Chapter 1

Literature Review
1 Literature Review

1.1 Introduction

1.1.1 Comfort and Discomfort

Comfort is the state of being relaxed and feeling no pain, no stress etc. Similarly discomfort is an uncomfortable feeling of painlessness or distress etc. However, there is no widely accepted definition of comfort and discomfort. The meanings changes according to environmental conditions, tasks, workstations and postures. In an Air conditioning system the meaning of comfort and discomfort is related to temperature, sitting like in a car, train or in plane, the comfort is related to painless sittings, similarly, in driving a vehicle, working on computer, working in clinics, the meanings of comfort and discomfort are relatively different as per the type of tasks. In industries where the tasks are performed manually, the awkward postures, repetitions, duration of operation, frequency of exertions and good environment are the main criterion of comfort and discomfort.

An important issue in ergonomics is to identify influential factors regarding comfort and discomfort and to improve working, environmental conditions and enhanced production (Kong et al., 2012), for effective and efficient human use. A relationship between comfort and discomfort in sitting was investigated by De Looze et al. (2003), they identified that pressure had a close association with subjective measures, and suggested a theoretical model which assumed that comfort and discomfort were independent entities. In their model, the physical factors of human, product, or environment were found reasons for discomfort. Zhang et al. (1996) presented the idea that comfort was associated with feelings of relaxation and well-being, whereas discomfort was closely related with pain, tiredness, soreness, and numbness. As far as occupational tasks are concerned, researchers performed studies in terms of comfort and discomfort while using hand tools, such as garden tools (Chang et al., 1999), handsaws (Mirka et al., 2009), knives (Claudon, 2006), pliers (Groenesteijn et al., 2004; You et al., 2005), sanders (Spielholz et al., 2001), screwdrivers (Freund et al., 2000), and wire-tying hooks (Li, 2002). Comfort is an important factor in hand tool ergonomics and discomfort is also frequently assessed as a predictor of musculoskeletal injuries. In the use of hand tools, comfort is associated with positive feelings of reliability, safety, ease, and satisfaction, whereas discomfort is associated with negative feelings of pain, pressure, hardness, and irritation (Vink, 2005).
Using hand tools generally involves gripping. Gripping exertion is the first appreciable objective measure affecting comfort and discomfort in hand tools (Kong et al., 2012). Still it is not known that what level of maximum voluntary contractions (%MVC) of gripping exertion would be able to change discomfort to comfort. Comfort and discomfort in terms of pain is also affected by physical factors like shape, size, weight and types of material of the hand tools, which is also evident from several studies by researchers, as handle length (Mirka et al., 2009), size (Cochran and Riley, 1986), shape (Kong et al., 2007; Kong et al., 2008), material (Chang et al., 1999), and weight (Björing and Hägg, 2000). Kuijt-Evers et al. (2005) reported that the descriptor of ‘adverse body effects’ could predict both comfort and discomfort, whereas other descriptors of ‘aesthetics,’ ‘functionality,’ and ‘physical interaction’ could also predict comfort.

1.1.2 Types of Work related Musculoskeletal Disorders

Musculoskeletal disorders include sprains, strains, tears, soreness, pain, carpal tunnel syndrome, hernias, and connective tissue injuries to human body. Work related MusculoSkeletal Disorders (WMSD) are injuries or dysfunctions affecting muscles, bones, nerves, tendons, ligaments, joints, cartilages, and spinal discs (Kumar, 2001) caused by occupational or non occupational tasks involving bad posture, high frequency of exertion or high force levels. The most common types of WMSDs are defined as follows:

1.1.2.1 Neck disorders

Neck/shoulder disorders are related to pain, discomfort or tenderness. Some people experience pain in neck or in shoulder only, while others experience pain in both areas. The causes of neck pain include abnormalities in the bone or joints, trauma, poor posture, degenerative diseases, and tumors (CCF, 2012). Pain in the soft tissues (muscles, tendons, and ligaments) is the most common cause of neck pain and usually occurs as a result of an acute or a chronic muscle strain. The posture of neck never remains stationary, which means that it is less stable than other areas of the body and gets more easily injured.

1.1.2.2 Shoulder musculoskeletal disorder

The shoulder works on the ball and socket joint with a large range of movement. Such mobile joints tend to be more prone to injury. Shoulder pain can shoot from one or more of the
causes such as: strains from overexertion, tendonitis from overuse, shoulder joint instability, dislocation, collar or upper arm bone fractures, frozen shoulder, pinched nerves etc. (Mote, 2010). The main causes of shoulder musculoskeletal disorders are the inability of performing the tasks with shoulder, the feeling of shoulder pop out or slide out of the socket or the lack the strength in shoulder to carry out daily activities (American Academy of Orthopedic surgeon, AAOS, 2012). The bones of the shoulder are held in place by muscles, tendons, and ligaments. Tendons are tough cords of tissue that attach the shoulder muscles to bone and assist the muscles in moving the shoulder. Ligaments attach shoulder bones to each other, providing stability. The rotator cuff is a structure composed of tendons that, with associated muscles, holds the ball at the top of the humerus in the glenoid socket and provides mobility and strength to the shoulder joint (Chaurasia, 1999). Many shoulder problems are caused by the breakdown of soft tissues in the shoulder region. Using the shoulder too much can cause the soft tissue to break down causing the shoulder injuries. The most common shoulder injuries are dislocation/separation, Rotator cuff disease, Rotator cuff tear, Frozen shoulder, Fracture and Arthritis (Bethesda, 2010). Some of the major shoulder injuries are as follows:

1. Sometimes, one of the shoulder joints moves or is forced out of its normal position. This condition is called instability, and can result in a dislocation of one of the joints in the shoulder. Individuals suffering from an instability problem will experience pain when raising their arm. They also may feel as if their shoulder is slipping out of place.

2. A shoulder separation is the stretching or tearing of ligaments where the collarbone (clavicle) meets the shoulder blade (scapula), also called the acromioclavicular or AC joint. If these ligaments partially or completely tear, the clavicle can slip forward and detach from the scapula. A shoulder separation is usually caused by an impact to the front of the shoulder or by falling on an outstretched hand.

3. Impingement is caused by excessive rubbing of the shoulder muscles against the top part of the shoulder blade, called the acromion. Impingement problems can occur during activities that require excessive overhead arm motion. The rotator cuff is one of the most important components of the shoulder. It is comprised of a group of muscles and tendons that hold the bones of the shoulder joint together. The rotator cuff muscles provide individuals with the ability to lift their arm and reach overhead.

4. Rotator cuff tears are tears of one or more of the four tendons of the rotator cuff muscles. A rotator cuff injury can include any type of irritation or damage to the rotator cuff
muscles or tendons. Rotator cuff tears are among the most common conditions affecting the shoulder.

5. Frozen shoulder, or adhesive capsulitis is a condition that causes restriction of motion in the shoulder joint. Frozen shoulder causes the capsule surrounding the shoulder joint to contract and form scar tissue.

6. The shoulder is a joint suspended by many muscles surrounding the upper extremity. The shoulder bones include the clavicle (collarbone), the scapula (shoulder blade), and the humerus (upper arm bone). The only connection of the shoulder girdle to the remainder of the skeleton is the clavicle. The scapula is an important part of the shoulder joint as it serves as an anchor for many muscles and contains the socket part of the shoulder (glenoid). The upper end of the humerus has a ball-like shape that articulates with the socket, and the humerus also serves as an attachment point for many muscles and tendons. One of the most important is the rotator cuff. Disruption of any of these parts called the fracture can create difficulty with the function of the shoulder.

7. Shoulder arthritis is a clinical condition in which the joint that connects the ball of the arm bone (humeral head) to the shoulder blade socket (glenoid) has damaged or worn out cartilage.

1.1.2.3 Elbow Musculoskeletal disorders (Epicondylitis)

Though every joint of the body is important but the elbow joint keeps a different significance because it is used in most of the tasks performed by hands. The elbow joint is made up of bone, cartilage, ligaments and fluid, muscles and tendons of forearm arm and upper arm which helps the elbow joint to move. When any of these structures is hurt or diseased, then injury will take place. A major injury of elbow joint is Tendinitis and the common cause of tendinitis is an inflammation or injury to the tendons that attach muscle to bone. Tendinitis of the elbow is generally known as a sports injury often from playing tennis or golf. However, tendinitis may also occur as a result of bad posture or over use of repetitive tasks. Tennis elbow is an overuse injury occurring in the lateral side of the elbow region, but more specifically, occurs at common extensor tendon that originates from the lateral epicondyle. This is also referred as Lateral Epicondylitis, also known shooter's elbow and archer's elbow. This is a condition where the outer part of the elbow becomes sore and tender. It is commonly associated with playing tennis and other racquet sports, though the injury can happen to almost anyone especially in occupational repetitive tasks.
1.1.2.4 Hand/wrist Musculoskeletal disorders

There are many injuries related to hand/wrist, some of them which are more frequent discussed below:

1.1.2.4.1 Carpal Tunnel syndrome

Carpal tunnel syndrome is pressure on the median nerve, the nerve in the wrist that supplies feeling and movement to parts of the hand. It can lead to numbness, tingling, weakness, or muscle damage in the hand and fingers. The median nerve provides feeling and movement to the "thumb side" of the hand (the palm, thumb, index finger, middle finger, and thumb side of the ring finger). The area in the wrist where the nerve enters the hand is called the carpal tunnel. This tunnel is normally narrow, so any swelling can pinch the nerve and cause pain, numbness, tingling or weakness. Carpal tunnel syndrome is common in people who perform repetitive motions of the hand and wrist. Typing on a computer keyboard is probably the most common cause of carpal tunnel. Other causes may be sewing, driving, assembly line work, painting, writing, use of tools (especially hand tools or tools that vibrate), sports such as racquet ball or hand ball, playing some musical instruments, etc. (Zieve and Eltz, 2010).

1.1.2.4.2 Hand/wrist Tendinitis

Since, hands are utilized to accomplish almost every single task, they often get stressed and overused, which often lead to hand problems like Hand Tendonitis. Hand Tendonitis is the tendency of the hand tendon to swell that is usually found in the fingers and wrist. This type of tendonitis causes irritation, discomfort, and pain in the hands (ITJII, 2012). It is not difficult to know if a person is suffering from a simple hand pain or Hand Tendonitis. Hand Tendonitis can cause tightness, aching or burning of the hands especially if they are used in gripping or holding things (ITJII, 2012). Once the inflammation gets serious, it can upset the median nerve and attack the body's weakest points such as the wrist, bicep, and forearm. This is because the bounding soft tissues of the hands are linked to the other parts of the body near the hands.

1.1.2.5 Hand arm vibration syndrome

Hand arm vibration is caused by the use of vibrating hand-held tools, such as pneumatic jack hammers, drills, gas powered chain saws, and electrical tools such as grinders. The nature of these tools involves vibration (a rapid back and forth type of motion) which is transmitted from the tool to the hands and arms of the person holding the tool. Vibration Syndrome is a
group of symptoms related to the use of vibrating tools and includes some or all of the following: muscle weakness, muscle fatigue, pain in the arms and shoulders, and vibration induced white finger. Many researchers believe that other symptoms headaches, irritability, depression, forgetfulness, and sleeping problems should also be included in descriptions of Vibration Syndrome (ISO 5349). Hand arm Vibration Syndrome and Vibration-Induced White Finger (VWF) are the major health hazards related to the use of vibrating tools. Carpal Tunnel Syndrome is another health problem that has been linked to the use of smaller hand-held vibrating tools.

1.1.2.6 Low-Back Musculoskeletal disorders

Low back region is comprised of up of five vertebrae In between these vertebrae lie fibro cartilage discs (intervertebral discs), which act as cushions, preventing the vertebrae from rubbing together while at the same time protecting the spinal cord. Nerves stem from the spinal cord through foramina within the vertebrae, providing muscles with sensations and motor associated messages. Stability of the spine is provided through ligaments and muscles of the back, lower back and abdomen. Small joints which prevent, as well as direct, motion of the spine are called facet joints which is also known as zygapophysial joints. Causes of lower back pain are varied. Most cases are believed to be due to a sprain or strain in the muscles and soft tissues of the back (Henschke et al., 2009). Over activity of the muscles of the back can lead to an injured or torn ligament in the back which in turn leads to pain. An injury can also occur to one of the intervertebral discs (disc tear, disc herniation). Due to aging, discs begin to diminish and shrink in size, resulting in vertebrae and facet joints rubbing against one another. Ligament and joint functionality also diminishes as one ages, leading to spondylolisthesis, which causes the vertebrae to move much more than they should. Pain is also generated through lumbar spinal stenosis, sciatica and scoliosis. At the lowest end of the spine, some patients may have tailbone pain (also called coccyx pain). Others may have pain from the sacroiliac joint, where the spinal column attaches to the pelvis, called sacroiliac joint dysfunction which may be responsible for 22.6% of low back pain (Bernard and Willis, 1987). Physical causes may include osteoarthritis, rheumatoid arthritis, degeneration of the discs between the vertebrae or a spinal disc herniation, a vertebral fracture (such as from osteoporosis), or rarely, an infection or tumor.
1.2 Factors associated with WMSDs

Several factors have been associated with WMSD such as repetitive motion, excessive force, awkward and/or sustained postures, prolonged sitting and standing (Moore and Garg, 1994; Hagberg et al., 1995). Musculoskeletal Disorders (MSDs) especially of the upper limb are a highly prevalent occupational health hazard in industry causing substantial costs. A close relationship has been shown between physical risk factors and MSDs, in particular, high levels of force, deviated postures and repetitiveness (NIOSH, 1997). These have each been associated with increased operator discomfort in occupational and non occupational tasks involving deviated postures. Ergonomic interventions reducing the effects of these risk factors have been demonstrated to lower discomfort and also increased productivity with cost benefits (HSE, 2006). Other studies have also identified that occupational risk factors leading to MSD are repetitive motion, forceful exertions with limited opportunity for recovery (Armstrong, 1986a & b), poor and awkward postures (Hertzberg, 1955), mechanical pressure, hand arm vibration (Armstrong et al., 1989), and exposure to cold. Continuous exposure to these factors can cause pain, swelling, tingling, sensation and decrease strength and range of motion in the upper arm and wrist which may ultimately lead to injuries. Previous researchers used discomfort assessment to evaluate the stress of working posture (Corlett and Bishop, 1976), force exertion (Olendorf and Drury, 2001) and task frequency (Radwin et al., 1994) in a job task. There are many case studies which have reported on the relationship between physical risk factors, associated discomfort and productivity, however, few attempts have been made to investigate the relationship and model it (Mukhopadhyay et al., 2007, 2009; Carey and Gallwey, 2002, 2005; O’Sullivan and Gallwey, 2002; Khan et al., 2009a & b, 2010). Other researchers have also investigated a potential causal relationship between risk factors and WMSD affecting specific body parts such as the low back and the upper limbs, etc. (Hoogendoorn et al., 1999, 2000a; National Research Council and Institute of Medicine (NRC/IOM), 2001).

1.2.1 Posture

Postures acquired by the workers at the tasks performed are of great importance. A good posture provides comfort to the worker, enhanced productivity and safety from injuries while awkward postures were recognized as key ergonomic risk factors for WMSDs (Armstrong et al., 1986; Putz-Anderson, 1988; Muggleton et al., 1999; NIOSH, 1997). Several epidemiological studies have established a correlation between awkward body postures and
the risk of developing WMSDs (Aaras et al., 1988; De Crome et al., 1990; Armstrong et al., 1993). Occupations with awkward postures, showed a higher prevalence of some WMSDs than other occupations. Several researchers have investigated the effects of posture on discomfort, as a precursor of injury if the work is continued. Especially in repetitive task upper limb postures have significant contribution in developing discomfort as risk of WMSDs. The details are discussed below.

1.2.1.1 Wrist/Hand

Upper extremity musculoskeletal disorders are most commonly associated with deviated postures such as excessive flexion and/or extension of wrist, radial and/or ulnar deviation of the wrists (Armstrong, 1986a & b). In addition to carpal tunnel syndrome, other problems such as De Quervain’s disease and lateral epicondylitis have also been associated with radial and ulnar wrist deviations (Armstrong, 1986a; Dimberg, 1987). Schoenmarklin et al. (1994) confirmed the view that flexion and extension might cause hand problems. Awkward wrist postures may be due to the result of bad workplace design/layout and the shape and orientation of the hand tool handles. The use of hand tools is linked with many cumulative trauma disorders (CTDs) of the upper extremity; especially those of the hand and wrist (Chaffin et al., 2006). Armstrong and Chaffin (1979) found that flexion and extension of the wrist were associated with the high incidence of carpal tunnel syndrome in sewing machine operators. Masear et al. (1986) associated extreme wrist motion, particular flexion and ulnar deviation with carpal tunnel syndrome problems in the meat-cutting industry. Radial and ulnar deviations have also been implicated in carpal tunnel syndrome (Tanaka et al., 1995). Carey and Gallwey (2002) evaluated the effects of wrist posture, pace, and exertion on discomfort. They concluded that extreme flexion caused greater discomfort than the other simple types of deviation, and the combination of flexion and ulnar deviation resulted in greater discomfort than the other combinations of deviation. In a recent study, Haque and Khan (2009) found that if the ulnar deviation and wrist extension would be reduced by the design change in the pliers it reduces discomfort and increases productivity.

