A COMPARISON OF FLEXION AND EXTENSION EXERCISES FOR WORKERS AT RISK FOR DEVELOPING CUMULATIVE TRAUMA DISEASE

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It is entitled:
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Abstract

Cumulative trauma disorders (CTDs) are soft tissue injuries of the muscles, nerves, and joints, such as carpal tunnel syndrome. CTDs are an accumulation of progressive pathological changes that ultimately culminate into an injury. The hallmark symptoms of clinical CTDs are discomfort, pain, and paresthesias. The severity of symptoms can vary between a transient aching, discomfort, and fatigue to significant pain and paresthesias that result in permanent disability.

Upper extremity CTDs are common in industries that have jobs that include highly repetitive motion tasks. The prevalence of CTDs in these industries is significant, and has a considerable impact on both industry and the individual worker. This study was guided by theory from three separate disciplines, Biomechanics, Exercise Physiology, and Ergonomics.

The purpose of this study was to test the effect of exercise on workers in an effort to reduce or delay discomfort, increase strength, and potentially reduce the progressive pathology of CTDs. Two exercise protocols at two intensities were performed by on workers doing occupational repetitive motion tasks. Flexion exercises were compared to extension exercises in a six-week exercise training program. Three industrial sites were used to conduct the study, all with a high incidence of upper extremity CTDs claims.

A convenience sample of 85 subjects was initially entered into the study. Fifteen subjects dropped out of the study. The remaining 70 subjects were randomly assigned to one of four treatment exercise groups or a control group.

The variables of interest were discomfort, as measured by a visual analog scale, and strength in six upper extremity muscle groups. A repeated measures ANOVA using a one-within, one-between design was used. The results of this study were as follows:
Discomfort: Discomfort was significantly reduced in all subjects doing exercise training across the groups after six weeks [F=43.85, (2, 62) p=.000].

Strength: An overall significant increase in strength was observed following six weeks of exercise training [F=12.32, p=.000]. A significant difference in strength across all six muscles tested was also seen [F=67.38, p=.000]. Finally, a significant interaction effect among the six muscle groups, the three time periods (baseline, three, and six weeks), and the five subject groups was observed [F=1.53, p=.035]. However, the Mauchly’s Test of Sphericity revealed that the sample had a high variance in strength across time. These data were interpreted cautiously due to the violation of this assumption.

This study provides initial support for two exercise programs in workers doing repetitive motion tasks. Exercise training may be a factor in diminishing the individual workers’ vulnerability to CTDs.
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Chapter I

Introduction to the study

Workers performing upper extremity repetitive motion-type tasks in industry are susceptible to injury development. Repeated movements using the same muscles leads to fatigue and discomfort. Following the development of fatigue, the continuation of use of these muscles can make them vulnerable to injury. This type of injury is one that occurs slowly and progressively as the repetitive motion is repeated. The most common clinical symptom of a repetitive motion related injury is localized discomfort to the extremity. Localized discomfort can be used as a marker of both fatigue and the progressive injury that occurs from doing repetitive motion tasks.

This study investigates methods to improve the resistance of the worker to injury when doing repetitive motion tasks. Exercise training of the upper extremity was used to increase the strength of the worker to improve their resistance to fatigue, and decrease the sensation of localized discomfort. Preventing or delaying fatigue and decreasing localized discomfort reduces the worker’s vulnerability to developing a cumulative-type injury.

Introduction to Cumulative Trauma Disorders

Over the past several years, scientists in occupational health have directed considerable focus toward disease states associated with repetitive tasks. These conditions are described in a variety of ways such as repetitive stress injury, but more commonly are now referred to as cumulative trauma disorders. From a historic perspective these conditions are far from new in the scientific literature. Almost three centuries ago, Ramazzini (1717/1940) described cumulative trauma in 1713 individuals involved in repetitive upper extremity tasks.
Upper extremity cumulative trauma disorders (CTDs) are regional impairments of muscles, tendons, ligaments, joints, and nerves due to chronic insult often associated with work related mechanical trauma (Chipman, Kasdan, & Camacho, 1991; Mosely, Kalafut, Levinson, & Mokris, 1991; NIOSH, 1986). Examples of CTDs of the upper extremity are nerve compression or entrapment syndromes and tendonitis (Chipman et al., 1991; Mosely et al., 1991).

CTDs are a class of musculoskeletal disorders in which chronic discomfort, pain, and functional impairment may develop due to numerous repeated movements (Guidotti, 1992). CTDs are often described as a pathology of pain and other symptoms that originate or are aggravated by workplace exposures (Melhorn, 1999). However, the description of this disorder is often vague, and the symptom complaints general in nature. CTDs occur slowly over time as a result of chronic exposure to repetitive movements, in contrast to acute injuries that occur from a single precipitating event. The lack of a single injury date and the general nature of symptoms make diagnosis and study of CTDs difficult (Guidotti, 1992).

The National Institutes of Occupational Safety and Health (NIOSH) defines CTDs as symptoms occurring from job demands that repeatedly exceed the biomechanical capacity of the worker, and result in job activity that becomes trauma inducing (NIOSH, 1986). CTDs in this definition are based on workplace biomechanical strain that contributes to adverse symptoms of the musculoskeletal system. This definition helps to describe the etiology of the disorder. However, most CTDs remain a cluster of symptoms, rather than a medical diagnosis.

The main characteristics of CTDs are that they have a multifactorial etiology, develop over time (weeks to years), and have a long recovery that may never return the person to baseline function (Grieco, Molteni, DeVito, & Sias, 1998; Himmelstein et al., 1995; Melhorn, 1999). In CTDs, muscles, tendons, and nerves are usually involved, but joints and ligaments can also be
affected (Grieco et al., 1998). Often damage to nerves and soft tissues are difficult to detect and the only symptom may be discomfort or fatigue.

Several acronyms have been used over the years to describe the disorder. The first was in 1982, when the condition was recognized by the National Health and Research Council and called repetitive strain injury (Gun & Jezukaitis, 1999; National Health and Medical Research Council, 1982). The condition was described as occurring from constant repetition of movements imposing a cumulative workload, which causes pain, weakness, and impaired function of the muscles and other soft tissues.

Other common terms describing this disorder are work-related musculoskeletal disorder and occupational overuse syndrome. However there is a lack of agreement regarding which term best describes the disorder (Grieco et al., 1998). The debate about naming centers on the fact that this disorder is not a medical diagnosis in itself, but a series of symptoms, some of which are not well described, but have a common etiology (Hales & Bertsche, 1992; Melhorn, 1999). Currently, there is no professional consensus regarding nomenclature, but the occupational and medical community has accepted the term “CTDs” to describe the slow and progressive injury that develops from doing repetitive motion tasks.

This concept of ‘cumulative’ was borne out by the worker’s compensation system in Australia when they adopted the ergonomic staging of CTDs (Gun & Jezukaitis, 1999). Three stages were adopted as progression of the CTD disease process (Browne & Nolan, 1984). Discomfort, aching, and fatigue that diminish at night or with removal from work activities characterize stage one. Stage one persists over weeks or months, but is reversible. In stage two, symptoms do not resolve between work sessions, and are possibly accompanied by objective physical signs such as a positive Phalen test or a slowing in nerve conduction. However, with an
extended rest period such as over vacations, symptoms do subside. Finally in stage three, symptoms do not resolve, and persist even after an extended rest period. Symptoms last from months to years, and may mean permanent incapacity for repetitive work. Ergonomic programs, such as the setting of maximum keystrokes for typist, work station design, job rotation, and rest breaks, are based on prevention using this staging system as a guide in an attempt to prevent the progression of disease (Worksafe Australia, 1986).

The inception of CTD symptoms can be linked to an occupational exposure, although the occupational exposure is often not the only culprit. Nonoccupational behavior such as hobbies can also be linked to CTDs. Sewing, knitting, quilting, and gardening all have repetitive exposures that add to the progressive damage that ultimately results in CTDs. The word cumulative allows for the possibility that non-occupational exposures, such as habitual behaviors, are contributory.

Finally, the word ‘cumulative’ in CTD allows for the individuality of susceptibility. Persons come to the workplace with different individual risk or mediating factors such as diabetes, rheumatoid arthritis or thyroid disorders (Melhorn, 1999). These inherent diseases make a worker more likely to be affected by repetitive exposure (Radecki, 1997). The worker’s inherent susceptibility is part of the cumulative effect.

Workers also have mediating physiologic factors that alter susceptibility to CTDs. Many factors such as gender, age, and body mass index can all be factors in developing CTDs, which will be discussed in a later section (Radecki, 1997). There is also evidence that muscle fiber composition plays a role in determining muscle fatigue level, and ultimately the development of CTDs. The amount of exposure that leads to symptoms varies greatly among workers and it is difficult to determine individual susceptibility. The difficulty in blending individual factors with
risk factors from the workplace is due to the complexity of individual factors making up the individual worker.

Although CTDs are considered a disorder rather than a distinct medical diagnosis, some CTDs do fall under a diagnostic name. The most common disorders are tendonitis, epicondylitis, DeQuervians disease, and entrapment syndromes such as carpal tunnel syndrome.

Historically, the medical community has recognized CTDs. However, significant mystery persists regarding its etiology. Much of this confusion is attributed to the complex blending of both individual and ergonomic factors that often result in the disorder.

CTDs can cause considerable discomfort to workers in the occupational setting, but they perform their job despite this daily discomfort. No relief for this discomfort is available to the worker, except anti-inflammatory or pain medication and ice. Preventing the discomfort that accompanies repetitive motion tasks could diminish the daily discomfort the worker endures and reduce the cumulative trauma associated with doing repetitive motion tasks. Exercise training may be preventative for CTDs in workers, and may diminish their daily discomfort.

Incidence and Cost of CTDs

Occupational illnesses and injuries such as CTDs are significant problems for both the individual worker and industry alike. Every five seconds a worker is injured in the U. S., and every ten seconds a worker is temporarily or permanently disabled (NIOSH, 1997). Occupational injuries result in $119 billion in lost wages and productivity per year, administrative expenses, and health care costs (NIOSH, 1997).

The work environment is rapidly changing with the distribution of jobs shifting towards longer hours, compressed workweeks, and shiftwork. These changes cause physical and psychological stress on the worker (NIOSH, 1997). The composition of the workforce also is
changing. By the year 2005, the general workforce will be older than that of the current work force, and 48\% of this force will be women (NIOSH, 1997). An older workforce comprised of almost 50\% women may alter the incidence pattern of CTDs injuries in industry. The increased age may make the workers more vulnerable to CTDs due to the accumulation of years of wear and tear on the soft tissues of the upper extremities. Also increasing the number of women in the work force means more repetitive motion type jobs. Women are most frequently hired for repetitive motion positions. More repetitive motion jobs in an aging workforce may result in more CTDs. Occupational CTDs injuries have been a significant concern in the past, but it may be even more of a concern in the future due to this changing workforce.

It is important to assess both past and current incidence rates of CTDs. However, determining the incidence rates of work-related upper extremity CTDs is a complex process. Unfortunately, statistics for nonfatal occupational disorders at the national level are not well documented, and are almost nonexistent at the state level (Atroshi et al., 1999; Tanaka et al., 1995). Existing data report the incidence in individual industries rather than representing the extent of the problem across multiple industries.

Studies conducted on the incidence and prevalence of CTDs report data from two sources: CTDs that are actually reported to their employers, and those that cause discomfort but are not actually reported. For the former, employees seek medical attention and have lost time from work. Generally research data are collected from medical records or employer injury logs. The second level of CTDs are those that exist as a matter of course in the usual work day, but the employee deals with the discomfort, and does not necessarily seek medical assistance. Research data are collected on this latter group by self-reported means.
Data from reported CTDs are obtained from workers compensation data, where workers seek medical assistance for their injury or illness. These data demonstrate that CTDs are a significant problem in industry. The Bureau of Labor and Statistics (1993) estimated that 63% (302,000 cases) of the reported 482,000 new cases of occupational illnesses were due to CTDs. In 1994, the number increased faster to 332,000 cases of CTDs, quadrupling the number from three years earlier (Anderson, 1998).

In 1995, The Bureau of Labor Statistics used a stratified random sample of employer log reports to estimate the rate of CTDs in industry workers (Bureau of Labor Statistics, 1997). However, the bureau did not include injuries that were associated with overexertion due to lifting, pushing, pulling, and carrying. The rate of disorders associated with repetitive trauma was estimated to be 37.8 per 10,000 full time workers (Bureau of Labor Statistics, 1997). Although hearing loss was included in this population, the majority of the injuries were attributed to the upper extremity, shoulder, arm, elbow, and hand/wrist.

A similar study was done to estimate incidence and cost of CTDs using data from the state of Washington. The state of Washington is often used to estimate both incidence and cost of occupationally related diseases because all employers are required to obtain worker’s compensation insurance through the Department of Labor and Industry (Silverstein, Welp, Nelson, & Kalat, 1998).

The unique aspect of the Washington system is that employees pays into the worker’s compensation system based on his/her job description, and the amount of injuries he/she sustain is not factored into the costs (Silverstein et al., 1998). The extant system in Washington State has truer reporting of injuries because there is no financial incentive to avoid injury reporting, making Washington a better site to evaluate occupational health problem than other states.
In a study by Silverstein, et al. (1998), using the worker’s compensation data from Washington State, the incidence and cost of CTDs was estimated for the years 1987 to 1995. The incidence for CTDs for 1995 was 83.1 per 10,000 full time employees, which is more than twice the amount reported by the Bureau of Labor Statistics for the same year. Likewise the estimate of carpal tunnel syndrome, the most common type of CTD, was 15.8 per 10,000 workers for those having at least four lost workdays (Silverstein et al., 1998). This is a four-fold increase over the Bureau of Labor Statistics numbers.

Reports of costs for CTDs are also variable in the literature; however all agree that CTDs are very costly to manage. For example, in two studies the estimated the average cost of upper extremity CTDs more conservatively as approximately $8,000 to $10,000 per case (Brogmus & Marko, 1992; Webster & Snook, 1994). Conversely, the Bureau of National Affairs (1995) reported that one case of carpal tunnel syndrome could cost up to $30,000, with medical cost rising at a rate of 25% per year, and indemnity benefits rising at 6% per year. The costs of CTDs are substantially higher when compared to the mean cost of $824.00 per case for all other injuries or illnesses (Melhorn, 1999).

The costs of CTDs have also been viewed in terms of both known (i.e. medical and indemnity costs) and unknown costs (i.e. lost worker productivity costs). Silverstein et al. (1998) reported that in the U.S. the direct medical and indemnity (worker’s compensation) costs were estimated to be 6.1 billion dollars in 1989. However, this figure did not take into account indirect costs such as lost worker productivity, worker replacement, and new worker training (Silverstein et al., 1998). Nor does this figure consider the workers who do not file worker’s compensation claims after sustaining a CTD injury. A worker may not file a claim in fear of job, seniority, or benefits loss.
A second scenario also described a significant problem for industry and provided evidence that the problem of CTDs is larger than is described by just those seeking medical attention: workers who have significant discomfort but do not seek medical attention. Many may fear losing their jobs and/or benefits, and some simply deal with the daily discomfort, because it is a way of life for them. This population is important to study because those having chronic discomfort may be the lost-time injuries of tomorrow. The chronic discomfort of CTD reflects both fatigue and a physiologic ‘wear and tear’ (Hart, Frank, & Bray, 1995; Mullaly & Grigg, 1988).

It is important to identify the full scope of the incidence of CTDs, including those who have not yet sought medical attention. Numerous studies are present that reveal self-reported symptoms of CTDs in the occupational arena. These cases, however, do not necessarily result in medical management and lost time from work. Self-report studies indicate that the incidence of musculoskeletal discomfort is ubiquitous in industry for workers who are exposed to repetitive tasks (Cancio & Cashman, 1999; Morgenstern, Kelsh, Kraus, & Margolis, 1991; Tanaka et.al. 1995).

Statement of the Problem

Because large numbers of the United States labor force are employed in jobs requiring repetitive use of their upper extremities, CTDs have demonstrated a substantial impact on industry and society. These jobs transcend multiple industries from those that require assembly and metal fabrication to keyboard work and food handlers. The individual manual tasks performed by these workers cannot in many cases be mechanized or automated and therefore repetitive manual task becomes the focal point for the completion of the industrial process. Since
industry emphasizes quantity and values speed of repetitive processes, the worker performs tasks at an accelerated speed using excessive wrist, hand, and arm movements.

The worker responds to the industrial demands with an increased output. Often workers are functioning near or above their own physical abilities to maintain an acceptable level of output, and they often experience fatigue and discomfort. The cumulative wear and tear ultimately lead to various forms of wear and tear on the soft tissues of the upper extremities, and the person develops CTDs.

A common sensation for workers doing repetitive motion tasks and developing CTDs is upper extremity discomfort (Cancio & Cashman, 1999; Morgenstern et al., 1991; Silverstein, et al., 1998; Tanaka et al., 1995). The discomfort associated with CTDs may be physiologically similar to that which occurs from a delayed post-exercise soreness and discomfort.

