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A Systematic Evaluation Technique for Assisting in the Identification and Prevention of Wrist Stress in the Work Place

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A SYSTEMATIC EVALUATION TECHNIQUE FOR ASSISTING IN THE IDENTIFICATION AND PREVENTION OF WRIST STRESS IN THE WORK PLACE

by

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A SYSTEMATIC EVALUATION TECHNIQUE FOR ASSISTING IN THE IDENTIFICATION AND PREVENTION OF WRIST STRESS IN THE WORK PLACE

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Western Michigan University, 1990

Carpal Tunnel Syndrome is a cumulative trauma disorder involving compression of the median nerve within the wrist. This disorder has become an industrial epidemic, striking workers whose daily activities involve repetitive motion, wrist deviation, awkward finger postures, and excessive forces to the hand. In an effort to identify and control existing trauma, as well as prevent the onset of further cases of CTS, a systematic evaluation technique has been developed to assist in the ergonomic analysis of the work place. This assessment technique identifies and quantifies occupational risk factors of a task that may predispose workers to CTS. With this type of work place evaluation, tasks can be ranked according to wrist stress levels and modifications implemented in a prioritized manner. Benefits involving the minimization of CTS can then be realized not only by the employee, but by the employer as well.

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CHAPTER I

INTRODUCTION

Introduction to the Problem

Each structural system within the human body is designed to accommodate the thousands of natural shocks that it is subjected to in daily living. When the magnitude, duration, or number of repetitions of those natural shocks exceed the structures' reparative potential, a physiological deficit results (Carragee & Hentz, 1988). Such a deficit could be categorized as a cumulative trauma disorder (CTD). Cumulative trauma disorders refer to chronic soft tissue injuries associated with repetitive motion or exertion of the body. Injury develops gradually over periods of weeks, months, or even years as a result of repeated stresses on a particular body part.

Structurally, the hand and wrist form one of the most intricate, yet vulnerable, systems of the body. Multiple tendons, nerve branches, muscles, joints and bones allow for a wide range of motion, flexibility and tactile discrimination, making the wrist and hand a vital structural system (Bazar, 1978). Thousands of nerve endings per square inch throughout this system, make it one of the most elaborate nerve supplies in the entire body

(Schenck, 1985). However, the peripheral nervous system of the upper extremities is constantly subjected to mechanical stresses which may jeopardize the efficient functioning of the system. Specific anatomic sites of the upper extremity exist wherein the peripheral nerves are prone to cumulative trauma involving entrapment and/or compression (Carragee & Hentz, 1988).

Carpal Tunnel Syndrome (CTS), is a cumulative trauma disorder involving compression of the median nerve within the carpal tunnel of the wrist (see Figure 1). This nerve compression results in the numbness, pain, and muscle atrophy associated with CTS. The occurrence of carpal tunnel syndrome has been linked to diverse personal and occupational factors. Of particular concern in this study are the industrial or occupational applications which may contribute to CTS.

Within recent years, Carpal Tunnel Syndrome has become an industrial epidemic. Depending on the severity of the trauma, employees afflicted with CTS may experience temporary or permanent disabilities resulting from muscular and/or neural disfunction of the wrist, hand and median nerve. However, the employee is not alone in suffering the effects of this disorder. Employers are impacted by CTS via increased costs, decreased productivity and lower employee moral (Morse, 1986). Increasingly, both employees and employers are recognizing the trauma associated with

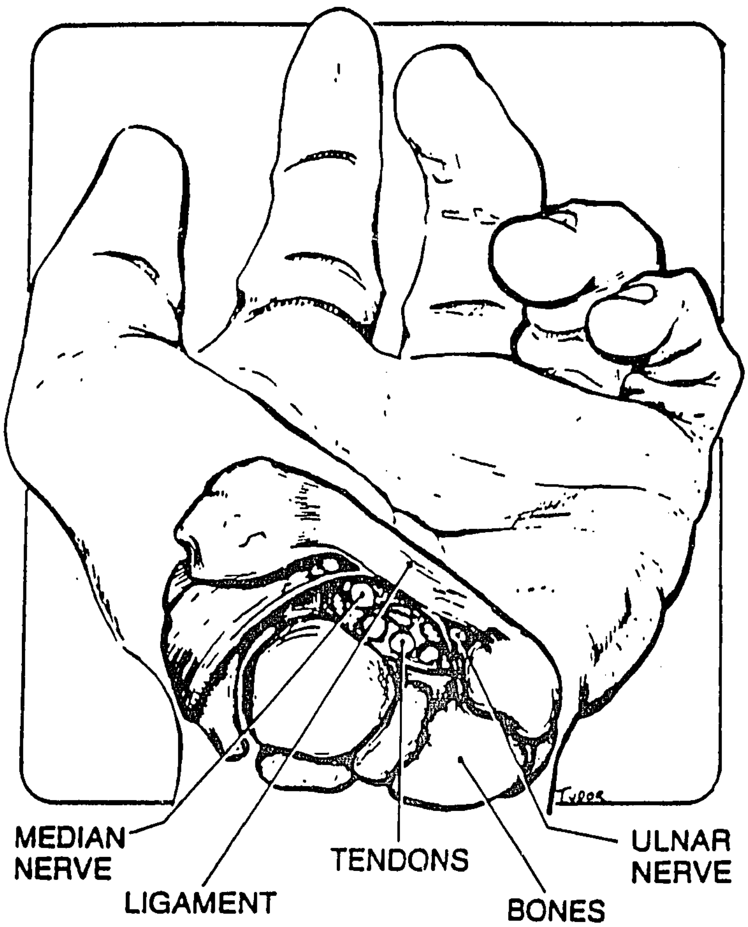

Figure 1. Carpal Tunnel.

Source: Putz-Anderson, V. (Ed.). (1988). Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs (p. 13). London: Taylor & Francis

CTS, and more importantly are recognizing the significant effect that the industrial work place can have on contributing to such cumulative trauma disorders.

Something, however, can be done to protect the integrity of one of the most intricate components of the human body. Currently, two main treatment strategies for CTS have been identified: (1) conservative (nonoperative), and (2) surgical (operative) methods (Dionne, 1984, April). The type of treatment prescribed depends upon the cause, duration, and degree of the disease. Conservative treatment, which is strongly recommended as the initial option, may include wrist immobilization (splinting), exercise/training, job reassignment, job rotation, rest, or ergonomic tool/work place/methods redesign (Dionne, 1984, Arpil). Of these treatment techniques, only ergonomic redesign, offers an elimination of the industrial causes of the trauma. The second strategy for treatment involves a surgical severance of the transverse carpal ligament which releases pressure within the carpal canal. This surgical decompression of the carpal tunnel may result in immediate relief and subsequent full recovery of the patient (Dionne, 1984, April). However, as with many of the conservative measures of treatment, if the employee returns to the same job that caused the trauma, he/she may have the same degree of problems, if not worse, despite this treatment.

Project Progression

Due to the explosive emergence of CTS as an industrial disorder, analysts have primarily focused on the identification of employee symptoms and the development of corrective measures necessary to alleviate existing work place trauma. Ergonomic work station, methods and tool redesign have offered some of the most promising steps towards minimizing and/or eliminating the industrial factors that have been associated with causing CTS. Although such corrective measures must be implemented to reduce existing trauma, the benefits of ergonomic analysis should ideally be applied toward preventative techniques. Therefore, organizational efforts should go beyond corrective reactions and focus on minimizing the incidence of CTS through initial work place and process design. To aid in this effort, the development of a method for identifying new or existing operations that may have a predisposition towards causing CTS would allow for work place analysis and modifications prior to employee injury.

It is thus the focus of this project to develop a systematic evaluation technique for assisting in the identification and prevention of wrist stress in the work place. This goal will be achieved by first determining those work-related motions and postures that are more stressful to the wrist than others. Relative stress indexes will be calculated representing the level of wrist stress caused by various groups of hand motions and postures. An ergonomic assessment model will then be developed to rank industrial tasks according to wrist stress levels. In summary, corrective and preventive measures such as work station, tool or methods design will be suggested to reduce the risk of occupational-related CTS.

CHAPTER II

REVIEW OF LITERATURE

Anatomical Structures

The structures of the upper extremity are particularly vulnerable to soft tissue injury due to the fact that almost all work requires some degree of arm, wrist, and/or hand use (Bazar, 1978). The hand contains bones, muscles, joints, nerves, tendons and ligaments which provide it with abilities for grasping, movement, sensation, and application of force. The phalanges in the fingers, metacarpals in the palm, and carpals in wrist, form a base for the strong and flexible wrist and hand. These bone structures support the complex system of pulleys and canals through which the tendons of the hand and wrist must smoothly glide to open and close the hand and bend the wrist (Putz-Anderson, 1988).

The carpal tunnel is a narrow fibrous canal bordered on three sides by an arch of wrist bones and on the palmer side by a dense, non-resilient transverse carpal ligament, also known as the flexor retinaculum. The wrist, or carpus, consists of eight bones bound by ligaments (Huntley & Shannon, 1988). The flexor retinaculum, a strong band approximately 20-30mm wide and 1-2mm thick, completes the fourth side of the tunnel and also offers great protection for the contents of the canal, yet like the arch of bones, it cannot expand to accommodate any extra mass that may be introduced into this tunnel (Macdonald, Robertson & Erickson, 1988).

Ten structures (see Figure 2) pass through the carpal tunnel including the four superficialis and four profundus tendons which flex all four digits, the flexor pollicis longus tendon, and the median nerve (Carragee & Hentz, 1988). These flexor tendons which connect muscles to bones, do not stretch or contract, merely transfer forces and movements from the muscles to the bones. Lubricated sheaths containing synovial fluid surround these tendons which glide back and forth in the sheath as muscles in the forearm contract and relax (Putz-Anderson, 1988). Within the carpal tunnel, the bundle of flexor tendons embrace the median nerve as it passes though the tunnel. This nerve is well protected under normal conditions, but is still vulnerable to damage.

The median nerve contains motor, sympathetic, and sensory fibers which support neural functioning of the hand (Carragee & Hentz, 1988). Nerve compression often results when the flexor tendons or the tendon's lubricated sheaths swell due to irritation. Under normal conditions, inflammation is a protective response of the tissue, designed to limit bacterial invasion and allow for the

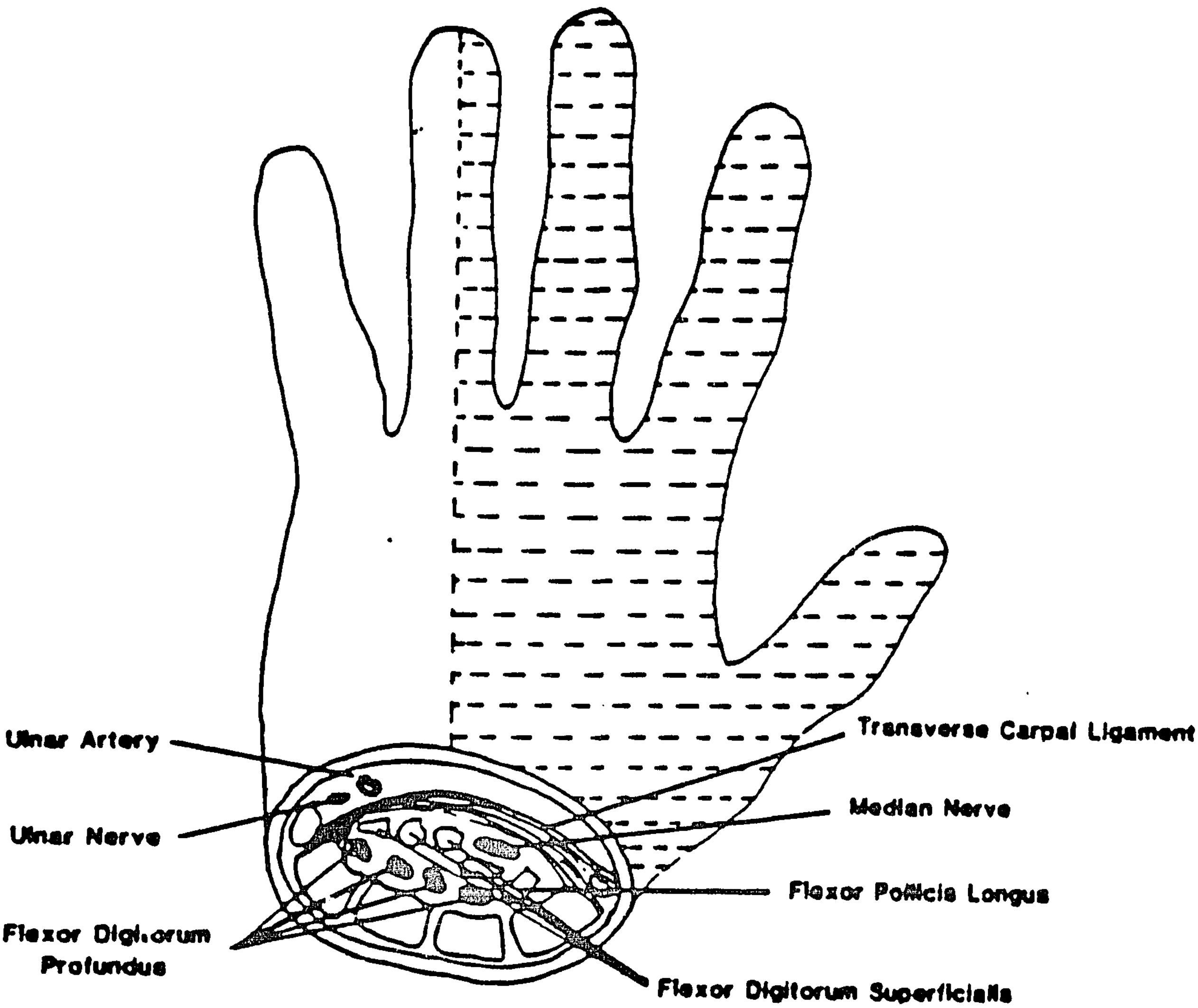

Figure 2. Carpal Tunnel Anatomy.