1.2.1.2 Forearm arm

Silverstein et al. (1987) found repetitive and forceful work involving the arms in pronation and supination, in different industries. A number of studies have documented cases of forearm/elbow injuries in industry, the majority of which include various forms of lateral epicondylitis. Epicondylitis has been associated with tasks requiring forceful work, e.g.
wallboard installation, roofing, masonry, foundries, building construction, furniture making, paper products manufacturing and meat dealers, all occupations that involve repetitive, forceful work involving the arms and hands and requiring pronation and supination (Silverstein, 1998). In a study of an engineering plant, Dimberg (1987) diagnosed epicondylitis in 7.4% of the 540 workers surveyed. Khan et al. (2009) examined the influence of wrist deviation combined with forearm rotation angle on subjective discomfort and found that the discomfort rating increased rapidly while both the wrist deviation and forearm rotation were greater than 30% joint range of motion. Grieco et al. (1998) reported that, along with other postural problems, pronation and supination of the forearm were related to upper extremity disorders. Mukhopadhyay et al. (2007) investigated the effect of forearm rotation, elbow flexion, task frequency and forearm torque exertion on perceived discomfort score. Discomfort was found higher at $45^\circ$ (elbow flexion) as compared to $90^\circ$ and $135^\circ$, and also higher in forearm pronation as compared to forearm supination or neutral posture. Similarly, awkward elbow posture may be caused due to extreme pronation and/or supination of the forearm, particularly when the motions are highly repetitive (Mukopadhyay et al., 2007). Cook and Burgess-Limerick (2004) proposed using a computer keyboard with the forearms unsupported as a causal factor for neck/shoulder and arm/hand diagnoses. The laboratory and field studies have demonstrated that forearm support might be preferable to work in the traditional ‘‘floating’’ posture. They concluded that use of forearm support has a number of advantages over a traditional floating posture and should be considered as an alternate working posture for keyboard users.

1.2.1.3 Elbow/upper arm

Herberts et al. (1980) studied elbow flexion combined with upper arm abduction and found an increase in localised muscle fatigue as abduction increased from $45^\circ$ to $90^\circ$. Hagberg and Wegman (1987) also reported, awkward postures involving upper arm abduction and repetitive forearm movement among various tasks like, assembly line packers, shop assistants, slaughter house workers, scissors makers, and data entry operators. Coury et al. (1998) observed upper arm flexion in the range of $0^\circ$ to $90^\circ$ in pencil packaging assembly as the main cause for the development of WMSD. Kilbom and Persson (1987) demonstrated the relation of upper arm abduction to the onset of symptoms for WMSDs. In a handmade brick manufacturing plant, Trevelyan and Haslam (2001) also found $45^\circ$ medial rotation of the
humerus accompanied by 45° abduction and 45° forward flexion of the upper arm were at the risk of developing WMSDs.

To identify the quantum of risk due to upper limb postures, Mukhopadhyay et al. (2003) used intermittent torque along with grip force, and reported an increase in discomfort with an increase in upper arm abduction angle from 0° to 90° while elbow angle was fixed at 90°. Therefore, it may be said that factors such as postural angle of shoulder in combination with the magnitude of applied load showed the influence on the fatigues of shoulder muscles (de Groot et al., 2004; MacDonell and Keir, 2005). In order to know the effects of upper limb deviation and to prevent upper limb WMSDs associated, further investigations were conducted. Attempts were made by few studies (Carey & Gallway, 2005; O’Sullivan & Gallwey, 2005; Mukhopadhyay et al., 2007a). Mukhopadhyay et al. (2007 a) investigated the effect of elbow flexion angle combined with forearm rotation, shoulder rotation and upper arm flexion, and concluded that posture had significant effect on discomfort for repetitive torquing task, which may create the risk of WMSDs. In another study, Mukhopadhyay et al. (2007b) investigated the effects of elbow flexion angle combined with forearm rotation for repetitive torquing task and found that elbow flexion had significant effect (at p=0.016) on discomfort score.

From the literature showed above, it was observed that, in industrial scenario, forward flexion of the upper arm along with forearm rotation and elbow flexion was common and was at the risk of causation of WMSDs. Mostly these were accompanied by lateral/medial rotation of the humerus. Similarly, in assembly line work internal and external rotation of the humerus coupled with forearm rotation and upper arm flexion as per Melin (1987) were causing WMSDs.

1.2.1.4 Shoulder/Neck

In recent findings (Lin et al., 2010) reported that upper limb posture also influences perception of discomfort, in whole body, shoulder and upper arm perceived discomfort with higher shoulder flexion angles, and especially high discomfort responses when reaching above shoulder height. Au and Keir (2007) reported that hand gripping increased the activity of some shoulder muscles and decreased the activity of others. The relationship of work risk factors and shoulder MSDs have been studied by many researchers, Hagberg and Wegman (1987) reported that the majority of shoulder injuries occurred in a variety of occupations to workplace exposure. Kuorinka et al. (1995) studied the shoulder tendinitis and concluded that
overhead tasks and repetitive work increases the risk of MSDs. Bjelle et al. (1981) reported that next to low back pain, neck and shoulder pain were most common. Hagberg and Wegman (1987) reported a high prevalence of neck and shoulder disorders among dentists, meat carriers and miners. Further, they found that the shoulder joint movements that were frequent and awkward in workplaces were abduction and upper arm flexion. In the electronics industry, working conditions often demand working with raised arms (Kilbom and Persson, 1987). In garment sewing, automotive trim sewing, metal parts assembly, packaging, etc., awkward postures affect the shoulder and upper limbs in general and can lead to musculoskeletal disorders in the long term (Ranney et al., 1995). Herbert et al. (2001) reported that sewing machine operators had a very high incidence of upper arm and shoulder-related musculoskeletal symptoms. Kilbom and Persson (1987) indicated a high prevalence of shoulder and neck disorders in the electronics industry, due to repetitive, manual short cycle tasks with the arms at $60^\circ$ to $90^\circ$ abduction. Sjøgaard et al. (1988) observed tasks in the woodwork industry that involved neck flexion/rotation, and repetitive arm movements requiring static contraction forces of 5% to 10% maximum voluntary contraction (MVC), including grip force. Järvholm et al. (1988) reported that fatigue and blood flow in shoulder muscles were affected at moderate shoulder abduction. They hypothesized that recurrent sustained periods of ischemia trigger degenerative processes in poorly vascularized areas of the muscular compartments, thus potentially affecting the blood supply to the affected tendons.

In continuation of previous studies (Mukhopadhyay et al., 2007a and 2007b; O’Sullivan and Gallwey, 2002) it seemed to be obligatory to further develop discomfort prediction models regarding shoulder rotations for different repetitive force types such as grip force.

### 1.2.1.5 Back/lower limbs

Factors due to occupational exposures such as static loading, heavy lifting, and repetitive bending have been noted as important risk factors for developing lower back disorders (Riihimaki et al., 1989; Hsiang et al., 1997; Elders and Burdorf, 2004). Since most of these factors are closely related to muscle fatigue, localized torso fatigue can be considered at least a surrogate measure of Lower Back Pain (LBP) risk. Conceptual models have been presented indicating a potential role for localized muscle fatigue (LMF) in injury causation, along with associated personal and task demand factors (Armstrong et al., 1993; Forde et al., 2002). Fully flexed postures are very common among rodmen, and are dominant when tying
reinforcement bars together (Saari and Wickström, 1978). Tying rods was experienced as one of the most tiring tasks having back fully flexed forwards, the knees usually over-stretched and the neck extended at times. During the tying the external load was relatively small, while other tasks such as cutting and bending the bars involve higher loads (Saari and Wickström, 1978). A correlation between low-back pain, injury and construction work has been reported by Riihimäki et al. (1990) and Nurminen (1997). Rodmen have higher injury rates especially in the back and hip joint/legs (3.9 and 4.6 times respectively more common among them than the mean of all occupations) (SCB, 1994). In other occupations, such as nursing and industrial assembly a large amount of the working time is spent in fully flexed postures. In such postures the work is often carried out until the discomfort, fatigue or pain becomes unbearable and a pause becomes necessary. The activities of lifting or carrying are generally assumed to be related to low back injury. Therefore, lifting and carrying tasks are being replaced by pushing and pulling tasks in many workplaces (Schibye et al., 1997). However, the physical load in pushing and pulling may also lead to health complaints. In fact, the effects of the force magnitudes on musculoskeletal loads depend on the force directions with respect to the body.

1.2.2 Force

In addition to awkward postures, excessive muscular force and high rates of manual repetition were also noted as risk factors (Silverstein et al., 1986; Moore and Garg, 1994). Human manipulative tasks are carried out by hand movements, which frequently involve forceful movements. Forceful movements exerted by the hands have long been associated with the development of several types of work-related musculoskeletal disorders (WRMSDs) that affect muscles, tendons, nerves and other musculoskeletal structures (Hagberg et al., 1995). Both passive hand and wrist movements as well as hand and wrist movements requiring the use of grip, force, or deviated postures can increase the risk of WMSD (Drury, 1987; Luchetti et al., 1998). Hand and wrist tendinitis, such as de Quervain’s disease, trigger finger epicondylitis or tenosynovitis were reported to be related to force exertions in several job tasks, such as food packers (Luopajarvi et al., 1979), automobile assembly lines (Byström et al., 1995) and diverse industrial activities (Armstrong et al., 1987). Carpal tunnel syndrome (CTS) has also been associated with forceful wrist motions in different types of work, such as industrial (Silverstein et al., 1987) and grocery store work (Osorio et al., 1994). Several reviews of epidemiological studies suggested that force exertions exceeding 15-20% of an
individual’s maximum capability may be linked with musculoskeletal disorders (Putz Anderson, 1988; Kroemer, 1989 & 1992). This suggestion appears to be based on the findings that force exertion below about 15% of maximum voluntary contraction (MVC) were associated with an essentially infinite endurance time and that >15% recovery period was necessary (Rohmert, 1973; Drury and Spitz, 1976).

The force exertion evaluation can be divided into initial force (to start the cart), sustained force (to keep the cart moving at a constant velocity), and ending force (to stop the cart). The initial force is usually greater than the sustained force and ending force (Van der Beek et al., 2000), and has been used to evaluate pushing and pulling tasks (Al-Eisawi et al., 1999b and Resnick and Chaffin, 1996). Musculoskeletal problems, particularly in the lower back, shoulder, and forearm areas, develop due to pushing and pulling (Chaffin, 1987; Macfarlane et al., 2000). The risk of musculoskeletal disorders increases as the pushing and pulling force exertion increases (Hoozemans et al., 1998). Looze et al. (2000) found that direction of force has significant effect on the task performance. They underlined the need for different terms of maximum acceptable pushing / pulling force to formulate the handle heights.

Sequential studies of Carey and Gallwey (1999, 2002, and 2005), Khan et al. (2009a &b, 2010) have shown the significant effects of flexion force of the metacarpalphelangeal joint of the wrist on the development of discomfort. Ciriello et al. (2002) reported high prevalence of torque exertions in industrial tasks and they have given limits for maximum acceptable torque for screw driving task. Further, O’Sullivan and Gallwey (2001) developed regression models to predict discomfort score for torquing tasks in supination/pronation. O’Sullivan and Gallwey (2002) showed the effect of torquing direction in pronation/supination showing the different effects on EMG activities of forearm muscles. In another studies O’Sullivan and Gallwey (2005) reported the development of discomfort for repetitive torquing task was more with pronation direction compared to supination. In continuation several other studies (Mukhopadhyay et al., 2007a, 2007b and 2009) have also reported the development of discomfort for torquing activities with power grip. However, very few experiments in the literature have shown the effect of grip force combined with postural deviations on the development of perceived discomfort score (Khan et al. 2003). Although some studies (Mc Gorry and Lin, 2007; Eksioglu, 2011; Roman-Liu, 2003; Roman-Liu and Tokarski, 2005; Mogk and Keir, 2003) have shown the effect of upper limb postures on grip strength.
1.2.3 Frequency

Repetitive monotonous work which represents a risk for developing musculoskeletal disorders, is characterized by highly repetitive movements and often short work cycle times. Silverstein et al. (1986) reported that a highly repetitive exposure, defined as work tasks with cycle times below 30 seconds or performing the same movements for more than 50% of the cycle time, was associated with an increased risk of developing hand/wrist disorders. Repetitive work activities, involving continuous arm or hand movements, which generate the loads on neck and shoulders area are responsible for the development of upper limb WMSDs (NIOSH, 1997). Repetitive awkward working postures have been reported by previous studies as main risk factors of WMSDs in various industrial tasks (Kilbom et al., 1986; Punnett and Keyserling, 1987; Silverstein et al., 1987; Aarás et al., 1988; Keyserling et al., 1988; Ryan, 1989; Burdorf et al., 1991; Moore et al., 1991; Punnett et al., 1991). Kilbom and Persson (1987) reported that manufacturing work in the electronics industry was associated with a high prevalence of shoulder and neck disorders, due to repetitive, manual short cycle tasks with the arms raised at 60° to 90° of abduction. Exposure to repetition alone has been found to increase the risk of CTS (Chiang et al., 1990; NIOSH, 1997; Silverstein 1985; Silverstein et. Al., 1987). Repetition contributes to the development of CTS by affecting the soft structures of the wrist, resulting in the production of excess synovial fluid from the tendon sheaths located in the wrist, which in turn increases pressure on the median nerve (Columbini, 1998; Drury, 1987; Putz Anderson, 1988). It was also found that combination of repetitiveness, force and posture lead to hand and wrist problems (Hagberg et al., 1995). Silverstein (1998) associated epicondylitis with tasks requiring forceful laborious work, for example, in foundries, building construction, manufacturing and meat handling. The investigations showed that similar postural deficiencies occurred in electronic assembly tasks in some Irish workplaces. The management of those companies reported cases of discomfort among workers involved in the repetitive tasks of small electronic assemblies and packaging. Most of the latter tasks involved repetitive wrist deviations and wrist flexion/extension, combined with forearm rotation which causes discomfort and WMSDs (O’Sullivan, 2001).

Yen and Radwin (2000) reported that in the industrial tasks the typical values for repetitiveness were in a range of 10 to 20 deviations per minutes. As per recordings by Armstrong et al. (1984), fundamental movements were of about 19.2 times per minute for an 8 hour shift. Several studies (Khan et al., 2010; Finneran and O’Sullivan, 2010; Carey and
Gallwey, 2002) have investigated the risk of developing WMSD due to high level of exertions per minute and found that 10 exertions were of better performance and developing lesser discomfort score compared to 20 exertions per minute. In a study (Lin et. al., 2009) effects of reaching frequencies 2 motions/min. and 4 motions/min. were evaluated on holding tasks in terms of perceived discomfort score and observed that the high frequency of arm reaching showed greater influence on female participant’s whole body discomfort than other factors taken in the study. Ciriello et al. (2002) performed a study for screw driving tasks at repetition rates of 15, 20, and 25 exertions per minute to find out the maximal acceptable torques. Garg et al. (2006) performed a laboratory experiment that consisted of a simulation of common automotive assembly job tasks. These different tasks were performed at three exertion times with the arm up for 2 seconds and down for 2 seconds (2-2) for ten exertions per minute, (3-3) seven exertions per minute and (5-3) five exertions per minute. The results revealed that the combination of (2-2) was the most stressful, fatiguing and painful, followed by the (5-3) and the (3-3) combination, having significant effect of exertions per minute.

1.2.4 Work duration/Rest

Work duration, exertion cycle time and rest periods plays important role in reducing the risk of WMSDs. Certain studies have emphasised the importance of work rest duration for controlling WMSDs (Snook et al., 1999; Christensen, et al., 2000; Hasegawa et al., 2001; Ciriello et al., 2002; Cote et al., 2005; Cook and Burgess-Limerick, 2004; Garg et al., 2006; Finneran and Gallwey, 2010; Law et al., 2010; Lin et al., 2010). Wiker et al. (1989) studied the effect of shoulder posture, load, and work-to-rest ratio on the whole body, neck and upper arm fatigue for a repeated Fitts’ tapping task. Christensen et al. (2000) proposed that the work/rest pattern in the work cycle time may be important factor in assessing the risk for developing MSD caused by repetitive monotonous work. The work cycle time of less than 30 seconds has been stated as borderline for repetitive work to identify in high risk tasks by Silverstein et al. (1986). Snook et al. (1999) conducted a study to find out maximum acceptable forces for repetitive wrist extension with pinch grip for a specific work schedule for 7 hours per day, 5 days per week for 4 weeks for different frequency of exertions. The results showed that maximum acceptable torque was higher for lower frequency of exertions that showed long rest duration between each exertion. In a study conducted on effect of sit-stand schedule by Hasegawa et al. (2001), it has been observed that the longer the task time, the lower the effects of changed posture. They suggested that on a short-term light repetitive
task change of posture is necessary at early stage. However, for the long-term task (e.g. over 90 minutes working time) a more effective improvement is required. Garg et al. (2006) studied short cycle times for different durations of over head task and reported that weight of lifting had significant role on working durations. As per their findings most subjects believed that they could perform the over head work for 8 hours with hand –tool weight of 0.45kg, and they could not last for more than 2 hours for work piece weight of 2.73kg and or hand tool weight of 0.91kg. Maximum holding time (MHT) is also one measure of task difficulty and tolerance that has been applied extensively in ergonomics to assess how long workers may endure a given task. Indeed, as intensity increases, MHT decreases exponentially (Elahrache et al., 2006).

