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CUMULATIVE TRAUMA DISORDERS: A REVIEW OF MAJOR INFLUENCE FACTORS AND SOME ERGONOMIC COUNTERMEASURES

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ABSTRACT

Cumulative trauma disorders (CTDs), also broadly referred to as work-related or musculoskeletal disorders, have increasingly become the focus of intense research over the past few years. CTDs, though known and described for close to 300 years, have only recently become a matter of urgent ergonomic concern over the past two decades, primarily as a result of rapid technological advances that have created totally new and previously unrecognised hazards in the workplace. These disorders are the cumulative results of many microtrauma that only become manifest after an extended period of time; they are considered to be primarily work-related though other non-occupational factors may be involved. Several work-related factors such as high rates of repetitive and/or forceful exertions, awkward postures of the wrist or shoulders, static muscle loading and regular use of vibration hand-held tools have been identified as prime influence or risk (as opposed to casual) factors in the etiology of CTDs. Though the exact dose/response relationship of these factors to the development of CTDs presently remains unclear, certain physical activities and job procedures have been identified that are statistically related to the occurrence of these disorders. Hence, this allows the establishment of generic and specific recommendations for the control and avoidance of conditions that may lead to cumulative trauma disorders in the workforce.

1.0 INTRODUCTION

Cumulative trauma disorders (CTDs), also broadly referred to as work-related disorders or diseases of the musculoskeletal system are increasingly being recognised as one of the most pervasive health conditions of today's modern workplaces. In 1960, the International Labour Office recognised repetition strain injury as an occupational disease (ILO, 1960). Recent reviews on the occurrence and prevalence of CTDs have been published by Ferguson (1971), Putz-Anderson (1988), Ayoub and Wittels (1989), Armstrong (1991a) and Kroemer (1992). Data from 1989 indicated that slightly more than half of the reported workplace illnesses were associated with CTDs (US Department of Labor News, 1990). The US Occupational Safety and Health Administration (OSHA) has made the reduction of these injuries a major goal of its investigation and enforcement programme, which, as a result, is of great concern to the engineering profession as it relates to the design of workplaces and the legal profession.

2.0 BACKGROUND

Cumulative trauma disorder is the generic term used to cover a wide group of disorders that primarily stem from often-repeated actions, forceful movements, static muscle loading, and/or inappropriate body posture whose *cumulative effects* finally result in an injury. The musculoskeletal and nervous systems are considered the prime body components at risk and in the context of CTDs, this involves primarily tendons, tendon sheaths, related bones, muscles, ligaments and nerves of the hands, wrists, elbows, arms, neck, back or legs. Injuries are apparently induced by the synergistic interaction of awkward posture and repeated forceful exertion that may be attributed to occupational and non-occupational activities. In contrast to single-event injuries called acute or traumatic, these disorders stem

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from often-repeated actions whose cumulative effects finally result in an injury.

A useful definition of CTDs can be constructed by combining the separate meanings for each word. ***Cumulative*** indicates that these injuries develop gradually over periods of weeks, months, or even years as a result of repeated stresses on a particular body part. The cumulative concept is based on the theory that each repetition of an activity produces some trauma or wear and tear on the tissues and joints of the body (Radin, 1976; Pugh, 1982). The word ***trauma*** signifies bodily injury from mechanical stresses and the term ***disorders*** refers to physical ailments or abnormal conditions. Thus, an operational definition of CTDs, as given by Kroemer (1989) is as follows:

> *"Cumulative Trauma Disorders, CTD, is a collective term for syndromes characterised by discomfort, impairment, disability or persistent pain in joints, muscles, tendons and other soft tissues, with or without physical manifestations. It is caused or aggravated by repetitive motions including vibrations, sustained or constrained postures, and forceful movements at work or leisure".*

In general, all CTDs share the following common characteristics:

- They are not a result of sudden or spontaneous injury, i.e., not an accident.
- They do result from sustained or repetitive application of low stress (trauma) over time (RSIs).
- They may also result from stress applied to previous injuries or already diseased structures or joints.

It is with the great upsurge in office-type work (and use of computer technology in particular), that an upsurge in the incidence of CTDs has been observed (Hunting *et al.*, 1980a & 1980b). There is a growing awareness by a number of researchers throughout the industrialised world that neck and upper extremity disorders are common and costly, not only in traditional areas of industry but increasing in white collar work. More and more, it has become evident that ***even light work may give rise to complaints of a CTD nature*** if it is poorly designed and does not accommodate the capabilities and limitations of those engaged in it.

Thus, generally speaking, though work has become progressively lighter, much of it remains repetitious and lacking in the variety of movements necessary for balanced, efficient musculoskeletal function. Despite the rapid development of computer technology and the concomitant widespread automation of office work, much white collar work has taken on the nature of light process work. Such technological development has been so rapid that it has often created new and totally unrecognised hazards which have resulted in occupational diseases and disorders even before they have been recognised as such. Hence, though traditionally sitting work (as opposed to standing) was looked upon as light work - given that such work made lesser demands on such features as lifting capacity and respiratory-circulatory function - recent research has shown that the way in which many sitting work tasks are organised often entails the maintenance of static neck, arm and hand positions, or demands monotonous, repetitive movements, so inducing sustained muscle work (Vezina *et al.*, 1992; Harms-Ringdahl & Schuldt, 1990).