Source: Wang, S. & Gross, C. M. (1988). Carpal tunnel syndrome: A review of the literature. Biomechanics Corporation of America (p. 48).

initiation of repair. However, with chronic abuse of the hand and wrist, the tendon's sheath will eventually thicken to the extent which impedes tendon movement (Putz-Anderson, 1988). Since there is limited room for expansion within the canal, and the nerve structure is softer than the tendons, compression of the median nerve occurs (Huntley & Shannon, 1988; Schenck, 1989).

Finger movements cause the tendons to be displaced past and against the adjacent walls of the carpal tunnel. Repetitive movement and the resulting contact forces between the tendons and adjacent surfaces may cause irritation of the tendon sheaths. Wrist deviation performed simultaneously with finger motion, however, can contribute to not only more severe contact forces from this "pulley-like" tendon movement, but also to acute compressive forces within the tunnel. Full flexion of the wrist can cause acute compression of the median nerve between the flexor tendons and the flexor retinaculum. Extreme extension of the wrist, on the other hand, may cause the median nerve to be stretched around the outside radius of the "pulley." Deviations of the wrist from side to side will displace the tendons against the inside of the carpal tunnel; however, it is questionable whether there is sufficient range of motion to produce excessive wrist stress (Armstrong, 1983; Bazar, 1978).

Finger, hand and wrist movements are primarily controlled by muscles located in the forearm and hand. Specifically, the muscles on the medial side of the forearm are connected to the pulley-like structures in the fingers by the tendons which run through the carpal tunnel of the wrist. The fingers close (flex) when the flexor muscles within the forearm are contracted (Putz-Anderson,1988). The flexor tendons provide for finger movement, and transmit forces from the flexor muscles in the medial side of the forearm to the fingers. These tendons are responsible for linking muscles with movement and account for the major source of strength during forceful exertion of the hand (Armstrong, 1983).

Different muscular sites are involved in contraction/relaxation depending on the particular motion performed. The muscles of the forearm and hand can be grouped into two main types. Muscles which move the wrist and fingers at their joints are considered to be extrinsic muscles. Shorter muscles which are responsible for fine and manipulative movements are categorized as intrinsic muscles (Bazar, 1978). In a power grasp, the whole hand is involved in performing the gripping or holding action, while in a precision grasp or pinch, two to four digits in addition to the thumb are involved. In a power grasp motion, the long finger flexor muscles of the forearm are involved, while in a precision or pinch grasp, the short muscles of the hand are most active (Bazar, 1978).

Symptoms

Over a period of time, compression of the median nerve results in impaired or lost nervous function of the first three and one-half digits and the thenar eminance at the base of the thumb. The median nerve is one of the three major nerves of the upper extremity that contains motor, sensory, and autonomic fibers. When nerve damage occurs, impairment results in one or more of these areas. Motor nerve impairment can result in reduced muscle control and eventual muscle atrophy. Sensory nerve impairment may exist in the form of numbness, tingling, and pain, or in the loss of sensory feedback from the hand. Autonomic nerve impairment, on the other hand, often results in the loss of the sweat function (Armstrong, 1983).

Symptoms of Carpal Tunnel Syndrome are manifested as a specific pattern of neurological deficits that result in discomfort and impaired use of the hand (Armstrong, 1983). As the disorder progresses, pain often radiates into the elbows and shoulders causing paralysis, cramps, swelling or tenderness of the affected hand, wrist and forearm (Hoyt, 1984; Macdonald et al., 1988). It is important to note that symptoms are often more acute during sleeping hours and can awake a victim from a sound sleep. However, active use of the hand may also exaggerate symptoms (Huntley & Shannon, 1988). Symptom relief is often obtained by shaking the hand, rubbing it, changing its position or running warm water over it (Greenspan, 1988; Schenck, 1989).

Although symptoms of CTS may develop slowly, the effect of the disorder can not be underestimated. CTS is a chronic, disabling condition that can immobilize any employee. As identified at a recent Occupational Therapy Forum (1989), CTS progresses through several stages from the initial development of symptoms to severe impairment. The following list identifies the progressive stages of CTS.

1. Stage 0 - Populations at risk for CTS
2. Stage 1 - Mild symptoms exist, but the individual is still able to work normally
3. Stage 2 - Severe symptoms impair work ability
4. Stage 3 - Symptoms recur after treatment, or muscle weakness develops

Corrective and preventive measures can be implemented at any stage, thereby reducing the probability of progression to the next stage (Johnson, 1989).

Causes

The occurrence of CTS has been linked to diverse personal and occupational factors which cause a reduction in the effective cross-sectional area of the carpal tunnel. Area within the canal can be reduced by either decreasing the diameter of the tunnel or by increasing the volume of the contents in the tunnel (Wang & Gross, 1988). Regardless of the cause, chronic compression of the median nerve gradually damages the tissues of the nerve and results in CTS.

Non-occupational Causes

Frequently reported nonoccupational factors of CTS include: (a) inflammatory diseases such as rheumatoid arthritis, lupus erythematosus, and tenosynovitis (Greenspan, 1988); (b) tissue swelling or fluid retention from systematic physiologic changes such as those that occur with pregnancy, menopause, diabetes, and obesity (Greenspan, 1988); (c) space occupying lesions such as leukemia, gout, tumor, lymphatic obstruction (Armstrong, 1983); (d) congenital defects such as bony protrusions within the tunnel; and (e) certain types of acute trauma which may change the anatomy of the carpal tunnel such as fractures, lacerations or burns (Armstrong, 1983).

Occupational Causes

Within the past decade, a well-recognized correlation between certain work-related tasks and CTS has been documented. Repetitiveness, forcefulness, mechanical stress, hand posture, wrist deviation, vibration, low temperature, and improper glove usage have all been consistently implicated as risk factors for developing

Carpal Tunnel Syndrome (Armstrong, 1986). Within normal levels of activity, the human body has great recuperative powers. However, when recovery time is insufficient, and an excessive amount of stress factors are present in daily activities, the worker is at risk of developing CTS (Putz-Anderson, 1988). This development occurs when industrial activities either create direct pressure on the median nerve, or when activity levels exceed the lubricating capacity of the tendon sheath, resulting in friction and mild inflammation of the flexor sheath. In the latter situation, intra-tunnel swelling causes indirect compression of the median nerve (Dionne, 1984, March; Hoyt, 1984). Following is a more detailed discussion of occupational risk factors of CTS.

Repetitive Motion

Repetitiveness of work is one of the most commonly cited risk factors of cumulative trauma disorders (Armstrong, 1986; Silverstein, Fine & Armstrong, 1987). Repetitive tasks require more rapid and frequent muscle contraction, hence require more muscle effort, tendon tension and consequently more time for recovery. Without this recovery time, high repetition rates can become a source of trauma. As a consequence, high repetition can cause fibrillar tearing and inflammation of the structures within the carpal tunnel (Johnson, 1989).

Excessive Wrist Deviation

Movements of the wrist such as flexion, extension, ulnar and radial deviation, cause the finger flexor tendons to be displaced past and against adjacent anatomic surfaces (Armstrong, 1986). Contact forces between the tendons and adjacent surfaces cause irritation of the tendon sheaths. Inflammation of these sheaths may ultimately lead to compression of the nearby median nerve (Armstrong, 1983). In addition to the forces caused by this "pulley" motion, flexion of the wrist may result in acute median nerve compression between the finger flexor tendons and the flexor retinaculum. Extension, in an opposite reaction, causes the nerve to be stretched around the tendons (Armstrong, 1983, 1986).

Awkward and Stressful Hand Postures

Certain job activities require the worker to assume a variety of awkward postures that may pose significant bio-mechanical stress to the joints of the hand and wrist and to the surrounding soft tissue (Putz-Anderson, 1988). Finger flexion while simultaneously deviating the wrist, has been found to compound tendon displacement and median nerve compression (Armstrong, 1983). In fact, the median nerve may be at considerable risk during repetitive hand activities which place extreme pressure on the profundus tendons of the second and third digits. Specifically, sizable compressive forces have been demonstrated in the median nerve when hand movements involve simultaneous pinching and extreme wrist flexion (Smith, Sonstegard & Anderson, 1977). For a given hand force, use of pinch positions can result in 20-50% more force on tendons adjacent to the median nerve than use of power or full grip (Armstrong & Chaffin, 1979).

Stresses on the finger flexor tendons are related to the magnitude of the exertion and posture of the hand. It has been determined that the hand is four to five times stronger in a full hand grasp posture than in a finger pinch posture. Restated, this suggests that roughly four to five times as much muscle strength and tendon force are required to pinch rather than grip an object (Armstrong, 1983).

Excessive Hand Force

The load or pressure on various tissues of the hand and wrist while performing work place activities, can be a critical factor in contributing to the onset of CTS. Excessive muscular effort in response to high task load is associated with a corresponding increase in the mechanical stresses placed on the tendons and nerves of the wrist and hand (Putz-Anderson, 1988). The hand and wrist are vulnerable to forces created internally by muscles during motion itself, as well as those created from external forces associated with stressful loads (Armstrong, 1986).

Mechanical Stress Concentrations

Mechanical stresses to the hand and wrist can produce reaction forces that are transmitted through the skin to underlying tendons and nerves (Armstrong, 1986). An exertion of force on the base of the palm or wrist, or on the palmer surface or sides of the digits can place pressure on the finger flexor tendons or on the median nerve (Armstrong, 1986; Johnson, 1989). These stress concentrations are often introduced through improperly designed tools, work stations, or work methods.

Cold Temperatures

Workers who are subjected to lower temperatures (below 25 degrees Celsius) may be at risk for CTS (Armstrong, Radwin, Hansen, & Kennedy, 1986) due to the fact that prolonged exposure can impair hand-sensory and motor function. Sensory and motor function impairments can reduce manual dexterity and exaggerate the amount of force needed to complete a task (Armstrong, 1986). As a result, excessive mechanical forces are placed on the hand and wrist. The fingers and hands may encounter low temperatures through environmental air, manipulation of cold materials or exposure to cold tool exhaust (Armstrong, 1986).

Improper Glove Usage

Improper glove usage can often produce the same hand-sensory and motor function impairments as extreme low temperature. Reduced sensory feedback may cause workers to compensate by gripping objects harder. This reaction results in a more intense force applied to hold and manipulate tools and objects (Johnson, 1989).

Due to the significant hand size variations among men and women, it is often difficult to purchase gloves that fit all workers properly. When a glove is not well suited to a worker's hand size, mechanical stresses can be placed on areas of the hand and wrist. If improper glove usage persists, internal damage may occur (Srachta, 1985).

Low Frequency Hand Tool Vibration

CTS has been strongly associated with exposure to vibration from power tools (Cannon, Bernacki & Walter, 1981; Radwin & Armstrong, 1985; Wieslander, Norback, Gothe & Juhlin, 1989). Low frequency vibration (10-40 Hz) can cause repeated microtraumas to the structures within the carpal tunnel (Johnson, 1989). In addition, localized vibration exposure stimulates muscle contraction and decreases tactility, thereby increasing the force exerted in the completion of a task (Silverstein et al., 1987).

History

Carpal Tunnel Syndrome is not a new industrial phenomenon. Ramazinni was the first to describe the concept of cumulative trauma disorders over 200 years ago. In his work, he describes a "harvest of diseases" reaped by workers in particular crafts and trades. This harvest of disease, Ramazinni believed, was attributed to the harmful character of the materials handled, and the irregular motions and unnatural postures of the body. As stated nearly 200 years ago (Pfeffer, Gelberman, Boyes, & Rydevik, 1988), "the natural structure of the vital machine is so impaired that serious diseases gradually develop therefrom" (p. 30).

Nearly one-hundred years later, in the mid 1800s Sir James Paget offered the first description of CTS in medical literature (Dionne, 1984, March). Half of a century later, in 1913, Marie and Foix recommended sectioning of the transverse carpal ligament as treatment for this disorder, a surgical strategy still in existence today (Greenspan, 1988). Unfortunately, CTS was not systematically studied until the mid 1900s, and is to this day, a growing industrial epidemic without certain cure.

Modernization of Work

The evolution of modern production processes has, in many ways, contributed to the epidemic of CTS in the work place. Today, automation and technology allow certain operations to be performed at a much higher production rate than 20 years ago. The effect on the worker is that he/she must increase his/her hand, arm, and shoulder movements to keep up with the equipment. In addition to higher production standards, industry has long since moved away from the former craft method of production, where one employee produced an entire product. Instead, assembly line operation is now standard in many fields of manufacturing. Again, the effect on the worker is that one person must constantly repeat the same operation hundreds or even thousands of times per day, using limited movements in rapid succussion, instead of varying his or her movements as tasks change (Morse, 1986).

A different aspect to the increase in work-related CTS involves knowledge of the disorder. Previously, workers often held the belief that aches and pains were an inevitable result of working hard and growing old. Today, we realize that this is not necessarily true. In concurrence with worker and management recognition of the disorder, the legal approaches of workers' compensation have changed greatly in the past years. The newly legitimized concept of "cumulative trauma" has created a legal framework for the compensation of diseases not previously recognized. With this change has come a systematic and more accurate reporting system for such disorders (Morse, 1986).