1.2.5 Vibration

When exposed to vibratory hand tools workers are exposed to vibrations (known as Hand arm vibrations) that constitute the risk of WMDSs in upper limbs (NIOSH, 1997). Exposure to vibration can contribute to the vascular disorders such as white finger syndrome, neurological disorders, carpal tunnel syndrome, and joint disorders in wrist/elbow/shoulder (NIOSH, 1997). Vibration-induced white finger usually occurs only in the fingers and hands, which is a unique component of the hand arm vibration syndrome (HAVS). The vibration perceptions at different locations on the hand arm system could vary greatly, largely depending on the vibration frequency (McDowell et al., 2007; Dong et al., 2010). Apart from hand transmitted vibrations, whole body vibration (WBV) also plays an important role in developing WMDSs. Several investigations have reported possible discomfort, musculoskeletal problems, muscular fatigue, reduced stability and altered vestibular function caused by WBV exposure (Seidel, 1993; Wasserman et al., 1997; Bongers et al., 1988; Griffin, 1998; Chen et al., 2009).

1.2.6 Gender

In modern industrial scienario females participation has increased, therefore it becomes important to find the gender based performance differences too. Gender difference was significantly reported by several studies (Yassierli and Nussbaum, 2009; Mastalerz et al., 2009; Shih, 2005; Mogk and Keir, 2003; Gilcoury et al., 1998; Porter et al., 2010). Gilcoury et al. (2002) investigated the influence of gender effects on work-related musculoskeletal disorders in repetitive tasks. Their analyses indicated that symptoms were primarily influenced by the work done and were secondarily influenced by gender, job tenure and age.
In another study, Lin et al., (2010) evaluated the force exertions and muscle activities while operating a manual guide vehicle, and observed that the average force exertions and muscle activities of females were slightly greater than those of males, except for EMG of the left erector spine. According to the study conducted (Lin et al., 2009), the effects of gender along with shoulder flexion, reaching frequency, holding weight, and holding duration showed significantly positive correlations on whole body discomfort, shoulder discomfort and upper arm discomfort. They also found that arm reaching over shoulder height was the main factor affecting whole body discomfort (WBD) for both males and females. Further, the high frequency of arm reaching showed greater influence on female participant's whole body discomfort. On the other hand, holding weight showed greater influence on male participant's whole body discomfort. In a study (Johnsson et al., 2004) surface EMG from two forearm flexor and two extensor muscles was recorded for grip forces were of 5%, 20% and 40% of maximal voluntary contraction (MVC), the study compared the difference between male and female participants. It has been concluded that the maximal hand force was 318 ± 66N for women and 535 ± 129N for men. The difference between women and men was significant, (p <0.01). As far as musculoskeletal system is concern, it gave different response with the gender difference. (Porter et al., (2010) reported that males tended to exhibit increased higher normalised mean EMG activity in right erector spine muscles compared to females (41% vs. 21%), while females exhibited increased mean EMG activity in the right deltoid (44% vs. 26%). Mogk and Keir (2003) also found that women produced 60-65% of the grip strength of men and required 5-10% more of both relative force and extensor activation to produce 50N grip. Similarly, Shih (2005) indicated that the gender effect was the most dominantly significant on maximal voluntary contraction, maximum acceptable sustained time and normalised exertion level. It was also found that males had more MVC (337 vs. 220N) and longer maximum acceptable sustained time (20.2 vs. 10.5 seconds), but less normalised exertion level (66.6 vs. 73.9 % MVC).

1.2.7 Psychological factors

Work related MSDs are not only caused by physical factors but also by psychological factors. In recent literature several studies have shown that WMSDs are related to physical as well as psychological job demands in the work environment (Fredriksson et al., 2001; Choobineh et al., 2006, 2009, 2011; Lee et al., 2008; Lapointe et al., 2009; Lin et al., 2009; Warming et al., 2009; Canjuga et al., 2010; Fernandes et al., 2010; Johnston et al., 2010; De Souza Magnago
et al., 2010; Dawson et al., 2011; Driessen et al., 2011; Gilbert-Ouimet et al., 2011; Haukka et al., 2011; Vandergrift et al., 2011; Westgaard and Winkel, 2011). Musculoskeletal disorders have followed working days lost, disability of workers (Shahnavaz, 1987; Genaidy et al., 1993; Tsauo et al., 2009) and wasting money/ economic losses (Kemmlert, 1994; Neumann, 2004; Punnet and Wegman, 2004; Eashw, 2008). Risk factors of WMSDs are known to include physical factors such as force, posture, and frequency (NIOSH, 1997; Haynes and Williams, 2008), while demographic characteristics and psychosocial factors are also important predictive variables for the development of WMSDs (d’Errico et al., 2010; Choobineh et al., 2011).

The predictors for the risk of developing WMSDs can be divided into individual (Johnston et al., 2008), ergonomic (Ye et al., 2007; Klussmann et al., 2008; Motamedzade et al., 2011), and psychosocial factors (Faucett and Rempel, 1994; Polanyi et al., 1997; Haufler et al., 2000; Hanse, 2002). Workers with WMSDs were advised to change work methods, use load carrying equipment etc., but interventional studies have showed that these recommendations have slight effect on reducing the prevalence of WMSD (Torp et al., 1999). There is evidence that ergonomic interventions (Motamedzade et al., 2003) are not solely sufficient to control musculoskeletal disorders, but psychosocial conditions should also be considered. Burton et al. (1997) found that workers with back pain had more negative psychological perception about their jobs as compared with those without back problem. Methods of educational intervention range from passive techniques to performance-based techniques. Lectures are common method used to present health- and safety-related information. Other passive techniques include videos and pamphlets (Burke et al., 2006). Active approaches to learning are superior to less active approaches. Therefore, as training moves from passive methods to the engaging methods, more transfer of training to the work setting will occur (Burke et al., 2006).

Marcoux et al. (2000) used a range of educational interventions, including posters, emails, pictures of stretching and stress relief activities, workshops, and informational booklets. These interventions increased the workers’ knowledge of MSDs and resulted in changes in the hand/wrist and neck/shoulder posture when using in instruments like computers. Lewis et al. (2001) conducted a study in a petrochemical facility and reported improvements in workstation posture and symptom severity, however, there was not any report regarding reduction in symptoms. Studies using different methods of ergonomics training have reported
positive results. For example, those who received education programs, such as participatory training and traditional training, reported less pain/discomfort and a positive perception of psychosocial work stress compared with those who did not receive training (Bohr, 2002). Laing et al. (2007) expressed that ergonomic interventions have been improved psychosocial conditions in different working groups. Choobineh et al. (2011) investigated psychosocial risk factors and musculoskeletal symptoms among office workers and the subsequent effects of ergonomics intervention on musculoskeletal discomfort and psychosocial risk factors. The study revealed that the low back problem (28.8%) was the most common problem among the office workers. Significant differences were found between prevalence rates of reported musculoskeletal in upper back, lower back and feet/ankle regions before and after intervention. Mehta & Agnew (2011) conducted a study to quantify the effects of concurrent physical and mental demands on the upper extremity muscle activity during static exertions. Participants performed isometric upper extremity exertions at five levels of physical intensity (5%, 25%, 45%, 65%, and 85% maximum voluntary contraction (MVC)) in the presence and absence of a mental task (Stroop color word test). Decrease in mean anterior and posterior deltoid muscle activity and co-contraction index (CCI) of the shoulder was observed in the presence of the mental task. However, these changes were more prominent at higher physical exertion levels compared to the lower levels. Furthermore, the additional mental task resulted in decreased upper and lower arm muscle activity. Motor performance improved at the middle exertion levels, but was adversely affected by the mental task at higher exertion levels. Morken et al. (2002) investigated randomized, controlled ergonomic intervention among operators in the aluminum industry in Norway to ascertain the effects of a 1-year training program on musculoskeletal symptoms, psychosocial factors and coping. It was found that participants in the intervention group, “operators without a supervisor”, used coping strategies more often and tended towards increased social support also there was no significant changes in musculoskeletal symptoms. Cao et al. (2011) investigated the interactive effect of job task and psychosocial factors on the outcomes of musculoskeletal disorders and concluded that higher physical load and greater psychosocial risk are more frequent self-reported symptoms of WMSDs than those of lower exposures.

1.3 Data related with WMSDs

Work related Musculoskeletal Disorders (WMSDs) are the most prominent work-related health problems of modern industrialized nations (Waters, 2004). Many studies have shown
that musculoskeletal disorders are related to physical and psychological perceived job demands in the work environment (Fredriksson et al., 2001; Choobineh et al., 2006, 2009; Lee et al., 2008; Lin et al., 2009; Warming et al., 2009; Canjuga et al., 2010; Fernandes et al., 2010; Dawson et al., 2011 etc). Musculoskeletal disorders includes working days loss, disability of workers (Shahnawaz, 1987; Genaidy et al., 1993; Tsauo et al., 2009) and waste of money (Neumann, 2004; Punnett and Wegman, 2004; Eashw, 2008). Risk factors for WMSDs include work place activities e.g. heavy load lifting, repetitive tasks and awkward working postures (Haynes and Williams, 2008). Musculoskeletal disorders (MSD) seems to be one of the most common occupational health problems to be faced in the industrial world from the very beginning but were focused by the ergonomists only a few decades back, during the 1990's. Putz-Anderson (1988) reported that an increase in service and high-tech jobs, an aging workforce, and a reduction in worker turnover have been the factors contributing to the increased cases of WMSD in the U.S workforce. In United States WMSDs have affected approximately 15-20% of workforce yearly (Melhorn, 1998). In 1999 a total of 246,700 work related musculoskeletal disorders (WMSDs) were reported to the US Bureau of labor Statistics (BLS, 2000a) related to the majority of workplace injuries and illness. The percentage of WMSDs to total injuries / illness has continued to increase from 62% in 1995 to 66% in 1999 (BLS, 2000a). Similarly in 1999, approximately 25,500 WMSD cases were reported in the metal-processing industries (BLS, 2000b). There were approximately 26266 new WMSD cases reported in 1998 (BLS, 2000c). According to a survey conducted in 23 states of United States, the hand tool related injuries were found to be approximately 9% of all work related compensable injuries i.e. an estimated 265000 hands tool related injuries reported annually and among all hand tool injuries, 79% were because of non powered hand tools (Hsu and Chen, 1999). Among the general personnel in government industries, upper extremity WMSDs showed 46% occurrence of the pain symptom in the neck, 66% in the shoulder, 29% in the elbow and forearm, 24% in the wrist and 42% in the hand, (Herbert et al., 2001) which amounted to 66% prevalence in the hand/wrist region. Bureau of Labor statistics, 2004 reported that during the past decade in the USA, powered hand tools caused about 26-33% of all hand tool related injuries annually. Struck by or struck against, and over-exertion were the two major exposures leading to powered hand tool related injuries.

In a review of MSD in telecommunication sector workers, the neck, shoulders, hand and wrists were the most affected parts of the body (Crawford et al., 2008). The Clinic of
Occupational and Environmental Medicine in Goteborg, Sweden, received yearly 10-15 computer operators with non-specific pain in the forearm. Moreover, the total time an operator uses the mouse seems to be related to the pain level in the forearm (Aarås et al., 1998). The prevalence of work-related upper extremity musculoskeletal disorders was very common among dentists and dental hygienists (Corks, 1997; Finsen et al., 1998; Fish and Morris-Allen, 1998; Akesson et al., 1999; Anton et al., 2002). Dental hygienists may be at greater risk than dentists for developing upper extremity WMSD due to the long hours of periodontal work (e.g. dental scaling and root planning) as reported by Rice et al. (1996). Among all occupations in the US, dental hygiene was ranked the highest by the Bureau of Labor Statistics in the number of carpal tunnel syndromes cases per 1000 employees (Leigh and Miller, 1998).

EUROSTATE (2004) reported that 45% of all work ailments were related to upper limb. In France, it was found that MSDs of the upper limb was approximately 2/3 of work related disorders (Aptel et al., 2002). The WMSDs are increasing very rapidly in USA, according to a report by Silverstein (1994). According to her, the incidence rate was lower than 5% per year in 1981 and, in 1994 it had reached 30% per year. WMSDs were found very common in all professions across the globe, neck and upper limb WMSD were found to be very serious problem in North America, 20% of newspaper employees in Canada (Polanyi et al., 1997), and 11.7% of US workers identify themselves suffering from upper limb discomfort (Morse et al., 2003). Further, 30% of non- manual UK workers reported discomfort in the neck or upper limbs (Palmer et al., 2001). Dimberg (1987) found that 7.4% of the workers had lateral epicondylitis in air craft engine plant. Kurppa et al. (1991) investigated a higher incidence of disorders in packers (25.3%) as compared to two groups of food processing workers (16.8% and 12.5%) and sedentary workers (7%). Yun et al. (2001) reported 51.4% cases of shoulder MSDs problems among Visual Display Terminal (VDT) workers in Bank of Korea. In the Netherlands, 22% of the working population reported work-related complaints in the neck, shoulder, arms or hands (Hupkens, 2002). In an investigation about nursing students in Japan for WMSDs, Smith et al. (2003) observed that the shoulder was the most affected part (14.9%). Similarly, among rural Australian nursing students, Smith and Leggat (2004) found 23.8% for shoulder WMSDs while Chyuan et al. (2004) reported rates of 58% for shoulder WMSDs among Taiwanese hotel restaurant workers. Upper extremity injuries, including those of the shoulder, resulted 22.7% in 2005 related to different body parts (12.8% included hand & finger injuries; 9.9% included wrist, arm and other upper extremity injuries), which
was very close to second 28.9% of lost time claims due to back disorders (Workplace Safety & Insurance Board, WSIB, 2005). In Taiwan, the prevalence of neck and shoulder discomfort was 14.8% and 16.6% in a survey of 17,669 workers, respectively (Lee et al., 2005).

Work related musculoskeletal disorders (WMSDs) of the shoulder are very common in manufacturing and construction industries. Roscrance et al. (1996) reported that, in a pipe trade about 41% workers complained of the work related shoulder pain with tasks performed in different postures including directly overhead. The occurrence of the disorders such as shoulder tendonitis has also been reported as high as 30-40% (Olson, 1987; Holmstrom et al., 1992). Herbert et al. (1981) reported 18% prevalence for supraspinatus tendonitis in shipyard welders and an overall incidence rate of 15-20% among welders. Earlier, the occupational risks among construction workers were high in comparison to other occupations. According to (SCB 1994) for concrete reinforcement workers, the reported occupational accidents and diseases in Sweden were 88.7/1000 employees in 1990, compared to a mean of 39.3/1000 for all other occupations. Among construction workers high prevalence and incidence rates for WMSD complaints have been reported who were exposed to manual materials handling worldwide (Roy et al., 1999; van der Molen et al., 2004; Bust et al., 2005).

Over exertion musculoskeletal disorders occurred due to push and pull activities. Approximately 9-20% of all back injuries are reported due to MMH activities. The exact estimated data of the number of injuries that occur during pushing or pulling of the loads are not available, though approximately 20% of over exertion injuries have been associated with pushing and pulling acts (NIOSH, 1981). In a survey of 516 injury cases conducted by the New York centre for Agriculture Medicine and Health, it was found that the most common occupational injury for the farmers was strain in the back and shoulders (31%), due to overdue/overuse (55%) and due to awkward postures (29%) (Earle- Richardson et al., 2003). Irrespective of various efforts to mechanize the production or manufacturing processes, the injury due to repetitive motions has been increasing over the past few decades. Bureau labor Statistics (BLS 1990) reported further, that there were approximately 705,800 (32%) cases of overexertion or repetitive motion injuries among all the reported cases of injuries in industries, and 13% were affected of the shoulder (NIOSH, 1997). It was also reported that 92,576 injuries or illness occurred as a result of repetitive motions including the use of tools, repetitive placing, typing, grasping or moving of objects other than tools. In comparison, the next highest incidence rate of repeated trauma illnesses in 1992 was 8.60 per
100 full-time workers, as reported by motor vehicle and car bodies industry (Bureau of Labor Statistics, 1993). Based on a cross-sectional study of 104 workers at an aluminum smelter, Hughes et al. (1997) recorded a prevalence rate of 11.6% elbow and forearm injuries. Similarly, Ritz (1995) recorded a prevalence rate of 14% for humeral epicondylitis, among gas and water work employees. WMSDs are very frequent in female workers in different tasks. Ranney et al. (1995) carried out detailed physical examinations on 146 female workers in highly repetitive industries, and found forearm/hand myalgia in 23% of the population. Work-related musculoskeletal disorders (WMSDs) is not confined to the workers doing heavy assembly work, but it is also very common in workers who do work with light to moderate load repetitive work (Veiersted et al., 1993; Ohlsson et al., 1994). In computer mouse work, most forearm muscle problems were found on the extensor side, where myalgia affected 19%. WMSDs are increasing (Fogleman and Brogmus, 1995). Health statistics reported an increased incidence of work-related muscular disorders among computer users (Statistics Sweden, 1999). Approximately 522528 cases of WMSDs in 2002 were reported by the Bureau of Labor Statistics (USA), out of these 55119 affected the shoulder, 265018 affected the back and about 60099 cases of injuries linked to repetitive movements.