Following an exercise session, an immediate soreness may occur from the acute strain placed on muscles, ligaments, tendons, and joints (McArdle, Katch, & Katch, 1996). A secondary soreness and discomfort may also occur at a later time such as 24 to 72 hours later after the exercise session, and last for three to four days (McArdle et al., 1996). This latter type of soreness is called delayed onset muscle soreness, or DOMS. The precise cause of DOMS is unknown, but the degree of discomfort appears directly proportional to the intensity and duration of the effort. Markers of muscle cell damage, such as serum creatine kinase and myoglobin, are elevated during the period of DOMS. DOMS is also associated with both mitochondrial swelling, and the mobilization of general signs of inflammation such as an increase in serum leukocytes and neutrophils. It has been hypothesized that DOMS is caused by microtears in the muscle, muscle cramping, tearing of the connective tissue, inflammation, an alteration in the
cell’s calcium regulation, osmotic pressure changes that causes retention of fluids in surrounding cells, or a combination of these factors.

The only outward symptom of DOMS is usually a localized discomfort in the muscles, such as aching or cramping (McArdle, et al., 1996). The discomfort is used as a marker of DOMS severity, and is the criteria used to determine when muscular disruption has resolved. Finally, discomfort is used to determine the optimum time to return to exercise. For example, it is recommended in the Exercise Physiology literature that exercises cease until the localized discomfort subsides, or injury may result (McArdle et al., 1996).

A similar event may occur on a low-grade chronic level in those workers doing repetitive motion tasks. A similar localized discomfort appears in both DOMS and those reporting CTDs, and like in DOMS, may be the only apparent overt symptom. The localized discomfort is a symptom of cellular tissue disruption, and it is possible that this disruption has similar characteristics in both DOMS and those doing repetitive movement. Theoretically, the cellular disruption in repetitive tasks may be less intense than in an exercise session that results in DOMS, but the muscular alterations may be physiologically similar.

Also similar is the need to have an adequate rest period following repetitive movements that result in cellular damage. However, workers doing repetitive motion jobs do not have the opportunity to rest between work sessions. The weekend or vacations can be an opportunity for rest, but may not sustain enough of a recovery if the tissue damage has been both significant and cumulative from the week’s work. Those not able to have an adequate rest time to resolve the factors causing the localized discomfort may be at risk for developing an injury such as CTD (Eastman Kodak, 1986; McArdle et al., 1996).
Strength may be an important factor in limiting the cellular damage that occurs from repetitive motion. The more strength the muscles have the greater the torque advantage (McArdle et al., 1996). The greater the torque advantages of the muscle, the less disruption to the cells when the muscles do work. Exercise training can increase muscular strength giving greater torque advantage to the muscle, and less cellular disruption from repetitive tasks.

As the torque advantage increases with the increase in muscular strength, the muscle is capable of doing more work, or the same amount of repetitive work for longer periods of time without fatigue (McArdle et al., 1996). Strength has shown to be a reliable predictor of the amount of work the individual can do, and the potential for future injury (Batte, et. al., 1989; Chaffin, 1974). Strength and injury are inversely related. Increasing muscular strength by exercise training can have a protective effect against injury such as CTDs.

What is not known is whether primarily flexion or extension exercise training would be more effective in decreasing the discomfort that occurs when workers do occupational repetitive motion tasks. Further, it is known what level of exercise intensity may be needed to increase muscle strength and decrease discomfort in persons at risk for developing CTDs.

**Purpose of the Study**

The soft tissues (muscles, tendons, ligaments, joints, and nerves) of the upper extremities are associated with cumulative stress, leading to fatigue, discomfort, or even injury. The purpose of this study was to test two exercise protocols at two different intensities in an effort to increase muscular strength and decrease discomfort in the muscles doing repetitive motion tasks. Flexion exercises were done at 100% of maximum ability and 50% of this ability. Flexion type exercises were chosen to increase the strength of the muscles most often used in repetitive motion tasks. These exercises were compared to extension-type exercises that were done at the same two
intensities. Extension exercises were chosen to increase the strength of the extensor muscles that are usually not generally involved in repetitive motion tasks. The extensor muscles are weaker than the flexor muscles, creating an imbalance across the joints of the upper extremity. By increasing the strength of the extensor muscles, there is potential to improve the imbalance across the joint, thereby decreasing discomfort and preventing future injury.

Background and Significance

Rationale for Exercise Strength Training

Physiologic adaptations in response to exercise training are numerous. The main adaptations occur in the metabolic system and the production of energy in the muscle, the cross sectional area of the muscle, neural transmission, anaerobic power, and blood flow. All these adaptations serve to make the muscle both stronger and more resistant to fatigue.

The metabolic changes that occur with exercise training affect the production of energy, which result in an improvement in the cellular respiration of skeletal muscles. For example, during short exercise or movement periods that are usually between ten and 90 seconds in length, the main energy source for the muscles is from the Phosphocreatine or PC system. After approximately 90 seconds the PC system is exhausted (Fox, Bowers, & Foss, 1989). The PC energy source is stored in the muscle and is rapidly available. This system is what provides the energy for power or quick start movements such as sprinting and shot put. Adaptations to the PC system occurs following exercise training. Enzymes are required to transform PC into usable energy for the muscles during movement. Exercise training results in more efficient enzymatic activity when using the PC system to generate energy.

When more sustained exercise or movement is required, the PC system cannot support this activity. The adenosine triphosphate or ATP energy system through the Kreb’s cycle is used
generates energy after the PC system is exhausted. This system requires the use of oxygen to generate energy, which takes time to get to the muscle, so it is not readily available for quick starts.

The ATP system also adapts with exercise training, enhancing the muscle’s ability to do work. The Kreb’s cycle, which occurs within the mitochondria of muscle cells, uses glucose, enzymes, and oxygen to make ATP, the cell’s energy source for sustained muscular movement (Fox et al., 1989). Following exercise training, the mitochondria of the involved muscle cells adapt to the exercise by becoming larger and more numerous (McArdle, 1996). As mitochondria increase in size and number, the opportunity and capacity to generate ATP for the muscle cell is increased.

Accompanying structural changes in the cell is an enhanced capacity of cellular enzymes to generate ATP. The enzymes act more efficiently along the Kreb’s cycle during the process of ATP formation, requiring fewer enzymes to accomplish this task. Both the levels of enzymatic activity and the increase in the concentration of enzymes involved in the Kreb’s cycle are responsible for the efficiency demonstrated during ATP formation.

Making ATP in the Kreb’s cycle requires oxygen and either circulating glucose or stored muscle glycogen. With exercise training, the ability of muscle to extract and use oxygen from the blood is enhanced. Also the available stores of muscle glycogen increased following an exercise training program. The combination of larger and more mitochondria, increased enzymatic activity, and the enhanced availability of oxygen and muscle glycogen provide a benefit to the muscle when work is required. ATP is made more easily and with less of the body’s resources. The advantage to these adaptations is that for equal amounts of work after exercise training, the muscles have more capacity to sustain work, and have less fatigability.
Other types of muscular adaptations occur with exercise training. The cross sectional area of the muscle is increased, a reflection of an increase in the muscle fiber size, and possibly fiber number that occurs with exercise training (Goldberg, Etlinger, Goldspink, & Jablecki, 1975; Gonyea, Sale, Gonyea & Mikesky, 1986). Increasing the cross-sectional area of the muscle results in an increase in strength and torque (force or power) advantage for that muscle. A reduction in muscular fatigue and an increase in endurance have been reported to occur following exercise training (Hickson, Rosenkoetter, & Brown, 1980; Kanehisa, Ikegawa, & Fukunaga, 1997; Marcinik, et. al., 1991; Yuko, 1997).

Exercise training also affects neural transmission to the muscles and is assessed with an electromyography test or EMG. The activity of the EMG is based on the number of nerves recruited to cause muscular contraction. The amount of work done is kept constant at absolute rate, which generates the same muscular tension. The EMG activity is compared to muscular tension to determine the number of recruited neurons required to maintain muscular tension for an absolute workload. With exercise training, the neural recruiting patterns are altered, and fewer neurons are required to maintain muscular tension. Neural adaptations are seen especially early in resistance exercise straining, demonstrated by a reduction in the EMG/muscle tension ratio at absolute work rates (Komi, Viitasalo, Rauramaa, & Vihko, 1978; Moritani, & deVries, 1979). It takes less neural activity for the same amount of absolute muscular work. Alterations in neural recruitment patterns appear to play a role in the attenuation of electrical tension either by a lower activation of the motor units, and/or activation of fewer motor units (McArdle et al., 1996). Using less neural activity for the same amount of work results in less fatigue in the muscle.
Another adaptation that occurs with exercise training is an improvement in anaerobic power. This improvement in anaerobic power manifests itself by the attenuation of lactic acid production for the same work rates. The etiology of these improvements is unknown. It is hypothesized, however, that reducing the force contributed by the active myofibrils, or by using fewer myofibrils, yields less of the by-product of anaerobic muscular work, lactate (Marcinik et al., 1991; Tanaka & Swenson, 1998). An improvement in anaerobic power correlates strongly with an increase in muscular strength (Inbar, Kaiser, & Tesch, 1981; Rutherford, Greig, Sargeant, & Jones, 1986).

Finally, exercise creates a residual effect on the blood flow to the exercised trained muscles. Most research indicates that the amount of increase in blood closely follows the amount of increase in muscle cross-sectional area (Fox, et al., 1989; McArdle et al., 1996). As muscle area increases, so does the blood supply to that muscle. The increase in circulation to the muscles allows for more cellular respiration. Oxygen is delivered in larger volumes, and by-products of cellular respiration such as lactic acid are cleared more efficiently. Circulation is very important in delaying or reducing the amount of fatigue to working muscles.

The frequency and intensity of exercise training needed to improve strength has been documented in the literature. Strength increases have been seen with as little as one session per week, doing one set of ten exercise repetitions per week (McArdle et al., 1996). The recommended frequency, however, is four to five days per week, doing three sets of exercise per day. The current study used a frequency of five days per week, but only called for one set of exercises per day. It was thought that more than one set per day might take too much time, and exercise compliance might have suffered.
The intensity of the exercises can be done at a maximum intensity to improve muscular strength (McArdle et al., 1996). However, similar changes can be gleaned from exercising at intensities much lower. In a study by Moss, Refines, Abilgaard, Nicolaysen, and Jensen (1997), subjects who exercised at an intensity as low as 50 percent of maximum strength three times per week for nine weeks had the same increase in muscular power as those exercising at 90 percent. The current study exercised subjects at both 100 percent and 50 percent of their maximum capacity.

The literature thereby supports that exercise training is an effective means to increase muscular strength and delay neural and muscular fatigue. Many studies have demonstrated significant increases in strength in men and women, following resistance exercise training in as little as three weeks (Conley, Stone, Ninmeas, & Dudley, 1997; Cullinen & Caldwell, 1998; Moss et al., 1997; Yuko, 1997). Strength continued to increase in these subjects with substantial strength gains occurring after six, nine, and twelve weeks of training performed two to five times per week.

Exercise training increases muscular strength by altering the physiology of muscular contraction. Stronger muscles generate more force, have less lactate production, and more endurance at each absolute sub-maximal work rate, by altering neural recruitment patterns, and reducing the force contribution from each active myofibril, or by using fewer of them. Exercise training also increases the circulation to muscles so that more oxygen is present, and less by-products of cellular respiration. The investigator hypothesized that the adaptations of exercise training will result in less muscular fatigue, less localized discomfort, and less chance of injury from CTDs.
Reflections on Current Ergonomic Practices

The current practice for managing CTDs is a four-pronged process. The Occupational Safety and Health Administration (OSHA) existing ergonomic standards have four key components (US Department of Labor, 1990). The first involves ‘work-site analysis’ to identify existing conditions where hazards may develop. The second component is ‘hazard prevention and control’ whose aim is to eliminate hazards by redesigning the workstation or other factors affecting the worker negatively. The third involves medical management of CTD by early identification of involved workers. The final component requires employee training and education on work place hazards to prevent CTDs. OSHA’s current ergonomic standard has been successful in reducing the incidence of CTDs by industry (Habes, 1996).

Although the OSHA ergonomic standard has been successful in reducing CTDs, the problem remains immense. Currently efforts to reduce CTDs are directed towards recognizing hazards, changing the environment, or treatment of the disorder. No documented attempt has been provided to alter the worker’s capacity to meet the challenges of the work environment, which is the ultimate goal of this investigation.

Workers enter the job with individual physical attributes based on influences of genetics, fitness, health, and habits. Since ergonomics is the interface between the work environment and the worker, this is a two-way process (Eastman Kodak, 1986). Logic would dictate that the better worker’s physical capacity to meet the demands of the job, the more likely workers will perform that job without hazard to their health.

This research study proposed an addition to the current OSHA ergonomic standard. Providing an opportunity for the worker to become more physically ‘fit’ represents a simple and logical adjunct to the four principles currently espoused by OSHA for ergonomic intervention.
Utilizing the rationale presented in this study, perhaps improving the worker’s level of fitness can assist in preventing and moderating the problems associated with CTDs.

**Research Questions**

Two research questions were explored through this study. The research questions are as follows: In persons doing repetitive motion tasks,

1. What is the difference in muscular strength of selected muscles across four groups with exercise training programs, (maximum flexor, 50% flexor, maximum extensor, or 50% extensor exercises of the hand and arm at three and six weeks), as compared to a control group not doing exercise training?

2. What is the difference in localized discomfort of the upper extremity across four groups with exercise training programs, (maximum flexor, 50% flexor, maximum extensor, or 50% extensor exercises of the hand and arm at three and six weeks), as compared to a control group not doing exercise training?

**Definitions of Dependent Variables**

Two dependent variables were selected in this study, strength and discomfort. Strength was selected as a variable in this study as a means to measure the neuromuscular and biochemical alterations that occur during the six week exercise training program done in this study. Discomfort was chosen as a means to subjectively measure the improvement in neuromuscular and biochemical alterations from the exercise training program.

**Strength**

In this study, strength was measured using computerized strength testing equipment manufactured by the Hanoun Medical Inc. (See Appendix A). Data regarding forearm flexors, forearm extensors, biceps, and triceps strength were gathered and analyzed per muscle group for
a change in strength measured in kilograms. Strength changes were operationally defined as the amount of increase, measured in kilograms, from baseline measures to three weeks and six weeks after the onset of exercise training.

Six muscle groups were measured in this study, the triceps, biceps, forearm flexors, forearm extensors, handgrip, and pinch grip. These six muscle groups were chosen because of their involvement in performing the exercises. The flexor exercises most likely affected the biceps, forearm flexors, handgrip, and pinch grip. The extensor exercises mostly affected the triceps, forearm extensors, handgrip, and pinch grip. However, some crossover to other muscles may have occurred.

Discomfort

In this study, localized discomfort will be measured using a 100-mm VAS (See Figure 1). Localized discomfort was operationally defined as a decrease in mean levels from baseline measures.

<table>
<thead>
<tr>
<th>No Discomfort</th>
<th>Unbearable Discomfort</th>
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**Figure 1.** Visual Analog Scale

**Conclusion**

First a brief introduction to CTDs was presented. Following this, the statement of the problem, purpose of the study, and definitions of the dependent variables were delineated. This chapter outlined the basis of this study.
The information in the literature regarding the incidence, prevalence, and cost of CTDs was difficult to ascertain due to the variability of the literature. Regardless of the complexities of obtaining information about factors for both reported and non-reported CTDs, the available studies indicate that the costs, incidence, and prevalence of CTDs are substantial. The current literature also supports the conclusion that these factors are a significant problem for industry.

Related to the discussion is the current means for dealing with this problem. The current method of ergonomically dealing with CTDs has been to use programs such as a federally mandated hazard identification, or and workstation redesign. Although the current method of dealing with CTDs has been beneficial, CTDs remains a significant problem. The addition of a program that increases the worker’s physical capacity with the goal of delaying or diminishing fatigue, would be a tremendous asset to the existing program. Intervention programs that involve exercise strength training have the potential to decrease discomfort symptoms and prevent injury.
Chapter II

Theoretical Framework and Review of the Literature

Theoretical Framework

The theoretical basis for this study arose from the separate disciplines of Biomechanics, Exercise Physiology, and Ergonomics. The two research questions in this study were based on the theoretical framework outlined in this chapter. The first research question addresses the impact of two exercise interventions at two different intensities on muscle strength in workers doing repetitive motion tasks. The second research question uses the same exercise interventions in an effort to reduce discomfort in the same population.

Biomechanics

The biomechanical model describes the forces that occur on the arm, wrist, hand, and fingers during repetitive motion tasks. The model outlined herein is one that has not been widely tested, but is commonly used to explain injury and CTDs (Chaffin & Anderson, 1991). Occupational biomechanics is a science that uses the laws of physics and engineering to describe physiologic motion and forces that act on the body during occupational activity (Chaffin & Anderson, 1991). In the case of upper extremity CTDs, it is a model that explains the forces that occur during repetitive motion that can result in CTDs.

