviations is higher as compared to larger wrist or hand. Body mass index (BMI), a measure of obesity, has also been found to be significantly associated with an increased likelihood of having CTS. It was found that individuals whose BMI exceed 29 were 2.5 times more likely to be diagnosed of CTS as compared to persons of BMI less than 20 [Nathan, et al., 2002; Werner, et al., 1994; Mieog, et. al., 2012]. Conceptual representation of risk factors, their interaction and mechanism of CTS is shown in Figure 1.4.

1.4.4 Work related CTS

The nature of profession, repetitive activities performed, equipments /tools used in performing a job and other ergonomic factors are major work related causes of CTS and are shown in Table 1.2.
Figure 1.4: Conceptual representation of the mechanism of CTS
Table 1.2: Work-related activities resulting into CTS development

<table>
<thead>
<tr>
<th>Job Tasks/ Activities</th>
<th>Occupations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasping and tugging fabric, pulling cloth</td>
<td>Production sewer, tailor, garment worker</td>
</tr>
<tr>
<td>Milking cows</td>
<td>Farmers</td>
</tr>
<tr>
<td>Handling objects on conveyor belts</td>
<td>Assembly-line workers</td>
</tr>
<tr>
<td>Pushing down ratchet, using screw driver</td>
<td>Mechanic</td>
</tr>
<tr>
<td>Hand weeding</td>
<td>Gardener</td>
</tr>
<tr>
<td>Using spray gun</td>
<td>Painter</td>
</tr>
<tr>
<td>Knitting</td>
<td>Home maker</td>
</tr>
<tr>
<td>Using scanner at checkout</td>
<td>Security person</td>
</tr>
<tr>
<td>Key punching, typing</td>
<td>Clerical worker</td>
</tr>
<tr>
<td>Cutting, de-boning</td>
<td>Butcher/poultry-processing worker</td>
</tr>
<tr>
<td>Turning keys</td>
<td>Locksmith</td>
</tr>
<tr>
<td>Pressing tool into palm</td>
<td>Painter, carpenter, Table hand</td>
</tr>
<tr>
<td>Stamping machine</td>
<td>Receipt processor</td>
</tr>
<tr>
<td>Using air-powered hand tools</td>
<td>Assembly workers</td>
</tr>
</tbody>
</table>

Internationally the relationship between CTS and repetitive motion is being debated and work is going on. OSHA has made investigations and based on its findings adopted rules and regulations regarding cumulative trauma disorders. The American Society for Surgery of the Hand (ASSH) has issued a statement that the current literature does not support a contributory relationship between specific work activities and development of diseases such as CTS. The relationship between work and CTS is still unfounded. But many cases of carpal tunnel syndrome has been found to be developed from repetitive grasping and manipulating activities, and cumulative exposure. The study carried out at National Institute for Occupational Safety and Health (NIOSH) indicates that job tasks involving highly repetitive manual acts or requiring wrist bending or other similar stressful wrist postures are connected with incidence of CTS or related problems [Singh et.al. 2005; Mieog et.al. 2012].
1.4.5 CTS treatment

When symptoms of carpal tunnel syndrome are mild or likely to be temporary, treatment includes rest, anti-inflammatory drugs, and a metal splint. Even if a patient wears a splint that has been prescribed, he or she should avoid activities that may cause or aggravate injury. Where this is not possible, patients should wear the splint after work and particularly during sleeping hours. Carpal tunnel syndrome goes diagnosed without treatment. Resting the affected hand at night in a splint may alleviate symptom. If symptoms persist, a small quantity of a corticosteroid drug may be injected into ligament of the wrist. If this fails to help, surgical cutting of the ligament may be performed to relieve pressure on the nerve. Surgery is a usual treatment of choice for classic carpal tunnel syndrome. Typically, 80-90% of patients will have permanent relief of their symptoms following division of the wrist ligament (transverse carpal ligament) which covers the carpal tunnel. The release of scar around median nerve and partial removal of tendon bursae (sheath) is added in selected cases. Surgery becomes necessary if symptoms are severe and other measures do not provide any relief. Surgery should not be the first choice for treatment. Even after surgery, a number of patients may still have some problems. It has been reported that weakness of grip in the operated hand persists in about 30 percent of cases [Carpal tunnel syndrome, Technical Learning College, 2008].