Bystorm et al. (1995) reported that a prevalence of 6.6 musculoskeletal injuries per 200,000 working hours in the working population in an electronic assembly plant. The prevalence’s of clinically verified WMSD of the wrist and hand, consisting primarily of tendon disorders, ranged from 1% to 25% in an industrial working population according to the force demands and repetitiveness of the work’s task. (Silverstein et al., 1986; Kurppa et al., 1991) reported an incidence density of tenosynivitis or peritendonitis of 13% to 25% in various hand-intensive food-processing tasks and Paoli (1997) reported a prevalence rate of 17% in general industry in the European Union for muscular pains in the arm or legs. There are many occupations like assembly line packers, shop assistants, slaughterhouse workers, scissor makers, and data entry operators in which awkward postures of upper arm abduction, repetitive forearm movement were involved (Hagberg and Wegman 1987). But such awkward postures also occur in combination with force or torque exertions, so that they account for approximately 45% of all industrial overexertion injuries in United States. In meat packing industry, the cumulative trauma disorder (CTD) incidence rate was very high about 13.65 per 100 full-time workers, corresponding to 19,300 cases reported in 1992 (US Bureau of Labour Statistics 1993). In 1993, upper extremity musculoskeletal disorders rate was 13 of every 100 workers in the US meatpacking industry, a rate of 34 times than that
observed among workers in general industry (0.38 disorders per 100 workers; Bureau of Labour Statistics, 1995). In the packing section of a pencil factory, 41% incidence rates of MSDs were found due to postural conditions (Coury et al., 1998).

The prevalence of carpal tunnel syndrome among dental hygienists is estimated to be between 6% and 8.5% (Liss et al., 1995; Lalumandier and McPhee, 2001; Lalumandier et al., 2000). It has been estimated that 1.7-3.6% of the workers in European countries in USA were found to be suffering from hand-transmitted vibrations. Muscular disorders and joint abnormality caused by hand-transmitted vibrations was compensated occupational diseases in 13% of total occupational disease in Croatia (Kacian, 1997). American Dental Association (ADA) 1997, reported that an estimated 9% of dentists had been diagnosed MSD, with carpal tunnel syndrome (CTS) the most common diagnosis. EUROSTAT (2004) reported that 45% of all work injuries were related to the upper limb.

In a review, Hoozemans et al. (1998) reported from various epidemiological studies that 9-18% of low back injuries were associated with pushing and pulling. In studies on positive associations between work-related risk factors and back disorders, the important feature is the fraction for manual materials handling ranges from 11% to 54% (Burdorf and Sorock, 1997). Although low back disorders (LBDs) are associated with many variables, a recent survey has shown that 37% of all LBDs are directly caused due to occupational risk factors (Punnett et al., 2005). The 12-month prevalence of (low) back complaints in Dutch workers in the finishing sector, where plasterboard used were found to be 40% (Arbouw, 2001). Neck and shoulder complaints are the next highest-ranking at 22% and 21%, respectively (Arbouw, 2001). Low back pain (LBP) represents one of the most substantial occupational musculoskeletal problems, accounting for about 20-30% of total worker’s compensation payments in United States (Baldwin, 2004). In the year 2006, 38290 WMSD cases which required days away from work have been reported by the U.S. private industry (U.S. Department of Labour, http://www.bls.gov/data/). In the same year, about 426,000 people were estimated to be suffering from MSDs in the U.K; there, MSDs affected mainly the upper limbs or neck and were more severe by job-related factors (Health & safety Executive, http://www.hse.gov.uk/statistics/causdis/musculoskeletal/uln.htm).

1.4 Cost associated with WMSDs

According to the Bureau of Labor Statistics of the Department of Labor (USA), Musculoskeletal disorders are associated with high costs to employers such as absenteeism,
MSD cases are more severe than the average nonfatal injury or illness (e.g. hearing loss, occupational skin diseases such as dermatitis, eczema, or rash). Musculoskeletal disorders account for nearly $70 million physician office visits in United States annually, an estimated $130 million total health care encounters including outpatient, hospital and emergency room visits. The Institute of Medicine estimates the economic burden of WMSDs, as measured by compensation costs, lost wages, and lost productivity, was between $45 and $54 billion annually. In 2003, the total cost for arthritis conditions was $128 billion- $81 billion in direct costs and $47 billion in indirect costs (Centers for disease control and prevention, USA, 2011). According to Liberty Mutual workplace safety index (WSI) 2006, the estimated U.S. direct workers compensation cost of the most disabling workplace injuries and illnesses occurring in 2004 (the most recent year for which data were available) was $48.6 billion. The top ten most costly causes of serious workplace injuries were: Overexertion ($13.6 billion); Falls on Same Level ($6.7 billion); Bodily Reaction ($4.7 billion); Falls to Lower Level ($4.6 billion); Struck By Object ($4.1 billion); Highway Incidents ($2.6 billion); Repetitive Motion ($2.5 billion); Struck Against Object ($1.9 billion); Caught In/Compressed By ($1.7 billion); and Assaults/Violent Acts ($0.5 billion). According to the Liberty Mutual workplace safety Index (2004), the leading causes of serious workplace injuries in 2004 were reported as, (In $ billions): Overexertion: 13.6, Falls on Same Level: 6.7, Bodily Reaction: 4.7, Falls to Lower Level: 4.6, Struck by Object: 4.1, Highway Incidents: 2.6, Repetitive Motion: 2.5, Struck Against Object: 1.9, Caught in or Compressed by Equipment: 1.7, Assaults & Violent Acts: 0.5. More than half of the $48.6 billion cost of serious workplace injuries stems from the top three injury causes, as it has since 1998-2004.( in $ billion) such as: Over exertion: 13.6, Fall on same level: 6.7, Bodily reaction: 4.7S, All others: 23.6. As per a report the cost of MSDs to UK business and society is well known, the Health and Safety Executive (HSE) estimate that in 1995/96 MSDs cost British society £5.7 billion, with 1.0 million people currently affected each year, resulting in 11.6 million lost working days (2004/05).

Aghazadeh and Mittal (1987) reported that the ratio of Medical costs associated with hand tool related injuries amount to roughly $400 million, and total cost of such injuries reaches approximately $10 billion annually. In 1996, firms in the United States reported 6.2 million work place injuries and illnesses, of which 2.8 million involved restricted work activity or at least 1 day lost from work (BLS 1997). Leigh et al., (1997) estimated the costs of these conditions to have been US$171 billion. According to Galizzi et al. (2003), in 1996, firms in
the United States reported 6.2 million workplace injuries and illnesses, of which 2.8 million involved restricted work activity or at least 1 day lost from work (Bureau of Labor Statistics, 1997). Leigh et al. (1997) estimate the costs of these conditions to have been US$171 billion in 1992.

Low back pain (LBP) is the most prevalent health problem in Switzerland and a leading cause of reduced work performance and disability. A study (Wieser et al., 2011) estimated the total cost of LBP in Switzerland in 2005 from a societal perspective using a bottom-up prevalence-based cost-of-illness approach. The study considers more cost categories than are typically investigated and includes the costs associated with a multitude of LBP sufferers who are not under medical care. The findings are based on a questionnaire completed by a sample of 2,507 German-speaking respondents, of whom 1,253 suffered from LBP in the last 4 weeks; 346 of them were receiving medical treatment for their LBP. Direct costs of LBP were estimated at €2.6 billion and direct medical costs at 6.1% of the total healthcare expenditure in Switzerland. Productivity losses were estimated at €4.1 billion with the human capital approach and €2.2 billion with the friction cost approach. Presenteeism was the single most prominent cost category. The total economic burden of LBP to Swiss society was between 1.6 and 2.3% of gross domestic product (GDP). Work related upper extremity disorders comprised 13% of the illness cases involving lost days from work and 69% of the total illness reported in 1994 (NIOSH, 1997). The annual cost of occupational musculoskeletal disorders is estimated to be between 13 billion and 20 billion (NIOSH, 1997). Garg et al. (2006) reported that shoulder MSDs causes a large proportion of lost or restricted days (Kelsley, 1997; BLS, 2004) and are costly, having an average total direct cost of $11,565 per shoulder claim and a cost of over $24,626 per case of rotator cuff tendinitis in Washington State, 2004.

In a study Smith et al. (2006) suggested that strong safety climates (shared perceptions of safe conducts at work) are associated with lower work place injury rates, but they rarely control for differences in industry hazards. Based on 33 companies, and observed association with injury rates using three rate based injury measures (claims per 100 employees, claims per 100,000 hours worked, and claims per US$ 1 million payroll), which were derived from workers’ compensation injury claims. According to a study conducted by Lipscomb et al. (2006), Construction injuries preceded by a slip or trip were documented using data from the building of the Denver International Airport (Denver, Colorado, USA), the largest
construction project in the world at the time. Slips and trips occurred at a rate of 5/200,000 hours worked accounting for 18% of all injuries and 25% of workers’ compensation payments, or more than $10 million.

In another study, it was reported that worker compensation claims from the privately insured US workers’ compensation market, found that upper extremity disorder cases accounted for 6.4% of all claims costs, totalling over $130 million (Hashemi et al., 1998; Khan et al., 2009). Galizi et al. (2009) reported that over few years workplace injuries and illnesses costs have been rising, with spending breaking $142 billion dollars in 2004, tracks these costs on a per incident basis and showed that the average incident costs business $40,000. The National Safety Council arrived at these figures by summing estimates of the total wages lost by the injured worker, lost productivity, medical expenses, administrative expenses, motor vehicle damages and the time lost by non injured workers because of the accident. According to Finneran and O’Sullivan (2010), when permanent absences, temporary absences and health insurance were included, the total cost of occupational health problems was quite considerable. This was estimated to be equivalent to 2.5% of GNP in Ireland (Indecon, 2006), of which MSD costs are a subset. This compares with other developed countries where occupational injury and illness costs approximately 2–4% of GNP (Indecon, 2006). Presenteeism on the other hand, is when an operator is physically present but their output is limited due to physical limitations in the task they are performing. Stewart et al. (2003) estimated that presenteeism accounted for 71% of the $226 billion worth of lost productive time per year.

1.5 Work evaluation techniques

The Physical methods are used to assess levels of musculoskeletal discomfort among workers, and are representative of the range of methods available to the ergonomist. These methods are very important to assess how work is being performed and how much it is crucial to the work due to lack of knowledge of ergonomic principles and conditions. These physical methods can also be used to obtain necessary data for the management of injury risks in the workforce. The discomfort is the major cause of injuries therefore, many musculoskeletal injuries begins with the worker feeling discomfort, and if avoided then, it will lead to an increase in the severity of symptoms, and will be producing aches and pains. If these are not cured then the aches and pains will start some cumulative trauma and may result in actual musculoskeletal injuries, such as tendonitis, tenosynovitis, or serious nerve-
compression injury like carpal tunnel syndrome. Discomfort will also badly affect work performance, in the sense of decreasing the quantity and quality of work, through increased error rates, or both. Reducing the levels of discomfort means decreasing the risk of an injury occurring. Consequently, changes in levels of discomfort can also be used to check the success of the design of an ergonomic product or the implementation of an ergonomic program intervention.

There are several methods to assess the level of discomfort, rate of injury, effects of postures in terms of endurance time etc. which gives the complete information about working conditions, work stations and work environments etc. some of them are discussed below. The most of the commonly used methods are categorised as Physical methods, Psychophysical methods, Behavioral –cognitive methods, Team methods, Environmental methods and Macroergonomics methods (Stanton et al,. 2005). The Table 1 describes the importance of the methods and their specific applications.

The U.S. National Institute of Occupational Safety and Health (NIOSH) discomfort questionnaires have been extensively used in U.S. studies of ergonomic hazards. This self-report method allows the ergonomist to easily assess measures of musculoskeletal discomfort in numerous body regions, such as the intensity, frequency, and duration of discomfort. A predictive method for determining back injury risks was pioneered by the NIOSH in 1981 and has undergone substantial revision and enhancement since then, with a revised equation being introduced in 1991.

The Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) posture-targeting methods are probably the most well-known methods for rapid assessment of risks. The RULA method is well suited to analysing sedentary work, such as computer work. The REBA method is ideal for rapid assessment of standing work. Both of these methods have been extensively used in ergonomic research studies and also in evaluating the impact of workplace design changes on body posture. The Strain Index (SI) is a more comprehensive method that specifically focuses on the risks of developing distal upper extremity musculoskeletal disorders, i.e., injuries of the elbow, forearm, wrist, and hand. All of these methods take little time to administer and can be used in a wide variety of work situations. These methods can be used to assess overall postural risks and/or those to specific body segments. Other posture-targeting methods, such as the Ovako Working Posture Analysis System (OWAS) (Karhu et al., 1977) may also be used. The OWAS method involves direct
observation and sampling of tasks using a whole-body posture-coding system to estimate injury risks. The Occupational Repetitive Action (OCRA) method is the most comprehensive, complex and the most time consuming. The OCRA index is a detailed analytical and reliable method that can be predictive of upper-extremity injury risks in exposed worker populations. The OCRA index can also be used as the basis for identifying opportunities for task and/or workstation redesign, and as a means of evaluating the success of any interventions. The description of some of these methods is shown in Table 1.

1.5.1 Strain Index job analysis method (SI)

The Strain Index is method used to evaluate a job's level of risk for developing a disorder of the distal upper extremity (DUE) i.e., hand, wrist, forearm, or elbow. The analyst evaluates six task variables (intensity of exertion, duration of exertion, exertions per minute, hand/wrist posture, speed of work, and duration of task per day). The product of the six task variable multipliers produces a number called the Strain Index score. This score is compared to a gradient that identifies level of task risk (Moore and Garg 1995). In terms of procedure, there are five steps:

1. Collect data on the six task variables.
2. Assign ordinal ratings using the ratings table.
3. Determine multiplier values using the multiplier table.
4. Calculate the SI score (the product of the six multiplier values).
5. Interpret the result.
Table 1 Description of Physical and Psychophysiological methods to evaluate the risk of WMSDS

<table>
<thead>
<tr>
<th>Type of Method</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Physical Methods | These include measurement of discomfort, observation of posture, analysis of workplace risks, measurement of work effort and fatigue, assessing lower back disorder, and predicting upper-extremity injury risks | 1. Musculoskeletal Discomfort Surveys Used at NIOSH (Sauter, et al. 2004)  
2. The Dutch Musculoskeletal Questionnaire (DMQ) (Hildebrandt, 2004)  
3. Quick Exposure Checklist (QEC) (Li and Buckle, 1999)  
4. Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett, 1993)  
5. Rapid Entire Body Assessment (McAtamney and Hignett, 2000)  
6. The Strain Index (Moore and Garg, 1995)  
| Psychophysiological Methods | This includes heart rate and heart rate variability, event-related potentials, galvanic skin response, blood pressure, respiration rate, eyelid movements, and muscle activity | 1. Electrodermal Measurement (Boucsein, 2011)  
2. Electromyography (EMG) (Basmajian and De Luca 1985)  
3. Estimating Mental Effort Using Heart Rate and Heart Rate Variability (Stanton et al., 2005)  
4. Ambulatory EEG Methods and Sleepiness (Stanton et al., 2005)  
5. Assessing Brain Function and Mental Chronometry with Event-Related Potentials (ERP) (Stanton et al., 2005)  
6. MEG and fMRI (Stanton et al., 2005)  
7. Ambulatory Assessment of Blood Pressure to Evaluate Workload (Stanton et al., 2005) |

1.5.2 Rapid entire body Assessment (REBA)

Rapid entire body assessment (REBA) is used to assess the type of unpredictable working postures found in health-care and other service industries. Data are collected about the body posture, forces used, type of movement or action, repetition, and coupling. A final REBA score is generated to give an indication of the level of risk and urgency with which action should be taken (Hignett and McAtamney, 2000).

REBA can be used when an ergonomic workplace assessment identifies that further postural analysis is required and:

• The whole body is being used.
• Posture is static, dynamic, rapidly changing, or unstable.