Although the occurrence, diagnoses and medical treatments of CTDs have been fairly well documented as of the middle of the twentieth century, their relations to occupational as well as non-occupational activities has still yet to be clearly defined and established, i.e., *quantitative thresholds* above which cumulative trauma disorders are expected to occur have not been clearly defined and established. Since such disorders are cumulative and develop over an extended period of time, defining such thresholds is not easy. For example, are three motions per week, per day, per hour or per minute likely to result in an injury? How many repetitive microtrauma have to occur to result in injury?

The difficulty in identifying the roles played by occupational and non-occupational factors in causing CTDs is further complicated by the role of personal factors or individual susceptibility. A worker's physical size, strength, prior injuries and joint alignment may contribute to injury or exacerbate the adverse effects of repeated microtrauma. Also, it has been shown that some individuals may be predisposed to CTDs, e.g., persons suffering from arthritis, diabetes, endocrinological disorders and vitamin B6 deficiency. Events such as pregnancy, the use of oral contraceptives and gynecological surgery seem to be related to statistical occurrence (Armstrong, 1991a; Ayoub & Wittels, 1989).

Hence, one of the greatest problems facing researchers of CTDs is to clearly distinguish between complaints that can be regarded as a normal part of life from those more serious and potentially disabling conditions which arise due to activity-related factors. This problem is further compounded by the fact that no simple, reliable tests exist which can measure these conditions quantitatively. However, even though quantitative thresholds above which cumulative trauma disorders are expected to occur are largely unknown and need to be researched, the prevalent position taken in the current literature is that certain occupational activities are causative, precipitating or aggravating.

Some of the prime factors thought to be responsible for the development of such disorders as well as several ergonomic countermeasures that can be implemented to control or minimise the occurrence of such are the primary focus of this paper.

3.0 CTD INFLUENCE (RISK) FACTORS

In general, CTDs belong to a collection of health problems that are considered to be work-related, i.e., the disorders are more prevalent among working people than among the general population. The major activity-related factors identified as components in the cause and precipitation of CTDs are: awkward **postures** of the wrist or shoulders, **static** muscle loading, high rates of manual **repetition,** excessive manual **force** and regular use of **vibration** hand-held tools.

It should be noted that cumulative trauma disorders are multifactorial, i.e., there may be more than one factor that causes, aggravates or precipitates a cumulative trauma disorder. Even those conditions which arise directly from work may be influenced by personal and perhaps social factors which modify symptoms and how they are reported (McPhee, 1980). These factors may pertain to personal conditions or activities, as well as work activities. As a practical matter, work activities appear to account for the greatest proportion of cases (Cannon *et al.*, 1981).

At this point, it should be clearly noted that although there is an abundance of clinical, biomechanical and epidemiological evidence supporting the relationship between work-related factors (such as force, localised mechanical stresses, constrained postures, low temperatures and vibration) and cumulative trauma disorders, most of it has been qualitative. No one can yet say that these factors are *casual* factors, i.e., that excess force, high degree of repetition, static postures and so on *cause* CTDs. All that can be presently inferred from research findings and studies conducted is that these factors are probably *risk* factors associated with the development of CTDs.

As such, work is a risk factor for CTDs. A risk factor is any attribute, experience or exposure that increases the probability of occurrence of a disease or disorder, though it is not necessarily a causal factor (Last, 1983). According to NIOSH, a CTD is job-related if it involves any of the factors mentioned above.

Among the non-occupational factors related to the occurrence of CTDs are age, gender, acute trauma, chronic diseases, use of birth control pills and circumstances of pregnancy or menopause (Sabour and Fadel, 1970). Some individuals could be predisposed (Ellis, 1951).

3.1 Occupational factors

Although it has long been recognised that CTDs have a multifactorial origin, almost all research findings have highlighted the role of working conditions, i.e., occupational factors. These studies have identified the following major occupational factors as being related to the occurrence of CTDs:

- Forceful and/or Repetitive Activities
- Static muscle load
- Body Posture
- Localised Mechanical Stress
- Vibration
- Low temperature

Each of the above factors are now examined in some detail.

(1) Forceful and/or Repetitive Activities

CTDs are often caused, precipitated or aggravated by repetitive and/or forceful motions, which may occur in many different occupational activities, such as in assembly, manufacturing, manual processing, packaging, sewing, keying and other manual hand manipulations. Sustained and constrained postures may be involved.