A biomechanical theory regarding the movement at the wrist, hand, and fingers is useful in bridging the knowledge between the concepts of CTDs and repetitive motion (Chaffin & Anderson, 1991). The tendons of the hand are inserted into the palmar side of the middle and distal phalanges. Each tendon is encased by a sheath, which is filled with synovial fluid to reduce friction as excursion of the tendon occurs through the sheath.
During repetitive motion tasks, a force is exerted on the tendons of the fingers. A force is a tension or pressure that can change the resting state of the body part to which it is applied, such as the fingers (Chaffin & Anderson, 1991). For example, a force is applied to the finger tendons during a grasping motion to hold a hand tool or a ball (See Figure 2) (Chaffin & Anderson, 1991).

**Figure 2.** Anatomy of the wrist, hand, and fingers and their flexor tendinous connection. This demonstrates the load on the tendons of the fingers and wrist as pressure is exerted on the fingers such as in gripping. (Adapted from Chaffin & Anderson, 1991).


By itself, load moment tension on the tendons of the fingers and wrist may not be permanently damaging. However, if a force is applied repeatedly to the tendons, the repeated load moment on the tendons could alter their physical structure. A transient over-stretching of the tendons can occur (Goldstein, Armstrong, Chaffin, & Mathews, 1987). The tendon can be stretched approximately one to two percent of its pre-load length. This amount of stretch on the
tendon results in some minor tendon damage, and a strain of the tissue. With rest, the tendon slowly recovers, but it is not clear if the tendon is permanently weakened, damaged, and/or fibrotic as a consequence of this reaction.

Depending on the amount of damage, the muscle/tendon unit requires time to recover from the over-stretching. If the load is repeated too often and recovery is not complete between repetitions, these actions may result in a residual strain of the tendon (Chaffin & Anderson, 1991). The ensuing condition consisting of a chronically strained and inflamed tendon is referred to as a tendonitis.

The posture of the wrist can also be a factor in determining the load moment forces that occur at the wrist. For example, when the hand is in neutral posture, the synovium, carpal ligament, and median nerve are relatively unstressed (Chaffin & Anderson, 1991). The tendon tension is also at its lowest in the neutral wrist posture. However, when the hand is in the flexed position the finger tendons are forced to curve around the transverse carpal ligament (See Figure 3) (Chaffin & Anderson, 1991). Likewise, when the wrist and hand is in an extended position, the finger tendons curve around the bones of the wrist. When the tendons are forced to wrap over a solid structure it results in a heightened state of tension. Not only does the median nerve become vulnerable to direct pinching and compression at the point of the transverse carpal ligament, but also the tendon load moment in the carpal canal is potentiated. This is a problem for highly repetitive type jobs because flexion and extension of the wrist often occurs in these.
Adding both the heightened state of tension from the postural change and the load moment of forces on the finger tendons from gripping, the amount of load moment transferred to the wrist is markedly increased. Chaffin and Anderson (1991) reported that flexion or extension of the hand could increase the load moment from forces exerted on finger tendons three to four-fold.

Eventually the damage to the tendon can be graded from a mild inflammation to an advanced damaged and inflamed tendon (Chipman et al., 1991). A clinical diagnosis of tendonitis is made based on complaints of pain and discomfort over a tendinous area. The damaged and inflamed tendon can result in significant discomfort in itself, or it can further lead to other pathology that results in localized discomfort such as nerve entrapment or compression.

Novak and Mackinnon (1998) delineated three hypotheses for nerve compression in repetitive motion injuries. These are not mutually exclusive and may occur concurrently. The discussion of the pathophysiology of nerve compression, one type of CTD, will begin with the first hypothesis. This hypothesis states that nerve compression is caused by direct pressure on the median nerve in the carpal tunnel at the wrist (Novak & Mackinnon, 1998). The median
nerve is compressed due to the narrow anatomical space through which it passes at the carpal tunnel. Because of the small space, the median nerve is vulnerable to entrapment at this site.

The Biomechanical Model presented above supports the first hypothesis of Novak and Mackinnon (1998). As the load moment is transferred to the wrist tendons, the tendons begin to become inflamed from the load moment tension. Inflammation reduces the amount of room in the carpal tunnel, and consequently the median nerve is compressed.

The nine tendons that pass through the carpal canal with the median nerve are equally compressed. However, they are not as vulnerable to damage due to their solid nature. The median nerve fibers are particularly vulnerable to compressive forces due to the inherent heightened sensitivity of neural tissue, their soft tissue nature, and the proximity to bony structures (Mosely et al., 1991).

This Biomechanical Model explains how direct compression of the median nerve occurs when a load is placed on the fingers, and/or the hand is shifted from a neutral posture. The heavier the load, the more potential compression of the nerve occurs (Chaffin & Anderson, 1991). However, just a gripping motion of the fingers is adequate to transfer an increased pressure to the carpal canal.

Although the Biomechanical Model explains the possible etiology of nerve compression, it provides only the beginning description of the disorder, and masks its complexity. As a result, confusion surrounding the pathophysiologic process is apparent in the literature. For example, some researchers have found a significant increase in intracarpal tunnel pressure with low finger tip loading or pinch gripping without flexion or extension of the wrist (Keir, Bach, & Rempel, 1998; Keir, Wells, Ranney, & Lavery, 1997; Rempel, Keir, Smutz, & Hargens, 1992). This
increase in intracarpal pressure was more than would be expected with a simplistic biomechanical explanation.

As the CTD progresses, then, there appears to be other factors that add to the pathologic process. Whether these other factors also contribute to this initial pressure in the canal remains unknown.

The Biomechanical Model for the development of nerve compression is supported by the epidemiologic research literature. A study by Archambault, Wiley, and Bray (1995) demonstrated that excessive repeated pressure in the carpal canal and its contents lead to intracanal damage, and the space in the canal can be reduced from this damage. They found that inflammation of the nine tendons and the median nerve passing through the canal occurs, secondary to the increased intracanal pressure. Werner, Franzblau, Albers, and Armstrong (1998) also found that the microtrauma to the canal structures from increased canal pressure leads to a synovial thickening, and an increased baseline intracarpal canal pressure (ICCP) and baseline fluid pressure. This heightened baseline ICCP was exaggerated during wrist movements such as flexion and extension, tending to have a heightened baseline pressure on the median nerve at rest, and excessive pressure during movements.

Epidemiologic research further elucidated the complex nature of the pathophysiology of nerve compression with its finding regarding the occurrence of a sustained increase in ICCP with repetitive motion of the wrist. For example, in the normal individual, repetitive wrist flexion and extension have been shown to cause an increase in ICCP, as would be expected based on the Biomechanical Model. Typically the transient increase in ICCP associated with flexion and extension returns to normal after the posture is returned to the neutral position. However Szabo and Chidgey (1989) demonstrated that patients with mild carpal tunnel syndrome, or nerve
compression at the wrist, the ICCP remained elevated for at least ten minutes after repetitive wrist activity. The elevated fluid and ICCP pressures in subjects with mild carpal tunnel syndrome suggest that they have difficulty getting rid of fluid build-up following repetitive hand movements (Werner et al., 1998). This aspect of the pathophysiology is not explained in the Biomechanical Model, and suggests a more complex process as the disease progresses.

**Exercise Physiology**

The injury associated with CTD has both a direct component involving the flexor muscles of the upper extremity, and an indirect component involving the antagonistic extensor muscles. Both of these muscle groups are vulnerable to fatigue and ultimately CTDs in that they are inefficiently functioning. Two hypotheses by Novak and Mackinnon (1998) will be used to guide this discussion. The second of three hypotheses from these authors will be used to present some of the concepts that affect the forearm flexors/hand, and the third hypothesis will address issues affecting the forearm/hand extensors and the development of CTDs secondary to doing repetitive motion tasks.

**The Upper Extremity Forearm Flexors**

The second hypothesis outlined by Novak and Mackinnon (1998) states that with a chronic shortening of a group of muscles, such as the forearm and hand flexors, a direct pinching of the nerve as it passes through the tightened muscles occurs. According to the hypothesis, carpal tunnel syndrome can occur from this process. Furthermore, this theory can be expanded to included factors that lead to all CTDs that occur secondary to doing repetitive motion tasks.

In the case of repetitive motion tasks, the muscles are not only shortened, but also overdeveloped with respect to other groups of muscles in the same limb such as forearm and hand extensors (Ostrem, 1995). As the hypothesis describes, the median nerve can be directly
compressed by the tightened muscles and pinched directly. However, whether the direct pressure on the median nerve is the entire etiology is debatable. The possibility of other pathologic processes will be discussed due to the tightened and overdeveloped flexor muscles.

The flexor muscles of the upper extremity are directly linked to CTDs due to their involvement in accomplishing job tasks. Flexor muscles of the arm and hand are the primary muscles involved in repetitive work due to the hand position, and pulling forces used in most jobs. The forearm flexors and the hand muscles directly accomplish job tasks, resulting in a chronic over development of these muscles, and excessive hypertrophy. For example, the flexed hand position and pulling forces are seen in a variety of occupations, such as dentistry, assembly work, and grocery checkers. The over development of one set of muscles can result in the inefficient use of this muscle group which can lead to premature fatigue and discomfort (Ostrem, 1995).

Fatigue is defined as a state of discomfort and a decreased in contractile efficiency that results in a decline of muscular tension with repeated stimulation (Fox et al., 1989; McArdle et al., 1996). The physiologic perceptions of fatigue are thought to be a complex integration of many discrete sensations (Noble & Robertson, 1996). Kinsman, Weiser, and Stamper (1973) were the first to develop a model describing a link between the sensations of fatigue and a physiologic process. Localized sensations were identified as limb aches, cramps, muscular and articular heaviness, and pain that were related to a reduction in physiologic muscular performance (Horstman, Morgan, Cymerman, & Stokes, 1979). These symptoms were grouped into two separate categories, pain and discomfort (Horstman et al., 1979).

When muscle fatigue occurs and the muscular torque is reduced, the capacity to do work is reduced (McArdle et al., 1996). To continue working at the same pace, more muscle nerves
and muscle fibers must be recruited, which serves to further spread the fatigue across the muscle. This requires more energy supply due to the recruitment of larger muscle fibers. It also requires more circulation to deliver more oxygen for the larger fibers, and to remove the now building lactic acid (Fox et al., 1989).

As the muscles continued to contract, a significant disruption of muscle contractile tissues and the other related soft tissues occur (Fox et al., 1989). The tissue damage to the soft tissues only adds to the muscular fatigue. Without an adequate rest period, the tissue damage cannot fully repair, leaving the muscle in a compromised state and vulnerable to injury.

Individuals who do repetitive motion in non-industrialized jobs such as professional baseball players, musicians, and dancers are cognizant of the concepts of muscle fatigue and its relationship to injuries (Silverstein, 1996). In these professions, it is known that some repetition builds muscles, and with adequate rest between repetitions, this process is positive. However, excessive repetition causes fatigue and even soft tissue damage. When repetitive movements continue without adequate time for muscle healing, the damage is progressive.

For example, baseball coaches know that after approximately 100 pitches from their star pitcher, the risk of fatigue, loss of control, and injury increases (Silverstein, 1996). It is also known that there is a slowing of the suprascapular nerve of pitchers as the season progresses. It is common practice to allow a pitcher to rest between games, and he is often pulled out of the game in the later innings. The purpose of the rest period is to repair the damage that occurred from repeatedly throwing the ball. Even with rest, a pitcher’s career is usually a matter of several years at the professional level due to the slow but progressive pathology that develops. The pathophysiology that occurs in the athlete is the same as the industrial worker who is doing repetitive motion tasks.
In the athlete, the strength of the muscles used most frequently in a sport is exercised in preparation for the physical demand (McArdle et al., 1996). Similarly, workers must also prepare their muscles used most frequently in their work. Strengthening the arm and hand flexors may better prepare the worker to meet the physical demands of the job, thereby delaying fatigue.

Improving the strength of the arm and hand flexor muscles to reduce the fatigue and discomfort associated with repetitive tasks is one of the theories proposed in this research study. Although the flexor muscles are tight and hypertrophied from daily repetitive work, the muscles may benefit from becoming stronger than is required from the usual occupational daily demands. Increasing muscular strength provides more reserve in these muscles, thus delaying fatigue and reducing discomfort.

Increasing muscular strength can prevent some of the precursors of muscular fatigue from occurring. A stronger muscle is a more efficient muscle in terms of energy use and neural muscular recruitment of muscle fibers. Challenging the flexor muscles at a higher than daily work demand through exercise may be the most effective means of both increasing strength and decreasing localized discomfort in the upper extremity.

In industry, muscular fatigue occurs in overused muscles such as the flexors of the upper extremity during repetitive motion as discussed above (Kanehisa et al., 1997). In this next section muscular fatigue will be discussed as a factor in inefficient muscles such as those with poor dynamic flexibility (muscular imbalance) like the extensor muscles used in repetitive motion tasks.
The third and final hypothesis by Novak and Mackinnon (1998) will be used to present relevant information related to issues affecting the extensor muscles used in repetitive motion tasks.

Imbalance of Muscles Across Joints

The third hypothesis by Novak and Mackinnon (1998) concerns opposing upper extremity muscles that are in an imbalance state due to the performance of repetitive tasks. This hypothesis explains nerve compression in terms of a mechanical disadvantage that occurs from the imbalance of flexor and extensor muscles in the forearm, hands, and fingers. This hypothesis also reflects a comprehensive explanation for the pathology that occurs with CTDs in relation to muscular imbalance.

In occupations requiring repetitive use of the upper extremity, the antagonistic extensor muscles of the hand, arm, and shoulder are not repetitively used to the same degree as the flexors, tending to set up a postural imbalance (Ostrem, 1995). The imbalance leads to a relatively shortened and hypertrophied set of flexor muscles, and a long and under-developed set of extensor muscles. The flexor tendons of the upper extremity also become less elastic and tight (Fox et al., 1989). The extensor muscles act antagonistically to the flexor muscles, and in that regard, are indirectly involved in the development of CTDs.

The imbalance between flexors and their corresponding antagonistic extensor muscles creates an inefficient joint that does not operate in the optimum neutral joint alignment. The range of motion of the joint is restricted in the case of this muscular imbalance in the direction of the flexion. Flexion-torque of the joint is present during both activity and rest. The unbalanced muscles and inefficient joint leads to early fatigue and discomfort (Ostrem, 1995).
After the initial fatigue, to continue to do work, more muscles or muscle fibers are recruited. Because it requires more muscle fibers to get the job done, more energy is used, more circulation is necessary, and more lactic acid accumulates in the muscles. The use of more resources and the build up of excessive by-products of metabolism result in widespread premature fatigue of these muscles.

Novak and Mackinnon (1998) have highlighted the pathological result of a muscular imbalance across the joint in their third hypothesis. However, this process has not been frequently addressed in the medical literature. In contrast, the concept of muscular imbalance across the joint has been extensively discussed in the exercise physiology literature. The physiologic concepts of muscle imbalance overlap with the concepts of muscular flexibility (Howley & Franks, 1986).

The type of flexibility that is most relevant is called dynamic flexibility (Fox et al., 1989). Dynamic flexibility, defined as the opposition or resistance of a joint to motion, refers to the forces that oppose movement over any range of the joint.

Dynamic flexibility issues are well documented in the athletic population. Athletes, such as gymnasts and power lifters, who depend on muscular strength in a particular muscle group for performance, need to have some joints excessively stabilized to acquire this strength. Flexibility of these joints would reduce their strength. In rare cases, such as with the inherently weak shoulder joint, this can help to prevent injury in these athletes. However, this is generally not the case. It is widely accepted that muscular flexibility is important for efficient body movement, delaying fatigue, and ultimately, injury prevention (Fox et al., 1989; Howley & Franks, 1986; McArdle et al., 1996).
According to Hartley-O’Brien (1980) two approaches can be used to increase flexibility in the case of muscular imbalance. The first is to stretch the tightened muscles, in this case, the flexors of the upper extremity. This was not done in this study. The second way to improve flexibility is to increase the strength of the antagonistic muscles, in this case the extensors. This was done in the current study. The researcher chose only one of these methods in an attempt to avoid clouding the outcome. Exercise was performed with the goal of increasing the strength of the antagonistic extensor muscles.

Exercising the extensor muscles can prove beneficial in reducing the localized discomfort associated with CTDs. Because the indirect extensor muscles do less actual work than the direct flexors, they are not as strong, and therefore fatigue more easily. Increasing the strength of the extensor muscles can correct the postural imbalance associated with repetitive work, and reduce the potential for fatigue and injury. The greater the muscular strength, the less fatigue and localized discomfort (Hickson et al., 1980; Kanehisa et al., 1997; Marcinik et al., 1991; Yuko, 1997).