• Animate or inanimate loads are being handled either frequently or infrequently.

• Modifications to the workplace, equipment, training, or risk-taking behavior of the worker are being monitored pre/post changes.

1.5.3 Rapid Upper Limb Assessment (RULA)

Rapid upper limb assessment (RULA) is a screening tool that assesses biomechanical and postural loading on the whole body with particular attention to the neck, trunk and upper limbs. The tool provides a single score as a “snapshot” of the task, which is a rating of the posture, force, and movement required. The risk is calculated into a score of 1 (low) to 7 (high). These scores are grouped into four action levels that provide an indication of the time frame in which it is reasonable to expect risk control to be initiated. RULA is used to assess the posture, force, and movement associated with sedentary tasks (McAtamney and Corlett, 1993). The four main applications of RULA are to:

• measure musculoskeletal risk, usually as part of a broader ergonomic investigation.

• compare the musculoskeletal loading of current and modified workstation designs.

• evaluate outcomes such as productivity or suitability of equipment.

• educate workers about musculoskeletal risk created by different working postures.

1.5.4 Occupational Repetitive Action (OCRA)

The occupational repetitive action (OCRA) methods to analyze workers’ exposure to tasks featuring various upper-limb injury risk factors like repetitiveness, force, awkward postures and movements, lack of recovery periods (Occhipinti and Colombini, 1996). The OCRA index can be predictive of the risk of upper extremity (UE) work-related musculoskeletal disorders (WMSDs). It is generally used for the (re)design or in-depth analysis of workstations and tasks (Colombini et al., 1998, 2002). The OCRA checklist, based on the OCRA index, is simpler to apply and is generally recommended for the initial screening of workstations featuring repetitive tasks (Occhipinti et al., 2000; Colombini et al., 2002).

The concise exposure index (OCRA index) is the ratio between the daily numbers of actions actually performed by the upper limbs in repetitive tasks, to the corresponding number of recommended actions (Occhipinti, 1998) mathematically it can be written as,
OCRA = Total number of technical actions actually performed during the shift / Total number of recommended technical actions during the shift.

1.5.5 Ovako working posture Analysis system (OWAS).

This method is used to analyze and control the poor work postural load during work in industries. Generally the postures of Neck/head, Trunk, Arms and legs are analyzed with the help of OWAS. Additionally, it allows the user to estimate either the amount of weight lifted or the strength required to perform a job. Entries are also provided for the time of the observation and the associated work activity and so it is possible to link each posture with the work activity that gave rise to it. The method can be applied for the development of a workplace or a work method, to reduce its musculoskeletal load and to make it safer and more productive. Planning of a new workplace or work method, ergonomic surveys and occupational health surveys (http://turva.me.tut.fi/owas).

1.5.6 Visual Analogue Scale (VAS)

Several studies (Aaras et al., 2002; Carey and Gallwey, 2002, 2005; Cote et al., 2005; Khan et al., 2010a & b; Kong et al., 2011; Lin et al., 1997; You et al., 2005, Mukhopadhyay et al., 2007 & 2009; Finneran and O’Sullivan 2010 etc.) have been found to use the Visual analysis scale (VAS) as a dependent variable to predict the risk of injuries associate with WMSDs in tasks involving awkward posture or inadequate force/frequency levels. VAS is a tool used to help a person rate the intensity of certain sensations and feelings, such as pain during working. In the analysis for checking the condition of pain, the visual analog scale is used as a horizontal straight line of 10 cm length with one end zero (0) meaning no pain; middle (5) means moderate pain and the other end (10) meaning the worst pain imaginable. A worker marks a point on the line that matches the amount of pain he or she feels (D’Gould et al., 2001).

1.6 Posture related Discomfort Predictions Models

There is a close relationship between certain factors like awkward postures, repetitive motions; force & frequencies etc. and WMSDs as discussed above. Different researchers (Khan et al., 2009a &b; Khan et al., 2010; Mukhpadhyay et al., 2007a & b, 2009; O’Sullivan and Gallwey, 2005; Finneran and O’Sullivan, 2010; Carey and Gallwey, 2005; Kong et al. 2012; Lin et al., 2010; Cook and Burgess-Limerick, 2004; Kuijt et al., 2007) have tried to investigate the influence of these factors on discomfort score, and have developed certain
models to predict the risk of WMSDs to avoid or to minimize the causes of WMSDs. The discomfort prediction models presented by a group of researchers (Carey and Gallwey, 2002, 2005; Khan et al., 2003; Khan et al., 2009a, 2009b & 2010) were developed for the repetitive tasks of wrist flexion force or wrist flexion force combined with gripping with respect to the deviation in the wrist posture or wrist deviations combined with forearm rotations. Other studies (O’Sullivan and Gallwey, 2002 & 2005; Mukhopadhyay et al., 2007a, 2007b & 2009) were also aimed to develop the discomfort prediction models for the rotation of forearm or forearm rotation combined with elbow flexion/shoulder rotations for repetitive torquing tasks. However, these models are presented below in details which highlight the need for developing other models for different types of tasks such as gripping / torquing for the different postural combinations of upper limbs.

Genaidy et al. (1993) conduct a study with the main objective to examine the effects of postural deviations on perceived joint discomfort ratings assessed under similar working conditions. Body movements were defined around major joints of the body, namely, wrist, elbow, shoulder, neck, low back, hip, knee, and ankle, for both standing and sitting positions. In total, there were 31 and 24 body movements for the standing and sitting positions, respectively. The standing posture experiments were conducted during the first two weeks of study, followed by experiments that involved sitting postures. Each treatment lasted for 30 s, followed by a 30 s pause. The discomfort ratings were recorded during the 30 s pause. At the end of the 30 s period, the subjects rated the degree of joint discomfort arising from maintaining a body part in a specific position around a joint. Based on the findings certain guidelines were made to reduce the risk of WMSD. Such that, upper extremity postures in which the arms were outstretched either forward, backward or sideways in the standing position lead to high levels of perceived shoulder discomfort ratings. Supination of the forearm should be given the highest ranking with respect to joint stressfulness, followed by pronation, and then both elbow flexion and extension. Lateral bending of the neck appears to be more stressful than its flexion, extension and rotation. Apart from this, in the standing position, extension of the back should be given the highest ranking for back movements, followed by lateral bending and rotation, then flexion. Straker et al. (1997) compared the risks assessed in single manual handling tasks with those in combination tasks. Ratings of discomfort, exertion and heart rate were collected, by performing combination and single tasks. Combination tasks consisted of sequences of pull, lift, carry, lower and push tasks. The dependent variables were, Discomfort, Rating of Perceived Exertion (RPE), Heart rate. These
results suggested that the risk in Combination manual task cannot be accurately assessed by using estimates from discomfort, RPE and heart rate measures of Single tasks. Olendorf and Drury (2001) investigated that in the design or redesign of workplaces it would be helpful to know in advance the postural stress consequences of a wide range of body postures. This experiment evaluated 168 postures chosen to represent those in the Ovako Working-posture Analysing System (OWAS) using Rated Perceived Exertion (RPE) and Body Part Discomfort (BPD) measures. The postures comprised all combinations of three arm postures, four back postures, seven leg postures and two forces (weights of held boxes). The study suggested that in a static box-holding task to instantiate the 84 OWAS standard postures at their lowest two force categories, the different OWAS standard postures gave reliably different judgments of exertion and discomfort even with a short exposure time (20 s). A simple additive model was derived that could form the basis of a simple design/redesign tool for workplaces.

To examine the importance of the use of comfort level or discomfort level assessment in industrial applications, Kuijt et al. (2007) identified the factors of the hand tools using principal components analysis. The relationships between comfort descriptors (i.e. statements in end-users’ own words that are related to comfort) and comfort factors (i.e. groups of comfort descriptors) with comfort experience were calculated. It was concluded that the same factors (functionality, physical interaction adverse effects on skin and in soft tissues) underlie comfort in different kinds of hand tools. Functionality and physical interaction were the most important factors of comfort in using screwdrivers and paintbrushes and functionality was the most important factor in using handsaws.

Efforts have been made to develop the prediction models for discomfort score for wrist flexion task with respect to wrist deviations by Lin et al. (1997) and Carey and Gallwey (2002). Lin et al. (1997) studied the relative effects of repetition, force and posture in order to examine how continuous biomechanical measurements can be combined into a single metric corresponding to subjective discomfort. In the study a full factorial experiment was conducted involving repetitive wrist flexion against a controlled flexion force. Seven subjects performed the task using two paces (20 and 4 motions/min), two force levels (15 and 45 N) and two angles (15° and 45°) for 1 hour each. Discomfort was recorded on a 100 mm visual analogue scale. Repeated measures analysis of variance showed that all main effects were statistically significant (p<0.05). A linear regression model was fitted to the data and used for generating repetitive motions and exertions into an output in to relative discomfort. Carey and Gallwey (2002) investigated the effects of exertion, pace and level of simple and combined
flexion/extension and radial/ulnar deviation of the wrist on discomfort for simple repetitive exertions. They concluded that extreme flexion caused the highest discomfort rating of the simple deviation types. (i) Combined flexion and ulnar deviation caused the highest discomfort of the combined deviation types. (ii) Exertion was a highly significant factor in discomfort for all of the deviation types. Posture was highly significant for the combined deviations. Pace was only highly significant for combined flexion with ulnar deviation. (iii) No significant interaction effects were observed between the main factors investigated, but more experiments need to be conducted in order to gain a full understanding of the development of discomfort. Furthermore Carey & Gallwey (2005) evaluated the wrist discomfort levels for combined movements at constant wrist flexion force and repetition rate of 15 times per minute and with a force of 10N+1N in 49 combinations of flexion/extension and radial/ulnar deviation to 0%, 18%, 38% and 55% of the range of motion (ROM) for 5 min each. The dependent measure was discomfort measured on a 100 mm visual analogue scale and for most of the analyses these were standardized by using the min – max procedure of Gescheider (1988). These Standardised Discomfort Levels (SDLs) were fitted to mathematical equations from which iso-discomfort contours were derived relative to the percentages of flexion/extension and radial/ulnar-deviation ROM used. The study finally concluded that when extension was combined with ulnar deviation the extension angle had a highly significant effect on discomfort (p< 0.001) but the effect of ulnar angle was not significant. However, when flexion was combined with ulnar deviation, both joint angles significantly affected discomfort (p< 0.001 and p< 0.025 respectively). In contrast to these, when extension was combined with radial deviation, discomfort was not significantly affected by extension but it was by radial deviation (p<0.001). Similarly, when flexion was combined with radial deviation, both had a significant effect on discomfort (p< 0.01 and p< 0.025, respectively). Linear regression equations for the relationship of standardized discomfort levels to percentage of ROM, for both simple and combined deviations, gave R² values between 0.548 and 0.712. These enabled contours of iso-discomfort scores to be drawn for a constant force of 10N+1N and a repetition rate of 15 times per min. Lowest discomfort was recorded for the neutral position, followed by 18% of extension combined with neutral in radial/ulnar deviation. It should be noted that these contours would be different for other levels of forearm rotation, as the ROM of the wrist is dependent on forearm rotation. The aim of the study conducted by Khan et al. (2009a) was also in line with the study of Carey and Gallwey (2005), to examine the pattern of the change in discomfort.
for combined wrist deviation and forearm rotation as joint angles increased away from neutral in a repetitive wrist flexion task. There were five levels of wrist deviation (neutral, 35% and 55% of the range of motion (ROM) in radial and ulnar deviation) and five levels of forearm rotation (neutral, 30% and 60% of the ROM in pronation and supination). A visual analogue scale was used for recording the discomfort scores. The results of the study showed that the main effects of wrist deviation and forearm rotation on discomfort were significant (p = 0.007 and 0.001, respectively) but the interaction was not significant (p = 0.966). The three-way interaction between wrist deviation, forearm rotation and participant was also not found to be significant (p =0.308). Discomfort prediction and iso-discomfort contours ($R^2 = 0.90$) were developed to predict discomfort with regard to forearm rotation and wrist deviation in terms of % ROM. The high discomfort scores for the combined wrist deviation and forearm rotation conditions above 30% ROM were found indicative of their synergistic relationship with discomfort and the regression models accurately projected this relationship. In continuation for wrist flexion task another study by Khan et al. (2009b) recorded the perceived discomfort in an isometric wrist flexion task. Independent variables were wrist flexion/extension (55%, 35% flexion, neutral, 35% and 55% extension ranges of motion (ROM)), forearm rotation (60%, 30% prone, neutral, 30% and 60% supine ROM) and two levels of flexion force (10% and 20% maximum voluntary contraction (MVC)). The study revealed that force, forearm rotation and force x forearm rotation (each p = 0.05) significantly affected discomfort. This indicated a strong independent but also synergistic effect for high forces and deviated pronation/supination postures and discomfort. These data obtained in the study suggested that forearm rotation up to 60% ROM may be acceptable for neutral wrist flexion/extension at low force exertions (<10% MVC). For the task studied, a discomfort level of 2.5 (on a scale of 0–10) would encompass posture combinations of 75/50% and 50/75% ROM for the wrist and forearm for low forces (<10% MVC). But this contracted to 50% ROM for the wrist and forearm for higher forces between 10 and 20% MVC. The data also indicated that discomfort remained low for forearm rotation within the range of + 60% ROM forearm when combined with a neutral wrist, at low forces (<10% MVC). The regression equations and iso-discomfort contours developed in the study may be used to predict discomfort score for the combined wrist deviation with forearm rotation for repetitive wrist flexion task. Further, (Khan et al. 2010) investigated discomfort for intermittent isometric wrist flexion exertions, at various levels of prone/supine forearm rotation combined with wrist flexion/ extension and wrist radial/ulnar deviation and to provide a basis for more
extensive studies and to develop a model of discomfort in wrist flexion tasks, especially to show the manner in which the discomfort changes as the posture changes towards the extremes. The researchers finally concluded that forearm rotation had a highly significant (p < 0.001) on discomfort for repetitive wrist flexion task. With the forearm at 60% ROM prone and 60% ROM supine, the cumulative means of the standardised discomfort score (SDS) scores were 85% and 90% more compared to neutral wrist. Deviation of the wrist in the vertical plane (flexion/extension) had a significant effect on discomfort (p = 0.001). Post hoc tests revealed that the values for 35% ROM wrist extension were not significantly different from neutral (p = 0.103). There was an increase in average cumulative SDS of 28% for 35% ROM wrist flexion compared to neutral. Wrist radial/ulnar deviation had a highly significant effect (p < 0.001) on SDS with an increase of 22% and 21% for 35% ROM radial and ulnar deviation, respectively. Frequency was also highly significant (p < 0.001) with an increase of 28% for 20 exertions/ min compared to 10 exertions/ min for 10 N wrist flexion repetitive exertions. Combining extremes of the three postures increased standardized discomfort scores markedly from neutral, by factors of 2.53 and 4.41 at frequencies of 10 and 20, respectively. But there were considerable differences between the effects on the participants, partly because the force exerted ranged from 12% to 26% of their MVC.

O’Sullivan and Gallwey (2005) investigated maximum forearm pronation and supination torques and forearm discomfort, for intermittent torque exertions in supine and prone forearm angles for the right arm. The study comprised of two parts, the first of which involved measurement of maximum forearm torque in both twisting directions at five forearm angles including neutral. This was followed by endurance tests at 50% maximum voluntary contraction (MVC) in both directions. The second part of the study involved subjects performing 5-min duration of intermittent isometric torque exercises at 20% MVC in both directions at 11 forearm angles. Regression equations were developed that accurately predict torques as a function of forearm angle expressed as a percentage of ROM. This study suggested that maximum forearm pronation and supination torque was significantly affected by forearm angle (p< 0.001) and the direction (p<0.05) of exertion (clockwise or counter-clockwise). A two-way interaction between forearm angle and torque direction was identified that demonstrated a decrease in torque strength over the range 75% prone to 75% supine of 30% and 8%, respectively for supination and pronation torque strengths. Forearm discomfort for intermittent torques at 20% of MVC was significantly higher for the pronation torques than supination (p< 0.001) and for both pronation and supination torques discomfort was
significantly affected by forearm angle (p< 0.001). The results provided important strength
and discomfort models for the design of tasks involving static or repetitive forearm twisting
and to predict discomfort for repetitive torquing tasks. In line with O’Sullivan and Gallwey
(2005) and Mukhopadhyay et al. (2007a), the effects of upper arm articulations on shoulder-
arm discomfort profile in a pronation task were evaluated, consisting of three forearm
rotation angles (60% prone and supine, and neutral), two elbow angles (45° and 90°), three
humeral rotation angles (45°, 90° and 130°), and two upper arm angles (45° flexion and
neutral). Based on the findings, Maximum standardized discomfort score (SDS) (7.1) was
found at 135° lateral rotation of humerus, neutral upper arm 45° elbow flexion and forearm
prone that is why this posture should be avoided. Minimum SDS (1.3) was also recorded at
90° humeral rotation, neutral upper arm, 90° elbow and neutral forearm hence work should be
designed to implement such a posture. Further, Mukhopadhyay et al. (2007b) presented
another laboratory study considering a full factorial model of three forearm rotation angles
(60% prone and supine and neutral range of motion), three elbow angles (45°, 90° and 135°),
two exertion frequencies (10 and 20/min) and two levels of pronation torque (10% and 20%
MVC). The study revealed that with the upper arm at 90° abduction and elbow angles of 135°
and 90°, there was no significant change in discomfort score showed no effect of elbow angle
within this range of articulations. In general, the prone condition of the forearm resulted in
more discomfort compared to the supine or neutral conditions, indicating that work at this
articulation should be undertaken with extreme caution. Discomfort in general was maximum
at 45° elbow angle compared to 90° and 135° indicating extreme caution for having operators
work at such articulations. Since there was lack of quantitative data on the effects of upper
arm flexion and extension angles combined with pronation torques, Mukhopadhyay et al.
(2009) extended their work to include forearm rotation, upper arm flexion and elbow flexion
effects simultaneously so as to cover a more complete set of postures as is mostly common in
industries. The study considered three levels of elbow angle (45°, 90° and 135°), three levels
of forearm rotation angle (neutral, +60% ROM, -60% ROM) and three levels of upper arm
angle (45° flexion, 45° extension and neutral), one exertion frequency (15 per min) and one
level of pronation torque (20% maximum voluntary contraction (MVC) relative to MVC at
each articulation). It was concluded that Forearm rotation angle (% ROM) affected MVC
pronation torque with maximum torque recorded with the forearm supine. However, forearm
angle, elbow flexion and upper arm flexion/extension did not have a significant effect on
discomfort in the analysis of covariance (ANCOVA). Further investigation of the data
revealed that some of the participants experienced posture affects more than others and, in these cases; some of the deviated postures resulted in considerably higher discomfort ratings, specifically for the forearm pronated, the elbow flexed and the upper arm extended.