Force: The force required to perform various occupational activities is a critical factor in contributing to the onset of CTDs (Armstrong *et al.*, 1982; Silverstein *et al.*, 1986). The load (stress) or the pressure put on various tissues of the body can easily amount to hundreds of pounds. Soft tissue respond to an imposed load (stress) by changing its shape - undergoing deformation (or strain). The amount of deformation (strain) is linearly related to the applied load (stress). Both stress and strain are time-dependent. Thus, for example, if stress is applied too fast or for a brief period, then a condition of impact loading results. Such loading may lead to a major damage or complete failure. More frequently though, the situation of repetitive (cyclic) loading is seen. Here, a tissue subjected to repetitive loading or stress may fail at a level well below its yield stress, which is approximately 40% of maximum yield strength for all biological materials (Ayoub, 1993).

This reduction in strength is attributed to muscle fatigue. As muscle effort increases in response to high task load, circulation to the muscle decreases, which in turn, further accelerates muscle fatigue. Recovery time can exceed actual work time for jobs where force requirements are high. Deprived of sufficient recovery time, soft tissue injuries will occur.

Obviously, bones will break and skin and muscles will tear if the strain is too great. What is not as obvious is the mechanical stresses on the tendons and nerves produced by contact with sharp edges of hard objects that are held in the hand. Scissors, for example, that rub on the sides of the fingers may cause compression of the digital nerves in the fingers (Greenburg & Chaffin, 1977). Manual forces are transmitted through the skin to underlying tendons. The palmar side of the fingers is a common site of stenosing tenosynovitis crepitans (trigger finger). Trigger finger is associated with forceful gripping of tools that have hard or sharp edges on their handles. Workers performing tasks where force is applied with the wrist in a laid back or dorsiflexion posture, such as in pushing, increase their risk of developing an entrapment of the ulnar nerve where it passes under the hamate bone in the wrist (Guyon canal).

Silverstein (1985) has proposed that for the hand, a force greater than 45 N may be considered a causative factor of a CTD. Also, if muscles must remain contracted at more than about 15% to 20% of their maximal capability, circulation is impaired. This can result in tissue ischemia and delayed dissipation of metabolites that constitute conditions of general physiological strain.

Repetition: The body soft tissues are viscoelastic; accordingly, their response to physical stress is influenced by its level, rate of its applications and its duration. Rate of stress application determines which component of muscle-tendon-bone unit is likely to fail. When stress is applied slowly, then a low level might be all that is required to initiate tendon/muscle failure. In cases of violent motions (typical of sports where force is applied for a very brief time), the failure is likely to be limited to stress fracture in the bone and in extreme cases, to tendon avulsion from its bone. As the graphs illustrate on the next page (see **Figure 1**), as the speed (right) and percentage of tendon stretching (left) increases, the degree of risk increases exponentially until failure occurs.

If a tendon is subjected to a large load that may result in it being stretched more than 8%, then collagen fibres are likely to fail or rupture (Chaffin and Andersson, 1984). In addition, the tendon vascular bed may be damaged in the process. Fibre failures will be experienced at the cell or microscopic level, therefore, they will remain undetected or invisible during clinical examination. Thus, the patient may report that he feels pain and discomfort but the physician may not see any physical signs that provide clues as to the nature or cause of injury.

Stress (loading) can have a significant effect on bone to which it is being applied. Bone can fracture from repetitive loading (Chaffin and Andersson, 1984). Although such fatigue fractures are uncommon, they can occur from repetitive loading in work-related activities. Three factors are important in this respect - the amount of load, the number of repetition and the frequency of loading. It should be remembered however, that bone is a living material capable of repairing small cracks given time, so that the repetition

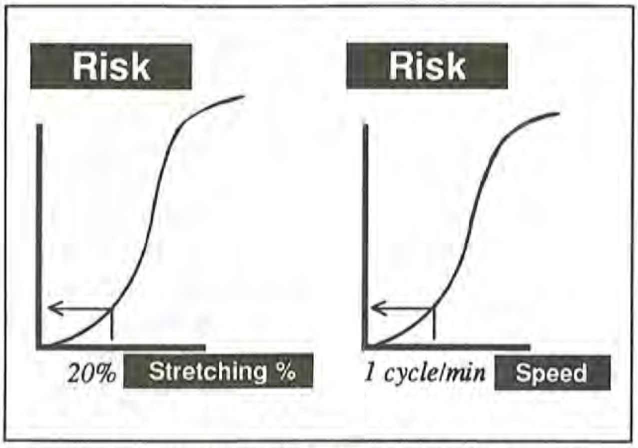

Figure 1: **Percentage of Stretch (left) and Speed of Tendon loading expressed in terms of Degree of Risk** ***(Source: Ayoub, 1993)***

rate or recovery period after exertions can become significant factors.

It should also be noted that because muscles act to distribute the major stress within bone and absorb material energy which otherwise could be transferred directly to the bone, continuous strenuous activity can cause abnormally high stresses on bones as the muscles fatigue and lose their contractile capacity.

Jobs that require the worker to perform highly repetitive motions have been found to contribute to the onset of CTDs (Hymovich *et al.*, 1966). Specifically, the more repetitive the task, the more rapid and frequent are the muscle contractions. Muscles required to contract at a high velocity develop less tension than when contraction at a slower velocity for the same load. Hence, tasks requiring high rates of repetitions require more muscle effort and consequently more time for recovery than less repetitive tasks. In this manner, tasks with high repetition rates can become sources of trauma even when the required forces are minimal and normally safe (Kaplan, 1983). Silverstein (1985) has proposed that high repetitiveness may be defined as a cycle time of less than 30 seconds or as more than 50% of the cycle time spent performing the same fundamental motion.