Incidence in the Work Place

CTS has become a worldwide industrial problem and represents the most common nerve compression syndrome of the upper extremity (Gordon, Bowyer & Johnson, 1987). Carpal tunnel syndrome can affect virtually anyone in a work place who is involved with repetitive motions of the hand or wrist area. A worker at risk may be performing direct hands-on work or may simply be holding an object. However, it is important to keep in mind that the object held may take the form of a power or hand tool, an assembly part, a button or a pencil (Dionne, 1984, March).

The occupations commonly associated with CTS include laborers, meat cutters and packers, assemblers, mechanics, machinists, painters and carpenters (Falkenburg, 1987). Although this disorder is prevalent in manufacturing environments, injuries have also been found in less industrial settings. Carpal tunnel syndrome is prevalent among grocery clerks, postal workers, retail clerks, dental hygienists and secretaries (Macdonald et al., 1988). The common denominator among the majority of occupational cases of CTS seems to be the repetitive and often forceful motions of the hand and wrist which are involved in performing the manual tasks of a job (Hoyt, 1984).

Of 240 million illnesses reported by employees for

1988, 115.4 million (48%) were associated with repetitive trauma (Fogel, 1989). An industrial sector within the United States that has been hit particularly hard by cumulative trauma disorders are the autoworkers. A Labor Department survey indicated that in 1988 autoworkers suffered more work place injuries and illnesses than any other sector of the work force (Fogel, 1989). In 1989, the UAW (United Auto Workers) told a congressional committee that as many as half of the jobs in auto assembly plants have design problems that could lead to cumulative trauma disorders (Goozner, 1989).

Although the Bureau of Labor Statistics has recently recognized CTD's as the single largest cause of occupational illness, there are reasons to believe that the actual incidence rate of cumulative trauma disorders, in general, is considerably higher than has been reported. Due to the fact that symptoms of cumulative trauma disorders develop gradually, occur at night and often resemble those of naturally occurring chronic diseases, workers may often seek help from their personal physicians rather than company medical personnel (Armstrong, 1986). In addition, CTS may be under-reported because some employees fear losing their jobs or being placed in an undesirable work area if a complaint is voiced (Armstrong, 1983).

Impact of CTS

Although early known to the medical profession, CTS has only recently attracted the attention of the National Institute of Occupational Safety and Health, ergonomics engineers, tool manufacturers, and the insurance business (Dionne, 1984, April). Manufacturing management, in particular, has gained an increasing interest and involvement in occupational safety and health. This increased interest has developed due to published literature on the topic, education and training programs offered by universities and colleges, and the recent research findings identifying the occupational causes of CTS. In addition, managerial interest has grown due to an acknowledgement of the benefits gained by organizations that have effectively implemented safety and health programs (Heath, 1987).

Cumulative trauma disorders such as CTS have, however, gained greatest attention due to the crippling impact that such disorders have had on the industrial work environment. Management now recognizes that although an employee may experience temporary or permanent disabilities resulting from muscular and/or neural dysfunction of the wrist, hand and/or median nerve, he/she is not alone in suffering the effects of Carpal Tunnel Syndrome. Employers are impacted by CTS via an increase in employee absenteeism, compensation costs, and displacement of workers (Dionne, 1984, April). In addition, a high incidence of CTS in the work place may result in lower productivity and lower employee morale, as well as intensified scrutiny by occupational safety and health organizations (Huntley & Shannon, 1988; Srachta, 1985).

In financial terms, workers' compensation systems are awarding benefits for partial or permanent disability, to claimants with occupational-related CTS or with non-occupational CTS that was aggravated by the occupation (Hoyt, 1984). Once a compensation claim has been awarded, an epidemic of claims may come from other workers. These claims however, are typically bona fide and forthcoming only when CTS has been recognized as an industrial problem (Hoyt, 1984). This type of chain reaction has rightfully created concern by management due to the fact that compensation claims affect insurance premiums and other costs including loss of training, loss of production, and increased administration costs. Not only does the employer eventually end up paying higher insurance premiums, he must also cover the direct expense of medical treatment for the afflicted employee (Srachta, 1985).

The non-monetary costs of human suffering created from a cumulative trauma disorder such as CTS cannot be ignored. The cost of employee pain, discomfort, and an ineffective functional ability, cannot be assessed as easily, but may far outweigh other direct costs of the disorder. Possibly the highest price to pay for CTS is the permanent loss of one's occupation (Huntley & Shannon, 1988). For all of the above mentioned factors, both employees and employers are recognizing the trauma associated with CTS.

The increased awareness of the devastation caused by CTS has influenced the way employers, employees and the public view the responsibility of work-related injury and illness. The burden of responsibility for occupational injuries has shifted away from the careless worker and towards the careless employer. This change in thinking has been supported by numerous court decisions that have held managers liable for employee injuries that occur in the work place (Heath, 1987). Every effort must therefore be made to impress upon managers and supervisors the importance of occupational health and safety. It should be well understood that safe work methods and a healthy work environment are necessary for smooth production. As many companies have found, preventing accidents and injuries may well be a profitable endeavor due to the fact that any disturbance in the work place, such as an injury and illness, directly or indirectly produces a cost (Heath, 1987).

Evaluation of the Work Place

Cumulative trauma disorders such as CTS can have a devastating effect on the employees and employers of a traumatized environment. For this reason, it is critical to prevent trauma, or at a minimum, halt the progression of current symptoms of CTS. In order to identify the prevalence of CTS in an organization, a work place analysis must be conducted. A complete work place analysis enables management to identify the incidence of CTS, understand the reasons for the injuries, and conclude the full costs/benefits and appropriateness of implementing correction or prevention programs (Gross, 1988).

A complete work place analysis consists of three basic segments including: (1) review of available records, (2) survey of workers, and (3) ergonomic work place assessment (Putz-Anderson, 1988). Following is a more detailed description of the work place analysis steps.

Reviewing Available Records

A variety of in-house records can be reviewed to identify groups of employees and/or work areas that have a high incidence of diagnosed or suspected CTS. The primary purpose of reviewing historical records is to identify jobs that may currently pose a wrist-trauma threat to employees. Plant medical records are often a good place to start the search for CTS. Employee medical records usually indicate medical visits, symptoms and treatment strategies, if any. It is often useful to record the employee name, job type and date of symptoms. Although this method of record review may seem tedious, it can be beneficial in that a trained ergonomics engineer may be able to detect symptoms of CTS more quickly than a general medical practitioner (Putz-Anderson, 1988). In a large organization, or in an organization that does not computerize medical records, this process of review may be overwhelming and impractical. In such cases, a more limited and controlled search, such as the following, may be necessary.

The Occupational Safety and Health Administration requires most employers to maintain records of work-related injuries and illnesses. A review of these OSHA Form 200 Logs may more quickly identify diagnosed cases of cumulative trauma such as CTS. Once again, it is critical to identify the employee afflicted, job type, department and date of the reported case (Postol, 1989).

Payroll records may also play a critical role in identifying job titles or departments in which there is a high incidence rate of absenteeism or turnover. Systematic research may indicate an association between cumulative trauma disorders and attendance problems (Putz-Anderson, 1988).

Once the total number of cases reported, the dates and specific jobs in which CTS developed, and the number of workers on that same job have been determined, this information can be used to calculate the incidence rates, or number of CTS cases per department or job for a specific time period (Putz-Anderson, 1988). Calculation of incidence rates can be used to make comparisons between and within departments so that excessive CTS incidence rates can be identified.

Quantification of the monetary costs of CTS often aids in justifying modifications to the work place. A review of workman compensation insurance records may be useful for such efforts. Reported costs can be broken down into medical costs which include any payment made to outside medical or rehabilitation facilities and disability costs which include any payment made directly to the afflicted worker for lost time or disability settlements (Putz-Anderson, 1988). Although worker compensation reports are useful in identifying work areas with excessive costs due to CTS, analysts must realize that only the most severe cases of CTS have reached this stage.

Surveying Workers

Although a review of records is an essential first step to assessing the extent or potential for CTS in the work place, seldom does it provide enough detailed information to accurately pinpoint the exact location and severity of CTS among the work force. Surveying workers can provide detailed information about the exact nature of injury and details describing the job activities that may have led to the onset of CTS. Survey and questionnaires can assist in identifying pertinent information about workers at risk of developing CTS or workers who currently are experiencing symptoms of the disorder.

Information often gathered on survey and questionnaires includes gender, age, prior health and work history, years on the job, prior upper extremity injuries, chronic diseases, reproductive status of females, recreational activities, prior and current job activities. Information is also gathered pertaining to the location, duration, onset and aggravating factors of any current upper extremity pain or discomfort (Silverstein et al., 1987). Questions pertaining to medical history are often a vital part of any questionnaire to try and differentiate between occupational and non-occupational CTS.

A common limitation of the survey method of gathering information is that it relies upon the workers' recognition of and willingness to report his or her health condition (Putz-Anderson, 1988). In some instances, workers do not correlate the aches and pains of the wrist and hand, which often occur at night, with job-related activities. In such cases, vital information regarding symptoms may be discarded by the employee.

Ergonomic Work Place Assessment

After the review of records and survey of employees reveal those job areas with an excessive incidence rate of cumulative trauma or CTS, it is necessary to complete a thorough ergonomic work place assessment to identify those aspects of the job that may be causing trauma to the wrist and hand. Currently, the majority of work place assessments do not offer the type of analysis needed for identifying the work-related factors that may cause wrist stress and contribute to CTS. A systematic ergonomic assessment includes a thorough analysis of work methods, work station and tool usage (Armstrong et al., 1982). An ideal work place assessment is a hybrid form of traditional work methods analysis and an ergonomic checklist. This combination would incorporate the techniques needed for identifying an employee's exposure to all major risk factors or suspected causes of CTS.

A traditional task analysis is patterned after techniques of time and motion study (Armstrong, Foulke, Joseph, & Goldstein, 1986). A work methods analysis offers a complete description of work content by describing the job as a set of tasks which are made up of a series of steps or elements. Elements are described as fundamental movements performed by the worker. Work methods analysis can be completed by reviewing job descriptions, interviewing supervisors and employees, and observing the job as it is performed or on video camera (Armstrong et al., 1986).

Once the job components have been documented, it is critical to review each work element to identify any evident occupational risk factors which may contribute to CTS. Occupational risk factors are those work place elements which may cause or aggravate CTS such as repetition, wrist deviation or awkward hand positioning, vibration, low temperature exposure, excessive mechanical stresses to the hand, or improper glove usage. To date, acceptable exposure levels have not been developed for such factors, however, when the presence of occupational risk factors are combined with non-occupational risk factors, employee injury may be inevitable (Armstrong et al., 1986). It must be noted that simply the presence of risk factors does not necessarily call for work place or methods modification. However, employee injury is often much more costly than job modifications, especially in the design stages of the work task (Armstrong et al., 1986).

It is the goal, of this research, to aid in the performance of this last step in work place analysis--ergonomic assessment. The following experimental research will identify and quantify the suspected primary causes of wrist stress. A hybrid form of work methods analysis and ergonomic assessment will then be developed for systematic job evaluation that recognizes all factors of work methods, layout and tool usage that may contribute to CTS. Such factors can then be minimized or eliminated to reduce the incidence and trauma of CTS in the work place.

CHAPTER III

DESIGN AND METHODOLOGY

Statement of the Problem

It has been established that many occupational activities and work factors can contribute to the onset of Carpal Tunnel Syndrome. The relative wrist stress severity of such factors, however, has not been clearly defined. It is then, the purpose of this experimental research, to identify the relative wrist stress produced by varying deviations of the wrist and postures of the hand. With such information, tasks can be evaluated and wrist stress can be quantified so that work stations can be prioritized for ergonomic modification.

Factor Selection

Wrist deviation and awkward hand postures are two critical risk factors that have been associated with the onset of Carpal Tunnel Syndrome in the work place. Therefore, the independent variables investigated in this study included the various degrees of wrist deviation and hand postures that would most likely be encountered during work performance in an industrial environment. Ten basic wrist movements were developed which included mid and full flexion, mid and full extension, ulnar deviation, radial deviation, and full flexion and extension with simultaneous ulnar and radial deviation (see Figure 3). The wrist deviation of each movement was selected based on its possible contribution to wrist stress, as well as for its ease of identification during methods analysis.

Figure 4 displays the four commonly used hand postures (Armstrong et al., 1982) selected for investigation in this study which include:

1. Medial Grasp (Grip #1) - The fingers are wrapped around the hand dynamometer or some object so that the load is distributed continuously between the palm and the fingers.

2. Pulp Pinch (Grip #2) - Keeping the fingers straight, pinch the dynamometer or object so that the load is supported between the finger tips and the thumb.

3. Palm Pinch (Grip #3) - The tips of the fingers are pressed towards the base of the palm while grasping the dynamometer or object.

4. Finger Press (Grip #4) - The fingers are relatively straight and pressed palm side down against an external surface or dynamometer.