Lin et al. (2010) investigated the effect of arm reaching and holding related factors on subjective discomfort rating among males and females and a comparison was made. Independent variables in the study were shoulder flexion ($60^0$, $90^0$ and $120^0$), reaching frequency (2 motions/min and 4 motions/min), holding weight (0.86 kg and 1.12 kg), and holding duration (5 s and 10 s). The response measures were as subjective discomfort ratings of the whole body (WBD), shoulder (SD) and upper arm (UAD). The results showed that shoulder flexion, holding weight, reaching frequency and holding duration affect discomfort rating. This experiment elevates muscular effort of the upper limb to support greater shoulder flexion and heavier weight, causing greater discomfort. Higher arm reaching frequency and longer holding duration causes disturbance of potassium homeostasis on upper limb muscles and increases discomfort accumulation. In addition, it has been found that Females’ subjective discomfort ratings are significantly greater than males under the same task condition. They developed nine regression models to predict WBD, SD and UAD from arm reaching and holding related factors. These results can be used as task design guidelines to reduce the incidence of work-related musculoskeletal discomforts and disorders. Kong et al. (2011) investigated the wrist discomfort levels for combined movements at constant force and repetition rate. Maximum grip strength and discomfort were measured at 15 different hand positions in standing posture. The hand position was defined by five hand directions (i.e. $0^0$, $45^0$, $90^0$, $130^0$, and $180^0$) of the shoulder flexion angle, and three hand-shoulder distances (i.e. 100%, 75%, and 50%) of arm reach. As per given task after gripping maximum strength, the subjects were asked to rate their perceived discomfort score on a visual analogue scale (VAS). The results showed significant effects of hand-shoulder distance, hand direction and their interaction ($p<0.05$). The study revealed different effects on grip strength when individuals used different hand positions in order to grip. It was recommended that hand position should be over 75% of arm reach and in the reach direction of between $45^0$ and $135^0$ of the shoulder angle for optimum grip strength and comfort. In another study by Kong et al. (2012) three different evaluation systems of comfort, discomfort, and a continuum for the force levels and hand regions when gripping hand tools were investigated. The postures considered were shoulder hanging down relaxed, the elbow at $90^0$, and the wrist in neutral position. The ten levels of %MVC (10% -100%MVC at intervals of 10%) were used as the
force levels for the experimentation. According to the results of the regression analyses, the continuum model showed a higher coefficient of determination ($R^2$) than those of the comfort and discomfort models. The model was proposed to be used for the assessment of the comfort and discomfort rating scale.

1.7 Relatedness of Posture and Grip force/grip endurance time

There are strong evidences (Marley et al., 1993; Richards, 1997; Snook et al., 1999; Rose et al., 2001; Mogk and Keir, 2003; Liu and Tokarski, 2005; Shih, 2005; Badi and Boushala, 2008; Eksiaglo, M., 2011) that postures affects grip strength and endurance time. If the posture is comfortable the grip force and endurance time will be more however if the posture is awkward then even grip force maybe more for a short while but the endurance time will definitely be short. Regarding this issue several studies (Kattel et al., 1996; Gil Coury et al., 1998; Rose et al., 2000; Garg et al., 2002; Nicolay and Walker, 2005; El ahrache et al., 2006; Garg et al., 2006; Wu et al., 2009; Soo et al., 2011; Li & Wu, 2011; Kong et al., 2011) were conducted by the researchers and they tried to investigate the effects of postures on grip force and endurance time so that tasks or tools may be redesigned as per human endurance to improve the productivity and to reduce the risks of WMSDs.

As per available literature, researchers (Marley et al., 1993; Kattel et al., 1996; Richards, 1997; and Li & Wu, 2011) have investigated the effects of upper limb postures on grip strength/maximum voluntary contraction of grip strength. A study by Snook et al. (1999) represented a continuation of a series of psychophysical studies; the purpose of the study was to quantify maximum acceptable forces for extension motions of the wrist performed with a pinch grip. Kong et al. (2011) proposed that maximum grip strength can be used in designing work methods or workstations ergonomically. The review of the literature regarding these effects highlights the need for further investigations.

Kattel et al. (1996) investigated the position of peak grip strength in different shoulder, elbow, and wrist posture combinations by taking two shoulder postures ($0^\circ$ and $20^\circ$ abducted), three elbow angles ($90^\circ$, $135^\circ$, and $180^\circ$ flexion), and nine different wrist posture combinations (neutral, $1/3$ maximum flexion, $2/3$ maximum flexion and neutral, $1/3$ maximum ulnar deviation, $2/3$ maximum ulnar deviation). Neutral posture consists of the wrist at $0^\circ$ flexion, elbow at $90^\circ$ flexion, and shoulder at $0^\circ$ abduction. The study showed that maximum grip strength was exerted in the 'neutral posture' of the body (shoulder at $0^\circ$, elbow at $90^\circ$, and wrist at neutral); the results of this study also revealed that maximum grip occurs
at elbow flexed at 135° with shoulder and wrist in the neutral postures. Similarly Richards (1997) found that grip strengths were found different when measured in supine and sitting positions among males/females. The data showed that men were stronger (49kg) than women (29kg; p < 0.001) and right hands were stronger (41kg) than left (39kg; p < 0.001). However, grip strengths while sitting were equivalent to those tested while supine (p > 0.59). Using identical upper extremity positions, grip strength was equivalent when tested in the supine and sitting positions. This study also highlighted the importance of gender effects on grip strength. Shih (2005) investigated the influence of gender, forearm position, wrist deviation, and splint (with and without) on grip performances including maximal volitional contraction (MVC), maximum acceptable sustained time (MAST), cumulated exertion output (CEO), and normalized exertion level (NEL). The forearm positions were set at 30° internal shoulder rotations, 0° internal shoulder rotations, and 30° external shoulder rotations, the angles being measured between the sagittal plane and the long axis of dominant forearm. The wrist deviations were extension 30°, neutral, and flexion 30°, the angles being measured between the sagittal plane and the long axis of the grip gauge. The study concluded that the gender effect was the most dominant among all the evaluated factors. Males have more MVC, longer MAST, and greater CEO, but less NEL. The forearm posture was found to be significant only on the MVC. In addition, the effect of wrist posture was not able to shift all responses, nor was the effect of splints. Snook et al. (1999) represented a continuation of a series of psychophysical studies on repetitive motions of the wrist conducted in the laboratory. The purpose of the study was to quantify maximum acceptable forces for extension motions of the wrist performed with a pinch grip. From the results of this experiment it was concluded that psychophysically determined maximal acceptable torques of wrist extension with a pinch grip were substantially lower than wrist flexion with a pinch grip, wrist flexion with a power grip or ulnar deviation. Studies have also shown effect of grip strength on forearm muscle loading. Mogk and Keir (2003) investigated the effects of posture on forearm muscle loading during gripping. The aim of this study was to quantify the response of the forearm musculature to combinations of wrist and forearm posture and grip force. This investigation demonstrated the levels to which the forearm muscles can be loaded statically during gripping tasks, as well as muscle loading differences due to variation in grip strength. Forearm posture only affected grip force when the wrist was flexed, but altered muscle contributions in each wrist posture, particularly without grip force or at low to mid-range grip force levels. Despite the muscle redundancy of the forearm, consistent muscle responses were
found. Regarding other type of effects such as pushing, lifting etc. along with grip, Liu and Tokarski (2005) analyzed values of the maximal forces of pushing, lifting, handgrip and torques of pronation and supination to develop predictive equations expressing maximal force in relation to upper limb posture for four upper limb activities. The participants exerted maximal forces of the above-mentioned five different upper limb activities in 24 upper limb postures. The analysis showed an influence of each of the seven angles on the exerted force. On the basis of the measurements obtained in the experimental study, predictive equations of the maximal force of pushing and lifting as well as torques of pronation and supination, in relation to the seven angles defining upper limb posture, were established. Badi and Boushala (2008) conducted an experiment to measure the maximal isometric strength and to investigate the effects of different handle heights and elbow angles with respect to middle sagittal plane on the pushing and pulling strength in vertical direction. The highest isometric strength was found in pulling at shoulder height (µ = 60.29 lb., σ = 16.78 lb.) and the lowest isometric strength was found also in pulling at elbow height (µ= 33.06 lb., σ = 6.56 lb.). Although, the isometric strengths were higher at shoulder height than at elbow height for both activities, the maximal isometric strengths were compared statistically. The results of the experiment revealed that there was a significant different between handle heights.

Wu et al. (2009) investigated, whether assessment of an individual’s upper limb function may be improved by using specific regional norms rather than consolidated global norms. Grip strengths were measured in a sample of 482 adults, across Taiwan, and compared with consolidated norms. As per the results of the study variables were defined (i.e. gender, age, palm length, grip span, grip position, and left/right hand) which could affect grip strength. It has also been found that palm length was after gender and age the most influential of the factors studied. A study about assessment of grip force and subjective hand force exertion under handedness and postural conditions was carried out by Li and Wu (2011). The hand exertions were measured under two hand conditions and two posture conditions (the postures included 90° and 180° at the elbow; each subject gripped the dynamometer to one of the four CR-10). It has been concluded the subjects tended to apply a higher power grip force (%MVC) than they perceived at levels 2, 5, and 7 on the CR-10 scale. The grip forces were significantly different between the two hands at level 10. Similar results were found for the arm posture conditions. At level 10, the grip forces at 180° posture were significantly higher than those at the 90°. The overall correlation coefficient between the CR-10 rating and the grip force was significant (r = 0.92; p < 0.001). Eighty regression models have been
established between the CR-10 rating and the grip force. The subjects reported higher subjective ratings than the estimations which were based on their own perception and grip force data, even though the regression models had very high $R^2$ values. Kong et al. (2011) worked on, whether maximum grip strength can be used in designing work methods or workstations ergonomically. The objective of their study was to measure grip strength and perceived discomfort at different hand positions and to investigate the effects of shoulder angle and reach distance on grip strength. Maximum grip strength and discomfort were measured in 58 male volunteers at 15 different hand positions in standing posture. The hand position was defined by five hand directions ($0^\circ$, $45^\circ$, $90^\circ$, $130^\circ$, and $180^\circ$) of the shoulder flexion angle, and three hand-shoulder distances (100%, 75%, and 50%) of arm reach. The study suggested that hand position should be over 75% of arm reach and in the reach direction of between $45^\circ$ and $135^\circ$ of the shoulder angle for optimum grip strength and comfort. For the grip force distribution, and twisting abilities, on different shapes of handles, also for other types of strength, Seo and Armstrong (2011) developed a generic torque model for various handle shapes based on experimental data. Maximum torques were 25%, 7%, and 31% greater for the elliptic, large-size, and rubber-finished cylinders than for the circular, medium-size, and aluminium-finished cylinders, respectively. Greater torque for the elliptic cylinders was associated with 58% greater normal force that the subjects could generate for the elliptic than circular cylinders. The model suggested that greater torques for the large-size and rubber cylinders are related to long moment arms and greater frictional coupling at the hand-cylinder interface, respectively.

Chang and Shih (2007), investigated the effects of glove thickness on hand performance and fatigue during two infrequent high-intensity gripping tasks, such as 5-s and sustained tasks. The hand performance was evaluated by maximum volitional contraction (MVC) and its associated time needed to reach the MVC (TMVC), and the total force generation (TFG) during the sustained task. The hand fatigue was assessed by MVC degeneration (DMVC), the shift in time needed to reach the MVC (DTMVC), and the maximal endurance time (MET) associated with the sustained task. The study indicated that wearing gloves decreased the grip MVC, and the thicker the gloves, the less the grip MVC, but the wearing style did not change the MVC (Cotton-2 MVC was indifferent from Covered-2 MVC). As to muscular fatigue, on the other hand, wearing gloves did not affect DMVC, MET, TMVC, or DTMVC. Due to the greater bare-hand MVC and indifferent MET, bare-hand TFG was better than those
conditions with gloves. Finally, the load specified here did not alter TMVC or DTMVC, but the greater the load, the more strength degeneration (DMVC) was induced.

Several studies (Rose et al., 2000; Rose et al., 2001; Garg et al., 2002; Mogk and Keir, 2003; Liu and Tokarski, 2005; Nicolay and Walker, 2005; Shih, 2005; El ahrache et al., 2006) have indicated the effects of posture on grip endurance time and other related factors. Nevertheless there is a need for further investigations in this regards to strengthen these data of the grip endurance time, that may be used for tools, workstation or task design. Law and Awin (2010) investigated static task intensity–endurance time relationships (e.g. Rohmert's curve) as were first reported decades ago. In this study a systematic literature review of endurance time for static contractions have been performed, and developed joint-specific power and exponential models of the intensity endurance time relationships, and compared these models between each joint (ankle, trunk, hand/grip, elbow, knee, and shoulder) and the pooled data (generalised curve). One ninety four publications were found, representing a total of 369 data points. The power model provided the best fit to the experimental data. Overall, the ankle was most fatigue-resistant, followed by the trunk, hand/grip, elbow, knee and finally the shoulder was most fatigable. It has been concluded that endurance time varied systematically between joints, in some cases with large effect sizes. Thus, it may be said that a single generalized endurance time model does not adequately represent fatigue across joints.

Gil Coury et al. (1998) conducted a study to measure the isometric shoulder adduction strength of healthy males and females in symmetric and asymmetric planes in different postures. The participants performed a two-handed maximal compression on the lateral sides of the adduction strength testing device. The strengths were recorded in 36 different conditions as a result of the combination of different shoulder and elbow positions in three planes (sagittal, 30° left and 30° right asymmetrical planes). A multivariate analysis of variance was carried out to determine differences between gender, conditions and anthropometric measures. A multiple regression was performed on two-thirds of the data to predict the shoulder adduction strength from anthropometric characteristics and validated against the remaining one-third. The study concluded that there was a significant drop in strength in three conditions shoulder flexed at 90° and elbow fully extended, shoulder extended at 30° and elbow flexed at 90°, and shoulder flexed at 90° and elbow flexed at 30° for males as well as females in all three planes. The males were significantly stronger than females, although the general strength pattern was similar. The analysis of variance
conducted for force by gender, condition and planes indicated main significant effects due to both condition and gender (p <0.001). There was no significant difference due to planes both in males or females. The regression equations were significant (p <0.001) and explained 72% and 84% of the variances due to gender, gender and weight, respectively. Some participants experienced some discomfort and pain when performing the experimental tasks. The results revealed a positive association between discomfort and pain, and strength. Rose et al. (2000) investigated the reactions in passively loaded, fully extended elbow joints, pain reactions during and after loading on endurance time and resumption time. The study showed that the relation between external load and endurance time was similar whether the elbow joint was exposed to full extension and passively loaded or actively loaded in a more `normal’ posture. An equation for estimation of the resumption time for a fully extended passively loaded elbow was suggested. Rose et al. (2001) conducted a study about Endurance, pain and resumption in fully flexed postures to investigate, (i) endurance and resumption times for fully flexed postures with low external loads, (ii) which structures limit the endurance time in such postures and (iii) whether there are differences as to endurance and resumption times between experienced workers and unskilled persons. The study showed that endurance times in relation to normalized total load in fully flexed postures differ little from those in more common postures. The results indicated that fully flexed postures might be assessed by more general prediction models for endurance. There were considerable differences between endurance and resumption times for skilled and non-skilled workers in the postures studied. Skilled workers had longer endurance and shorter resumption times as compared to non skilled workers. Garg et al. (2002) investigated endurance times as percentages of maximum voluntary contractions (MVCs) for females in 5 postures and at 7% MVCs. The shoulder postures utilized were 30°/90° (shoulder forward flexion 30° and included elbow angle 90°), 60°/90°, 90°/120°, 120°/150°, and 150°/180°. The %MVCs were 5%, 15%, 30%, 45%, 60%, 75%, and 90% of MVC at each of these postures. Outcome measures included: endurance times, ratings of perceived exertion, fatigue ratings, pain ratings, and surface electromyography (trapezius and mid deltoid). The study revealed that shoulder posture (shoulder forward flexion angle) had a significant effect on endurance time. In general, endurance time decreases with an increase in shoulder flexion angle up to 120° and then it increases. Nicolay and Walker (2005) examined grip strength and endurance in three experiments: single-repetition, 10-repetition, and 30 seconds static hold. The relationships between anthropometric variation and grip performance were assessed. Measurements of the
forearm and hand were found to be better predictors of grip strength than were height and weight. It was found that in contrast to strength, anthropometric variation was completely unassociated with relative grip endurance (percent change in force production). While larger males produced greater average grip force than females, no significant differences existed between the genders in measures of relative endurance. The dominant hand was significantly stronger than the opposite hand, but also fatigued more rapidly. This trend was more pronounced in females than in males, indicating the gender difference on endurance time.