Carpal tunnel syndrome (CTS), for example, appears to be induced more by the repetitiveness of the task than by the force levels (Armstrong *et al.*, 1985). Findings from another study on repetition indicated that the prevalence of tenosynovitis and humeral tendinitis is significantly higher for workers engaged in machine-paced assembly work than for shop assistants with variable tasks. Repetitive motions of the hands for some assembly-line workers in the study reached 25,000 cycles per workday (Luopajarvi *et al.*, 1979). In general, the speed, intensity and work pace typical of modern industry has been proved debilitating to many millions of workers (Ohara *et al.*, 1976). Researchers are just beginning to assess the acceptable or safe limits of repetition (Putz-Anderson, 1988).

(2) Static Muscle Load

Sustained muscular tension is known to cause a mechanical vascular type of pain (Cailliet, 1991). Sustained isometric muscular contraction in an extremity has been well-documented as the cause of ischemic muscular pain (Travell and Simons, 1983) and termed *myofascial pain*. The mechanism of this pain has been postulated to be anxious, postural, occupational and microscopic traumatic.

Sustained muscular contraction accumulates excessive muscular metabolites (lactic acid, carbon dioxide and others), which become irritants and cause resultant muscular contraction. The contracted muscles literally constrict the intrinsic blood vessels, so that while there is excessive muscular contraction requiring blood supply, there is diminished blood flow, ischemia results and there is venous lymphatic compression, which prevents 'washing out' of the accumulated metabolites. A viscous circle results, with ischemic pain as the end point. The waste products cause acute localised fatigue in the statically loaded muscles; tiredness, pains and even cramps are the symptoms of excessive static load.

(3) Body Posture

Posture is the attitude the human being assumes upon standing or sitting in the erect position. Posture is influenced by familial and congenital factors, modified by training and habit, influenced by peer appearance, dictated by occupational demands and adversely affected by illness of orthopedic or neurologic consequence.

Posture can also cause or influence numerous orthopaedic and neurologic diseases or syndromes of pain and impairment. Faulty posture augments tissue changes in bony, ligamentous, and muscular structures and is thought to adversely affect the spinal column discogenic tissues (Cailliet, 1991). Therefore, it merits thorough evaluation to determine how various postures relate to the etiology of CTDs.

Postural efforts are static efforts and therefore are associated with long-lasting static contractions of muscles. As mentioned already, static effort compresses blood vessels and reduces blood irrigation of the muscles precisely at a time when it is greatly needed. Therefore, *all postures are stressful if they are maintained long enough.* Some postures may be more stressful than another for two reasons:

(1) Some posture require more effort than others (e.g., the body must work harder to produce the same force in a pinch position than a grip position).
(2) Some postures produce pressure in certain parts of the body (e.g., extension of the fingers with a flexed wrist position results in pressure on the median nerve).

Certain jobs require the worker to assume a variety of awkward postures that pose significant biomechanical stress to the joints of the upper extremity and surrounding soft tissues. Research has established that posture is a significant factor in the development of CTDs (Armstrong, 1985b). Stressful upper limb postures for repeated or prolonged work include elevation of the elbow, reaching behind the torso, extreme elbow flexion, extreme forearm rotation, wrist deviation, flexion or hyper-extension and pinching. Other postures considered undesirable include those that:

(1) Overload the muscles and tendons;
(2) Load joints in an uneven or asymmetrical manner; or
(3) Involve a static load on the musculature (Van Wely, 1970).

CTDs that have been identified include tenosynovitis of the flexors and extensors of the forearm and carpal tunnel syndrome (CTS) arising from extreme flexion and extension of the wrist (Smith *et al.*, 1977; Armstrong & Chaffin, 1979). Ulnar and radial deviations of the wrist are associated with De Quervain's disease (Muckart, 1964). Various shoulder ailments, including thoracic outlet syndrome have been associated with jobs that require workers to reach behind or above their shoulder level repeatedly (Bjelle *et al.*, 1979; Hagberg, 1984). Shoulder disorders are also associated with reaching down and behind the torso (Nichols, 1967). Extreme flexion of the elbow is associated with cubital tunnel syndrome (Feldman *et al.*, 1983). Extreme rotation of the forearm is associated with medial and lateral epicondylitis (golfer's and tennis elbow, respectively) (Gardner, 1970; Tichauer, 1976).

Postural efforts not only decrease performance and productivity but in the long run, they also affect well-being and health. If postural efforts are repeated daily over a long period, more or less permanent aches will appear in the limbs concerned and may involve not only the muscles but also the joints, tendons and other parts of the connective tissue.