Throughout the experiment, the ten basic motions and four basic hand formations were performed alone and then in combination with one another, performing each of the four grips in every basic wrist deviation. As a result, fifty-

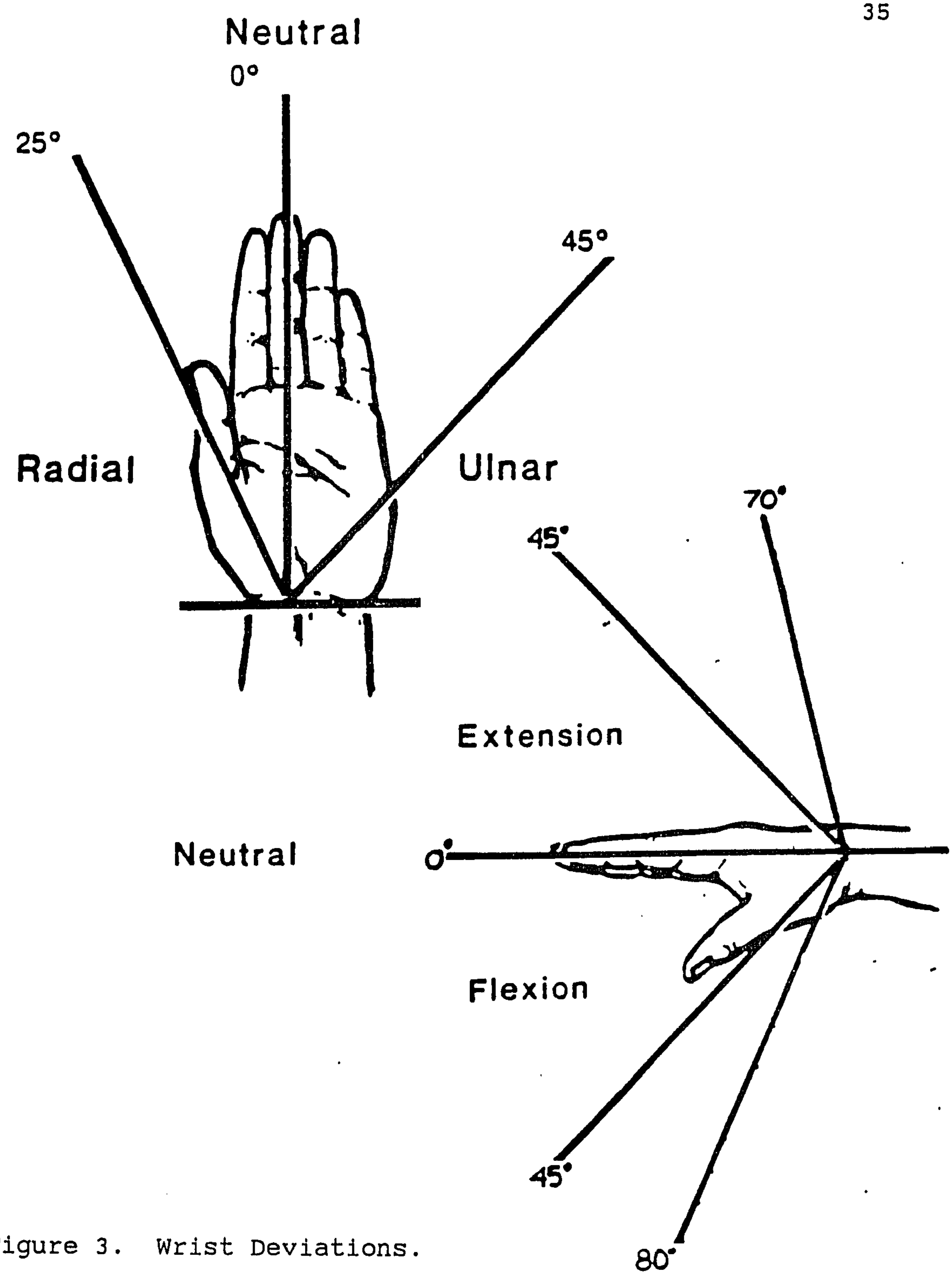

Figure 3. Wrist Deviations.

Source: Putz-Anderson, V. (Ed.). (1988). Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs (p. 57). London: Taylor & Francis.

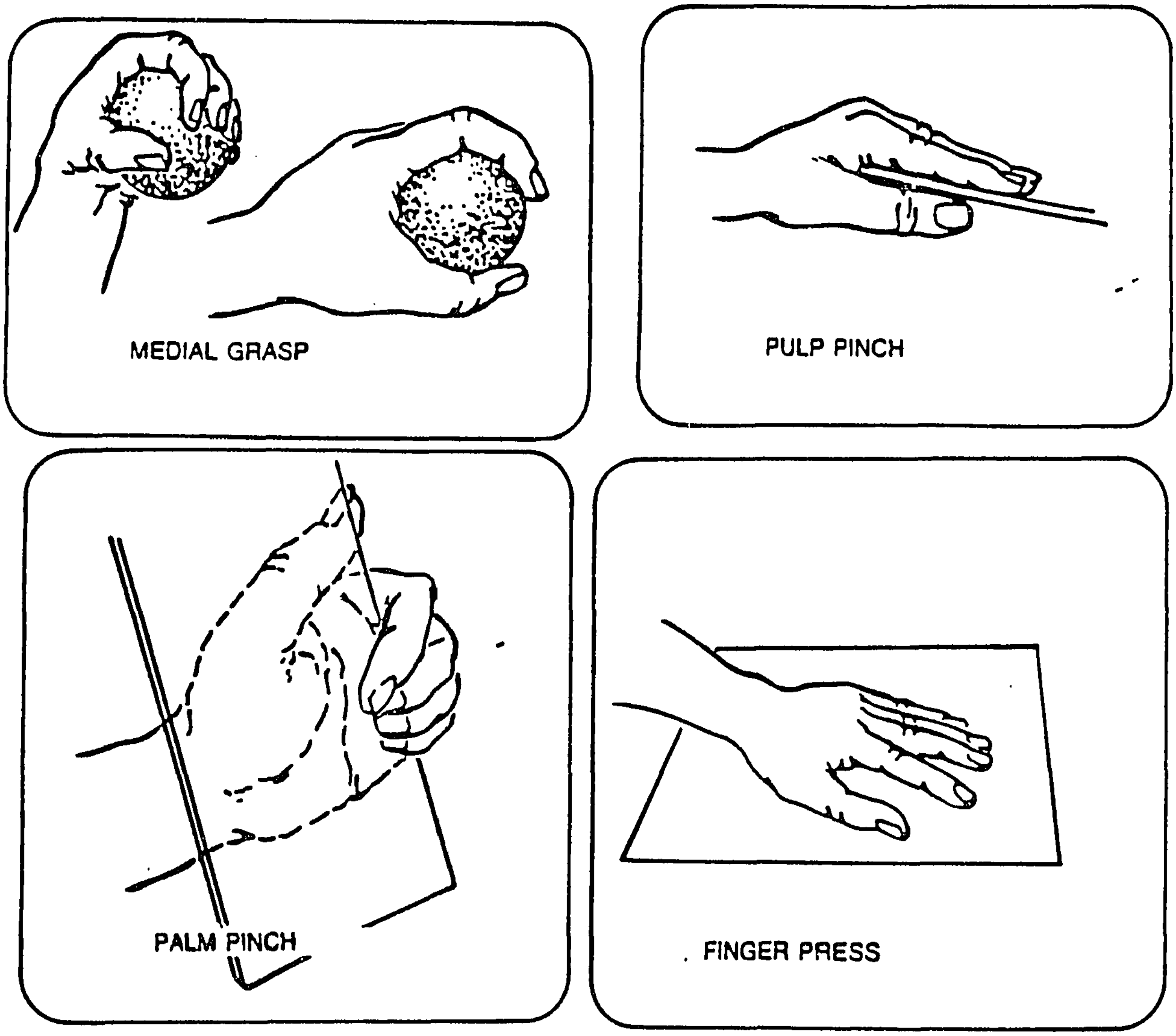

Figure 4. Hand Formations.

Source: Putz-Anderson, V. (Ed.). (1988). Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs (p. 56). London: Taylor & Francis.

four independent variables were identified and evaluated as potential wrist stress contributors (see Table 1 and Table 2).

Table 1

Critical Wrist Deviations Under Study

Passive Motions (no force)
1. Flexion 45
2. Full Flexion
3. Extension 45
4. Full Extension
5. Ulnar Deviation (UD)
6. Radial Deviation (RD)
7. Full Flexion & Ulnar Deviation
8. Full Flexion & Radial Deviation
9. Full Extension & Ulnar Deviation
10. Full Extension & Radial Deviation

Response Variable Selection

The problem under study concerns the determination of wrist stress caused by various work place activities (e.g. motions and/or hand positions). Therefore, the measured response to the performance of the 54 independent variables must be some measurement of "wrist stress." The way in which wrist stress is measured, and the probable accuracy of those measurements may vary.

Few investigators have attempted, in rather complex manners, to determine the effect of wrist position on intra-canal pressure. Abbott and Saunders (1933) injected

Table 2

Critical Hand Formations Under Study

Active Motions (with force of 10 kg)

Grip Only - wrist in neutral position

1. Medial Grasp - #1 Grip
2. Pulp Pinch - #2 Grip
3. Palm Pinch - #3 Grip
4. Finger Press - #4 Grip

Grip plus wrist deviation

#1 Grip, Flex 45	#1 Grip, Full Flexion
#2 Grip, Flex 45	#2 Grip, Full Flexion
#3 Grip, Flex 45	#3 Grip, Full Flexion
#4 Grip, Flex 45	#4 Grip, Full Flexion
#1 Grip, Extend 45	#1 Grip, Full Extension
#2 Grip, Extend 45	#2 Grip, Full Extension
#3 Grip, Extend 45	#3 Grip, Full Extension
#4 Grip, Extend 45	#4 Grip, Full Extension
#1 Grip, Ulnar Deviation	#1 Grip, Radial Deviation
#2 Grip, Ulnar Deviation	#2 Grip, Radial Deviation
#3 Grip, Ulnar Deviation	#3 Grip, Radial Deviation
#4 Grip, Ulnar Deviation	#4 Grip, Radial Deviation
#1 Grip, Full Flex & UD	#1 Grip, Full Flex & RD
#2 Grip, Full Flex & UD	#2 Grip, Full Flex & RD
#3 Grip, Full Flex & UD	#3 Grip, Full Flex & RD
#4 Grip, Full Flex & UD	#4 Grip, Full Flex & RD
#1 Grip, Full Extend & UD	#1 Grip, Full Extend & RD
#2 Grip, Full Extend & UD	#2 Grip, Full Extend & RD
#3 Grip, Full Extend & UD	#3 Grip, Full Extend & RD
#4 Grip, Full Extend & UD	#4 Grip, Full Extend & RD

Berlin blue and Lipidol into the median nerves of cadavers to determine at what degree of wrist deviation the free flow of the solution from the forearm into the palm was prevented. In a study reported in 1947 by Brain, Wright and Wilkinson, carpal canal pressure was measured using manometers in experiments with cadavers during variations in hand and wrist postures. In 1959, Tanzer reported findings from a study investigating relative carpal canal pressures during wrist deviation by introducing a mercury bag into the carpal canal and attaching it to a manometer.

In more recent times, researchers have adopted the use balloon transducers for replacing the median nerve in cadavers (Smith et al., 1977) or wick catheters in CTS patients (Gelberman, Hergenroeder, Hargens, Lundborg & Akeson, 1981) to measure the intra-compartmental pressures within the carpal canal during various wrist deviations and hand postures. As was the case with earlier methods of canal pressure measurement, such complex measurement strategies deterred extensive investigation into stresses of the wrist.

In 1979, however, a study published by Armstrong, Chaffin and Foulke reported a low cost method of estimating the hand force associated with various hand positions used in manual tasks. The hand forces were estimated from the integrated surface EMG of the medial side of the forearm. From studies conducted by Lippold (1952), DeVries (1968) and Bouisset (1973), it is known that the integrated EMG output is directly related to the force of exertion for a given hand position (as cited in Armstrong et al., 1979).

Across most submaximal force ranges, a straight line correlation is achieved (Armstrong et al., 1979). From this study, it was concluded that within a certain hand posture, the integrated EMG recording would indicate the relative increases or decreases in forces to the hand.

Hand force is then directly related to wrist stress based on a study conducted by Smith et. al (1977) which concluded that the pressure placed on the median nerve is directly related to the load placed on the flexor digitorum profundus tendons of the second and third digits. Pressure on the median nerve increases as tension or force applied to the flexor tendons of these digits increases. Smith et al. (1977) determined that other tendons within the carpal canal have only a minor effect on median nerve pressure.

This correlation between hand force and median nerve compression caused by tendon loading is supported by the theory which states that forces on the hand are transmitted through the skin to underlying tendons (Putz-Anderson, 1988). Tension on these tendons of the hand, which run through the carpal tunnel, can then be measured indirectly by determining the corresponding integrated EMG of the finger flexor muscles of the forearm. In simple terms, increased hand force or tendon loading results in an increased integrated EMG recording for a particular hand posture. An increased hand force, or tendon loading, corresponds to increased pressure on the median nerve.

Putting these two factors together, we can conclude that relatively speaking, an increase in pressure on the median nerve is indicated by an increased integrated EMG recording of the finger flexor muscles of the forearm.

Wrist stress, which is the dependent variable of this current experiment, can therefore be effectively and easily measured in relative terms based on the integrated EMG recording of the finger flexor muscles of the forearm. As an independent variable motion is performed, the corresponding amplitude of the integrated EMG recording will be noted. EMG amplitudes can then be compared to identify which wrist deviations and hand positions produce greater amounts of wrist stress.

Design of Experiment

A randomized complete block design was selected for this experiment so that the variability arising from the human subjects could be systematically controlled. With the use of a randomized complete block design, human subjects can be blocked during the statistical analysis, so that the experimental error will reflect only random error, minimizing error due to the variability among subjects. For this type of experimental design, each block or subject is tested under each independent variable. By using this design strategy, the blocks (subjects) form a more homogeneous experimental unit on which to compare the independent variables (wrist deviations and hand postures). The accuracy of comparison among the independent variables is then greatly improved (Montgomery, 1984).

The primary purpose of this experimental study is to determine which wrist deviations and hand positions are significantly more stressful than others, and then to determine the relative magnitude of the difference. To achieve this purpose with resulting accuracy of data, it was necessary to determine an appropriate sample size that maintained a balance among statistical accuracy, time and cost. A total of 31 subjects participated in the study, however, due to experimental errors in testing, only 28 subjects were included in the statistical analysis. Four observations per independent variable were collected for each subject, thus a total of 216 motions/hand formations were completed by each participant. Subjects were instructed to perform the independent variables in a random manner so as to maintain the integrity of the experimental results.