Ergonomics

The final discipline included in the theoretical framework of this study is Ergonomics. Ergonomics is the study of the interface between the worker and the work environment (Eastman Kodak, 1986). Many ergonomic factors are present in the occupational arena. When injuries occur, it is usually interplay of these factors that have resulted in the injury. This is especially true with CTDs. One facet of ergonomic consideration is the repetitive nature of occupational tasks.

Repetitive motion tasks require a consistent movement pattern that is repeated in a cyclic fashion. The same muscles are continuously involved in this pattern of movement. In this case,
the upper extremities are used in a consistent and continual pattern of movement as a cycle in order to complete job tasks.

In industry, the time to complete one unit of an assembly or task is defined as a cycle (Eastman Kodak, 1986). An activity is considered repetitive if the cycle time of a task is two minutes or less, and is continuously repeated during an eight-hour shift (Eastman Kodak, 1986). Further, an activity is determined to be highly repetitive if it has a cycle time of 30 seconds or less, in contrast to an optimum cycle time greater than two minutes (Eastman Kodak, 1986). Because workers do not do repetitive tasks throughout the working day, an adjunct definition has been used to further define repetitive tasks. If workers spend at least 50 percent of their time doing cyclical tasks, then this is also considered heavy repetitive motion (Armstrong, Fine, Goldstein, Lifshitz, & Silverstein, 1987; Silverstein, Fine, & Armstrong, 1987).

The current study adopted the definition of heavy repetitive motion as a cycle time of 30 seconds or less, with more than 50 percent of the cycle time involved in the same kind of motion or pattern (Armstrong et al., 1987; Eastman Kodak, 1986; Silverstein, et al., 1987). In this research study, all subjects were employed full time, and did their repetitive motion tasks 100 percent of the time.

The heavy repetitive tasks practiced by the workers in this study are a significant risk factor for developing CTDs. Repetition is an ergonomic consideration that has been given significant attention, and its connection to upper extremity CTDs is a current ergonomic priority (NIOSH, 1999). Ergonomic factors that relate to repetition are a primary concern to industry.

Current practice toward addressing ergonomic problems such as CTDs involves the alteration of the worksite environment, and/or treating those clinical conditions that have arisen. This two-pronged approach to addressing ergonomic problems ignores the entire interplay
between the worker and the work environment. A third factor, the individual worker, also is involved in this interplay. The thrust of the current study centers around the additional impact of focusing on worker factors to alter the trend of developing CTDs from the performance of repetitive motion tasks.

**Physiologic Model for CTDs**

The current study considers science derived from three disciplines in an effort to test interventions to reduce symptoms and reduce CTDs. A physiologic model (See Figure 4) can be used to pictorially depict the interplay among the science of these three disciplines. Theories from Biomechanics, Exercise Physiology, and Ergonomic set the stage for interplay. The three disciplines, acting in conjunction with individual worker mediating factors, result in the development of fatigue and discomfort.

Mediating factors are individual physiologic variation of the worker that makes them more or less susceptible to CTDs. Examples of mediating factors are factors that slow nerve conduction such as diabetes, smoking, drinking, and prior carpal tunnel surgery. Other potential relevant mediating factors are body mass index, a positive Phalen exam, and loss of sensation in the fingers. All these factors have been shown to be associated with CTDs.

When the factors outlined in the three disciplines are present, muscular fatigue and discomfort can result. These factors causing fatigue and discomfort, if continued, can lead to CTDs.

Fatigue in itself sets up a physiologic process that leads to CTDs. Fatigue can also secondarily reduce the strength of muscles. In a cyclic manner, as strength is reduced secondary to fatigue, the reduction is strength further accentuates the fatigue.
Exercises can intervene by increasing the strength of the muscle involved in repetitive motion tasks. Increasing the strength of the muscles can reduce fatigue and accompanying discomfort, and ultimately reduce CTDs.
Physiologic Model for CTDs

Ergonomic Factors  Biomechanical Factors  Exercise Physiology Factors

Mediating Factors

Discomfort  Fatigue  CTDs

Strength  Exercises

Figure 4: This physiologic model of CTDs has been designed to provide a clear picture of the theoretical framework as a whole. It is meant to demonstrate the process that occurs when repetitive motion that occurs in occupational settings leads to the development of CTDs. The review of the literature in the next section will provide epidemiologic data that supports the connection between occupation and CTDs.
Review of the Literature

Occupational Risk for Developing CTDs

Many occupations are known to increase the risk of developing CTDs. Occupations most commonly associated with CTDs include meatpacking, assembly, typing, and musicians due to the repetitive nature of their jobs (Hymovich & Lindholm, 1966; Silverstein et al., 1998). However, not everyone agrees that occupational risk is the cause of CTDs, especially carpal tunnel syndrome (Hadler, 1997; Nathan, Keniston, Myers, Meadows, & Lockwood, 1998). This debate is very important because it determines who will ultimately pay for medical treatment and worker’s compensation costs if the worker must be off work. The answer to this debate is dealt with on the state level. Some states offer unquestioning compensation for occupational CTDs, while others do not recognize the disorder as occupationally related, and consequently do not pay compensation or medical costs. The greatest debate lies with carpal tunnel syndrome, the most common, disabling, and costly of the CTDs (Bleecker, 1984). For example, in Virginia, carpal tunnel syndrome is rarely compensable from workers compensation and is not considered work-related (Derebery, 1998). However, Texas is very liberal in connecting carpal tunnel syndrome and employment. If hands are involved in the performance of a job, and there is a diagnosis of carpal tunnel syndrome, it is compensable by the state of Texas (Derebery, 1998)).

In 1986, NIOSH first publicly recognized and defined CTDs. CTDs were said to occur from job demands that exceeded the biomechanical capacity of the worker and resulted in injuries affecting the musculoskeletal system (NIOSH, 1986). Inherent in this definition is the assumption of both injury and exposure that produced such injury. The concept of exposure and the linkage of that exposure to an injury or illness reflect a central focus for debate. It is very difficult to define a minimum exposure, which would lead to tiny, but progressive wear and tear
on tendons, ligaments, bones, joints, and nerves. Contrast this concept of exposure and injury with an acute forceful event, which is immediate, apparent and easily recognized, such as a slip and fall injury.

CTDs can develop in people who work in an industrial setting and are part of an occupational population who are exposed to risk factors such as repetitive motion. CTDs can also occur in people not employed and are in the general population where the exposure to risk factors is not clearly defined. The first study below explored the differences in the presentation of CTDs in these two populations.

Controversies surround the issues of CTDs. Consequently, the scientific literature is replete with studies directed toward these issues. The direction of the literature has been toward the evaluation of the etiology, demographics, ergonomic factors, and work-relatedness of CTDs. This section will present a short analysis of the major research studies investigating the association between occupational ergonomic exposure to repetitive motion tasks, and the subsequent development of CTDs.

One study was reviewed that explored demographic factors, and how they can be used to make a distinction between occupational carpal tunnel syndrome and nonoccupational carpal tunnel syndrome. Studies were reviewed using two types of ergonomic exposure classifications to evaluate the association between the exposures and the development of CTDs. Exposures are classified according to the length of the exposure to repetitive motion tasks and by job-type. Lastly, this section will take a broader view of the link between exposure to repetitive motion and developing CTDs by exploring review articles and meta-analyses.

**Demographic study.** Franklin, Haug, Heyer, Checkoway, and Peck (1991) examined the Washington State workers compensation database from the years 1984 to 1988 between
occupational and nonoccupational carpal tunnel syndrome. Occupational carpal tunnel syndrome was identified by ICD9 codes from physician billing data. There were 7,926 reported occupational carpal tunnel syndrome claims. The mean age of occupationally acquired carpal tunnel syndrome was 37.4 years, and the mean female to male ratio was 1.2:1 in this population. However, the demographic data obtained in this study were very different for those reporting non-occupational carpal tunnel syndrome. According to these researchers, for the nonoccupationally acquired carpal tunnel syndrome, the mean age was 51 years, and male to female ratio of 3:1. The demographic differences observed between occupationally and nonoccupationally acquired carpal tunnel syndromes suggested that occupational carpal tunnel syndrome is a distinct entity.

This study also reported industry-specific carpal tunnel syndrome rates. The highest industry-specific carpal tunnel syndrome was found in food processing, carpentry, egg production, wood products, and logging industries, which have a high repetitive component. These industry-specific carpal tunnel syndrome rates consistent with workplace exposures further suggested that those occupationally acquired carpal tunnel syndromes were different from carpal tunnel syndrome occurring in non-occupational settings. It is not clear from this study if occupational carpal tunnel syndrome may have a distinct etiology, or may just accelerate the process of disease development.

Exposure is another way to assess the occupational link between repetitive motion tasks and CTDs. If a group of exposed workers were compared to those unexposed and an increase in prevalence was found in the exposed group, then it is a good indication that those with the exposure have a greater risk for developing CTDs.
Ergonomic exposure: Hours of exposure to repetitive motion jobs. Five studies were found that explored the hours of exposure and the risk for developing CTDs. The length of exposure strengthens the connection between occupation and the development of CTDs. It goes beyond supporting an association between occupational repetitive exposure and CTDs. It also explains the dose-response for the development of disease.

It is interesting to note that the studies reported here are for people who do highly repetitive tasks. This is often not the case because most tasks that have hand use also have the added risk of force or vibration such as in the use of hand tools. These first studies are particularly useful in looking at repetition without other confounding risk variables.

Hess (1997) studied transcriptionists employed for greater than 40 hours per week doing heavy repetitive motion work. Workers typing for 50% or more of the eight-hour day were assessed for musculoskeletal complaints, and compared to those typing less than 50% of the day. The results showed that those typing for greater than 50% of the day had greater musculoskeletal complaints than those typing less than 50% of the day.

Harber, Pena, Bland, and Beck (1992) studied subjects obtained for a combination study done for the UCLA Occupational Medicine Association, the United Food and Commercial Workers Union, and the management of a California supermarket chain of supermarket workers. Both recent exposures and cumulative exposures were assessed. The recent exposure was assessed by the working history of the preceding two weeks. The investigation found that the number of hours working as a checker using a laser scanner in the preceding two weeks was predictive for both proximal and distal upper extremity symptoms. The average number of hours worked per week for all workers was 37 hours. The highest prevalence was for female checkers who worked greater than 25 hours per week in the preceding two weeks. To assess a cumulative
work effect, a combination of the number of hours worked in the preceding two weeks was coupled with the number of years worked. Those with the smallest risk for symptoms were checkers working less than 16 hours per week over the preceding two weeks, and employed for less than one year. These workers may be compared to a significantly higher risk group of employees working 64 hours over the preceding two weeks, and employed for 15 years.

In another study with grocery store checkers using laser scanners, 1,087 female checkers belonging to one union in California completed a self-reported symptom survey. Morgenstern, Kelsh, Kraus, and Margolis (1991) found that 12% of checkers reported symptoms consistent with carpal tunnel syndrome. This number was compared to an estimated 5.4% of carpal tunnel syndrome symptoms in the general population. The prevalence was highest for those working greater than 25 hours per week, and those who had worked for ten years or more. They also found that the highest prevalence occurred in workers younger than 45 years of age. The fact that a young age was associated with a high prevalence may be due to the healthy worker effect. Older workers with more severe symptoms may have already left this job, or the work force altogether, as a consequence of their symptoms.

Margolis and Kraus (1987) found that female supermarket checkers using laser scanners greater than 29 hours per week had more wrist, hand, and finger symptoms than those working 20 hours or less. There was no increase in symptoms in workers after 30 or more hours per week. The study also showed that symptoms were lowest for workers who had been on the job for less than one year and highest among workers on the job for five to ten years.

Lastly, DeKrom, Kester, Knipschild, and Spaans (1990) looked at the exposure in terms of the number of hours worked per week, and the development of carpal tunnel syndrome-like symptoms (131 women and 25 men). A self-reported survey was completed to assess
symptoms, followed by nerve conduction studies were on those reporting symptoms in order to confirm carpal tunnel syndrome. Those employees working in a flexed, extended, or combination flexed and extended wrist posture for greater than 20 hours per week had a four to five fold increase in relative risk for carpal tunnel syndrome, as opposed to those with less working hours.

**Ergonomic exposure: Based on job-type or job classification.** Several studies found a strong occupational link between CTDs and repetitive motion tasks (Latko et al., 1999; Park, Nelson, Silverstein, & Mirer, 1992; Punnett, Robbins, Wegman, & Keyserling, 1985; Silverstein et al., 1987; Stock, 1991; Welch, Hunting, and Kellogg 1995). Although the prevalence of women was found to greater in these studies, it was thought that the overrepresentation of women in repetitive motion type jobs was the cause. In fact, the study by Silverstein et al., (1987) found that when men and women were compared and both were doing the same job, there was no difference in the prevalence of CTDs.

**Reviews and meta-analyses.** Two reviews of the literature found evidence for a link between occupational repetitive motion tasks and the prevalence of CTDs (Hagberg, Morgenstern, & Kelsh, 1992; Muggleton, Allen, & Chappell, 1999). The authors claim that at least 50%, and as much as 90% of all carpal tunnel syndrome cases in the exposed population appeared to be attributable to occupation.

The occupational link between the development of CTDs and repetitive motion tasks is further supported by two meta-analyses (Abbas, Afifi, Zhang, & Kraus, 1998; Stock, 1991). Both meta-analyses found a strong association between occupational exposure to repetitive motion tasks and CTDs. One meta-analysis also found the evidence was strong enough to indicate a causal link (Stock, 1991).
Summary of the literature review. In summary, the amount of information that is in the literature on this topic can be overwhelming. The evidence must be reviewed in a systematic fashion to determine its message.

Clearly, a review of the body of scientific literature demonstrates the impact of CTDs on industry and individual workers. NIOSH and other researchers have linked repetitive motion type tasks to various CTDs. Based on these studies two conclusions can be inferred. The first conclusion is that although some data exists that fails to support the link between occupational repetitive tasks and CTDs, the preponderance of evidence supports this connection.

The second conclusion has to do with the amount of repetitive tasks it takes to result in a CTD, a form of a dose-response to repetitive motion. The studies reviewed here report a higher prevalence of CTDs in those working more than between 20 and 29 hours per week in repetitive motion tasks. This was also true for those doing repetitive tasks for more than 50% of their workday. No substantial increases in CTDs were noted for workers doing repetitive tasks more than 30 hours per week. The one exception was for workers performing these tasks for more than 64 hours in a two-week period. These workers had a higher risk than those who stated they worked more than 25 hours per week did. It is not known how the 64 hours were distributed over the two-week period; therefore conclusions are difficult to draw for the heaviest working group.

An indication of dose-response was also given for the number of years working in repetitive motion jobs, for the risk of developing CTDs. Two studies reported an increased risk of CTDs for workers employed in their job for greater than 10 to 15 years. One study found those employees working less than one year had the least number of upper extremity symptoms. Although these data give some insight into a dose-response relationship between repetition and
CTDs, it is not a complete image. The duration of exposure is not clearly delineated in these studies, nor is the prior employment history. Prior employment history would consider past exposure to repetitive motion and may give more insight into an actual dose-response.

Regardless of exposure level predicting who will develop CTDs has not been possible. It is possible that individuals possess factors that determine their vulnerability to CTDs.

Mediating Factors of the Individual Worker.

Mediating factors that the individual worker brings affect their susceptibility to CTDs. The relevant mediating factors in this study are gender, age, and body mass index.

**Gender.** The effect of gender and its impact on the development of CTDs is controversial. Although most CTDs, especially carpal tunnel syndrome, are found in women, some researchers think the higher incidence is due to the over representation of women in repetitive motion jobs (Park, 1992; Silverstein et al., 1987). Another aspect reported by Latko et al. (1999) was that although more women reported occupationally related discomfort, more men had objective pathophysiologic alterations such as slowed nerve conduction of the median nerve at the wrist. Finally in a study by Franklin et al. (1991), occupational CTDs were approximately equally distributed between males and females.

**Age.** Age has been shown to be a significant covariate in the development of occupational CTDs especially with carpal tunnel syndrome (Gordon, Johnson, & Gates, 1988; Nathan, Keniston, & Meyers, 1992; Siegel, Kuzma, & Eakins, 1995). Radecki (1995) found that patients with median nerve slowing were 4.2 years older than those without slowing regardless of the work-relatedness of the complaints.

**Body mass index.** A significant relationship between body mass index (BMI) and CTDs is found in the literature in both patients and non-patients. In a study of 429 workers, an
association between an increased BMI and median nerve slowing was found (Nathan et al., 1992). Similar results were also found in both healthy individuals in the military and symptomatic patients in hospitals (Letz & Gerr, 1994; Werner, Albers, & Franzblau, 1994).

Vulnerability to CTDs due to mediating factors may not be easily altered. However, the individual can be physically made stronger, which may help to reduce this vulnerability to CTDs. Increasing the strength of the worker with exercise training may diminish the damage that occurs from doing chronic repetitive motion. A reduction in the pathological changes in the soft tissues that occur from repetitive motion can be overtly observed by a reduction in the localized discomfort in the upper extremity.