Different aspects of endurance time evaluations have been found as seen in the study of El ahrache et al. (2006) that the maximum endurance time (MET) is a key parameter for the ergonomic evaluation of static work. The aim of their study was to offer practitioners MET values in relation to the %MVC. Twenty four published MET models were combined to extract MET percentile values that reflected the inter-individual variability and differences among the experimental methods used to develop the models. The results of the study showed that, there was a significant difference between the MET values for the back/hip and the MET values for the upper limbs, for a same % MVC value, and the model-generated MET values followed a lognormal distribution. In another study, Garg et al. (2006) determined the shoulder girdle fatigue for different combinations of weight of work pieces, weight of hand-tools, shoulder postures, arm up time and arm down time that are commonly used in automotive assembly operations. Both objective [surface electromyography (sEMG) and subjective measures (ratings of perceived exertion, (RPE), fatigue and pain) were used to assess stress, fatigue and pain in the shoulder girdle among females. The posture angles were shoulder flexion of 60°, 90° and 120° combined with an included elbow angle of 90°, 120° and 150°, respectively. The study concluded that the response variables included: surface electromyographic signals from the middeltoid/ upper trapezius muscles, ratings of perceived exertion, fatigue ratings and ratings of pain in the shoulder girdle. Mehmoot Eksiaglu (2011) studied the effects of grip-span, shoulder posture and anthropometric characteristics on endurance time of grip-force during sustained 30% of maximal voluntary grip-force and the combinations of three different grip span settings and two shoulder postures. The results revealed that the endurance time decreased significantly as the grip span deviates from the optimal in both directions. Further analysis indicated a significant negative correlation between endurance time and rest pause and a marginal positive correlation between maximum voluntary grip-force and rest pause. Body mass index and volume of forearm and hand had also significant negative correlation with endurance time. Soo et al. (2011) tried to
propose a recovery model to represent the relationship between the muscle fatigue and the rest time. Three experiments were conducted at 50% MVC with the contraction time of 10 s, 30 s and 50 s. Each experiment consists of 5 handgrip tasks with different rest interval. The maximal isometric forces during the pre-fatigue and post-fatigue were recorded to compute the muscle fatigue developed from each handgrip tasks. With this model, the amount of muscle fatigue that was recovered gave the rest duration could be estimated. In this study, a method was introduced to quantitatively estimate the degree of muscle fatigue during cyclic handgrip tasks. The comparison between the two fatigue models with and without the consideration of muscle recovery showed significant difference when the repetitive motion was increased. In addition, it has been suggested that the experiment conducted at 50% MVC was the most appropriate for calibrating the recovery model.

1.8 Upper limb posture and Electromyographic (EMG) activities

Electromyography is useful in diagnosing disorders of the nerves and muscles and EMG is performed most often to help to diagnose different diseases causing weakness. It may also help to identify abnormalities of nerves or spinal nerve roots that may be associated with pain or numbness, atrophy, stiffness, fasciculation, cramp, deformity, and spasticity recordings usually are done while the muscles are relaxed, during voluntary contraction, and during muscle activity produced by nerve stimulation. With the help of EMG it is possible to determine the presence of a disorder, to localize the site, and identify the specific disease producing muscle weakness. EMG can also determine whether a particular muscle is responding appropriately to stimulation, and whether a muscle remains inactive when not stimulated, in determining whether symptoms are due to a muscle disease or a neurological disorder, and, when combined with clinical findings, usually allow a confident diagnosis. EMG has been used in ergonomics (Marras, 1990; Kumar, 1996) as an important parameter for getting knowledge regarding effects of different factors like awkward postures, forces and frequencies and repetitive tasks etc on the WMSDs. It has been used to assess the activity of specific muscles in many experimental design (Jarvholm, 1991; Kumar et al., 1996), and field studies (Jonsson, 1988; Westgaard, 1988). It is also especially used for the understanding of how specific muscles may be affected by different work positions and activities (Hagberg, 1981; Herberts, 1980; Kumar, 1979), work station lay-out (Kumar, 1994; Strasser et al. 1991) or tools (Kumar, 1995). All these studies have provided ergonomic principles and guidelines for the design of safer work. Although the EMG technique has limitations (Kumar, 1996;
Marras, 1990), the foregoing and other studies have provided helpful ergonomic information for the safer design of occupational activities.

The studies have also used EMG for ergonomics point of view in investigations of upper limb posture and their effect in repetitive or non repetitive tasks. Ringelberg (1985) conducted a study in which surface EMG was recorded on three different occasions from the three parts of the deltoid muscle to see the postural effects. During abduction in the scapular plane the middle and posterior parts of the deltoid muscle showed significantly less activity than in the frontal plane. He also presented a simple two dimensional model to calculate the deltoid force out of total external moment at the shoulder. Coury et al. (1998) studied the EMG activity of shoulder and arm muscles during force generation in different shoulder and elbow positions when performing an isometric adduction. EMG from four pairs of muscles (biceps, anterior deltoid, pectoralis and flexor carpi radialis) were recorded. The experiments were conducted in 14 different postures as a result of seven combinations of shoulder and elbow positions in two planes (sagittal and 60° right trunk rotation). It has been found that the EMG activity was significantly affected by posture (p <0.001) but not by symmetry. The results also revealed that the EMG activity increased with the increase in forward flexion of the shoulder, whereas the forces decreased. Amell et al. (2000) investigated the effect of trunk rotation and arm position on gross upper extremity adduction strength and muscular activity. The study was performed graded maximum voluntary contractions under isometric conditions in seven upper extremity positions and three trunk postures (neutral and 90° left/right rotated) in a simulated manual materials handling task. The study showed that shoulder adduction strength was not significantly affected by trunk rotation, but the strength profile of the upper extremity was highly affected by position and those positions where the upper extremity was capable of producing the greatest adduction force should be kept in mind in manual materials handling tasks. The EMG activity recorded indicated that the biceps brachii and the flexor carpi radialis were two highly active muscles and they should not be overloaded. Anton et al. (2001) studied the effect of overhead drilling tasks on EMG activity and shoulder joint moment. The results revealed that, compared to the far reach position, using the close reach position significantly decreased anterior deltoid muscle’s amplitude (AMP), biceps brachii AMP and moment, but increased triceps brachii AMP. When compared to the lower step, using the higher step significantly decreased anterior deltoid AMP and triceps AMP and moment, while increasing biceps AMP in the close position. There are several other studies which have showed the significant effects of upper limb posture on EMG activities and their
importance in task analyses or design. Politti et al. (2003) concluded the electromyographic study of the muscles involved in the complex movements of the shoulder, to quantify the static and dynamic joint’s behaviour. In particular, the deltoid medium EMG produced a phenomenon similar to a hysteresis cycle when its amplitude was plotted as a function of the lateral angular position during a static, step by step, sequential abduction and adduction of the arm. The paired Student t-test, after comparing the mean EMG values of the rectified wave for the same arm opening angle between abduction and adduction, produced a highly significant difference (p < 0.001) in all subjects.

Chen and Leung (2007) investigated the effect on forearm and shoulder muscle activity in using different slanted computer mice using EMG recording. The considered muscles were extensor digitorum (ED), extensor carpi ulnaris (ECU), and pronator teres (PT) muscle. The study showed that the activity of the four examined muscles was affected by the slanted angles of designed ergonomic mice in repetitive, long duration computer mouse tasks. Among the five tested mice, the 25° or 30° slanted mice caused lower muscle activity and more neutral working postures for ECU, Trap and PT muscles. For the ED muscle, a larger slanted angle increased the height of the tested mouse, and this might lead to larger wrist extension and a higher risk of carpal tunnel syndrome (CTS). Antony and Keir (2009) examined the influence of arm posture, hand loading and dynamic exertion on shoulder muscle. Surface electromyography was collected from 8 upper extremity muscles on participants who performed isometric and dynamic shoulder exertions in three shoulder planes (flexion, mid-abduction and abduction) covering four shoulder elevation angles (30°, 60°, 90° and 120°). Shoulder exertions were performed under three hand load conditions: no load, holding a 0.5 kg load and 30% grip. It has been observed that adding a 0.5 kg load to the hand increased shoulder muscle activity by 4% maximum voluntary excitation (MVE), across all postures and velocities. EMG was collected from eight muscles of the right upper extremity: anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), pectoralis major (PM), infraspinatus (INF), latissimus dorsi (LD), biceps brachii (BB) and superior trapezius (TR). Gripping led to a decrease of 2% MVE in anterior and middle deltoid activity and an increase of 2% in posterior deltoid, infraspinatus and trapezius activity. In addition, it was also found that gripping increased biceps brachii activity by 6% MVE. There are numerous studies on the use of EMG of shoulder muscles. Brookham et al. (2010) conducted a study to find the effects of shoulder flexion and humeral rotation on shoulder muscle activity during light hand tool use. It has been found that shoulder rotation/flexion
had significant effects on EMG activities of the shoulder muscles. An investigation has been carried out by Fagarasanu et al. (2004) to evaluate the forearm muscles activity in different wrist deviated positions and wrist neutral zone. The EMG of the forearm muscles flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), extensor carpi radialis (ECR) and, extensor carpi ulnaris (ECU) in deviated and neutral wrist postures was recorded. The significantly higher EMG activity was recorded for each muscle in the wrist deviated postures when compared to neutral position (p < 0.001). Significantly lower EMG muscle activity was recorded while the wrist was positioned within neutral zone as compared to deviated postures. Gordon et al. (2004) studied the torque produced during axial forearm rotation and the electromyographic (EMG) activity of the muscles involved maximum isometric voluntary contractions in five positions of axial forearm rotation for both pronation and supination. EMG data were collected simultaneously from the supinator, biceps, pronator quadratus, and pronator teres muscles using fine-wire bipolar electrodes. The study showed that supination torque generation was greater in the pronated forearm positions, and pronation torque was greater in the supinated positions (p < 0.05). Mukhpadhyay et al. (2007) investigated the involvement of upper arm abduction which had a strong association with musculoskeletal disorders and injury. EMG activity of the PT and the Extensor Carpi Radialis Brevis (ECRB) was also evaluated in the study. EMG activity of the PT and the ECRB revealed that both muscles were affected by forearm rotation and level of MVC torque.

In continuation to the studies of postural effects evaluation on EMG activities, several studies have been found in literature showing the use of EMG for tasks evaluation and design using EMG recording and analyses for different types of forces. Ramon et al. (1999) used EMG recording for the evaluation of Laparoscopic instruments, which generally incorporated a pistol-grip handle type with rings for the fingers. This study evaluated the hypothesis that the use of the palm grip requires less muscle tension than the finger-grip when grasping with laparoscopic instruments. Surface EMG signals were acquired from the FCU, flexor digitorum profundus (FDP), flexor digitorum superficialis (FDS), extensor carpi ulnaris (ECU), extensor digitorum comunis (EDC) and the thenar compartment (TH). The results showed that the palm grip was more powerful than the finger grip when grasping with laparoscopic instruments, particularly at angles perpendicular to the surgeon’s sagittal plane. Bressel et al. (2001) examined whether handgrip position during arm cranking exercise influences the neuromuscular activity of muscles biceps brachii (BB), lateral head of triceps brachii (TB), middle deltoid (DT), infraspinatus (IS) and brachioradialis (BR). The study
concluded that muscle BR displayed greater activity in the neutral handgrip position, which may reflected its anatomical effectiveness as an elbow flexor when the forearm was in a neutral position. Muscle IS, a rotator cuff muscle, exhibited less activity in the supinated handgrip position. Oda and Kida (2001) investigated the muscle fatigue measuring changes in force output and force tremor and electromyographic activity (EMG) during two sustained maximal isometric contractions for 60 s: (1) concurrent hand grip and elbow flexion or (2) hand grip and elbow extension EMGs were recorded from the flexor digitorum superficialis (FDS), extensor digitorum (ED), biceps brachii (BB) and lateral head of triceps brachii (TB). The decrease in EMG amplitude was observed not for the FDS muscle but for the ED muscle. The hand grip tremor amplitude for each frequency band showed similar decreasing rate, whereas the decrease in elbow flexion and elbow extension tremor amplitudes for the lower band (below 10 Hz) were slower than those for the higher band (above 11 Hz). Several studies (Mogk and Keir, 2003; You et al., 2005; Nijhoff and Gabriel, 2006) have shown the combined effects of upper limb posture and grip forces on EMG activities of muscles. Mogk and Keir (2003) conducted a study to quantify the response of forearm musculature to combinations of wrist and forearm posture and grip force. The study was performed by taking five relative handgrip efforts (5%, 50%, 70% and 100% of maximum and 50 N) for combinations of three wrist postures (flexed, neutral and extended) and three forearm postures (pronated, neutral and supinated). ‘Baseline’ extensor muscle activity associated with holding the dynamometer without exerting grip force was greatest with the forearm pronated and the wrist extended, while flexor activity was largest in supination when the wrist was flexed. Extensor activity was generally larger than that of flexors during low to mid-range target force levels, and was always greater when the forearm was pronated. A flexed wrist reduced maximum grip force by 40 – 50%, but EMG amplitude remained elevated. Forearm rotation affected grip force generation only when the wrist was flexed, with force decreasing from supination to pronation (p <0.005). You et al. (2005) evaluated two design modifications (rubber grip and torsion spring) to the conventional manual Cleco pliers by electromyography (EMG), hand discomfort, and design satisfaction. Four major forearm muscles for flexion/extension and abduction/adduction of the hand/wrist: flexor digitorum superficialis (FDS), extensor digitorum communis (EDC), flexor carpi ulnaris (FCU), and extensor carpi ulnaris (ECU) were selected for the investigations. The study concluded that lower EMG values were obtained for the pliers with rubber grip and at 60° of work surface angle. Nijhoff and Gabriel (2006) measured the maximum isometric force at the
hand in eight directions in the horizontal plane and at five positions in the workplace. Surface electromyographic (sEMG) activity was recorded simultaneously with the force measurements. The eight directions of force corresponded to $45^0$ intervals was taken. The results showed that the normalized maximum forces deviated less than 15%, despite intra-subject differences in muscle strength of more than a factor of two. The largest forces were found in a direction approximately along the line connecting shoulder joint and hand, and the smallest forces perpendicular to that line, thereby forming an elliptically shaped pattern. The elongation of the pattern was the largest for those hand positions having the more extended elbow joint. This study indicated the strong affects of posture on EMG.

Few literatures (Li, 2002; Forsman et al., 2002; Oliviera et al., 2007) on EMG analyses regarding the performance evaluation in tools design were also found. Li (2002) designed hand tools mechanisms to reduce the risk factors. The new designs, together with the traditionally used pliers, were evaluated in simulated wire-tying tasks in the laboratory. Results from these experiments showed that EMG (%MVC) of the flexor digitorum superficialis and the flexor carpi ulnaris of the right forearm may be significantly reduced when using the new designs compared to pliers. The number of unnatural postures, including flexion, extension, radial deviation, and ulnar deviation were all significantly decreased when using the new designs. Forsman et al. (2002) studied about the powered hand tools at a bus assembly plant where pneumatic nut runners were the dominant powered hand tool. The electromyographic activity in five muscles was measured during different phases of the securing, in comparisons of soft and stiff joints, three different joint positions, and two tools were used. The results showed that variance in muscular activity were large. The EMG peaks caused by stretch reflexes were seen for the wrist extensor muscles, and trapezius muscles, for a right-angled tool. Unloading reflexes were noticed for the erector spinae and the trapezius muscles. Joint position strongly contributed to differences in muscular activity in all five muscles, which together with the finding that the tools caused very small differences, were regarded as the most valuable results for the production engineers.