(4) Localised Mechanical Stress

A mechanical stress is produced any time that a force is exerted on a material or a tissue. It is calculated as the force divided by the area. For example, **Figure 2(A)** shows the area of contact made by someone's forearm and hand as it rests on a flat surface; it can be calculated as 174 square centimetres. It is assumed that the weight of the forearm and hand is 25 N and that the work surface is compliant so that the force is distributed uniformly over the surface, the contact stress between the work surface and the body is 1,435 N per square metre. **Figure 2(B)** shows the weight of the forearms and hand-supported by the arm rests of a chair. In this case, the stress is calculated as 9,687 N per square metre. The level of insult and discomfort increases with the magnitude contact stress (Armstrong, 1985a).

Some parts of the body are more tolerant than others. For example, 1,435 N per square metre contact force may be tolerated longer if it is distributed in the fleshy areas of the forearm than over the ulnar nerve at the elbow or the finger flexor tendons and median nerve at the wrist (Lundborg *et al.*, 1982). It is possible to apply sufficient pressure on the volar surface of the wrist to interfere with median nerve function.

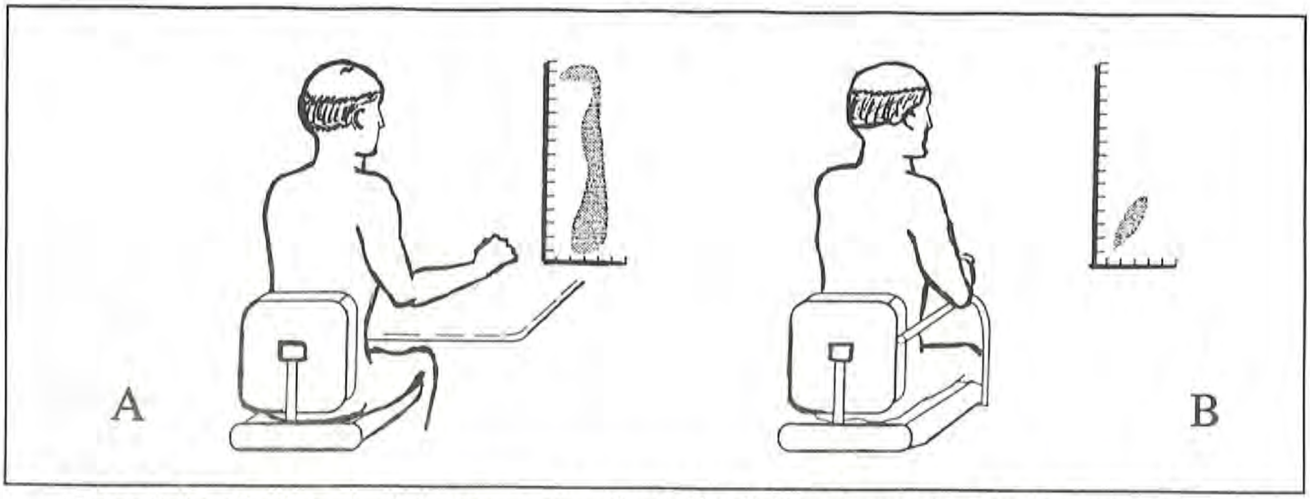

Figure 2: **Localised mechanical stresses are estimated by dividing the weight of the forearm and hand by the area of contact. The area of contact is approximately 175 square centimetres when the forearm and hand are lying on a flat work surface (A) and 25 cm when they are supported by a tubular arm rest (B).** *(Source: Ayoub, 1993)*

(5) Vibration

Vibration is a frequently reported causative factor of upper limb cumulative trauma disorders, particularly peripheral nerve and neurovascular disorders. Mechanical stress produced by vibrating tools such as power tools, holding the controls of a powered machine or using percussion tools, such as hammers and chisels can contribute to the development of vibration syndrome that affects primarily the fingers (Brammer, 1982).

Vibration influences the human body in several ways. The reaction to a vibration exposure is greatly dependent on the frequency, amplitude and the duration of exposure, but several other factors are also important, such as the direction of vibration input, the location of different body segments, the mass of the different body segments, the level of fatigue and the presence of external body supports.

When vibrations are attenuated in the body, the vibration energy is absorbed by tissues and organs. The muscles are important in this respect. Vibration leads to both voluntary and involuntary contractions of muscles and can cause local muscle fatigue, particularly when the vibration is at the resonant-frequency level. Further, mechanical stimulation of muscles can cause reflex contractions, which will reduce motor performance capabilities.

Segmental vibration (and in particular, the hand-arm system) causes a symptom complex usually referred to as *vibration syndrome*. Symptoms originate from injuries to the blood vessels, nerves, bones, joints, and muscles. Injuries can occur after exposure times from months to decades and are usually, at first reversible. The most well-known of these symptoms is *Raynaud's Syndrome* (white finger) or *Traumatic Vasopastic Disease* (TVD).

Vibration syndrome reduces tactile sensitivity, preventing precision work. The symptoms can be present only a few minutes, sometimes for several hours. Exposure to cold may serve to trigger vasospasm in the fingers. The condition is caused in part by forceful gripping and prolonged use of power grinders. Common symptoms include intermittent numbness and tingling in the fingers; skin that turns pale, ashen, and cold; and eventual loss of sensation and control in the fingers and hands (NIOSH, 1983; Bovenzi, 1986).