Strength

Strength is defined as the maximum forces (tension) generated by a muscle or muscle group (McArdle et al., 1996). Strength training increases the cross-sectional area of the muscle. There is a linear relationship between cross-sectional area of the muscle and muscular strength (McArdle et al., 1996). There is some evidence that the early changes in strength that occur with exercise training are mostly from neurologic adaptations (Behm & St.-Pierre, 1998). Regardless of the factors that affect the muscular changes from exercises training, the strength of the muscle is increased. As muscle strength is increased, muscular fatigue is reduced, and endurance is improved (Fox et al., 1989).

Discomfort

Corlett and Bishop (1976, p. 175) generally defined discomfort as a “summation of sensory stimuli experienced via all sense organs, judged as a totality”. Discomfort is more specifically defined as an annoyance of mental and/or bodily distresses (Webster’s New World Dictionary, 1991).
Occupational discomfort is considered a precursor to musculoskeletal disorders such as CTDs (Hunting, Welch, Cucherini, & Seiger, 1994). Discomfort is one of the earliest adverse markers of CTDs secondary to repetitive hand and wrist movement (Latko, et. al., 1999; Margolis & Kraus, 1987).

In a study by Zhang, Helander, and Drury (1996) discomfort was associated with pain, fatigue or tiredness, soreness, and numbness. Helander and Zhang (1997) found fatigue to be the most significant factor in describing discomfort. When these symptoms were measured in the occupational setting discomfort was found to increase with time during the workday, or with an increase in work pace, further supporting the role of fatigue in the development of discomfort (Michael & Helander, 1994; Ulin, Armstrong, Snook, & Keyserling, 1993).

Discomfort has been associated with poor work performance, while relieving discomfort is related to an increased work production, with an accompanying reduction in production costs (Bhatnager, Drury, & Shiro, 1985; Corlett & Bishop, 1978; Corlett & Bishop, 1976; Schoenmarklin, & Marras, 1989). Discomfort can be used to make assessments in the occupational environment. For example, localized discomfort has been used to determine the maximum acceptable frequency of exposure to repetitive tasks in industry (Dahalan & Fernandez, 1993; Kim & Fernandez, 1993; Marley & Fernandez, 1995). The degree of localized discomfort has also been used over time to assess exertion and fatigue with a visual analog scale (Lin & Radwin, 1998; Randolph, 2000).

Although discomfort has been associated with CTDs, no studies were found that related the level of discomfort to the strength or fitness of the individual. However, one study was found that related poor physical training of ballet dancers to the level of discomfort they experienced (Ramel & Moritz, 1994).
From a theoretical standpoint the degree of strength and the level of discomfort are highly interrelated. For the same intensity of workload, the muscle with the greater strength uses less of its overall capacity and has less cellular disruption than a muscle that is weaker (McArdle et al., 1996). With the stronger muscle, less of the muscle’s resources would be used during this work, and the muscle would be farther away from fatiguing. The less cellular disruption and fatigue result in lower levels of discomfort.

Exercise Training

Strength of muscles is improved with exercises to the arm, and hand flexors. This is known as the overload principle. The overload principle involves progressively increasing the intensity of workouts over the course of the training program as fitness improves (Fox et al., 1989).

Overload is the principle on which strength and endurance development depends (Fox et al., 1989). In order to increase the strength or endurance of a muscle or group of muscles, the muscles must exert a force against a resistance that is greater than what is normally encountered. A more contemporary term used to describe this principle is progressive resistance, which emphasizes the need to increase the amount of exercise as the person gets stronger to produce further strength gains (Howley & Franks, 1986).

Progressive resistance exercise training can be either an increase in the amount of weight used in the exercise, an increase in the amount of time exercised, or an increase in the number of repetitions done per exercise session (Fox et al., 1989; Howley & Franks, 1986). In this study, the progression of exercise was accomplished by increasing the number of repetition per exercises session. In two of the exercise groups, this increase was not measured; however the subjects were instructed to exercise until maximum fatigue. Theoretically, exercise training at
maximum levels should substantially increase strength, as well as the maximum number of exercise repetitions. (McArdle et al., 1996).

Industrial Exercise Programs to Increase Strength and Decrease Discomfort

Occupational exercise programs have been attempted with mixed reviews. In a study by Genaidy, Davis, Delgado, Garcia, and Al-Herzalla (1994) workers doing manual materials handling jobs, or those requiring heavy work using the whole body, was done to see if strength and endurance could be increased in this population. Injuries often occur in workers doing manual materials handling due to overexertion and fatigue. Increasing strength and endurance reduces the potential for injury.

Subjects in this study exercised to the point of maximum fatigue, using whole body exercise training. A whole body exercise program was appropriate in that the subjects used their whole body to accomplish their daily jobs. Exercises were done four times per week, for four weeks. The results of this study demonstrated a significant increased in both strength and endurance with resistance exercise training.

In another study by Berg, Berggren and Tesch (1994) seventeen women doing repetitive motion to the neck and shoulder in their employment setting were assessed for pain and discomfort. All women initially complained of either intermittent or continuous neck and upper shoulder pain. The women enrolled in an eight-week exercise training program using resistance isotonic exercise to the neck. Following the exercise program, all women had a significant reduction in perceived pain.

Not all investigators with occupationally based exercise programs found favorable results. In another study, a yearlong exercise program was prescribed in the work setting in an effort to decrease discomfort in the neck and upper extremity of workers doing repetitive motion type jobs
(Silverstein, Armstrong, Longmate, & Woody, 1988). Measured discomfort was not improved in the exercised subjects. However, although discomfort was not improved by the exercise, the majority of subjects reported that they “felt better” after the program.

The merit of this study is questionable. First, it is difficult to measure exercise compliance over a long period of time such as a year. Second, most industries have a high employee turnover rate, which would bias the original sample. Last, it is unclear how these researchers monitored exercise participation, or when in the yearlong program the subject’s level of discomfort was assessed. If assessment was done at the beginning and end of the yearlong program, the level of discomfort over the year may be difficult for the subject to remember, and many intervening factors may interfere with an accurate assessment.

Conclusion

The concepts espoused in this chapter on the theoretical framework arose from interplay of the science from three disciplines: Biomechanics, Exercise Physiology, and Ergonomics. The precepts of these disciplines and their interaction to explain the pathophysiology of CTDs were discussed, as was an overview of the histologic changes associated with the development of CTDs.

Exercise is a preventive intervention with the potential to correct the soft tissue pathophysiology associated with CTDs and reduces discomfort. Exercise training can potentially effect fatigue by increasing strength of the upper extremity. Reducing or delaying fatigue may also be an important component of diminishing CTDs.

Two exercise protocols were explored. The first was directed at the overdeveloped tight arm and hand flexor muscles that are actually the working muscles in repetitive motion tasks. The question here is if increasing the strength of the muscles actually doing most of the work
could reduce fatigue factors and discomfort by increasing strength of these muscles. Increasing
the strength of muscles delays fatigue and ultimately discomfort.

The second exercise protocol focused on returning the neutral muscular balance across
the joints to the upper extremity muscular. The question here is if the joint was in a neutral
position and dynamic flexibility were restored, would fatigue be delayed such that discomfort
from doing daily repetitive tasks would be reduced.
Chapter III

Experimental Design and Methods

As discussed in chapter two, ergonomic exposure to repetitive motion may lead to pathology in the soft tissues. Some individuals are more susceptible to this type of injury due to several mediating factors. However, despite individual differences in vulnerability, increasing the individual’s strength through exercise training may diminish soft tissue pathology. This chapter outlines the methodology used to test the effect of two exercise research questions regarding increasing strength and decreasing discomfort in the upper extremity.

This chapter describes the specific plan involved in the conduct of this study. Included in this section are research questions, study design, methods to increase rigor, evaluation of job types at recruitment sites, and subject selection. A discussion regarding instruments, testing procedure, and data collection ensues. The plan for statistical analysis is also introduced.

Specific Aim of the Study

The purpose of this study was to evaluate two types of exercise protocols, flexor and extensor exercises. Each type of exercise was performed at both maximum intensity to fatigue, and at 50% of maximum intensity. The first group (100%-flexor) did exercise training of the flexor muscles of the arm, wrist, hand, and fingers at maximum intensity until complete fatigue. The second group (50%-flexor) did exercise training of the flexor muscles, but at 50% of maximum intensity. The third group (100%-extensor) did exercises of the extensor arm, wrist, hand, and finger muscles at maximum intensity until complete fatigue. The last exercising group (50%-extensor) did exercise training of the extensor muscles, but at 50% of maximum intensity.
The exercise training was performed five times per week for six weeks, for a total of 30 exercise sessions. A control group did not receive exercise training.

Increasing the strength in the upper extremity muscles would serve to delay fatigue during repetitive motion tasks. Delaying fatigue would diminish the discomfort felt by workers from this occupational exposure to repetition. What is not known is if it would be more beneficial to increase the strength of the flexor muscles affecting the muscles directly involved in occupational tasks, or the extensor muscles which are counterbalanced across the joint. Increasing the strength of the extensor muscles would improve the balance or flexibility across the joint in the upper extremity, and result in more efficient use of soft tissues during the performance of work tasks. The more efficient use of soft tissues would result in delaying the fatigue felt during repetitive motion. Delaying fatigue would manifest itself as a reduction in the sensation of discomfort in the upper extremity. The specific aim of this study is to increase the strength of the flexor and extensor muscles in the upper extremity and decreases the discomfort associated with repetitive motion trauma.

Restatement of the Research Questions

Two research questions were explored through this study. The research questions are as follows: In persons doing repetitive motion tasks,

1. What is the difference in muscular strength of selected muscles across four exercise training programs, 100%-flexor, 50% flexor, 50%-extensor, or 50% extensor exercises of the hand and arm at three and six weeks in persons doing repetitive motion tasks, as compared to a control group not doing exercise training?
2. What is the difference in localized discomfort of the upper extremity across four exercise training programs, 100%-flexor, 50% flexor, 100%-extensor, or 50%
extensor exercises of the hand and arm at three and six weeks in persons doing repetitive motion tasks, as compared to a control group not doing exercise training?

**Study Design**

**Description**

An experimental research design was used to conduct this study. Although a convenience sampling technique was used to obtain subjects for the study, the subjects were randomly allocated to one of four exercise or the control groups.

A one within, one between repeated measures research design was used to investigate the influence of upper extremity exercise on the reduction of discomfort and increase in strength. The one within factor is the repeated measure of the same subjects over time during the exercise training. The one between factor is the different exercise treatments, which is the independent variable.

The dependent variables in this study are both the level of discomfort as measured by a visual analog scale, and the strength of each of the upper extremity muscle groups, as measured using computerized strength testing equipment.

**Sample**

**Population**

The population for this study included workers employed in industry doing highly repetitive upper extremity tasks. All subjects in this study were exposed to heavy repetitive motion jobs for at least 40 hours per week. Heavy repetitive hand use was defined as a cycle time (time to complete one assembly or task) of 30 seconds or less, for 50% of a 40-hour work week (Eastman Kodak, 1986). The researcher, to verify exposure level to repetition, ergonomically evaluated each job (Appendix B).
To obtain a potential sample population, local businesses or self-employed individuals having healthy employees with heavy repetitive hand use were first identified. The researcher was familiar with those companies in the metropolitan area that have heavy repetitive motion type jobs and significant CTD injuries. With this in mind, a wide variety of over twenty companies representing a vast array of industrial processes were then approached to participate in the study. These industrial processes included meatpacking and processing plant, heavy metal fabricator, foundry, grocery store, post office, paper product manufacturer, automotive sub-assembly plant, metal fabricating plant, and cosmetic manufacturing plant. Of these, three companies agreed to participate in this study.

Occupational Setting

Subjects were recruited from three industrial plants in Southwestern Ohio. The job analyses for each job performed by subjects were included in the appendix (See Appendix B). A brief discussion of each plant follows.

The first plant was a meat packing plant with approximately 800 employees. The majority of the jobs in this plant were upper extremity intensive. The jobs performed by subjects for recruitment in this study included meat grinder, meat packer, and box maker. Although the forces of these jobs were not measured, it is observed that these jobs required the lowest force of all the subjects. Generally, employees worked in an environment of between 35 and 40 degrees Fahrenheit. Double gloves were worn for both warmth and protection from moisture.

The second plant was a foundry that made industrial pumps with approximately 350 employees. In this process, models of the pumps were constructed out of wax and dipped in fibrous slurry to construct a heat resistant mold. Metal alloy was then heated to between 3000 and 5000 degrees Fahrenheit, and poured into the prepared molds. Jobs represented in this study
were welder/grinder, investor, molder/core maker, wax assembler, machine operator, assembler, and shake-out/pour off.

The third plant was a heavy metal fabrication plant that built eight railroad coal transport cars per day with approximately 350 employees. The jobs in this plant were both whole body and upper extremity intensive. Three jobs were represented at this plant, assembly/drill operator, welder/grinder, and track mobile operator. The forces of these jobs were not measured. These jobs, however, appeared to require the greatest amount of force when compared to jobs of the other two plants.

Subject Recruitment

The researcher gained approval for subject recruitment at three industrial plants known to have numerous jobs with heavy repetitive hand tasks. In the meatpacking and heavy metal fabricating plants, the Occupational Health Nurse (OHN) posted information regarding this study on the general plant communication bulletin board. A similar approach was used in the foundry, but the plant Risk Manager (RM) posted the message. Those responding to the OHN or RM were referred to the investigator for assessment.

This convenience sampling technique was used to obtain potential subjects for the study. Subjects reporting heavy repetitive arm, hand, or finger use in their occupation were initially entered into the study. Even though the investigator was familiar with the job classifications of the plants, an ergonomic assessment of the relevant jobs was done to confirm heavy occupational repetitive hand use. The researcher observed each job to evaluate cycle time, which was then recorded on a job ergonomic assessment sheet (See Appendix B). All workers were employed for at least 40 hours per week in their repetitive motion jobs. Occasionally during the study period workers were temporarily moved to other jobs, however these were also ergonomically
evaluated as heavily repetitive. The jobs of the subjects were simple tasks that were repeated without much variation, making for an easy evaluation of the task cycle time. For example, wax assemblers at the foundry making the molds for the water pumps did continuous hand carving and sculpting of wax using dental tools for at least 40 hours per week.

Each subject was randomly assigned to one of the five groups by drawing numbers out of a hat. Ten slips with each group number were placed in a hat and drawn until all the groups were filled. Half of the slips in the hat were pink for women, the other half blue for men. If subjects were lost from the study prior to completion, slips were added to the hat until 50 subjects completed the study. Several extra subjects were added to the study to allow for attrition.

Subjects and controls had the same experience except that the control group did not receive the exercise intervention. Nor were the controls asked the questions regarding the effect of the exercise training administered at the three and six week follow-up.

Inclusion Criteria

Inclusion criteria for this study mandated that subjects must be over the age of 21 years, and employed at least 40 hours per week (full time), with at least 50% of work time requiring heavy repetitive hand use. Doing a task for at least 50% of the workday was found to be enough repetitive motion to result in a CTD (Hess, 1997; Silverstein et al., 1987). The subjects must also have a baseline discomfort score of greater than 20-mm on a 100-mm visual analog scale. An initial discomfort score of at least 20-mm was arbitrarily chosen by the researcher. It was felt that for people with less than 20-mm of discomfort it would be difficult to see a reduction or improvement in their level of discomfort.
Exclusion Criteria

Subjects were excluded if they had significant upper extremity symptoms, or any other condition that would preclude safe performance of the prescribed exercise training. Exclusion from the study was based on the judgement by the research team. Evaluation of these exclusion criteria was based upon interpretation of the historic data provided at the time of the initial assessment. Some of the criteria used for exclusion were a combination of current treatment for upper extremity disorder, swelling or atrophy, a significant reduction in strength as compared to the opposite limb, and complaints of significant pain with movement. Because these workers were in a physically intensive environment, it was anticipated that most workers would be capable of participating in this exercise training program.

Those subjects with cardiovascular disease (including blood pressure greater than 140/90) were required to obtain clearance from their treating physicians prior to entrance into the study. This criterion was selected because subjects may elevate their blood pressure above safe limits while doing the exercise training (American College of Sports Medicine, 1995). The investigator sent a letter to their treating physician requesting consent to enter the patient in the study (See Appendix C). Subjects with cardiovascular disease who did not have clearance from their treating physicians were excluded from the study. One subject was being treated for hypertension. The blood pressure of this subject was normal on the day of baseline data collection. A letter was sent to the physician followed by a phone call to discuss participation in the study. The physician gave his written and verbal permission for the subject to participate in the study.

One subject was excluded from the study for a systolic blood pressure of 210 mm Hg. He was under a doctor’s care for hypertension. He was immediately sent to his treating physician
and his medication was adjusted. He did not return to the study because stabilizing his blood pressure took several weeks to accomplish.