Performance of the Experiment

In compliance with Western Michigan University policy, all research involving human subjects must be reviewed and approved prior to its undertaking. All participants must partake in the informed consent process and proper documentation must be retained by the investigator supporting such activities. A copy of the research protocol clearance by the University's Human Subjects Institutional Review Board and the Human Subject Consent Form used in the study can be found in Appendix A.

Subject Selection

Participants in this experiment were obtained through personal contact by the principle investigator with acquaintances, and through a classroom announcement. All subjects were selected on a volunteer basis and were either students, faculty or staff of Western Michigan University. Participation or refusal to participate in this research project in no way involved penalties of any kind. Subjects could discontinue participation at any point in the research experiment.

The desired subject population consisted of healthy males and females between the ages of 18 and 65. Pre-experimental data collected on each subject included name, age, sex, height, weight, hand preference, and hand measurement. The majority of participants were young males between the ages of 19 and 25. This factor was due to the university and curriculum setting of the experiment. Table 3 summarizes the subject anthropometric data.

Confidentiality of records was maintained by the issuance of an identification number to all subjects prior to experimentation. From that point on, subjects were only

Table 3

Subject Anthropometric Data

ID #	Sex	Age	R/L	Height	Weight
1	F	21	R	69"	175 lbs
2	F	22	R	69"	125 lbs
3	M	27	R	68"	150 lbs
4	M	23	R	72"	155 lbs
5	M	22	R	68"	165 lbs
6	F	28	R	65"	117 lbs
7	M	20	R	71"	160 lbs
8	M	22	R	70"	195 lbs
9	F	21	R	66"	125 lbs
10	M	21	R	66"	150 lbs
11	M	20	R	68"	155 lbs
12	M	22	R	73"	230 lbs
13	M	22	R	74"	190 lbs
14	M	21	R	64"	135 lbs
15	M	20	R	67"	145 lbs
16	M	24	L	70"	168 lbs
17	M	23	R	74"	180 lbs
18	M	22	R	72"	152 lbs
19	M	21	R	66"	135 lbs
20	M	26	R	72"	140 lbs
21	M	57	L	68"	160 lbs
22	M	39	R	73"	285 lbs
23	M	23	R	69"	185 lbs
24	F	20	R	61"	115 lbs
25	M	20	R	75"	195 lbs
26	M	21	R	69"	140 lbs
27	M	22	R	74"	170 lbs
28	F	60	R	65"	139 lbs
Female	6	28.7	6-R	65.8"	132.7 lbs
Male	22	24.4	20-R	70.1"	170.0 lbs
Total Subjects	28	25.4	26-R	69.2"	162.0 lbs

identified by that identification number, age, and sex.

There were no foreseeable physical, psychological, or social risks associated with subject participation in this research. CTS is a cumulative trauma disorder, thus develops over a prolonged period of time involving excessive stressful activity. The subjects for this research conducted wrist and hand motions for a limited period of time (1 hour), involving a minimum amount of force (less than 10 kg). Therefore, no foreseen risks of CTS development were created from the activities performed in this experiment.

Apparatus

The apparatus utilized in this experiment guided the subject in the proper execution of the specified wrist deviation and hand positioning. A stationary Jamar Goniometer was used to ensure accurate and consistent wrist deviation among subjects. A Lafayette hand dynamometer provided for consistent muscle exertion and hand positioning among subjects. A specially designed force gauge and pivoting table combination allowed for completion of the finger press grasp at differing angles. In addition to the above mentioned goniometer and dynamometers, a variety of tables, blocks and chairs were used to gain consistency in performance of the independent variables given the differing anthropometric measurements of the subject group.

The electrical activity of the finger flexor muscles in the forearm was recorded using a Lafayette Model #76409

EMG amplifier/EMG integrator and #76102 data graph recorder. Three Lafayette 23 mm diameter surface electrodes, Model #76623, transferred the electrical potential for measurement. Surface electromyography is a non-invasive procedure routinely employed in clinical practice, and did not place the subject at any foreseen risk.

Procedure

Subjects were assigned one-hour appointments for the completion of the experiment. Participants were provided with an informed consent form (see Appendix A) which briefly described the purpose of the study, the procedure for experimentation and any possible ramifications from participating in the experiment. After each participant voluntarily signed the consent form, he/she was verbally instructed as to the anatomical structures of the wrist and hand, carpal tunnel development, and benefits of such experimentation. Each subject was then asked if he or she had any questions or concerns regarding the experimental procedure.

Information was then gathered from each subject concerning age, height, weight and hand preference. A tracing of the preferred hand of each subject was completed so that hand measurements could be attained if needed at a later date.

The subject's forearm of his/her preferred hand was then prepared for electrode placement. Prior to electrode placement, the subject's skin resistance was reduced by scrubbing the skin with alcohol and a textured cloth. Cleansing the area in such a manner removes the outer most layer of epidermis as well as the sebum from the pores of the skin. In addition to reducing skin resistance, this procedure increases the adhesive property of the double sided adhesive washers of the electrodes.

After the skin surface was prepared, the three electrodes were secured. Each double-sided adhesive washer was centered over the cavities in the electrodes. Each electrode cavity was then filled with electrode jelly so that no voids or air bubbles existed in the cavity. Each subject was then asked to flex the forearm muscles by holding a tight fist. The three electrodes were then securely placed, one to the elbow for grounding and two over the belly of the finger flexor muscles, approximately one inch apart. The subject was then instructed to relax the forearm.

For each subject, the EMG amplifier/ EMG integrator settings and controls were unchanged to obtain consistency among the relative EMG amplitude recordings of the subjects. A sensitivity level of 2 uv/cm, a 0.02 sec integrated EMG time, and a 60 Hz filter were maintained throughout all experimentation.

The experimental recording form for each subject contained a listing of all 54 independent variables to be performed. The various wrist deviations and hand postures were arranged into 6 groups depending on the apparatus needed to perform the motion and/or grasp, and on the subject location required to perform the variable. Following is a listing of each group, the independent variables within that group, and the specific instructions explaining subject placement and variable performance.

1. Group 1 - The subject is seated in a chair with the preferred hand/forearm resting on a table, parallel to the floor. With the use of the goniometer, the experimenter guides the subject as to the desired wrist deviation. In a random order, 5 variables are performed, each variable being repeated a total of 4 times. The subject's hand must always start in a neutral position (no deviation) and return to a neutral position after the performance of each motion. Each motion is held for three seconds before releasing to the neutral position. After 5 variables have been performed, a rest period of 20 seconds is given. The remaining five variables are then performed. A one-minute rest period is given at the completion of all variables.

Flexion 45	Full Flexion
Extension 45	Full Extension
Ulnar Deviation (UD)	Radial Deviation (RD)
Full Flex with UD	Full Flex with RD
Full Extend with UD	Full Extend with RD

2. Group 2 - The subject is standing next to the vertical tilt table/force gauge with his/her forearm resting on a block parallel to the floor. With the wrist in a neutral position, variables are performed to an exertion of 10 kg from the palmer surface of the fingers and hand. Each variable is held for 3 seconds and repeated four times. The performance order of the variables is random. A one-minute rest period is given after performance completion.

#4 Grip - neutral position
#4 Grip - UD
#4 Grip - RD

3. Group 3 - The subject is seated in a chair across from the horizontal tilt table with his/her forearm resting on a block parallel to the floor. With the wrist in a fully deviated position, variables are performed to an exertion of 10 kg from the palmer surface of the finger and hand. Each variable is held for 3 seconds and repeated four times. The performance order of the variables is random. A one-minute rest period is given after performance completion.

#4 Grip - Full Extension
#4 Grip - Full Extension with UD
#4 Grip - Full Extension with RD

#4 Grip - Full Flexion
#4 Grip - Full Flexion with UD
#4 Grip - Full Flexion with RD

4. Group 4 - The subject is standing next to the tilt table which is at a forty-five degree angle. The forearm

is resting on a block which is parallel to the floor. With the wrist in a partially deviated position, the variables are performed to an exertion of 10 kg from the palmer surface of the fingers and hand. The same directions involving randomness, holding time and rest period apply.

#4 Grip - 45 degree Extension
#4 Grip - 45 degree Flexion

5. Group 5 - The subject is seated in a chair with the forearm resting on a block parallel to the floor. With the wrist in a neutral position, and with the hand dynamometer in the appropriate position, a grasp is exerted to 10 kg. The same directions involving randomness, holding time and rest period apply.

#1 Grip - Full grasp around handle which is set at 2.5 cm
#2 Grip - Fingers straight and pinch handle set at 0.5 cm
#3 Grip - Fingers flexed and pinch handle set at 0.0 cm

6. Group 6 - The subject is seated with his/her forearm resting parallel to the floor. The goniometer guides the subject as 5 variables are randomly selected and performed followed by a 30-sec rest period. The same directions involving holding time, repetition and rest between motions is applicable. The 5 variables should be selected from within the same hand posture (grip) category so as to minimize the amount of dynamometer set-up time necessary.

#1 Grip - Flex 45
#1 Grip - Extend 45
#1 Grip - UD
#1 Grip - Full Flex & UD
#1 Grip - Full Extend & UD
#1 Grip - Full Flexion
#1 Grip - Full Extension
#1 Grip - RD
#1 Grip - Full Flex & RD
#1 Grip - Full Extend & RD

#2 Grip - Flex 45	#2 Grip - Full Flexion
#2 Grip - Extend 45	#2 Grip - Full Extension
#2 Grip - UD	#2 Grip - RD
#2 Grip - Full Flex & UD	#2 Grip - Full Flex & RD
#2 Grip - Full Extend & UD	#2 Grip - Full Extend & RD
#3 Grip - Flex 45	#3 Grip - Full Flexion
#3 Grip - Extend 45	#3 Grip - Full Extension
#3 Grip - UD	#3 Grip - RD
#3 Grip - Full Flex & UD	#3 Grip - Full Flex & RD
#3 Grip - Full Extend & UD	#3 Grip - Full Extend & RD

The random order of performance of each variable required the experimenter to match the EMG recording with the corresponding independent variable for each individual subject. To accomplish this, the experimenter derived the random order of variable performance for each subject prior to experimentation and numbered all variables from 1 - 54 on the subject's individual recording form. As the variables were performed and the electrical potential recorded, the experimenter labeled each EMG read-out with the corresponding independent variable number previously assigned.

Throughout the duration of the experiment, the subjects were encouraged to respond verbally regarding perceived wrist stress level caused by the independent variables. If such comment was made, it was recorded next to the corresponding variable EMG read-out. At the completion of the experiment, each subject was asked for further comment, and all questions regarding the study were answered.

The control features built into this experiment were as follows:

1. Settings for the goniomete,er and hand dynamometer remained constant across all subjects so as to standardize wrist deviation and hand positioning.

2. The hand dynamometer used across all subjects assisted in standardizing the force exerted by subjects during different grasping postures.

3. To minimize and standardize the effect of fatigue, consistent rest periods were given to all subjects.

4. EMG amplifier/ EMG integrator setting remained constant across all subjects.

5. To standardize the placement of the electrodes, anatomical landmarks and measurement strategies were used in electrode placement.

6. To ensure that the EMG readings reflected true relativity among one subject's independent variables, all variables for that subject were performed in the same sitting, using only one electrode placement.

CHAPTER IV

RESULTS AND ERGONOMIC ASSESSMENT MODEL DEVELOPMENT

At the completion of the experiment, the collected data was analyzed to quantify the level of wrist stress caused by the observed motions. A statistical analysis of the data was conducted to determine if any motions or groups of motions were significantly more stressful to the wrist than others. Stress indexes were then calculated based on the mean stress level (EMG amplitude) of each group of motions. Once the relative stress indexes for the different groups of motions were identified, an ergonomic assessment model was developed to evaluate the overall stress ratings of work tasks. Within a work environment, the overall stress ratings for tasks can then be compared, and modification for jobs prioritized according to stress levels. This analysis can be conducted in the work place design phase or on existing operations to identify current or potential wrist trauma. Modifications to the work station, tools or method can then be implemented to reduce the overall wrist stress level of a task, and minimize the trauma of CTS in the work place.

Quantifying the EMG Amplitude

After all data collection was complete, it was necessary to quantify the amplitudes of the EMG recordings. Each of the fifty-four independent variables were performed a total of four times, resulting in 216 corresponding EMG readings to be interpreted for each subject. By quantifying the EMG recordings for each motion and/or hand position, relative stress levels among variables can be identified. EMG amplitudes were quantified by identifying the peak amplitude of an electrical potential reading, then counting the graphical blocks or divisions on the recording paper of that peak. For each studied motion, the average EMG potential was calculated for a single subject. The average EMG potential for each motion was then calculated over all subjects.

Figure 5 represents a subject's quantified EMG recording for various wrist deviations and hand positions. For example, if full flexion has a mean EMG amplitude of 10 blocks and 45 degrees flexion has a mean EMG amplitude of 5 blocks, it can be interpreted that full flexion is twice as stressful as mid flexion for that subject.