(6) Low Temperature

Exposure to cold causes vasoconstriction of peripheral blood vessels, thus affecting the circulation to different soft tissues. The opposite of this is true, in the case of a warm-up; the muscle and tendon temperature is raised causing improvement in circulation. Low temperature can lead to impaired circulation, depriving soft tissues (in particular, tendons) from its oxygen supply. If exposure to cold is coupled with a large static force, such as when a tendon is maintained under constant tension, in time, this may lead to focal cell death. In all cases of impaired circulation, tendonitis is a strong possibility.

Cooling of the highly innervated skin of the fingers from 0° to 20°C has been shown to profoundly affect strength, dexterity, and sensitivity (Shiefer *et al.*, 1984). When working in a cold environment, people with normal finger sensory function usually exert slightly more force than is required to keep objects from slipping out of the hand. For example, Flatt (1961) estimated that normal subjects exert approximately 4 pounds per square inch on the handle of a hammer; however, when the hand is anesthetised they responded by exerting as much as 16 pounds per square inch. Increased force due to low temperatures will make the job more stressful. Cases of tenosynovitis due to frostbite have been reported even when there is no dermal necrosis (Georgitis, 1978). Sources of cold exposure include ambient air, work materials, and the exhaust from air tools.

3.2 Non-occupational factors

Occupational activities may be only partially responsible for the development of disorders associated with repetitive trauma. Non-occupational activities that stress the musculoskeletal system can produce the same types of disorders (Cannon *et al.*, 1981). Some studies have even found that non-occupational factors could be more important than occupational factors (Loslever and Ranailosoa, 1993).

Athletic activities such as racket sports and throwing have been associated with the development of tendinitis, tenosynovitis, degenerative joint disease, and peripheral nerve entrapments. Hobbies such as knitting, sewing or the playing of musical instruments have also been associated with the development of these disorders (Armstrong and Chaffin, 1979). Traumatic accidents that result in fractures of the bones of the upper extremities may predispose a person to many of the disorders that are discussed in this paper (Ellis, 1951). Various systemic diseases or conditions may also predispose a person to many of the common CTDs. Examples include: rheumatoid arthritis, hypertension, diabetes, thyroid disorders, kidney disorders, gout, alcoholism, pregnancy, use of oral contraceptives and gynaecological surgery (Barnes and Currey, 1967; Sabour and Fadel, 1970).

Only one non-occupational factor, age, is now discussed in greater detail to determine its relationship to the occurrence of CTDs.

Age: An aging workforce in many industrialised countries has been noted and tied to the increase in CTDs recorded today (Putz-Anderson, 1988). As a worker ages, his or her body's resilience to chronic wear and tear is reduced (Hansson & Ross, 1981). Hence, a worker pays an increasingly higher health price for performing the same task as he or she grows older.

Age has an effect on the process of bone formation, called *ossification*. From the beginning of the ossification process until skeletal maturity is reached, bone growth occurs. The maximum skeletal mass is attained at about age 30, after which bone loss occurs continuously and with accelerated rate as the person gets older. At first, there is little difference in the rate of bone loss between men and women, but after menopause a sharp increase in the rate at which bone mineral loss occurs in women has been noted (Chaffin and Andersson, 1984). The gradual aging process changes "normal" bone into "osteoporotic" bone. The age related changes are characterised by:

(1) A progressive decrease in bone mineral content.
(2) A reduction in cortical bone thickness.
(3) An increase in the outer diameter of long bones, resulting in an increase in the moment of inertia around the long bone axis.
(4) A decrease in the number of trabeculae in cancellous bone.

The resulting bone is weaker and as a consequence, fractures are much more common after trivial trauma in older people, particularly in older women.

Age also has an adverse effect on cartilaginous joints, i.e., joint where cartilagê bridges the joint. Cartilage has a poor ability to repair and regenerate because it is void of capillaries. As age progresses, a gradual degeneration of all joints occurs, called *osteoarthritis* (OA). Primary OA is a condition in which there is no obvious previous abnormally in the joint, while secondary OA has some previous detectable cause. This detectable cause is usually mechanical in nature. In other words, secondary osteoarthritis occurs when joint are deformed by disease or injury. Mechanical factors appear to be important in joint osteoarthritis not only in the secondary situation, however, but also in primary osteoarthritis. Recurrent trauma, joint instability, stress magnitudes, and their geometric concentration are important, but the precise relationships and mechanisms remains unclear.

4.0 ERGONOMIC COUNTERMEASURES

There are two key issues that management (or those responsible for designing and implementing a safe, comfortable, and healthy work environment for the workforce) have to considered with regard to CTDs:

(i) Are CTD symptoms present among the workers? In addition, is it likely that workers will develop CTDs in the near future?; and

(ii) What ergonomic countermeasures can be taken to eliminate or at least minimise exposure to CTD risk factors?