**Intervention**

**Exercises**

Exercising subjects were given a box that contained their exercise equipment, a calendar and pen to track their daily exercise, and the investigator’s pager number to call with any concerns. Workers were encouraged to keep the exercise box with equipment in their lockers at work. The researcher checked exercise-tracking calendars on a weekly basis. A reminder card was given to subjects the week before data collection, along with a verbal reminder.

Exercises were demonstrated individually to all exercising subjects. The subjects were allowed to practice and were observed for correct exercise technique. Following demonstration and instruction, exercises were done on an individual basis five times per week. The researcher re-checked the subjects at least weekly, and more often if difficulty with the exercise procedure was apparent. All exercising subjects kept track of their exercise sessions with a calendar log.

One upper extremity per subject was used to measure the dependent variable in the study, however all exercising subjects were encouraged to exercise both upper limbs. All subjects reported exercising bilaterally. The study hand chosen was the one with the greatest repetitive use on the job, unless both hands were used equally, in which case the dominant hand was used. The dominant hand was used in all subjects in this study.

The researcher was available to address questions or concerns from all subjects, both intervention groups and controls. Subjects had access to the researcher at least one time per week, and the researcher to encourage contact provided donuts and beverages. The researcher kept the same day of the week at each plant as the visitation day.
Some of the anticipated problems with the exercise training were addressed with the subjects. Initial soreness was anticipated to occur, as this was a new exercise program. Such transient soreness would be expected with any new exercise training program (McArdle et al., 1996). Subjects were advised to call the researcher by pager, use ice, and skip a day of exercise if excessive soreness occurs. Skipped exercise days were monitored. The number of skipped exercise days was to be made up at the end of the six weeks, until 80% of the exercise program was completed (24 of the total 30 exercise sessions). All exercise was to be completed within eight weeks of the first exercise day. The subject had to complete 80% of the exercises during the week of data collection (four of the five exercise sessions for that week). Skipped days from illness were dealt with in the same manner.

This plan for missed days of exercise only came into practice in the short term. If subjects missed an exercise day, they either took their equipment home, or made up the missed day(s) on the weekend.

Exercises were performed at the subject’s discretion during the workday. Subjects were encouraged to perform exercises at the job-site, either before work, after work, or on one of their three breaks. A few subjects exercised at home, but brought their calendar log of exercises for the scheduled weekly assessments by the researcher. Subjects generally had a preferred exercise time, and were consistent about their time of exercise. The exercises varied for each of the four intervention groups by either type of exercise, or intensity.

Groups 100%-flexor and 50%-flexor did flexion exercises to the hand and arm, and groups 100%-extensor and 50%-extensor did extension exercises of the antagonistic hand and arm muscles. The duration of exercise sessions was approximately five to ten minutes. The frequency of exercise was five times per week, for six weeks, for 30 exercises sessions.
Exercise intensity was set at both 50% and 100% of maximum capacity. The literature has shown that exercising at 100% of maximum capacity results in an increase in strength (Chilibeck, Calder, Sale, & Webber, 1998; Hisaeda, Miyagawa, Kuno, Fukunaga, & Muraoka, 1996). It has also been shown that exercising at 50% of maximum capacity leads to increases in strength (Moss et al., 1997). The advantage to exercising at 50% of maximum capacity is that it produces less strain on the individual, and there is less potential for injury from exercise training.

Flexion exercises (groups 100%-flexor and 50%-flexor) were done with a commercially available exercise ball called the Powerball™ (See Figure 5). The Powerball™ is sold at department stores, and toy stores for the purposes of hand and arm exercises. The ball has a hard outer shell that is squeezed (gripped) by the hand. The outer ball encases an inner ball that is a gyroscope. To exercise, the hand and arm pronate and supinate (rotate), while the shoulder internally and externally rotates. As the hand and arm move, the inner gyroscope ball spins, causing a counter motion or “jump” of the outer ball. The handgrip has to tighten to hold on to the ball and continue exercising. The subjects in the 100%-flexor group were instructed to rotate the ball at maximal speed, and rotated the ball until maximal fatigue, about five to ten minutes. The length of exercise time for this group was expected to increase over the six-week course. The 50%-flexor group was tested during baseline and weekly for maximum number of rotations of the Powerball™. The subjects exercised at an intensity rate of 50% of the maximum number of rotations, which was re-set and adjusted weekly.
The method used to re-set subjects exercising at 50% of maximum ability was to have subjects do their exercise to fatigue on the re-set days. It would be anticipated that the number of exercise repetitions would increase weekly, as subjects became stronger. The maximum number of repetitions would then be cut in half, and the next week’s exercise training would be re-set at this new number. All subjects would keep track of the number of repetitions on their tracking calendar.

Extension exercises (group 100%-extensor and 50%-extensor) were done with a commercially available exercise rubber band (Carpal Care™) designed for therapeutically exercising the upper extremity to diminish the pain and discomfort of carpal tunnel syndrome (See Figure 6). The fingers of the hand are extended or pulled against the resistance of the Carpal Care™ exercise band, while extending the arm and shoulder.
The arm, wrist, hand, and finger extensor muscles are exercised against the resistance. The non-exercising hand provides counter pressure to the Carpal Care™ exercise band by holding the opposite end of the band. The amount of resistance from the Carpal Care™ exercise band can be adjusted by altering its length. The resistance of the exercise band was set the same for all subjects. In the extensor-100% group subjects exercised until maximal fatigue, about five to ten minutes. Subjects were instructed to exercise continuously without delay between each repetition. The length of exercise time for this group was expected to increase over the six-week course. The extensor-50% group was tested during baseline and weekly for the maximum number of times they could stretch the band. The subjects exercised trained at a rate of 50% of the maximum number of band stretching, which was re-set and adjusted weekly. A weekly re-adjustment was done based on the possibility of workers gaining enough strength from the exercises that they no longer would be exercising at 50% of their maximum ability. Exercise
training results in changes in the muscles with each session so one week of exercise training should result in an increase in strength (McArdle et al., 1996). Weekly re-setting was done based on both the physiological changes in the muscles from exercise training, and the convenience of the subjects.

The control group received no exercise training. They only had contact with the researcher for baseline, mid-study (three weeks), and post study (six weeks) measures. The controls were welcome to make contact with the researcher during the weekly visits to the plants.

Procedure

Subjects were assessed using two psychometric instruments and strength testing instruments. The Short-Form-36 General Health Survey and a visual analog scale to measure upper extremity discomfort were used. Strength testing equipment was also used to assess muscular strength of specific muscles in the upper extremity.

Instruments

**Short-Form-36 General Health Survey.** The Short Form-36 General Health Survey (SF-36), which has both a physical health and mental health component, was used (Ware, Snow, Kosinski, & Gandek, 1993). There are 36 Likert-type questions and eight subscales for this instrument (Ware et al., 1993). Information from the SF-36 was collected as demographic data only to compare for differences between subjects and across groups. The eight subscales are general health perceptions, physical functioning, bodily pain, physical role limitations, mental health, social functioning, vitality, and emotional role limitations (Ware et al., 1993). The various items are rated on three, five, or six point interval scales and the number of items in subscales varied. Therefore scores are transformed to a 0 to 100 scale for each subscale using a standard SAS\textsuperscript{TM} program provided by the MOS Trust. The eight subscales are combined to form
two composite scores. The first composite score is for physical health and the second for mental health. In multiple studies with persons with variety of health disorders, high levels of internal consistency for the subscales were reported.

**Visual analog scale.** “Localized discomfort” of the upper extremity was measured by a 100 mm horizontal visual analog scale (VAS) with anchor words at each end (Randolph, 2000). The anchor words to the left of the line were ‘no discomfort’, and the words to the right of the line were ‘maximum discomfort’. The investigator in a study that will be briefly summarized next developed this scale.

In a preliminary study, the author assessed the sensitivity and validity of four psychometric instruments (Randolph, 2000). The concept of interest was localized discomfort of the upper extremity. This study had fifty subjects almost equally divided between groups with either severe carpal tunnel syndrome, mild carpal tunnel, or a control group with no hand or arm complaints.

The four discomfort scales were two forms of the BORG scale, and two forms of the visual analog scale (Borg, 1982; Randolph, 2000). The first BORG (unipolar-BORG) was a ten-point scale ranging from zero to ten, whereas the second BORG (bipolar-BORG) ranged from minus ten to plus ten. The visual analog scales were both 100-mm, but one scale was numbered from one to ten.

The four localized discomfort scales were administered to the subjects, followed by a physical challenge using the PAT unit. The PAT unit consisted of screwing and unscrewing nine nuts and bolts with the hand in a forced position. This physical challenge is often part of the exam done on workers to determine the level of physical functioning of the hand and wrist.
The four scales were then re-administered. Using a repeated measures ANOVA statistical analysis, all four scales were found to show sensitivity, or the ability to detect a change in discomfort following a physical challenge. However, only the unipolar-BORG and the 100-mm visual analog scales (VAS) (without numbers) were found to have strong construct validity (See Figure 7). People with more severe disease were distinguished on these two scales. The magnitude of discomfort was greater for those with carpal tunnel syndrome disease than those with no disease especially for the unipolar-BORG and the VAS (without numbers). The mean difference discomfort scores for the unipolar-BORG following a physical challenge were 6.2 for severe carpal tunnel syndrome, 4.4 for mild carpal tunnel syndrome, and 1.3 for no carpal tunnel syndrome, which was statistically significant [F=59.38 (2, 47), p< .001]. The mean difference scores for the VAS (without numbers) for the same population was 7.4 for severe carpal tunnel syndrome, 6.1 for mild carpal tunnel syndrome, and 2.3 for no carpal tunnel syndrome, which was also statistically significant [F=36.27 (2, 47), p< .001].

The discomfort VAS (without numbers) from the preliminary study was used in the present study. Although the unipolar-BORG also demonstrated construct validity the VAS was chosen for its ancillary advantage of the ease of administration. It was also chosen due to its wide use in sensory assessment of discomfort or pain (Bhatnager, Drury, & Shiro, 1985; Corlett & Bishop, 1978; Corlett & Bishop, 1976; Himmelstein, et. al., 1995; Schoenmarklin, & Marras, 1989).
Hanoun strength testing equipment. The equipment is commercially available through Hanoun Medical, Inc. (See Appendix A). Hanoun equipment is a computerized device used to test the static strength of muscles. Strength has shown to be a reliable predictor of the amount of work the individual can do, the level of fatigue the person will develop while working, and the potential risk for future injury (Batte et. al., 1989; Chaffin, 1974; McArdle et al., 1996). Hanoun has a portable version of strength testing equipment widely used in the occupational arena to test the physical capabilities of individuals for fitness for work, job placement, or returning to work following an injury. The advantage of portability is that it allows for testing at the job site. The

**UNIPOLAR BORG DISCOMFORT SCALE I:**

0
0.5 just noticeable discomfort
1
2 weak discomfort
3 moderate discomfort
4
5 strong discomfort
6
7
8
9
10 maximum discomfort

**VISUAL ANALOG SCALE**

No | Unbearable
---|---
Discomfort | Discomfort

**Figure 7.** Construct Valid Instruments: The Unipolar BORG scale and Visual Analog Scale (Borg, 1982; Randolph, 2000).
validity and reliability of the equipment is not compromised by the portability, as using a laptop computer provides an internal means for calibration of the equipment.

Calibration of the strength testing equipment was done according to the procedure outlined by the Hanoun Medical. Three pieces of equipment, the load cell, pinch grip, and handgrip, were individually calibrated to the zero mark. The load cell is a device that measures the amount of force generated by pushing against it. This was calibrated with three separate weights, ten, 20, and 30 pounds. The computer reads the amount of weight placed on the load cell, and the researcher assigns a number to that weight. For example, if 20 pounds were put on the load cell the researcher types in 20 pounds as a reference point for the computer. The hand and pinch grips were also each calibrated using ten pounds of weight. Following calibration, the weights were then individually placed on the equipment to test if the correct weight would register. Calibration was accepted only at the correct weight.

The strength of six muscle groups in the upper extremity was measured, the triceps, biceps, forearm flexors, forearm extensors, handgrip, and pinch grip. It was anticipated that the strength would increase from baseline with exercise training. These muscles were chosen, as these are the anticipated muscles involved in the exercise training. It would also be anticipated that the strength of the control group would not increase over the six-week period.

Data Collection

Data were collected in a structured manner whereby the researcher and a Board Certified Occupational Health Physician were responsible for specific data collection. The process of initial data collection was as follows:

- Recruitment of Subjects
- Consent Form Reviewed and Signed
Initial Assessments
- Visual Analog Scale for Discomfort
- SR-36
- Medical history and Physical Exam
- Strength Testing

Randomization to Groups

Intervention of Flexion or Extension Exercises

3 Week Follow-up Assessment

6 Week Follow-up Assessment

Each of the two data collectors was blinded to assessments of the other. Data were also collected in the same order or pattern: the health assessment, medical history, and physical exam prior to strength testing. Baseline measures were collected on all subjects regardless of group assignment. The initial assessment was approximately one hour in length, and subsequent assessments were 30 minutes. All baseline measures were collected at the first plant during the same week period. Information of a baseline nature was collected from plants two and three concurrently upon completion of the study at the first plant.

Data collection for two of the plants was conducted in a conference room, which was a warm comfortable environment. Data for the third plant was collected either in the cafeteria or in the nurse’s medical unit, which were comfortable environments.

Baseline Assessment (prior to exercise program)

Baseline assessments were completed before beginning the exercise training program for groups 100%-flexor, 50%-flexor, 100%-extensor, 50%-extensor, and group-control. Data were collected during the subject’s eight-hour shift. Both first and second shift employees were included at all three plants. Baseline data collected included the following:
Medical history and physical exam. A medical history and physical exam of the upper extremity was done to obtain information regarding mediating factors that might alter subject susceptibility to CTDs. (See Appendix D). Included in this exam was a history of height and weight to calculate the body mass index, smoking and drinking consumption, and work history. The physical exam included measurement of the Phalen exam and Semmes-Weinstein sensation exam. These exams provided a baseline measure of clinical neurologic disease in the upper extremity. The Phalen test is often used as a screening tool for median nerve compression at the wrist (D’Arcy & McGee, 2000; Dickerson & Horvath, 1994). The Phalen has been shown to have a broad range of sensitivity (25 to 71%), and specificity (47 to 80%) for diagnosing nerve compression at the wrist. Despite the low sensitivity, this exam was included because it is still widely used in clinical evaluation of persons with CTDs.

The Phalen exam was performed with the subject sitting and the arm bent at the elbow and the wrist at 90 degrees for 60 seconds. A positive result would be paresthesias in the first three fingers, and the medial half of the forth finger. A positive result may indicate median nerve entrapment at the wrist, which is seen in carpal tunnel syndrome.

The Semmes-Weinstein was used to detect sensation loss in the fingers from neural damage, and can be one of the earliest signs of CTDs (Dickerson & Horvath, 1994). Semmes-Weinstein is not as widely used as the two-point discrimination test to test a diminution of sensation. However, it is reported to have greater sensitivity (91%) over the two-point discrimination test (22 to 33%), and can pick up earlier cases of sensation loss. The specificity of the Semmes-Weinstein test is reported to be 80%.

The Semmes-Weinstein test was done with the two smallest monofilaments (2.83 and 3.61 mm) to test for loss of touch sensation in the second and fifth digits. For this test, the
subjects closed their eyes while the researcher touched their finger with the monofilament. The subject indicated if they could feel the filament by saying the word “touch”. The finger was touched three times, and the number of correct touches was recorded.

**Visual analog scale.** A visual analog scale (VAS) for measuring levels of localized discomfort of the upper extremity was done to obtain baseline data on discomfort (See Figure 2). Prior to subjects marking their level of discomfort, the researcher defined what was meant by discomfort. Discomfort was defined as a fatigue, heaviness, aching, pain, pins and needles, or numbness.

**Short Form-36.** The Short Form-36 was administered to all subjects. The subjects filled out this questionnaire on their own time. The questionnaire was given along with a stamped addressed envelope sent to the researcher. All subjects filled out this form. The eight subscales were reviewed, however the subscale most relevant to CTDs was the “Bodily Pain” sub-scale (See Appendix E)

**Hanoun strength testing equipment.** Hanoun strength testing equipment was used to measure handgrip in position three on the hand dynamometer, pinch grip of 1st, 2nd, and 3rd digits, forearm flexor muscles, forearm extensor muscles, biceps, and triceps. These six muscles were chosen to measure due to their involvement in the performance of the exercises. The flexor exercises predominately used the biceps, forearm flexors, and the hand and pinch grips. The extensor exercises predominately used the tricep and forearm extensors. The extensor exercises may also effect the hand and pinch grip as the exercises are hand and finger intensive. Eccentric contraction, or contractions of the extensor muscles when the hand and fingers are returning to their resting position, may result in some strength changes in the hand and fingers. Strength was measured in kilograms of force (See Appendix A and See Figure 8).
Mid-program (3 weeks) and Completion Assessment (6 weeks)

Data were collected on groups 100%-flexor, 50%-flexor, 100%-extensor, 50%-extensor, and group-control at three weeks, and six weeks after the onset of the study. The same assessment data as baseline were collected except medical history and Short Form-36 were not performed at follow-up data collection points.