Statistical Analysis

Statistical Analysis System (SAS) Version 5, developed by the SAS Institute Inc. (1985), was the computer package used to analyze data for this study. SAS is a

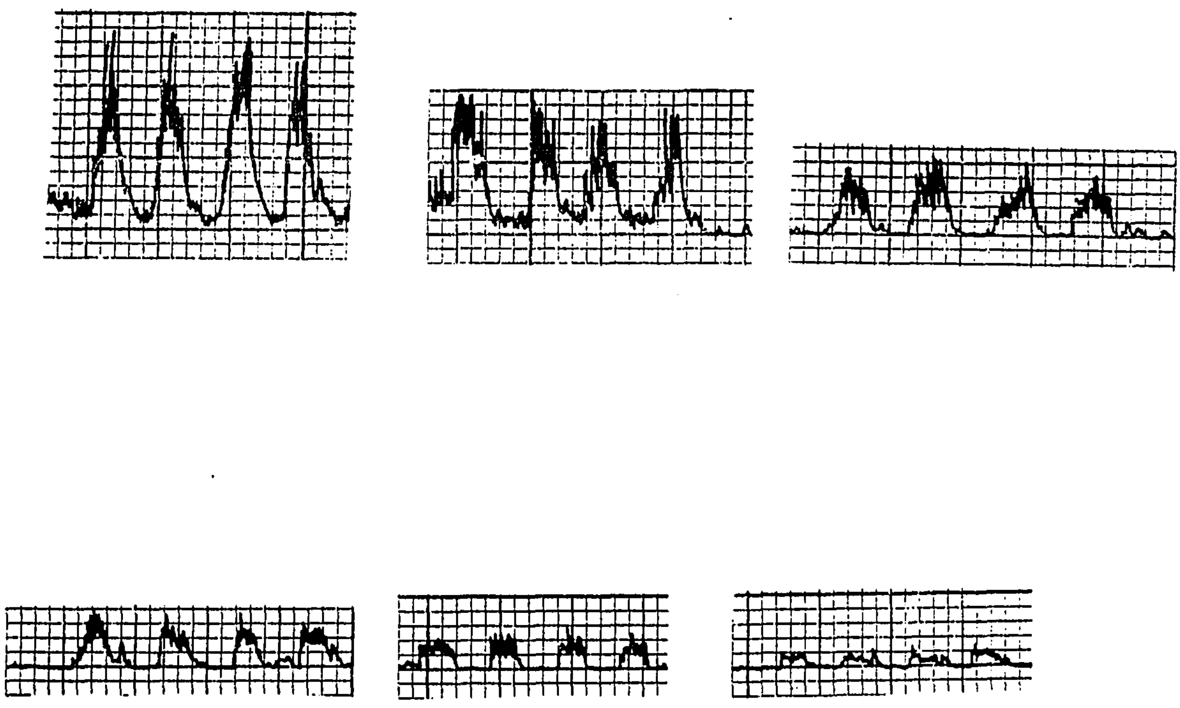

Figure 5. Electromyography Output

powerful statistical tool, offering ease in application of a variety of procedures. An analysis of variance (ANOVA) was completed on the quantified stress readings to determine if there was a significant difference among the independent variable means. With a randomized complete block experimental design, 28 subjects were blocked, 54 motions were considered as treatments, and the dependent variable was mean wrist stress measured by the amplitude of the EMG reading for each motion. A summary of the ANOVA results of this experiment can be found in Table 4.

Table 4

Analysis of Variance for a Randomized Complete Block Design

Source	DF	Sum of Squares	Mean Square	F Value
Treatment	53	23066.31	435.21	38.02
Blocks	27	4417.01	163.59	
Error	1431	16381.32	11.45	
Total	1511	43864.65		

The ANOVA results indicated that at an alpha level of 0.05, there was a significant difference among the means of the independent variables, or the tested wrist deviations and hand motions. This is to say that the type of wrist and/or hand motion performed does have a significant effect on the level of stress inflicted on the wrist. To determine exactly which independent variables differed from one another, Tukey's Studentized Range Test was conducted. Tukey's test was chosen for the post-hoc analysis due to the fact that it is relatively conservative in its analysis of data, and effectively controls the Type I family-wise error rate.

Table 5 gives a listing of the overall calculated mean for each independent variable, from highest amplitude, or stress level, to lowest amplitude. Table 6 then displays a summarized version of the Tukey results, breaking down the wrist and hand motions into appropriate groups and identifying which means within each group were significantly different from one another. Full documentation of the ANOVA results and Tukey analysis can be found in the Appendix B.

Eliminating Suspect Results

After analyzing the relative wrist stress ranking of all independent variables, a decision was made to drop Grip 2 (Pulp Pinch) and Grip 4 (Finger Press) from the study. This decision was made because it was felt that the amplitudes determined from the experiment did not accurately reflect the level of wrist stress caused by the respective motions. It is suggested that further studies be conducted which more appropriately evaluate the wrist

Table 5

Wrist Stress Ranking

Motion	Mean	Motion	Mean
1. 4RD	15.9420	28. RD	5.1205
2. 4F90	15.2991	29. 2UD	4.8054
3. 4F90RD	14.9442	30. 3G	4.8036
4. 4F45	14.7969	31. 2G	4.7790
5. 4F90UD	14.0223	32. 2E90RD	4.4799
6. F90RD	11.8817	33. 2E45	4.4799
7. F90	11.8173	34. 2F45	4.4040
8. 4N	11.5692	35. 3RD	4.3661
9. F90UD	10.4643	36. 2RD	3.9509
10. 4E45	10.1496	37. 3E90UD	3.7790
11. 3F90	9.0402	38. 3E90	3.6763
12. 3F90RD	8.5625	39. 3E45	3.5804
13. 4E90RD	8.4911	40. 3E90RD	3.2076
14. 3F90UD	8.1964	41. 1UD	2.8884
15. 1F90UD	7.6719	42. F45	2.8217
16. 4UD	7.2589	43. 1F45	2.7098
17. 4E90	6.4754	44. E90RD	2.7054
18. 3F45	6.2478	45. 1E90UD	2.4085
19. 2F90UD	6.0179	46. 1RD	2.1786
20. 2F90	5.9174	47. 1E90RD	2.1339
21. 3UD	5.8772	48. 1E90	2.0491
22. 1F90	5.7277	49. E90	1.9911
23. 1F90RD	5.6295	50. UD	1.9330
24. 4E90UD	5.4420	51. 1E45	1.8460
25. 2F90RD	5.3170	52. E90UD	1.8192
26. 2E90UD	5.2746	53. E45	1.7545
27. 2E90	5.1451	54. 1G	1.6540

Key:

1,2,3,4 = Grip number
F = Flex
E = Extension
UD = Ulnar Deviation
RD = Radial Deviation
45 = mid deviation
90 = full deviation

Table 6

Motion Grouping Development

Independent Variables Divided by Significant Differences within Groupings

Motion	Grip 1	Grip 2	Grip 3	Grip 4
F90RD	F90UD	F90UD	F90	RD
F90	F90	F90	F90RD	F90
F90UD	F90RD	F90	F90UD	F90RD
		E90UD		F45
RD	UD	E90	F45	F90UD
F45	F45	UD	UD	
E90RD	E90UD	G	G	N
E90	RD	E90RD	RD	E45
UD	E90RD	E45	E90UD	E90RD
E90UD	E90	F45	E90	UD
E45	E45	RD	E45	E90
	G		E90RD	E90UD

Note: Gaps within a group signify significant differences among means.

stress caused by these two hand positions. The following comments give justification for this decision.

Numerous verbal comments made by subjects during the experiment indicated that Grip 2, or the Pulp Pinch, was relatively more stressful to the wrist than other gripping positions. The experimental results, however, did not correspond to this subject perception. This variation in perceived wrist stress and observed wrist stress could be explained anatomically, by the fact that it is primarily the intrinsic muscles within the hand which control fine movement by the fingers (Wang & Gross, 1988). Thus, during a pulp pinch, it is the intrinsic muscles that are stressed more severely than the extrinsic muscles of the forearm. Evaluation of the electrical potential of the finger flexor muscles in the forearm therefore, may not accurately measure the wrist stress caused by exertions in this hand position.

Based on this result, it is not appropriate for this study to quantify the level of wrist stress caused by a pulp pinch. However, it will be assumed that a pulp pinch is an unacceptable gripping position which may cause severe wrist stress and should thus be eliminated from any work activity. Basis for this conclusion rests in the observation that many subjects could not achieve the full exertion required for this experiment (10 kg) in that hand position. In fact, with any level exertion, discomfort in the wrist was experienced, especially with extreme deviation.

The experimental results of this study also indicated that the most stressful hand position was grip 4, or the finger press. All motions involving the finger press were performed on a force gauge different from the one in which the other three hand positions were evaluated. Features associated with the measurement of a subject's level of finger press exertion could not be effectively controlled with the experiment instrumentation, thus it was not appropriate to compare the levels of wrist stress associated with each measurement tool. All eleven finger press motions were dropped from the study, and only motions performed on the same instrumentation were analyzed.

Group Index Development

The Tukey analysis allowed for the identification and separation of wrist deviation and hand position groups which differed significantly in the amount of associated wrist stress. A wrist stress index representing the group EMG amplitude mean can be calculated by averaging the EMG amplitude of all motions within a group. Table 7 and Table 8 display a breakdown of the previously developed motion groups and their respective calculated wrist stress indexes. Since this index value will only be used as a rough guide to identifying relative wrist stress in the work place, it was not necessary to specify index values to any great degree of mathematic certainty. To simplify the index value associated with each group, the relative group means were reduced by a factor of two.

Ergonomic Assessment Model

The primary purpose of this experimental study was to determine the relative wrist stress caused by various wrist deviations and hand positions so that an ergonomic work place assessment model could be developed. This model will allow for the identification of these postures in existing

Table 7

Motion Mean Wrist Stress Index (WSI)

Wrist Deviation Only	
Motion Group	Group Mean / Two
F90RD F90 F90RD }	$\frac{11.4}{2}$ approximately 6
RD F45 E90RD E90 UD E90UD E45 }	$\frac{2.2}{2}$ approximately 1

operations, or the prediction of potential CTS risk in newly designed operations. As indicated by the literature review, no current work place assessment technique exists for identifying the occupational risk factors associated with CTS.

An appropriate work place assessment for CTS encompasses the identification of all risk factors, and can be simply applied by all organizational personnel. The procedure suggested here is designed only to be used as a tool to aid in the systematic evaluation of work methods, work station, and tool usage. This model for task evaluation should be used as a supplement to the earlier

Table 8

Grip Mean Wrist Stress Index (WSI)

Gripping in a Deviated Posture	
Motion Group	Group Mean / Two
1F90UD 1F90 1F90RD	$\frac{6.3}{2}$ approximately 3
1UD 1F45 1E90UD 1RD 1E90RD 1E90 1E45 1G	$\frac{2.3}{2}$ approximately 1
3F90 3F90RD 3F90UD	$\frac{8.6}{2}$ approximately 4
3F45 3UD 3G 3RD 3E90UD 3E90 3E45 3E90RD	$\frac{4.4}{2}$ approximately 2

mentioned review of records and employee interview processes of work place evaluation.

In order to effectively evaluate an industrial task, it is necessary to use an established, consistent technique for conducting methods analysis. MODAPTS (MODular

Arrangement of Predetermined Time Standards) was chosen as the predetermined time system used for this model development. Using a unique coding system, MODAPTS allows for a relatively quick and easy analysis of all motions required of a person to complete a task. MODAPTS has been in use for over 20 years in more than 40 countries, and is a reliable tool for methods timing and improvement.

An abridged version of MODAPTS was developed that not only calculates the time standard for the job under study, but computes an overall wrist stress rating for the entire task, including a breakdown of the primary elemental motions that are stress producing. The associated supplementary risk factors of job performance are also identified with this model. The wrist stress portion of the MODAPTS analysis was designed as a separate supplement to the original MODAPTS analysis form, so that it is the option of any analyst to bypass the wrist stress portion of the evaluation form, or use in alone or in combination with traditional MODAPTS analysis.

If an analyst, supervisor or engineer does choose to evaluate a task using the wrist stress identification technique, a simple analysis of work place tasks will quickly determine and prioritize those jobs that would most likely produce serious repercussions from wrist stress injuries. Engineering efforts can then be focused on those work stations within the manufacturing facility that offer the highest employee risk of CTS. Through the use of ergonomic guidelines that describe motions/methods that contribute to cumulative trauma disorders, work station, tool or process modifications can be implemented to reduce the Wrist Stress Index (WSI) for the task.

The stress rating developed in this study will be used in identifying the repetitive stress injuries of the hand and wrist. However, similar rating techniques could be developed to focus on any part of the body such as the back or neck, by using a similar process of index development and activity evaluation. In addition, it would also be possible to combine all individual stress ratings to determine an overall body stress index for a given task.

In developing the Ergonomic Assessment Model, the various relative stress indexes quantified in the study's experiment were utilized to formulate MODAPTS Stress Codes for elemental motions of a task. The primary suspected causes of CTS which include repetition, awkward hand postures and wrist deviation are therefore quantified in the model. Table 9 summarizes the identified relative stress indexes and MODAPTS coding associated with wrist deviation and hand postures. Due to constraints in research, at this point it must be assumed that the relative stress indexes remain constant across all levels of load.

Table 9

MODAPTS Stress Index Coding

		Grip 'G'		
Wrist Deviation	Motion Only 'M'	Power	Palm	Pinch
Flex ≤ 45 Extension Radial Deviation Ulnar Deviation	M1	G1	G2	G**
Flex > 45 (with or without radial or ulnar deviation)	M6	G3	G4	G**

Key:
M = Wrist Movement/Deviation
G = Get/Grasp in a certain deviated position

The MODAPTS language in evaluating work activities primarily consists of a series of Gets and Puts. Each Get and each Put is connected with a corresponding Move of either a finger, hand or arm. To stay consistent with the current format of the MODAPTS language so that the wrist stress evaluation technique is simple to understand, similar logic and notation are used. In terms of evaluating wrist stress, all noted 'Moves' will consist of wrist deviation only and will be denoted by a M_1 or a M_6 depending on the degree of wrist deviation or movement. A coding of M_0 represents a neutral wrist position. The type of hand posture or 'Get' denoted on the work place evaluation form will be either a G_1, G_2, G_3, or G_4 depending on the type of grip and wrist deviation involved. A code of G** refers to a pulp pinch which has been designated as an unacceptable hand position, thus should be eliminated if at all possible from the work method.