Four specific ergonomic countermeasures are recommended and discussed below.

(1) Establish a Control Programme

Given that it is still not possible to predict acceptable levels, i.e., dose/response levels for CTD risk factors either alone or in combination with one another, problems often are not identified until after the fact when workers complain of pain or other problems with their upper limbs, shoulder, neck and/or back. Even when a good faith effort is made to eliminate all possible stresses from the job, some workers may still be affected. Therefore, one of the first ergonomic countermeasures that should be taken is to establish a control programme that includes a sensitive surveillance program for identification of affected workers and jobs. This will ensure that effective ergonomic countermeasures are devised before impairments develop into disabilities.

Armstrong (1992) has outlined an overall organisational control programme (see **Figure 3**) which included surveillance, evaluation and interventions for affected jobs, as well as evaluation of all interventions that could be run by a team. Surveillance is the cornerstone of Armstrong's control programme. He points out that it should be designed to identify problems while they are in their earliest stages. This aim may be achieved through either passive or active surveillance. Passive surveillance relies on voluntary reporting of problems by workers and generally requires the worker to take the initiative to seek help. Active surveillance entails the use of questionnaires, interviews, and physical examinations to survey the health status of the work force. Such surveys may be administered to the entire work force or to a representative sample of workers.

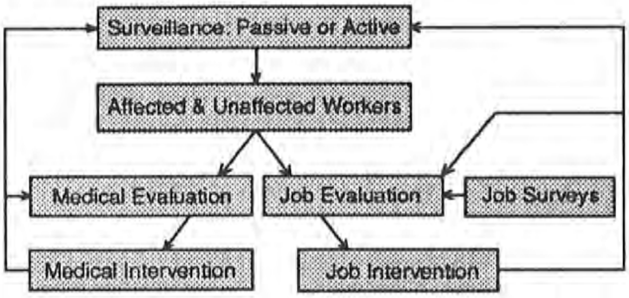

Figure 3: **An Ergonomic Control Programme for Cumulative Trauma Disorders**
(Source: Armstrong, 1992)

A control programme such as the one suggested by Armstrong above draws on many resources: medical, supervisions, management, safety, health, engineering, and labor. It therefore is recommended that a team of people from each of these areas be assembled to run the programme (Liker *et al.*, 1984). The team should be provided with training so that they can interpret worker and job evaluation data to identify problems, set goals and priorities, and allocate or recommend resources. Specific activities may be delegated to team members or to persons from a team member's department or area. One person may be designated as team coordinator or leader to arrange and conduct meetings and to document the progress of the programme. Such documentation is important for identifying what works and what does not. Also, it provides evidence of an active program should the company come under investigation by OSHA.

(2) Evaluate ALL jobs based on CTD Criteria

All jobs should be analysed for their movement and force requirements using, for example, the industrial engineering procedure of motion and time study. Each element of the work should be screened for factors that can contribute to CTDs, especially to carpel tunnel syndrome (CTS): these factors include posture and strength required.

(3) Re-engineer and Re-organise to reduce CTD Likelihood

After the job analysis has been completed, work stations, equipment, and work procedures can be ergonomically re-engineered and reorganised to reduce the stress on the operator's body. In **Table 1**, taken from Kroemer (1992), an overview of generic ergonomic countermeasures is provided. Proper design of the work task and use of suitable tools can be facilitated by careful design and positioning of the work object.

Avoidance of cumulative trauma injuries, whether by re-design of an existing workstation or by appropriate planning of a new workstation, can be achieved by following these simple rules:

(1) Let the operator perform 'natural activities' (i.e., those for which the human body is suited).
(2) Avoid highly repetitive activities.
(3) Minimise or eliminate tasks that require the operator to exert a straining force.
(4) Minimise postures that must be maintained over prolonged time, i.e., static postures.

For jobs that involve primarily the upper body and in particular the arm and shoulder, Armstrong (1983) in his 1983 ergonomics guide, lists organisational and technical measures that can be taken in the workplace to prevent CTS from occurring. As a general rule, tools and tasks should be so designed that they can be used and performed without causing the wrist to deviate much from the straight (in line with the forearm) position. The forearm should be mostly horizontal (and not rotated, i.e., supinated or pronated) and the upper arm mostly hanging relaxed at the person's side.

In terms of work re-organisation, an active microbreak system (AMS) as proposed by Genaidy *et al* (1995) is a possible administrative intervention that may be used to decrease the discomfort perceived by employees on the job, and subsequently to reduce musculoskeletal injuries.