Weekly Assessment of Subjects by the Researcher

The researcher made at least weekly visits to each plant in order to be available to the subjects to answer questions, address problems, and assess progress. It also provided a means for the researcher to determine if the subjects were doing their exercise, and to assess for correct exercise technique. The calendar tracking logs for each subject was reviewed each week, which encouraged exercise participation.
Flexion and Extension strength testing

Bicep and Tricep Strength testing

Hand and Pinch Grip strength testing

Figure 8. Strength Testing Equipment

The researcher brought donuts and drinks to the plant for each visit. Both the controls and the exercisers came in frequently to enjoy donuts. Since the researcher became fairly visible in the plant, the subjects, both exercisers and controls, had at least weekly contact with the researcher.
In addition, weekly assessments were done on those exercising at 50% of maximum ability to re-set the number of exercise repetitions. Subjects exercised at the re-set level of exercise repetitions for the week. Tracking of the subject’s weekly number of prescribed repetitions was kept on the subject’s calendar log.

Each week it was anticipated that the number of exercise repetitions would increase as the worker became stronger from the exercise. The workers in groups II and IV increased their maximum number of repetitions every week. However, some exercisers increased a large amount each week, whereas others had modest progress. The weekly exercise-maximum test was done in lieu of that day’s exercise.

Standardization of Research Protocol

Several aspects of this research study were standardized to increase its rigor. The first aspect was during the process data collection. The same member of the research team always collected the same data and did so in the same order. The questionnaires and visual analog scales were always done first before strength testing so as to avoid influencing questions regarding discomfort. The forms for the three data collection points, baseline, three week, and six week were color coded so as to avoid confusion regarding which points in time the forms pertained. Matching stickers were placed on the front of each subject’s chart to indicate the point they were in the study.

The second aspect that increased the rigor of the study was in the manner questions were asked by the researchers. The dialog for each question was pre-planned and consistent between subjects and data collection points for the same subjects. Care was taken to describe what was meant by localized discomfort prior to doing every visual analog scale using the same languaging.
The members of the research team were blinded to data collected by the other member during the data collecting process, prevented undue influence on the data collected. The researchers did remain blinded to the data after the day’s collection. Both researchers worked together to enter data into the computer, reducing the chance of transcription error.

The research team standardized the order of strength data collection. The order of muscular strength testing was the triceps, biceps, forearm flexors, forearm extensors, handgrip, and pinch grip.

Strength training was also standardized by type of collection. A load cell was provided with the exercise equipment to measure upper extremity muscular strength. When doing strength measures, the subject pushes against the load cell, while the tester applies counter force. Muscular strength was determined by the amount of displacement by the load cell. The counter force provided by the tester may have some variability, especially if the subject is particularly strong. To reduce the chance of this variability the researcher provided a means to hold the load cell consistently stable. Three wooden boxes were designed and constructed by the researcher to provide a consistent counter force when using the load cell to test the muscular strength of the triceps, biceps, forearm flexors, and forearm extensors (Appendix K). The boxes were adjustable such that all arm lengths were accommodated. The hand and pinch grip were assessed by the equipment provided, and did not require adaptation.

Finally, the computerized strength testing equipment was calibrated prior to each use. Calibration was done on site so as to prevent an alteration in calibration during transport.

However, the strength testing equipment had one episode resulting in unusable data due to inadequate calibration of the equipment. The initial baseline strength testing performed on some subjects at plant one resulted in erroneous and physically impossible numbers. For this
session, the calibration of the equipment was done at an earlier location and moved on-site without re-calibration. For the remaining sessions the equipment was calibrated and checked on-site. No other apparent problem occurred with the equipment.

Data Management

Data were collected on-site from subjects. All forms were color-coded based on data collection time to avoid confusion. Each subject’s data was kept in a separate folder, except for the strength data, which was kept in the computer. A log of the completed data collection times were written on the front of the subject’s folder so it was clear to see where the subject’s were in the collection process. Subject folders were kept in a separate file box for each of the three companies. Data were entered into an Excel$\text{TM}$ spreadsheet within one week of collection. A re-check of the data was done to assess accuracy following data entry. Statistical analyses were done using the SPSS$\text{TM}$ (version 10) statistical package.

The sample size of the study was determined to be a minimum of 10 subjects per group (n), for a total sample (N) of 50 subjects. In reviewing the literature, the effect of resistance training on strength gains is very significant, so a medium to large effect size was assumed (Conley, et al., 1997; Cullinen & Caldwell, 1998; Moss, et al., 1997; Yuko, 1997). The strength variable was chosen to determine the effect size for this study because it is closely coupled with the intervention. Exercise training is known to increase strength, and the literature was rich with studies to support this premise (Conley et al., 1997; Cullinen & Caldwell, 1998; Moss et al., 1997; Yuko, 1997). Unfortunately the second variable of interest in this study, localized discomfort, did not have studies that could give an idea of the effect size needed for the current study. Because the strength variable was a good variable and is widely studied in the literature,
and localized discomfort, also a good variable, but has less literature support, the strength variable was chosen to determine effect size for this study.

A power analysis was done based on Cohen’s (1988) method for determining sample size for repeated measures. Cohen (1988) bases the effect size on a complex multivariate calculation using a set of correlations. In contrast, the effect size most commonly seen is calculated using simple bivariate correlations. The effect size based on Cohen’s calculations appears different than those usually reported effect size. According to Cohen, a medium to large effect size of .55, and an α of .05, a sample-size of 50 subjects results in a power of 0.80, which is adequate power (Cohen, 1988, McArdle, et al., 1996; Polit & Hungler, 1995; Stevens, 1992). Doing a repeated measures power analysis using Stevens (1992), for a power of .80, and an alpha of .05, a large effect size (.89) calls for eight subjects per group, and a medium effect size (.50) calls for 14 subjects per group. Consistent with Cohen’s power analysis, for a medium to large effect size, ten subjects per group were adequate sample size. Two subjects were added per group to allow for 20 percent attrition.

Data analysis

Data were first analyzed using descriptive statistics to describe the variable of interest in sample. For example, the body mass index and the smoking history of the subjects were described. In the current study, care was taken to keep observations independent. Data collection was individually collected for each subject reducing the interactive effect of subject responses. Also, data collection was directed to one extremity only, making it the unit of analysis. Although the exercises were performed on both extremities, the research study focused on one extremity. The research extremity was determined by the most frequently used in their occupation. If both extremities were used equally, the dominant side was used.
The second assumption, multivariate normality, does not have serious consequences for violation. A violation of multivariate normality in the repeated measure analysis is fairly robust, and consideration is not necessary.

**Research question #1.** A repeated measure MANOVA was used to measure a mean change in muscular strength (kg.) for the dependent variables biceps, triceps, forearm flexors, forearm extensors, handgrip, and pinch grip.

**Research question #2.** A repeated measure ANOVA was used for analysis for the dependent variable localized discomfort of the upper extremity.

**Protection of Human Subjects**

Prior to data collection, approval was obtained from the University of Cincinnati Medical Center Institutional Review Board. All potential subjects were made aware that participation was voluntary and that all data would be kept confidential. All subjects read and signed the informed consent at the first contact and preceded data collected. Subjects were asked if they understood the consent during the initial contact.

The consent form included a statement that all information is confidential, would only be seen only by the research team, and only reported as group data. The investigator has maintained the subject’s information in a locked file cabinet and will keep files for at least two years after completion of the study.

Subjects may have feared that answering the questions on the health assessment survey may alter their employment status or workers compensation/insurance options. To reduce the fear all forms, questionnaire and data collection information were kept coded, confidential, and unavailable to the employer. Only the research team was privy to the coded contents. The
employer was, however, provided access and explanations regarding aggregate results of this study, without violation of the integrity of the subjects’ confidence.

Potential Risks and Benefits

The risks of injury from resistance exercises are soft tissue irritation and soreness. Some soft tissue soreness is anticipated when beginning a new exercise program. Subjects were advised to call the researcher by pager, skip a day of exercise, use ice, and rest the involved limb if substantial soreness occurs. Once soreness was reported, the researcher continued to check the subject frequently, and maintained phone contact until the soreness subsided. If soreness persisted for more than two weeks after the onset of exercise, the subject was advised to stop exercising and possibly seek medical care from a health care professional. In this study, several subjects in the extensor-100% group complained of initial soreness. The exercise was adapted to work the arm lighter by holding the arm closer to the body while pulling on the Carpal Care band. One subject adapted the arm posture that was closer to the body as the exercise posture. In all the subjects, the arm and wrist soreness subsided and they were able to continue with the exercise program.

Before entering the exercise program, subjects were informed of these risks, and that they would be responsible for all expenses incurred from exercise participation, including missed workdays and medical expenses. The employer for the subjects was also informed of the risks for employee’s participation, and that the researcher was not be responsible for possible cost incurred from lost time or medical care.

Inconvenience to the subject was considered and discussed. There was an inconvenience to the subject in that they were asked to complete an exercise training program. This requires a daily time commitment of approximately five to ten minutes per day for six weeks. They also
need to commit to a 30 to 60 minute assessment three times during the study period. All subjects agreed to this commitment.

The direct benefit to subjects of study participation was that they received an exercise prescription, which may reduce the localized discomfort that comes from doing repetitive work. Further, these exercises may assist in delaying, or preventing all together, the chronic physiologic insult that can lead to CTDs. The subjects were provided an opportunity to incorporate exercises into their workday, and possibly have a first hand perspective on the effects of discomfort reduction.

A prominent but indirect benefit of participation in this study is the contribution to the scientific knowledge base. The localized discomfort associated with CTDs is significant. The identification of an intervention such as exercise that can reduce this discomfort would be beneficial.

**Conclusion**

This chapter addressed the methods used in this research study, specifically, what type of plant was used and the process of subject selection. Other issues addressed in this chapter included research tools and equipment, and the technical aspect of data collection. Characteristics of the study groups were presented. Also presented was information outlining the criteria for performance of the different exercises, and how the subjects were monitored during the study. Finally, a plan for data analysis was provided.
Chapter IV

Results

Subject Description

Demographics

The original sample consisted of 85 subjects. Fifteen subjects withdrew from the study. More subjects (n=5) from the control group withdrew than from the four intervention groups (10). All subjects dropped out of the study prior to the three-week data collection point. All five subjects from the control group who withdrew from the study and most of the intervention dropouts stated that they were unable to continue in the study due to lack of time. Other reasons for not continuing in the study included: medical leave, surgery, and National Guard attendance. One subject was no longer employed at the company.

Seventy subjects finished the study. Fifty-two subjects were in the intervention group, and 18 were controls. Of the seventy subjects who completed the study, initial strength testing data are missing on eighteen subjects due to equipment failure on the initial data collection day at one of the occupational settings. There was an error in the internal calibration of strength measures that was not discovered until data entry. Therefore, all strength analyses will be reported for fifty-two subjects but the demographics and discomfort variables will be reported on the entire sample (n=70).

The age of subjects ranged from 21 to 59 years with a mean of 40 (sd 10). No significant age difference was found across the five groups [F=1.2 (4,76), p=. 32]. Fifty-four subjects were Caucasian, ten African American, one Asian, and three Hispanic. The number of subjects by
group and gender are found in Table 1. There was no significant racial difference among the five
groups [\( \chi^2 = 20.74 \ (4), \ p = .054 \)].

Table 1. Distribution of Subjects who Completed the Study by Gender.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Females</th>
<th>Males</th>
<th>Number per group</th>
<th>Number-complete data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- 100% Flexor</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>2- 50% Flexor</td>
<td>6</td>
<td>6</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>3- 100% Extensor</td>
<td>8</td>
<td>6</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>4- 50% Extensor</td>
<td>7</td>
<td>7</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>5 (control)</td>
<td>8</td>
<td>10</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Totals</td>
<td>34</td>
<td>36</td>
<td>70</td>
<td>50</td>
</tr>
</tbody>
</table>

Chi square (4, N=70) =2.69, p=.61

Mediating factors

**Personal characteristics.** Fifty percent of subjects were current smokers, and 62.5 percent
were past smokers (12% of past smokers quit smoking). Only two subjects reported that they
were current drinkers, defined as having more than two drinks on the average per day for more
than six months, but 13 subjects (18.6%) reported drinking in the past. No group differences
were found for either of these lifestyle factors (p>.05).

**Occupational factors.** The time working at the plant ranged from 2 months to 28.5 years.
No significant group difference was found in length of employment [F= 583 (4,76), p=.68].
However, the length of time working was significantly related to the need for carpal tunnel
surgery (r= .27, p= .02) and past or current worker’s compensation claim (r= .32, p= .01 level)
for injury in that extremity. There were no significant group differences in the number of current
or past worker’s compensation claims or history of carpal tunnel surgery.

**Physical Examination.** The ideal range for body mass index is 18 to 25 (American
College of Sports Medicine, 1995). In this sample, the mean body mass index was 27.7 (sd ±
10). The mean wrist size was 17 centimeters (sd ± 1.46). No group difference was found for
body mass index \[F=0.72 (4,65), p=.58\] or wrist size \[F= 1.29 (4,65), p=.28\]. Body mass index was associated with the need for carpal tunnel surgery \((r=.24, p=.03)\) and wrist size \((r=.30, p=.007)\).

The Phalen Test is considered to be a clinical indicator of median nerve pathology, although the sensitivity of this test is low (D’Arcy & McGee, 2000). At the initial examination, 20 (28 %) subjects had a positive Phalen sign. There was no significant difference in group assignment but fewer subjects with a positive Phalen test were in the 50% flexor \((n=2)\) and control groups \((n=2)\) \(\chi^2 = 8.2 (4), p=.09\). Of interest, the presence of a negative Phalen exam was correlated with subjects who were current smoking \((r=.24, p=.03)\); however, a positive Phalen was associated with current drinking \((r=.278, p=.01)\). No association was seen for past smokers or drinkers.

The Semmes-Weinstein test detects the ability to sense a 2.83 or 3.61 monofilament. Three attempts to detect sensation are traditionally used. All but three subjects were able to detect the 3.61 monofilament on at least two of the three touches to the fourth digit. When the 2.83 monofilament was used, 11 subjects could not sense the touch at any of the trials involving the index finger and 12 could only sense it once. There was a significant group difference with fewer subjects with sensory impairment in the 50% flexor group \(\chi^2 = 27.42 (12), p=.007\). There was no relationship between a negative Semmes Weinstein and Phalen test \((r=.21, p=.06)\).

**General Health.** The subjects completed a subjective general health assessment. Two composite scores of the SF-36 were used to as used to provide a general description of the physical and mental health status of the subjects. Scores can range from 0 to 100 on both scales with a higher score indicating a higher level of health in each dimension. In this sample, the
mean physical composite score was 48 (sd ± 18) and the mental composite was 48 (sd ± 11).

There were no significant group differences in either measure [F=0.79 (4,62), p=. 56 and F=1.92 (4,62), p=. 12 respectively]. The internal consistency of these measures was strong (Cronbach alpha > .80). Of interest, when the analysis was performed on the initial set of 85 subjects recruited for the study, the mean physical composite score was 83, indicating that those who withdrew from the study had higher self-reported physical functioning than those who remained in the study.

Baseline Comparison of Dependent Measures. Initial discomfort as rated on a 100-millimeter visual analog scale was 50.6 (sd ± 21) for the entire sample. There was no significant group difference [F=2.17(4,62), p=. 07]. However, there were baseline differences in some of the muscle strength measures. The six baseline measures of muscle strength were analyzed using a multivariate analysis of variance. A significant difference among groups was found [F=1.81, p=. 009]. When the post hoc analyses were examined, it was determined that the baseline strength differences involved biceps, extensors, and pinch muscle strength. There were no significant group differences in triceps, flexors, or hand muscle strength (p>.05).

A 25-kilogram difference in bicep strength was found between the 100% flexor and 100% extensor groups at baseline with the later group demonstrating greater weakness. Table 2 provides the mean strength scores for all six-muscle areas for the five research groups. Two significant group contrasts were found in the measurement of extension strength in subjects at baseline. There was a 14 kilogram difference between the 100% flexor and 100% extensor exercise groups with the later again demonstrating greater weakness. In addition, the difference between the 100% extension and control groups was 18 kilograms with the control group demonstrating greater strength. The final difference was found in the comparison of the 100%
extensor group with the control group on the measure of pinch strength. The control group demonstrated greater strength at baseline in five of the six muscle groups. Thus, the control group was stronger at baseline despite the random assignment to the five study groups.