The M or G in the MODAPTS wrist stress code describes respectively either a movement of the wrist or a grasp of the hand. The corresponding numeric portion of the code refers to the experimentally determined relative wrist stress index involved in that particular wrist and/or hand motion. A basic MODAPTS time value code of MG, MP typically corresponds to a MODAPTS wrist stress code of MG, M. To date, the wrist stress associated with 'placing' an object, or a MODAPTS 'Put' has not been determined.

To determine the time standard associated with a MODAPTS code, the numerical values, or MODs, of the coding system are cumulated and converted to standard time units. Similarly, to determine the Wrist Stress Index associated with a MODAPTS wrist stress code, the numerical values of the coding system are cumulated. The technique used for determining the overall time standard for a task and the overall wrist stress rating for a task is based on an additive principle of cumulating all numerical values associated with each elemental motion (Move & Grasp).

The following example displays the MODAPTS wrist stress coding procedure:

	Description of motion	Stress Code	WSI
1.	Flex 70 deg, pulp pinch, ext. 45	M_6G^{**}, M_1	7
2.	With wrist neut., medial grip, UD	M_0G_1 , M_1	2
			9

In addition to quantifying the stress caused by repetition, wrist deviation and awkward hand postures, the evaluation form developed in this study recognizes the possible wrist stress associated with exposure to Supplementary Risk Factors (SRF) such as vibration (V), cold temperatures (T), mechanical stresses (S), improper glove usage (G L) and extreme forces (L) to the hand. Although these factors are not quantified as to the relative stress associated with their occurrence, it is necessary to note their existence as possible risk factors for CTS. This recognition has been designed into the evaluation form by simply checking in respective columns when employee contact with such risk factors occurs. The respective checks can then be cumulated and recorded for each task.

The following MODAPTS Ergonomic Assessment form (see Figure 6) has been designed for use in the ergonomic evaluation of wrist stress in the work place. The evaluation form can be used to analyze existing operations or operations undergoing modifications. Ideally, wrist stress evaluation is simultaneously conducted when determining the time standard for a new task, thus

MODAPTS
ERGONOMIC WORKPLACE ASSESSMENT

Department	Part Number	Date	Sheet ______ of ______
Part Description		Operation	
Operator		Analyst	Comments

N	Description	Time Code	Freq	Mods	Stress Code	Freq	WSI	V	S	T	L	G L
Time Standard Evaluation		Total Mod Units			Ergonomic Assessment Summary							

Layout Sketch Of Workstation	Total Minutes		Wrist Stress Index ____ Pulp Pinch ____ Vibration __ Mech. Stress Point __ Extreme Low Temp(<25C) __ Extreme Load __ Improper Glove Use ____
	Allowances		
	Allowed Time per Piece		

Overall Task Assessment Ranking : Wrist Stress Level MAX ________ MOD ________ MIN ________

Figure 6. MODAPTS Ergonomic Assessment Form.

preventing the occurrence of CTS.

When this type of time standard and ergonomic assessment form is utilized in an industrial setting, not only can an appropriate time standard for the task be developed, but any task can be evaluated for its predisposition to CTS. By assessing the Wrist Stress Index (WSI) and Supplementary Risk Factors (SRF), tasks within the work place can be compared to determine specifically which tasks have the highest stress levels and need immediate attention for modification.

A ranking format, similar to the one shown in Table 10, can then be developed to categorize the urgency of engineering attention for work place modification. The rating can be indicated on the corresponding task evaluation form.

Table 10

Wrist Stress Rating Scale

Overall Task Rating	Course of Action
MIN	Minimum Risk of developing CTS - minimum wrist stress. Task should be monitored on a regular basis to verify that the methods of performance have remained the same.
MOD	Moderate Risk of developing CTS - moderate wrist stress. Affected employees should be interviewed to determine if any symptoms of CTS are present. Ergonomic modifications should be made to reduce high stress indexes of elemental motions. Temporary preventive techniques such as job rotation or wrist splinting may be used during the process of permanent ergonomic modifications.
MAX	High Risk of developing CTS - high wrist stress. Tasks that produce a stress rating in this category should be top priority for supervisors, analysts or engineers--corrective steps as listed in the MOD category should be taken immediately.

CHAPTER V

DISCUSSION

Main Conclusions

As verified by the experimental results, some wrist deviations and hand positions do present more stress to the wrist than others. In summary, at a load of 10 kg, extreme flexion of the wrist appears to be approximately six times more stressful than lesser degrees of flexion, all degrees of extension, radial and ulnar deviation. In addition, grasping motions of the wrist appear to be more stressful when the wrist is in extreme flexion. Of the three hand positions investigated, pulp pinching resulted in the maximum perceived wrist stress. Often subjects could not achieve specified pinch formations of the hand and could not exert the required force of the pinch without extreme wrist and hand discomfort. Although the level of stress caused by this type of pinch was not quantified, it was concluded that until further research could indicate otherwise, all pinching hand positions should be eliminated from work activities, if at all possible. The palm pinch followed by the medial grasp concluded the ranking of stressful hand positions.

The results of this study concur with previous research work which has indicated that repeated, extreme flexion is a major contributor to wrist stress and the onset of CTS (Smith et al., 1977). Robbins (Gordon et al., 1987) explained that the median nerve is susceptible to compromise by extreme wrist flexion for the following reasons: (a) the nerve becomes superficial just proximal to the wrist and is therefore not easily displaced during extreme flexion; (b) the flexor retinaculum's sharp border impinges upon the nerve during acute flexion; and (c) the carpal bones must rotate to such a degree during extreme flexion, thereby significantly decreasing the volume of the carpal tunnel.

The innovatation of this research, is the quantification of relative stress associated with different wrist deviations and hand postures. The development of the MODAPTS Ergonomic Assessment Technique for quantifying wrist stress in the work place will allow for more effective evaluation of work activities with corresponding efforts to minimize trauma by implementing corrective and preventative measures. Corrective measures, such as ergonomic work place redesign, can be implemented after the ergonomic assessment has identified and ranked existing jobs based on wrist stress. Prevention of CTS, however, can occur through the implementation of the MODAPTS Ergonomic Assessment as the primary tool for the initial creation of work standards and work place design. Methods, work station and tool design can be based on this MODAPTS analysis, thus the incidence and trauma of CTS may be reduced.

Correction Measures

Since CTS is a chronic degenerative disorder, prevention or at the least, early treatment, will result in a reduction in cost, lost time, and pain. Inevitably, the job must fit the worker. Optimum employee performance can only be achieved through developing the optimum task method, work place design, and tooling that not only considers the production time, but more importantly the overall health and safety of the employee. In turn, short-term and long-term benefits involving the minimization of cumulative trauma disorders such as CTS can be realized not only by the employee, but by the employer as well.

A work place assessment to identify whether or not an organization has a problem with Carpal Tunnel Syndrome begins with the three step process mentioned earlier in this study: (1) reviewing records, (2) surveying workers, and (3) ergonomic work place assessment (MODAPTS Ergonomic Assessment). If a high incidence of cumulative trauma involving the wrist and hand does exist, action must be taken to immediately reduce the level of existing trauma in the work place.

Two primary control classifications describe the types of action that can be taken to reduce CTS trauma. Administrative controls primarily focus on personnel solutions, while engineering controls are devoted to the ergonomic redesign of tools, methods or work stations (Putz-Anderson, 1988). Each control technique offers different advantages to the worker and to management, and should be considered complementary, not mutually exclusive. Together, administrative and engineering controls should focus on optimizing the work environment.

Administrative Controls

Certain types of administrative controls may offer immediate relief from job stress, thus are often appropriately applied during the lapse in time between ergonomic modification development and implementation. Worker rotation serves such a purpose, by reducing the duration of exposure any one worker may have to tasks involving stressful postures, forces and repetition. However, "safe" exposure limits for such factors have not yet been developed, so caution must be taken when implementing rotation programs. In addition, appropriateness of job rotation is often subject to employment agreements, task complexity and management/employee acceptance.

Worker training programs are further examples of administrative controls which have achieved limited acceptance in the industrial environment. Although training programs appear to be easily implemented and rational in their approach to change behavior, success in the effective reduction of CTS has not been so apparent. Employee work habits, pressure to take short-cuts for increased production, and the perceived distant threat of CTS have made modifying employee behavior difficult. In light of the above mentioned challenges to training programs, some managers still pursue such activities hoping to achieve cost reductions over ergonomic interventions. However, the need for on-going training programs often produces costs in excess of initial expenses of ergonomic changes (Putz-Anderson, 1988).

Selecting workers to fit specific jobs, or job screening, has also received limited acceptance as a method for reducing cumulative trauma due to the fact that no valid technique exists for accurately predicting an employee's susceptibility to CTS (Armstrong, 1983). Relatively complex legal factors for maneuvering around discrimination further deter employers from fully utilizing screening techniques (Ayoub, 1982).

Engineering Controls

Once the ergonomic work place assessment (MODAPTS Ergonomic Assessment) has identified the locations of excessive wrist stress and the probable sources of this trauma, a plan for the control and prevention of further injury must be developed. Administrative controls are simply temporary people solutions, to what is considered a true job design problem (Putz-Anderson, 1988). Changing the job, not the worker is a guiding principle which suggests that all permanent solutions to employee trauma strive toward implementing work place, tools and method designs which are safe for all employees, regardless of human capability or work technique.

Practical guidelines for redesigning the work environment to avoid the recognized occupational risk factors of CTS revolve around the ergonomic principles listed below:

1. Reduction of extreme wrist deviation: Worker posture can often be controlled through the location and orientation of either the part, the worker or the tool. Work station and tool design should focus on minimizing the elevation of the elbow, the deviation of the wrist, and awkward positioning of the hand (Armstrong et al., 1986).

2. Reduction of excessive force and awkward hand postures: Excessive forces involved in task completion can often be minimized by altering the objects or tools held in the worker's hand through decreasing its weight, changing its size or shape, balancing the load between two hands, or reducing the torque required to hold a tool (Armstrong, 1983). In addition, the type of hand position used in

grasping objects is critical to reducing the amount of force placed on the hand and wrist. Using a medial grasp, where fingers and palm are wrapped around an object, in place of a pinch posture increases a worker's mechanical advantage and reduces the stress placed on the finger flexor tendons by spreading the force more evenly over the hand (Armstrong et al., 1986; Dionne, 1984, April).

3. Reduction of highly repetitive movements: The repetitiveness of a task can be reduced by either increasing the variety of tasks performed by a single employee or by introducing automation into the work environment. Repetitive tasks are often performed most efficiently by a machine. However, to be cost-effective, the required volume must be high and demand fairly long-term (Putz-Anderson, 1988).

4. Reduction of mechanical stresses to the hand and wrist: Mechanical stress concentrations can usually be reduced by modifying the size and length of handles, eliminating or rounding sharp edges, and using flexible work materials. Work stations should be designed to eliminate contact with hard, sharp edges of benches, containers or fixtures. Tool handles should be large enough to fit comfortably in a worker's hand, keeping the wrist in a near-neutral position when at all possible (Armstrong et al., 1986).

5. Reduction in exposure to cold temperatures: The

environmental air, tool exhaust, and materials a worker comes in prolonged contact with should not be colder than 25 degrees celsius (Armstrong et al., 1986). To avoid low temperature contact, powered tool exhaust air should be directed away from the hand and wrist area. In addition, metal tool handles which conduct low temperatures should be insulated with a thin layer of rubber or plastic.

6. Proper Glove Usage: Properly fitted gloves may be used to protect the hands from harsh environmental temperatures, chemicals, or limited impact. However, gloves can inhibit dexterity, and depending on the fit, can reduce the effective strength of the worker by as much as 30% (Armstrong et al., 1986). If gloves are used in the work place, it is suggested that a variety of sizes and styles be made available to the work force so that those gloves which are most comfortable and appropriate for the specific worker and application can be selected. When wearing gloves, no more of the hand should be covered than necessary (Armstrong et al., 1986).

7. Reduction in vibration exposure: In attempts to reduce the amount of wrist deviation, stressful hand postures, and excessive forces associated with manual tool usage, particular care should be taken to not select power tools that cause excessive vibration exposure. Factors considered in controlling exposure include the frequency and magnitude of the vibration source, the duration of

exposure, the forces applied by the tool operator, and the posture of the hand, arm and body during exposure (Armstrong et al., 1986). In some instances, the risk factors associated with power tools may equal or exceed those of manual tools if poor posturing continues and excessive exposure to vibration occurs.

These ergonomic guidelines can be introduced into work station, tool or methods design to reduce the trauma of CTS. However, particular consideration should be given to specific aspects of each design phase. Work stations, for instance, should be arranged to accommodate 90-95% of the worker population, not just the "average" worker (Putz-Anderson, 1988). Flexible work stations will allow performance of the job in several different working positions (e.g. sit, stand). In addition, frequently used tools, controls and materials should be kept within a comfortable range of motion.

Effective tool design and selection not only considers work productivity, but also focuses on minimizing the development of worker fatigue and physical stress. To increase productivity and reduce stressful hand postures, special-purpose tools should be utilized so that it is the tool rather than the employee adapting to the task. Form-fitting tool handles should be avoided to allow for the tool flexibility necessary to adapt to differing hand sizes between and among men and women (Srachta, 1985).