(4) Provide Training

Training in physiologically correct activities and providing of alternate work functions that allow breaks in otherwise repetitive work or activities can be essential (Prieto *et al.*, 1995). Training should include specific instructions on proper work habits. Grieco *et al.*, (1989) highlight the need and benefits of instructing persons specifically in a "health and movement education" programme. Such a programme can help workers to suitably organise work habits and lifestyles in a manner that will help them to keep in good physical shape. It should be noted, however, that although such a strategy has proved efficacious for prevention of musculoskeletal disorders, success tends to be directly proportional to the cultural level of the subjects concerned (Postacchini *et al.*, 1994)

The overall principle should always be to fit the job to the person, and not to attempt to fit persons to the job. Thus, the general process of work, the particular hand tools to be used, or the parts on which work needs to be performed, should be altered as needed to fit human capabilities. The opposite way i.e., selecting persons who seem to be especially able to perform work that most people cannot do, or to let several people work at the same workstation alternately so that nobody has to work long periods of time on the same job - are basically inappropriate measures which should be applied only of no other solution can be found.

Kroemer (1989) lists seven conditions that specifically need to be avoided:

(1) Job activities with many repetitions.
(2) Work that requires prolonged or repetitive exertion of more than 30% of the operator's muscle strength available for that activity (Silverstein, 1985).
(3) Putting body segments in an extreme position, such as severely bending the wrist.
(4) Work that makes a person maintain the same body posture for long periods of time.
(5) Work in which a tool vibrates the body or part of the body.
(6) Exposure of working body segments to cold, including air flow from pneumatic tools.
(7) Combinations of the conditions just described.

For the specific case of material handling (lifting, lowering, pushing, pulling and carrying), the

CTD	AVOID IN GENERAL	AVOID IN PARTICULAR	DO	DESIGN
Carpal tunnel syndrome	Wrist deviation, finger pinch	Dorsal and palmar glexion grip	Use large muscles but infrequently	The work object properly
Epicondylitis	'Bad backhand'	Dorsiflexion, pronation		
Pronator teres syndrome	Forearm pronation	Rapid and forceful pronation		The job task properly
Shoulder tendonitis, rotator cuff syndrome	Arm elevation	Arm abduction, elbow elevation	Let wrist be in line with the forearm	Hand tools properly (bend tool, not the wrist)
Tendonitis	Often repeated movements, particularly with force exertion, hard surface in contact with skin, vibrations	Frequent motions of digits, wrists, forearm, shoulder	Let shoulder and upper arm be relaxed	Round corners, pad Place work object properly
Tendosynovitis, De Quervain's syndrome, ganglion	Finger flexion, wrist deviation	Ulnar deviation, dorsal and palmar flexion, radial deviation with firm grip		
Thoracic outlet syndrome	Arm elevation, carrying	Shoulder flexion, arm hyperextension	Let forearms not be elevated more than horizontal	
Trigger finger	Finger flexion	Flexion of distal phalanx alone		
Ulnar nerve entrapment	Wrist flexion and extension, pressure on hypothenar eminence	Wrist flexion and extension		
White finger, vibration syndrome	Vibration, tight grip, cold	Vibrations between 40 and 125 Hz	Alternate head/neck postures	
Neck tension syndrome	Static head posture	Prolonged static head/neck posture		

Table 1: **Ergonomic Measures to avoid Common Repetitive Strain Injuries**
(Source: Kroemer, 1989)

compendium by Kroemer, Kroemer and Kroemer-Elbert (1994) and Kuorinka and Forcier (1995) provides comprehensive managerial and engineering procedures to avert CTDs.

5.0 DISCUSSION AND CONCLUSIONS

Today, the group of hazards observed in the workplace that arise from chronic exposure to microtrauma have commonly come to be known and identified by the term Cumulative Trauma Disorders (CTDs). A common feature of these disorders is the element of overuse superimposed on the progressive changes that accompany the normal aging of the body.

Though current knowledge about the relationships between activities (on the job or during leisure) and CTDs has increased significantly over the years, is it mostly limited to exertion of fairly large forces/torques and their associations with exertion frequencies and body postures. Yet, even for those gross muscular activities, uncertainty about the causal relationship between them and CTDs exists. If a causal relationship between job activity and disorder is presumed, the exact job factors are not well defined nor are their critical threshold values established. It appears from the investigations carried out to date that such conditions (i.e., CTDs) arise from a range of factors, both physical and psychological, and may be exacerbated by social factors. Even if their occurrence appears to be predictable, given certain combinations of factors, and therefore, theoretically at least, preventable in the workplace, the mechanisms by which such symptoms develop into pathological conditions, requiring treatment and other action to reverse, is still very poorly understood.

Clearly, much research must be conducted to single out and describe the components of activities that may lead to CTDs and to understand how these physical events overload body structures and tissues so that specific CTDs develop. When these relationships are understood, it will be possible to establish threshold values or exposure doses for activity (job) factors - such as force, displacement, repetition, duration, and posture - that separate suitable from unacceptable conditions. Statements of such thresholds or doses could replace the generic recommendations presently being used today.

Notwithstanding the present ambivalence among researchers on whether CTDs are work-related at all and if so, in what manner, generic ergonomic countermeasures can be implemented that at the very least, will lead to safer and more comfortable work environments. **Table 1** lists some of these ergonomic countermeasures which if applied can lead eliminate or at least minimise the occurrence of CTDs. In addition to using this checklist, a proactive surveillance control programme coupled with training in physiologically correct activities should ensure a workforce that is minimal effected by CTDs.

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