1.5 Motivation and objectives

Manufacturing industries suffer from absenteeism and heavy compensation caused due to CTS symptoms. A study of circumstances in which CTS occurs at workplace under repetitive manual postural movements of upper extremities can help in growing awareness of CTS among industrial personnel and identifying idiopathic nature of RSI, in general, and CTS in particular. The main objectives of the present work are-

i) To identify specific upper extremities of assembly line workers involved in repetitive manual work and subsequent comparison of other wrist/hand symptoms/signs, they show, and prevalence of CTS in actual industrial environment by conducting appropriate surveys.
ii) To investigate and identify a relation between CTS symptoms and state of demographics.

iii) To have an identification of CTS and its quantification among the workers suffering from CTS symptoms by making use of sEMG signals.

iv) To study effect of manual and semi ergonomic work on prevalence of CTS.

v) To have an identification of potential injury caused by hand arm vibration (HAV) and its relation with CTS symptoms.

vi) To study the relation between pinch strength and potential CTS symptoms.

1.6 Significance of work

Manufacturing companies are faced with diverse and mounting pressure due to more sophisticated market, changing customer choice and global competition. With globalization the marketplace has broadened and the pace of competition has in fact brought customer’s demand on manufacturer side to enhance the quality of the product and its flexibility at even lower price [Dangyach and Deshmukh, 2006]. This demand has led occupational people to do work at a relatively fast pace and hence repetitively. This has led to trigger Repetitive Strain Injury and several other musculoskeletal disorders, whereby main work force i.e. adult population of a nation get affected. This suffering has arisen by putting muscles of arms and hands beyond limit of safer strain at the cost of nerve conductivity and muscle strength [Kumar, et. al., 2010; Montgomery, K., 1995]. This has been a guiding force for the research work being carried out and detailed in this thesis.

The present research work is aimed at investigating and making use of the findings in predicting possibility of CTS the workers involved in manual assembly units may suffer and hence enable the management to take preventive measures for avoiding the possible loss. Methods for identification of CTS may also be utilized in industry to redefine process in order to reduce prevalence of CTS in workforce and to develop suitable process planning accordingly.

1.7 Scope of research

The present research work aims at identifying and studying Carpal Tunnel Syndrome (CTS) among workers involved in repetitive job in manual assembly line units. For quantifying CTS, the case studies of workers involved in repetitive nature of job in different industrial units have been under taken.
This research has been carried out to serve industrial purpose and hence, the medical intricacy and required surgical treatment lies outside the domain of the present study.

1.8 Originality of research

Having carried out an extensive survey of literature in line it has been found that a sort of literature on systematic study of CTS is available but that related to assembly line of manufacturing industry has been very rarely found. Keeping this in mind data on CTS were collected from some industrial pockets in northern part of India. In good compliance with aim and objective of research work, it is capable of making following contributions -

i) The effect of repetitive postural movements of upper extremities on prevalence of CTS has been investigated in manual assembly line of manufacturing units.

ii) Out of the other upper extremities (e.g. hand, wrist and shoulder), repetitive use of finger dominated manual work has been studied and it has been found to be playing a vital role in occurrence of CTS in assembly line of manufacturing units.

1.9 Organization of the thesis

The thesis is organized in eight chapters. Basic review of the phenomena of musculoskeletal disorders including repetitive strain injury and carpal tunnel syndrome (CTS) has been discussed in First chapter. It also contains defined objectives for the work. In the Second chapter review of the past work in the same field has been mentioned along with identified research gap. Material and methods for the study are covered in the Third chapter. In the Fourth chapter focus is on investigating prevalence of CTS occurrence in EPDM assembly line workers. The comparison of prevalence of CTS in a traditional and a semi-ergonomic shocker manufacturing assembly line has been presented in Chapter five. In Chapter six potential CTS symptoms, symptoms severity scale and hand arm vibration exposure to find out their relation with CTS occurrence are discussed. The study of pinch strength on prevalence of CTS in workers has been presented in Chapter seven. Finally conclusion of the thesis and scope for further research are presented in the Chapter eight.