Determining the optimal method or sequence of motions for performing a task is often a complex endeavor. To aid in determining the work method that minimizes wrist stress, a series of MODAPTS WSI evaluations can be made on various production methods. Reductions in the overall wrist stress rating of the task can be achieved by (a) reducing the repetition of stressful elemental motions, (b) reducing the degree of wrist deviation, and/or (c) reducing the stress level of the hand posture employed by changing from a pulp pinch or palm pinch to a medial grasp. The method design which minimizes the overall Wrist Stress Index for the task as well as provides for an acceptable Supplementary Risk Factors (SRF) summary should be accepted for use.

Improvements in the work place design are usually the result of trial and error by management and by the employee. Often one single change can not be made, but rather some combination of multiple redesign efforts minimize the level of wrist stress encountered by the worker. An analysis of the number of worker complaints, medical records, and compensation claims can often aid in determining whether or not ergonomic alterations have created a positive effect (Armstrong et al., 1986).

Prevention Measures

Once the existing trauma in the work place has been controlled, the organization must focus on preventing further cumulative trauma disorders such as CTS. This effort can be accomplished by considering the aforementioned ergonomic guidelines in the initial work station, tooling and method designs. In the design stage of the work environment, or prior to any modifications to existing operations, an ergonomic task assessment should be conducted. By evaluating the job activity with the MODAPTS Ergonomic Assessment, task analysis and modification can be completed prior to employee involvement, thus employee injury.

By conducting the MODAPTS assessment in the work place and methods design stage, many of the same advantages that general Predetermined Time Standards offer in simple time standards use can be achieved. That is to say that wrist stress ratings as well as time standards, can be calculated and improved through a concentration on methods, tool, and station analysis prior to actual production operations. The ergonomic solution of improving the fit between the job and the worker not only contributes to the well being of the worker, but to the improved productivity of the manufacturing facility as well (Putz-Anderson, 1988).

Management Approval and Support

Regardless of the correction or prevention strategy adopted, it is critical to gain the support of key organizational personnel. Upper management must fully understand the impact of cumulative trauma disorders such as CTS, in order for them to justify and approve work place modifications. Engineering and safety personnel must also support modifications, for they will be the staff members in charge of implementation. And lastly, the workers who are affected by CTS and the work place modifications to prevent it, must understand and accept the need for change.

The proposed plan of action for reducing or preventing the incidence of CTS will inevitably require formal justification. This justification may include a summary of the number and severity of CTS cases and estimates regarding the time, expense and disruption involved in a control program. Two basic methods exist for justifying the need for a control program: social-legal justifications and economic justifications. The social-legal justifications focus on an employer's obligation to protect its employees from undue harm. The economic justifications involve the forecasted costs of CTS versus the costs and benefits associated with preventing the disorder (Putz-Anderson, 1988).

At the forefront of any discussion of CTS must be the unacceptable ramifications from the option to do nothing. There are potentials for abuse in any corrective/preventive strategy employed. However, unless these challenges are met and the treatment and prevention of CTS begun, thousands of workers and employers each year will continue to be afflicted with the trauma associated with this disorder.

Limitations of Study

The recognized limitations of this study primarily revolve around the performance of the experiment, the choice of wrist stress measurement and the quantification of data. Slight variation in the subjects' performance of the independent variable existed due to the fact some subjects could not achieve the proper positioning and/or exertion required for differing wrist and hand deviations. In addition, variations existed in the amount of "full" flexion or extension achieved by the subjects. Difficulty was found in controlling these variations due to the differing flexibility and strength levels of the subjects under study.

Limitations of this study also involve the technique used to measure wrist stress. The surface EMG technique was a practical and feasible method for determining the activity of the muscles within the forearm. However, due to the fact that the finger flexor muscles were targeted directly, and surrounding muscles in the forearm contributed a certain amount of "noise" to the finger flexor EMG reading, observed EMG activity may partially represent the contribution of muscles other than the finger flexors. More accurate EMG recordings from the finger flexor muscles could be obtained through the use of needle electromyography. However, this technique is quite complex.

The EMG amplitude observed may have also been affected by the placement of the electrodes on the subjects. Consistency in placement was strived for, however, due to differing anatomical features of subjects, exact placement of electrodes in relation to muscular mass may not have always been achieved.

The final limitation of this study involves the assumption in the formulation of the MODAPTS Ergonomic Assessment that the relative stress indexes of the motions remained the same across all levels of force or load. This assumption should be tested by further research.

Suggested Research

It is suggested that future research on this topic should focus on improving the validity and scope of the MODAPTS Ergonomic Assessment. In addition to testing the relative stress indexes across different loads, further gripping postures could be examined. The stress index associated with a "hold" or "carry" function could also be investigated. Experimentation utilizing needle EMG may improve the accuracy of the relative stress indexes. In addition, more accurate and consistent quantification of the EMG recording could be achieved through the use of a digitized integrated EMG output reading.

Future research concentrating on quantifying the wrist stress produced by risk factors such as vibration, mechanical stress, cold temperatures and improper glove usage could greatly improve the utility of the MODAPTS Ergonomic Assessment. A task, therefore, could be analyzed, and an overall wrist stress index developed based on all known CTS risk factors.

Appendix A

Human Subjects Institutional Review Board:
Protocol Clearance

A variety of wrist deviations and hand positions involving varying forces can be encountered during manual work. Particular motions are more stressful to the wrist and hand than others. Repetitive and forceful motions of the hand and wrist, over a significant period of time, may cause a disorder such as Carpal Tunnel Syndrome (CTS). CTS involves a compression of the median nerve which runs through the arm, wrist and hand.

This research is aimed at identifying the stress caused by various deviations of the wrist and hand. Stress levels can be measured through the attachment of surface electrodes to the forearm flexor muscles which pass through the carpal tunnel of the wrist. As a specific motion is performed (i.e. grasp, pinch), an EMG reading can be recorded. An analysis can then be made to compare the various motions and associated EMG stress levels. Subjects in this research project will be instructed to perform various wrist deviations and hand positions (see Appendix A), some of which will involve a small load of 10 pounds. An attached surface electrode will record activity and stress levels of the forearm flexor muscles.

Participation will involve a time commitment of less than 2 hours, which will include approximately 15 minutes of instruction and 1 hour of testing.

Once specific hand and wrist positions have been identified as stressful, industrial tasks can be designed and/or modified to minimize the occurrence of such exertions. A reduction in CTS in the work place, thus a reduction in employee trauma, may be the result.

There are no foreseeable risks to a subject participating in this research. Due to the limited hand and wrist motions performed and the minimal forces involved, there is no risk of developing CTS. The EMG procedure is of common practice in clinical settings, and presents no risk to the participant.

Confidentiality of records will be maintained by the issuance of an identification number to all subjects prior to experimentation. Subjects will only be identified by that number, his/her age, and sex.

Any questions regarding the research, its purpose and intent, or subject rights can be forwarded to:

Karen Kleinfeld - Principle Investigator: 387-3754
Dr. Bob Wygant - Faculty Advisor: 387-3744

Participation in this research project is completely voluntary. The subject may discontinue participation at any time. Participation or refusal to participate will in no way involve penalties of any kind or will in no way affect grades of students.

Subject ______________________________ Date ____________
(signature)

HSIRB Approval Letter

Human Subjects Institutional Review Board

Kalamazoo, Michigan 49008-3899

WESTERN MICHIGAN UNIVERSITY

Date: March 25, 1990

To: Karen Kleinfeld

From: Mary Anne Bunda, Chair Mary Anne Bunda

This letter will serve as confirmation that your research protocol, "Carpal Tunnel Syndrome - A Preventative Model", has been approved as expedited by the HSIRB. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the approval application.

You must seek reapproval for any change in this design. You must also seek reapproval if the project extends beyond the termination date.

The Board wishes you success in the pursuit of your research goals.

xc: R. Wygant, Industrial Engineering

HSIRB Project Number 90-02-03

Approval Termination March 25, 1991

Appendix B

Statistical Analysis

ANOVA

SAS

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJECT	28	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
MOTION	54	E45 E90 E90RD E90UD F45 F90 F90RD F90UD RD UD 1E45 1E90 1E90RD 1E90UD 1F45 1F90 1F90RD 1F90UD 1G 1RD 1UD 2E45 2E90 2E90RD 2E90UD 2F45 2F90 2F90RD 2F90UD 2G 2RD 2UD 3E45 3E90 3E90RD 3E90UD 3F45 3F90 3F90RD 3F90UD 3G 3RD 3UD 4E45 4E90 4E90RD 4E90UD 4F45 4F90 4F90RD 4F90UD 4N 4RD 4UD

NUMBER OF OBSERVATIONS IN DATA SET = 1512

ANOVA

SAS

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: AMP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	80	27483.32436634	343.54155458	30.01	0.0	0.626548	55.4481
ERROR	1431	16381.32064009	11.44746376		ROOT MSE		AMP MEAN
CORRECTED TOTAL	1511	43864.64500642			3.38341008		6.10193796

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUBJECT	27	4417.01568763	14.29	0.0001
MOTION	53	23066.30867870	38.02	0.0

SAS

ANALYSIS OF VARIANCE PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: AMP
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0.05 DF=1431 MSE=11.4475
CRITICAL VALUE OF STUDENTIZED RANGE=5.708
MINIMUM SIGNIFICANT DIFFERENCE=3.6498

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING								MEAN	N	MOTION
					A				15.9420	28	4RD
					A						
	B				A				15.2991	28	4F90
	B				A						
	B				A		C		14.9442	28	4F90RD
	B				A		C				
	B				A		C		14.7969	28	4F45
	B				A		C				
	B		D		A		C		14.0223	28	4F90UD
	B		D				C				
	B		D		E		C		11.8817	28	F90RD
	B		D		E		C				
F	B		D		E		C		11.8173	28	F90
F			D		E		C				
F			D		E		C		11.5692	28	4N
F			D		E						
F	G		D		E				10.4643	28	F90UD
F	G				E						
F	G				E				10.1496	28	4E45
F	G				E						
F	G				E		H		9.0402	28	3F90
F	G				E		H				
F	G		I		E		H		8.5625	28	3F90RD
F	G		I		E		H				
F	G		I		E		H		8.4911	28	4E90RD
F	G		I				H				
F	G		I		J		H		8.1964	28	3F90UD
	G		I		J		H				
K	G		I		J		H		7.6719	28	1F90UD
K	G		I		J		H				
K	G		I		J		H	L	7.2589	28	4UD
K			I		J		H	L			
K	M		I		J		H	L	6.4754	28	4E90
K	M		I		J		H	L			
K	M		I		J	N	H	L	6.2478	28	3F45
K	M		I		J	N	H	L			
K	M		I	O	J	N	H	L	6.0179	28	2F90UD
K	M		I	O	J	N	H	L			
K	M		I	O	J	N	H	L	5.9174	28	2F90
K	M		I	O	J	N	H	L			
K	M		I	O	J	N	H	L	5.8772	28	3UD
K	M		I	O	J	N	H	L			
K	M	P	I	O	J	N	H	L	5.7277	28	1F90

SAS

ANALYSIS OF VARIANCE PROCEDURE

TUKEY GROUPING	MEAN	N	MOTION
K M P I O J N H L			
K Q M P I O J N H L	5.6295	28	1F90RD
K Q M P I O J N H L			
R K Q M P I O J N H L	5.4420	28	4E90UD
R K Q M P I O J N L			
R K Q M P I O J N S L	5.3170	28	2F90RD
R K Q M P I O J N S L			
R K Q M P I O J N S LT	5.2746	28	2E90UD
R K Q M P I O J N S LT			
R K Q M P I O J N S LT	5.1451	28	2E90
R K Q M P I O J N S LT			
R K Q M P I O J N S LT	5.1205	28	RD
R K Q M P O J N S LT			
R K Q M P O J N S LT	4.8054	28	2UD
R K Q M P O J N S LT			
R K Q M P O J N S LT	4.8036	28	3Q
R K Q M P O J N S LT			
R K Q M P O J N S LT	4.7790	28	2Q
R K Q M P O N S LT			
R K Q M P O N S LT	4.4799	28	2E90RD
R K Q M P O N S LT			
R K Q M P O N S LT	4.4799	28	2E45
R K Q M P O N S LT			
R K Q M P O N S LT	4.4040	28	2F45
R K Q M P O N S LT			
R K Q M P O N S LT	4.3661	28	3RD
R Q M P O N S LT			
R Q M P O N S LT	3.9509	28	2RD
R Q M P O N S LT			
R Q M P O N S LT	3.7790	28	3E90UD
R Q M P O N S LT			
R Q M P O N S LT	3.6763	28	3E90
R Q M P O N S T			
R Q M P O N S T	3.5804	28	3E45
R Q M P O N S T			
R Q M P O N S T	3.2076	28	3E90RD
R Q M P O N S T			
R Q M P O N S T	2.8884	28	1UD
R Q P O N S T			
R Q P O N S T	2.8217	28	F45
R Q P O N S T			
R Q P O N S T	2.7098	28	1F45
R Q P O N S T			
R Q P O N S T	2.7054	28	E90RD
R Q P O S T			
R Q P O S T	2.4085	28	1E90UD
R Q P S T			
R Q P S T	2.1786	28	1RD
R Q P S T			
R Q P S T	2.1339	28	1E90RD
R Q S T			
R Q S T	2 0491	28	1E90
R Q S T			

TUKEY

TUKEY

SAS

ANALYSIS OF VARIANCE PROCEDURE

TUKEY GROUPING			MEAN	N	MOTION
R	S	T			
R	S	T	1.9330	28	UD
R	S	T			
R	S	T	1.8460	28	1E45
R	S	T			
R	S	T	1.8192	28	E90UD
	S	T			
	S	T	1.7545	28	E45
		T			
		T	1.6540	28	1Q

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