Oliviera et al. (2007) conducted a study to compare sEMG activities during axial load exercises on a stable base of support and on a medicine ball (relatively unstable). Surface EMG was recorded from the biceps brachii, anterior deltoid, clavicular portion of pectoralis major, upper trapezius and serratus anterior using surface differential electrodes. The RMS normalized values of the deltoid were found greater during the exercises performed on a
medicine ball in relation to those performed on a stable base of support. The trapezius showed greater mean electric activation amplitude values on the wall-press exercise on a medicine ball, and the pectoralis major on the push-up. Williams et al. (2002) assessed differences in fatigue-related changes in variables related to structures within the neuromuscular system, between the dominant and non-dominant elbow flexor muscles of right-handed individuals. Two experimental sessions were performed on the right arm and one on the left arm. For each session, maximum voluntary torque, level of voluntary activation, M-wave amplitude, twitch/train or twitch/doublet torque ratio and EMG median frequency were obtained before and up to 20 min after a sustained maximum isometric fatigue task. The results suggested that the preferential use of elbow flexor muscles with the dominant arm leads to more fatigue resistance in certain structures/mechanisms of the neuromuscular system, but not in others.

1.9 Relatedness of Ergonomics interventions to enhance productivity with reduced risk of WMSD

It is a well known fact that the progress of a country depends upon its industrialization. The progress of industrialized world depends upon the production. Therefore, it can be said that the success of industries depends upon productivity in industries. It was felt that for the fast development of the country setting up of new industries, adopting new changes in the old set up, and new technologies are necessary for good working environment and faster production rate. The nineteenth century witnessed far-reaching changes in the nature and organization of industrial production. Traditional non-mechanized establishments, artisan shops were gradually displaced by capital-intensive, mechanized plants and extensive division of labor increased the average size of firms (Chandler, 1977; Sokoloff, 1984). Productivity may be considered as the output of goods and/or services per unit investment of human capital. Under conditions where the main production depends upon human productivity, must control the immediate input of human capital, the work-effectiveness of the individual employees, immediate loss of time due to absenteeism, acute or chronic illness, and the long-term loss of human capital due to early retirement or premature death. The changes in industries for improved productivity were depending upon so many factors required according to the needs of industries, like modernization of industries, disciplined labor, improved work environment, shift towards factory and an increase in the average length of the work year despite declining daily hours of work (Atack and Bateman, 1992;
Atack et al., 2002; Engerman and Goldin, 1993; Attak et al., 2003). Productivity varies with occupancy, effectiveness, and efficiency. Performance often reflects much more than the abilities, motivation, and experience of the individual employee. Output may be affected by absence or lack of cooperation from a key colleague, insufficient management, union restrictions, a lack of essential equipment or materials, failure to invest in automation, a poor overall quality of the working environment, seasonal factors, or a lack of consumer demand for a product (Shephard, 1986a and 1986b).

In earlier days, the people were unaware how to control the causes responsible for affecting the productivity in both senses increment and decrement. Then Ergonomics was introduced as an important tool for controlling these causes. There are strong evidences that ergonomics and productivity have close relationship in industrialized world. Ergonomics as the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession, may apply theory, principles, data and methods to design in order to optimize human well-being and overall system performance (Vink, 2006). Ergonomics has been used to decrease the number of occupational injuries by discovering those postures and tasks that create significant musculoskeletal stresses. However, the principles of ergonomics can be used to improve productivity as well (Resnick and Zanotti, 1997). In addition, ergonomics improvements results in quality and operators productivity (Drury, 2000; Eklund, 1995 and 1997; Battini, 2011). Effective application of ergonomics in work system design can achieve a balance between worker characteristics and task demands. This can enhance worker productivity, provide worker safety and physical and mental well-being, and job satisfaction. Several studies have shown positive impacts of applying ergonomic principles in workplaces, machine design, job design, environment and facilities design (Hasselquist, 1981; Schanauber, 1986; Das, 1987; Rayan, 1989; Burri and Helander, 1991; Shikdar and Das, 1995; Das and Sengupta, 1996; Resnik and Zanotti, 1997; Das and Shikdar, 1999). The features of ergonomic design of machines, workstations, and facilities are well known. However, still there is a low level of acceptance and limited application in industry due to lack of awareness. The main concern of work system design is usually the improvement of machines and tools alone but that is not all, the overall task design plays significant role in productivity. Generally, poorly designed work systems were found in industries (Das, 1987; Konz, 1995). An ergonomically deficient workplace can cause physical and emotional stress, low productivity and poor quality of work (Ayoub, 1990a, b).
Productivity is generally seen in terms of efficiency—the number of output units given the usual or less input hours. However, the worker’s ability or capacity to produce goods or deliver services while suffering from work-related musculoskeletal disorders (WMSD) has been of particular interest in the area of occupational research related to productivity. The productivity creates a new WMSD dimension (O’Donnell, 2000) that has made a conceptual linkage between productivity and human performance, and the linkage between physical and emotional ability to work and human performance.

Work productivity as a measure has been a common subject for examination in various studies on musculoskeletal disorders affecting workers (Hagberg et al., 2002; Beaton et al., 2005; Pransky et al., 2002; Lötters et al., 2005). Interestingly enough, however, published figures on incidence and prevalence related to WMSD do not necessarily reflect lost productivity and quality, recruitment and training of replacement workers, and costs to the injured worker and the worker’s family (Silverstein et al., 1998). A study on the federal workers’ claims on upper extremity disorders in the United States (Feuerstein et al., 1998) found that upper extremity disorders were costly to the health care and resulted in long-term work. In addition, upper extremity disorders accounted for a disproportionate share of the wage replacement and health care costs (Hashemi et al., 1998). In a study by Pransky et al. (2000), workers with lower back and upper extremities injuries were found to have their work performance affected and have had associated negative economic consequences.

Being known to certain factors responsible for affecting the productivity still studies being carried out to gather knowledge regarding basic causes which may affect productivity in relation to WMSDs (Columbini and Ochipinti, 2006; Escarpizo, 2008; Korhan and Mackieh, 2010; Van der Molen et al., 2011; Finneran and O’Sullivan, 2010; Xu et al., 2012), new techniques and tools (Asselt et al., 2008; Attack et al., 2003; Battini et al., 2011; de korte and van Lingen, 2006; Groentjeign et al., 2004), working conditions (Dempsey et al., 2004; Frederick & Fernandez, 1999; Kahya, 2007), safety of workers (Montorselli et al., 2010; Shikdar and Das, 2003a; Shikdar and Das, 2003b), task design (Shikdar & Das, 1995; Escarpizo and Moore, 2007; Resnick and Zanotti, 1997; Vink et al., 2006), aging (Shephard, 2000), improvement of work stations (Freieling et al.,1997; Juslen et al., 2007; Yeow and Sen, 2003), new innovations (Cowan et al., 2011) and also related to regional industrial structure (Drucker and Feser, 2012).
Colombini and Occhipinti (2006) studied the upper limb WMSDs, which are the most common form of occupational diseases in industrialized countries and the main cause of reduced working capacity. The aims of the study were to summarize experiences of close cooperation between ergonomists, machinery designers and job designers to enhance productivity and to prevent musculoskeletal disorders, to examine current ergonomics standards in the field of manual physical work and to suggest preliminary criteria for their implementation taking into account the capabilities and needs of specific sub-groups of the working population. Escorpizo (2008) presented a conceptual model of work productivity, within the area of paid work and within the context of WMSD, they made use of work productivity as an outcome measure in capturing WMSD-associated socioeconomic burden and in evaluating WMSD management programs.

Korhan and Mackieh (2010) studied about the computer user that occupational injuries pose a major problem in workplaces. Intensive, repetitive and long period computer use results in costly health problems (direct cost), and lost productivity (indirect cost). Use of mouse and keyboard supports, together with elbow support helps to prevent the pain in the fingers and elbow. Arm support will help to relieve the heaviness in the shoulders. Supporting the back should be also taken into consideration to avoid the complaints on upper back and lower back pain that may account for relationship between productivity and WMSDs. Finneran and O’Sullivan (2010) found a link between physical risk factors and causation of MSDs particularly, high level of force, deviated postures and repetitive movements. A laboratory study was conducted to test the hypothesis that physical risk factors affect the discomfort and productivity. The parameters considered for the present study were taken as repetitive grip exertions involving combinations of three levels of grip force (10, 20 and 30% MVC), repetition (10, 15 and 20 repetitions per minute) and wrist posture (50% flexion/extension and neutral). The results showed that Discomfort and Productivity data were significantly affected by wrist posture (p < 0.001 and 0.01 respectively). This implied that wrist flexion postures may have a more negative impact of productivity than extension (and neutral). Average discomfort and self paced cycle time (SPCT) values were similar for 10 and 20% MVC, but higher for 30% MVC (both p < 0.001). Forces above 20% will most probably reduce the capacity of the person in self-paced work. For set-paced-work where workers are unable to adjust cycle time for high discomfort tasks, there would be an accumulation of strain and this may, over time resulted in increased risk of injury. Longer duration studies and modelling of discomfort and self paced times is needed for wrist postures greater than 50%
ROM and above 30% MVC. This will enable the generation of profiles that may be useful in predicting productivity effects for industrial tasks that induce such conditions.

Repetitive motion is major source of WMSDs in many tasks, Xu et al. (2012) while investigating assembly workers’ performance due to repetitive motions or heavy workloads by developing linear models to link work/worker assignment to the upper extremity ergonomic measures to allow ergonomic and productivity measures to be integrated as a mixed-integer programming model. Based upon the basics principles of ergonomic and applications of models given by various researchers many studies were carried out. Shikdar and Das (1995) reported productivity improvements in a repetitive production task performed under ergonomic working conditions. This study gave an important result that under good working conditions, challenges and incentives provided to the workers, might be advantageous to improve worker productivity. In continuation of the applications of the principles of ergonomics another study was conducted by Resnick and Zanotti (1997) to study about using ergonomics to target productivity improvements. They found that workstations could be designed to maximize performance and reduce costs by considering both ergonomics and productivity together. Friedrich and Fernandez (1999) also conducted a laboratory experiment to determine maximum acceptable task frequencies (MAF) for males performing a simulated riveting task at different wrist postures and applied force levels using an operational rivet gun. They found that MAF decreased significantly with a deviation in wrist posture and an increase in applied force. These results supported that ergonomic intervention may decrease the development of work-related musculoskeletal disorders thus, reducing workers compensation costs and lost productivity of the worker.

Shikdar and Das (2003a) identified factors affected worker productivity, occupational health and safety in selected industries in a developing country. Fifty production managers participated in that study. Management (88%) acknowledged not having knowledge or access to ergonomics information. Ninety-four percent of the companies did not carry out ergonomic assessments. Lack of skills in ergonomics and training, communication and resources were believed to be some of the factors contributing to the poor ergonomic conditions and consequent loss of worker productivity and reduced health and safety in these industries. Further, Vink et al. (2006) focused on the positive aspects of ergonomics in improvement of the working environment. A model was made that classified the success factors e.g. arrange direct workers’ participation; arrange strong management support, carry
out a good inventory, use a step-by-step approach, arrange that a steering group is established with responsibilities, check the effects, including side effects in an early stage, in involvement, process and goal of the ergonomics project.

Van der Molen et al. (2011) found the differences in the number of laying paving stones (productivity), task demands, energetic workload, body region discomfort and preference of laying paving stones with or without use of a paver’s trolley. It has been found that task design which reduces WMSDs may enhance productivity. In another study related to task performance, Escarpizo and Moore (2007) studied the effects of the cycle time of a pick-and-place task on muscle activity, grip force, posture, and perception-based measures. The study showed that a pace threshold exist for a hand transfer task that precedes the physical limitations of the ability to speed up the task and enhanced productivity.

As it is well known that some of the important factors causing WMSDs affecting the productivity are working conditions and working stations, many studies were carried out, one of them was conducted by Kahya (2007). He investigated the effects of job characteristics and working conditions on job performance by considering the effects of job characteristics and working conditions in addition to experience and education level on task performance and contextual performance. The results showed that there were substantial relationships between employee performance both job grade and environmental conditions. In another study, Dempsey et al. (2004), investigated the effects of work height, work piece orientation, gender, and screwdriver type on productivity and wrist deviation during a repetitive screw driving task among males and females. They found that females having a greater performance difference (30%) between the two screwdriver designs than males (10%). There were strong work piece orientations by work height interactive effects on productivity and measures of wrist deviation, which also shows the gender differences.

Productivity also depends on modern technologies, improved working conditions and new tools. Considering the new tools and its effect, Groenjeign et al. (2004) studied about one set of pliers for more tasks in installation work: and its effects on discomfort/comfort and productivity. To improve aspects of the work situation, frequently used pliers were redesigned to make them suitable for more cutting tasks. The multitask pliers appeared to result in more comfort during working, more relaxed working and more satisfaction. In another study, Battini et al. (2011) developed new methodological framework to improve productivity and ergonomics in assembly system design and he developed a new theoretical
framework to assess a concurrent engineering approach to assembly systems design problems, in conjunction with an ergonomics optimization of the workplace. It was proposed to provide professionals with a new and detailed approach to assembly system design procedures that includes ergonomics issues. The methodological framework developed takes into account technological variables (related to work times and methods), environmental variables (i.e. absenteeism, staff turnover, work force motivation) and ergonomics evaluations (i.e. human diversity) to create a comprehensive analysis.

It is observed that teamwork, verbal communication and visual display etc. are the major causes to enhance productivity; therefore, studies were carried out to investigate the effects of these factors on productivity. Yeow and Sen (2003) conducted an ergonomic study to improve the workstations for electrical tests in a printed circuit assembly factory in an industrially developing country. Subjective assessment and direct observation methods were used on the operators to discover the problems in their workstations. It has been found that there were average savings in yearly rejection cost, reduction in rejection rate, increase in monthly revenue, improvements in productivity, quality, operators’ working conditions and occupational health and safety and enhancement in customers’ satisfaction. In another study, Juslen et al. (2007) investigated whether or not a controllable task-lighting system that allowed people to select high lighting levels will enhance productivity under real working conditions. They found an increase of productivity for the test group was +4.5% compared to a reference group. Shikdar and Das (2003) evaluated the manner by which production standards or goals, performance or production feedback and monetary or wage incentive affected or moderated the relationship between worker satisfaction and productivity in a repetitive production task in a fishing industry. The result suggested that the production standards with feedback generally improved worker satisfaction and productivity. The incorporation of production standards, performance feedback and monetary incentive affected worker satisfaction and productivity differently and this had an effect on the worker satisfaction–productivity relationship.

New innovations are very important for industries in many ways like new technologies, new machines, new methods, etc. Montorselli et al. (2010) studied about the comparison of the performance of four different logging crews with respect to productivity, organization and safety. For this purpose, a data collection method was developed which was capable of providing a quantitative analysis of risk-taking behaviour. Motor-manual working methods
were applied, since these methods are still prevalent in the specific study area, despite the growing popularity of mechanical processors. The best safety performance was offered by the crew that had been administered formal safety training. Productivity was increased by introducing more efficient working methods and equipment.

1.10 Research plan

In light of the literature review presented above it was felt that there is a need to have a prediction model for evaluating the risk associated with WMSDs due to awkward posture of upper limbs. Hence, in the present research it was thought to investigate the effects of shoulder rotations combined with elbow flexion on discomfort for repetitive gripping tasks was investigated. The plan of the investigations was presented as follows:
Effects of Posture on Grip strength & Grip endurance Time

- **Experiment -1**
  Effect of elbow flexion, forearm rotation and upperarm abduction on Grip MVC & Grip endurance time

- **Experiment -3**
  Effect of shoulder rotation, upper arm rotation and elbow flexion on MVC grip & Grip endurance time

- **Experiment -5**
  The combined effect of shoulder rotation and elbow flexion on MVC grip & Grip endurance time

Effects of Posture on Discomfort & EMG activities for repetitive Gripping Task

- **Experiment -2**
  Effect of upperarm abduction combined with elbow flexion on discomfort for repetitive isometric gripping

- **Experiment -4**
  Effect of shoulder rotation, upper arm rotation and elbow flexion on discomfort in a repetitive gripping task

- **Experiment -6**
  The combined effect of shoulder rotation and elbow flexion on discomfort score for repetitive gripping task

Effects of Posture on Self Paced Cycle Time

- **Experiment -7**

**Part -1**: Effects of upperarm abduction on self paced cycle time (SPCT)

**Part -2**: Effects of Shoulder rotation on self paced cycle time (SPCT)

**Part -3**: Effects of Shoulder flexion/extension on self paced cycle time (SPCT)

**Part -4**: Effects of Elbow flexion on self paced cycle time (SPCT)