Table 2  Baseline mean strength measures of six muscles

<table>
<thead>
<tr>
<th>Groups</th>
<th>Tricep</th>
<th>Bicep</th>
<th>Flexor</th>
<th>Extensor</th>
<th>Hand</th>
<th>Pinch</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Flex</td>
<td>36.3</td>
<td>48.8</td>
<td>33.4</td>
<td>27.6</td>
<td>84.2</td>
<td>18.2</td>
</tr>
<tr>
<td>50% Flex</td>
<td>31.9</td>
<td>44.9</td>
<td>31.4</td>
<td>23.9</td>
<td>71.7</td>
<td>19.7</td>
</tr>
<tr>
<td>100% Ext.</td>
<td>23.4</td>
<td>22.8</td>
<td>19.6</td>
<td>11.3</td>
<td>52.0</td>
<td>11.4</td>
</tr>
<tr>
<td>50% Ext.</td>
<td>29.7</td>
<td>36.1</td>
<td>24.7</td>
<td>23.2</td>
<td>74.5</td>
<td>14.2</td>
</tr>
<tr>
<td>Control</td>
<td>39.1</td>
<td>44.7</td>
<td>35.2</td>
<td>31.0</td>
<td>100.0</td>
<td>19.5</td>
</tr>
</tbody>
</table>

Because the three plants where the subjects worked differed in job activities, additional analyses were performed. Baseline measures of strength in the six muscle groups were compared by work site. The first work site was a meat packing plant, the second was a foundry, and the third a railroad boxcar maker. An analysis of variance found no overall significant difference in strength across sites \(F= 1.57(12), p=.28\). Of interest, the mean scores of the subjects who worked at the foundry (second plant) had the highest strength measured in all six-muscle areas. However, significant differences were only found in two of the six muscle groups: triceps \(F= 3.53(2,47)\) and \(p=.037\), biceps \(F= 3.76(2,47), p=.03\).

Gender differences in baseline strength were also explored. Multivariate analysis of variance results found that gender had a significant overall effect \(F= 10.057(1,43), p=.000\). When each muscle group was examined, there were significant differences in five of the six muscle groups with men demonstrating greater strength \(p<.05\). The one muscle group that was not significantly different was the group of hand muscles. Despite the differences in baseline strength, the analyses proceeded as planned because repeated measures analysis could possibly demonstrate differences in muscle strength over time.
Results

Research question #1- Muscle Strength Changes

The first research question asked “What is the change in muscular strength of selected muscles across four exercise training programs (maximum flexor, 50% flexor, maximum extensor, or 50% extensor) or control condition at three and six weeks?” Six muscle groups were tested for strength increases in the upper extremity after six weeks of exercise training: the tricep, bicep, forearm flexors, forearm extensors, handgrip, and pinch grip. A three way repeated measures general linear model was used to analyze the data. The first within subject variable was time of strength measurement. The three time points included baseline, a three-week follow-up and a six-week follow-up. The second within subject factor was the type of muscle group examined. The final variable included in the model was the between subject factor of group assignment.

The overall repeated measures analysis of variance demonstrated significant within subject effects in strength over time (F=12.32, p=. 000). There was also a significant difference in strength across the six muscle groups (F=67.38, p=. 000). This was anticipated and is the normal occurrence as the muscle groups vary in terms of strength based on size and degree of use. There was also a significant interaction effect between the six muscle areas and the three time periods. (F=3.04, p=. 007). Thus, muscle strength differences were across time.

The mean strength difference of the muscle groups support the ANOVA finding of increasing strength at both the three and six week data collection points, as compared to baseline measures. Table three demonstrates the difference scores for muscular strength for each group from baseline to three weeks after doing the exercise intervention. Table four demonstrates these differences from baseline to six week after the intervention.
Table 3  Mean difference in muscular strength from baseline to the 3 week data collection point for four exercise intervention and one control group, for six muscle groups (standard deviation in parentheses)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Tricep (5.2)</th>
<th>Bicep (8.5)</th>
<th>Flexor (5.3)</th>
<th>Extensor (2.3)</th>
<th>Hand (32)</th>
<th>Pinch (4.6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Flex</td>
<td>.167</td>
<td>2.57</td>
<td>1.89</td>
<td>1.3 (2.3)</td>
<td>15.89</td>
<td>.153</td>
</tr>
<tr>
<td>50% Flex</td>
<td>1.56</td>
<td>1.43</td>
<td>-2.24</td>
<td>2.19 (2.9)</td>
<td>20.24</td>
<td>-.99 (2.5)</td>
</tr>
<tr>
<td>100% Ext.</td>
<td>.88 (5.3)</td>
<td>9.06 (9.2)</td>
<td>5.4 (5.9)</td>
<td>7.18 (9.9)</td>
<td>18.08</td>
<td>1.25 (1.8)</td>
</tr>
<tr>
<td>50% Ext.</td>
<td>6.2 (19.8)</td>
<td>1.99 (9.7)</td>
<td>4.12 (5.4)</td>
<td>3.38 (3.3)</td>
<td>15.02</td>
<td>1.55 (2)</td>
</tr>
<tr>
<td>Control</td>
<td>-1.5 (4.5)</td>
<td>-2.61 (16)</td>
<td>1.25 (6.1)</td>
<td>-.55 (3.4)</td>
<td>4.5 (38.3)</td>
<td>-.54 (2.1)</td>
</tr>
</tbody>
</table>

Note. Most muscle groups in all the intervention groups demonstrated an increase in strength, whereas the control group either showed a decrease in strength or minimal strength gains. The standard deviations show the significant variability in muscular strength.

Table 4 Mean difference in muscular strength from baseline to the 6 week data collection point for four exercise intervention and one control group, for six muscle groups (standard deviation in parentheses)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Tricep (4.9)</th>
<th>Bicep (8.3)</th>
<th>Flexor (4.8)</th>
<th>Extensor (13)</th>
<th>Hand (34)</th>
<th>Pinch (9.4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Flex</td>
<td>-1.11</td>
<td>4.21</td>
<td>1.56</td>
<td>-2.62 (13)</td>
<td>20.86</td>
<td>.255 (9.4)</td>
</tr>
<tr>
<td>50% Flex</td>
<td>3.68 (3.6)</td>
<td>1.61 (7)</td>
<td>-.81 (2.3)</td>
<td>.78 (3.6)</td>
<td>11.82</td>
<td>.700 (2.9)</td>
</tr>
<tr>
<td>100% Ext.</td>
<td>2.22 (5.6)</td>
<td>13.12 (13)</td>
<td>5.65 (7.2)</td>
<td>9.21 (12)</td>
<td>25.86</td>
<td>3.02 (4.3)</td>
</tr>
<tr>
<td>50% Ext.</td>
<td>4.96 (11)</td>
<td>3.14 (12)</td>
<td>6.49 (9.5)</td>
<td>5.25 (5.9)</td>
<td>2.25 (36)</td>
<td>3.58 (2.3)</td>
</tr>
<tr>
<td>Control</td>
<td>1.41 (3.4)</td>
<td>1.88 (7.6)</td>
<td>.28 (4.2)</td>
<td>-2.92 (9.6)</td>
<td>-.84 (46)</td>
<td>-.94 (3.1)</td>
</tr>
</tbody>
</table>

Note. Just as in the three-week data collection point, most muscle groups in all the intervention groups demonstrated an increase in strength, whereas the control group either showed a decrease in strength or minimal strength gains. The standard deviations show the significant variability in muscular strength.

Furthermore, there was a significant interaction effect among the six muscle groups, the three time periods, and the five subject groups (F=1.53, p=.035). However, the Mauchly’s Test of Sphericity revealed that the sample had a high degree of variance in strength across time [$\chi^2 = 0.61 (2), p=.737$]. Thus a major assumption for the use of this statistical test was violated. Despite this violation, several additional analyses were performed.

To explore the specific group differences over time and muscle area, the Tukey comparisons were examined. Significant differences in flexor muscle strength were found between the control group and the 100% extensor exercise group after six weeks of exercise training (p = .049). Likewise, a significant difference in bicep muscle strength was found
between the same two groups after six weeks of exercise (p=.025). Two additional significant group comparisons were found between the control group and the 50% extensor exercise groups. This exercise group demonstrated greater increases in flexor (p=.003) and extensor (p=.039) muscles over the six weeks.

Because there were baseline differences in muscle strength by work (plant) site where subjects were employed, additional multivariate analyses were performed. Plant was considered as an additional between subject variable in a multivariate analysis of variance that was set up with the same variables as the main analysis. No significant main effect or interaction effect was found (p>.05).

Another approach to explore whether there were differences in exercise effect was done by combining the two flexors into a single group and doing the same for the two extensor training groups. No additional significant findings were uncovered when exercise groups were collapsed.

In a final effort to unveil additional significant group differences over time, a series of repeated measures ANOVAs were performed in which six tests were done. These results will be reported by muscle group.

Overall significance was found for an increase in strength in the triceps muscle over the six-week exercise program (p = .010). An overall plant effect was also seen (p = .031), and a post hoc Tukey test showed significance between plants one and two (p = .004). Although there was not enough of a difference to demonstrate an overall group effect (p = .189), contrast analysis between the groups showed a significant difference between the 50%-extensor and the control group (p = .016). Only one interactive effect was seen, plant by week (p = .043).
The bicep muscle showed overall significance for increased strength after the six-week period (p = .047). A plant effect was also seen (p = .028), and contrast analysis showed this was significant between plants one and two (p = .005).

Forearm flexor muscles showed an overall significant effect (p = .029). A plant effect was again found (p = .047). Contrast analysis showed the plant effect was significant between plants one and two (p = .010).

Forearm extensor muscles showed an overall significant effect (p = .029). An overall group effect was not strong enough to be significant (p = .162), however, contrast analysis showed that there was a significant effect between 50%-extensor group and the controls (p = .015). A plant effect was seen (p = .013), and a post hoc Tukey test showed the plant effect was significant between plants one and two (p = .026).

Handgrip had an overall significant change over the six weeks (p = .009). Even though an overall group effect was not seen (p = .234), contrast analysis showed a difference between 50%-extensor group and the controls (p = .042).

The pinch grip only showed an overall group effect, with contrasts showing significance between 50%-extensor group and the controls. The plants did not show an overall significant difference in strength, however a post hoc Tukey revealed a significant difference between plants one and two (p = .016).

Research Question 2. - Discomfort Changes

The second research question asked “What is the difference in localized discomfort of the upper extremity across four exercise training programs, maximum flexor, 50% flexor, maximum extensor, or 50% extensor exercises of the hand and arm and a control group?” The Discomfort Visual Analog Scale (VAS) was used to measure discomfort in the upper extremity.
The within group factor was the time interval: baseline, three weeks post intervention, and six weeks post intervention. Significance was found for the main effect of group changes in the VAS across the six week period \( [F=43.85, (2,62) p = .000] \). The interaction effect between treatment group and time point was likewise significant \( [F=4.53, (8,126), p = .000] \). See Table 5 for the mean discomfort scores for each group at the three time periods. Of interest, when discomfort was examined by plant site, there was not significant difference over time \( (p=.54) \).

### Table 5  Baseline, 3 week, and six week mean visual analog scale scores measuring discomfort

<table>
<thead>
<tr>
<th>Group</th>
<th>Baseline</th>
<th>3 weeks</th>
<th>6 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Flex</td>
<td>50.2</td>
<td>22.1</td>
<td>20.1</td>
</tr>
<tr>
<td>50% Flex</td>
<td>54.5</td>
<td>16.1</td>
<td>4.8</td>
</tr>
<tr>
<td>100% Ext.</td>
<td>56.9</td>
<td>32.5</td>
<td>21.2</td>
</tr>
<tr>
<td>50% Ext.</td>
<td>50.9</td>
<td>23.5</td>
<td>23.5</td>
</tr>
<tr>
<td>Control</td>
<td>39.3</td>
<td>41.7</td>
<td>40.9</td>
</tr>
</tbody>
</table>

**Note.** The mean scores show a statistically significant drop in discomfort from baseline to 3 and six weeks post exercise.

### Summary

Two main research questions were asked. There was mixed improvement in strength after participating in exercise training when using the planned analysis. The assumption of sphericity was violated indicating that the amount of variability across intervention groups and variables was high. Furthermore, the control group had greater strength than all intervention groups at baseline. Additional analyses were performed to examine the effect of the intervention considering these two major concerns. Results from these found greater significant changes in muscle strength with training. The extensor groups generally demonstrated greater increases in strength in selected muscle groups.

Improvement in discomfort was statistically significant in the exercise groups over time. Sphericity was not violated with this analysis. The largest reduction in discomfort was found in
the 50%-flexion exercise group. Furthermore, there was additional support for improvement in symptoms and function after intervention.
Chapter V

Discussion

The purpose of this study was to explore the role of exercise training to increase muscular strength and decrease discomfort in workers doing repetitive motion tasks. The types of exercises were flexion or extension, and were done at two intensities, 100% and 50% of maximum capacity. This study was based on the interplay of science from three separate disciplines, Biomechanics, Exercise Physiology, and Ergonomics. A model for developing CTDs was presented including factors from the three disciplines.

A convenience sample of 70 subjects doing occupational repetitive motion tasks from three sites participated in the study. Thirty-two women and thirty-eight men with an age range of 21 to 59 years were included. Subjects were randomly assigned to one of four intervention groups and a control group. Ten intervention subjects equally divided across groups, and one control subject dropped out of the study. The reasons given for dropping out of the study were not enough time to do the exercises or a medical condition. All subjects dropped before the three-week data collection point.

Discussion of Results

Research Question #1

Research question one examined the increase in strength of the upper extremity following exercise training at 100 and 50 percents of maximum training intensity. The exercise types were either flexion or extension, and were each done at the two intensities.
**Study Findings.** When examining and interpreting the results in this study, there are two concerns that must be kept in mind. The control group was stronger than the experimental groups at baseline, despite the random assignment to the groups. This unusual situation makes comparison of intervention groups to controls problematic. In addition, there was a high degree of variability within groups, thus violating the assumption of sphericity. The planned analysis did not demonstrate significant findings in all of the anticipated main effects and contrasts.

However, the additional univariate analyses did find a significant difference in intervention groups over time. Because the number of analyses increased with the change from multivariate to univariate statistical tests, there is a greater risk of a type II error. It is possible that some of the statistically significant univariate results could have occurred by chance.

It must be noted that even though the absolute values of the groups may have been unequal at baseline, there was a significant increase in strength across all muscle groups over the six-week exercise training for all the intervention groups, but not the control group. The results of this study show an overall increase in strength with exercise training in all exercising groups, but did not show a difference between the groups. It should be noted that in the post hoc statistical analysis, some of the intervention groups showed an increase in strength as compared to the control group, but only in one muscle group. For example, there was a significant increase in strength in both the 100%-extensor and 50%-flexor intervention groups but only in the flexor muscles of the forearm. Likewise the 50%-flexor group developed significant strength in the forearm extensor muscles, and the 100%-extensor group showed increases in the extensor muscles. The results are not easily interpreted. The combination of the stronger control group, and the high variability of the strength data only allow for interpretation that all the exercise interventions increased strength, but do not delineate which group was most effective.
The results of this research support the premise that exercise training increases muscular strength. This premise is also widely supported in the literature (Fox et al., 1989; Genaidy et al., 1994; Howley & Franks, 1986; McArdle et al., 1996). One notable aspect of the strength changes that occurred with exercise training for all groups in this study was that most of the increase in strength occurred during the first three weeks of exercise. The increase in strength between the three and six-week data collection points was substantially smaller.

It is also interesting to note that the subjects reported a preference in exercise type. Those using the Powerball\textsuperscript{TM} for flexion exercise appeared to enjoy the exercise training more than those using the Carpal Care\textsuperscript{TM} band for extensor exercises. Following the six-week exercise training period, many subjects expressed an interest in keeping or purchasing the Powerball\textsuperscript{TM}. One of the three companies participating in this study is in the process of purchasing the Powerball\textsuperscript{TM} for use with their employees doing repetitive motion. Despite the preference for exercise type, both flexion and extension exercises resulted in similar increases in strength.

Research Question #2

The second research question is concerned with the amount of discomfort experienced by workers doing repetitive motion jobs. It would be expected that with exercise training and accompanying increases in muscular strength, the amount of fatigue experienced by the worker would be diminished, as would localized discomfort.

The visual analog scale showed a significant drop in discomfort at three and six weeks post exercise. The greatest drop in localized discomfort was after three weeks of exercise training. A second drop was seen after the six-week of exercise training, but the change was not as dramatic.
When subjects were asked after three and six weeks of exercise training if the exercise changed how they felt. Most people reported a feeling of being stronger while they were doing their usual jobs. Those that were pulled to different, more strenuous jobs during the study period stated that they did not get as fatigued or tired from the temporary job switch, whereas this type of switch in the past would have left them very fatigued. Finally, many people stated they were not as tired after their eight-hour shift after both three and six weeks of exercise training.

The drop in discomfort lends support to the theoretical framework presented in this study. According to the theoretical framework, increasing strength acts to attenuate muscular fatigue during occupational tasks such as repetitive motion. Reducing fatigue reduces the sensation of localized discomfort in the upper extremity (Fox et al, 1989; McArdle et al., 1996). The reduction in discomfort supports the basic underpinnings of the theoretical framework: Exercise training, which leads to an increase in strength, can reduce fatigue, which is manifested by the level of localized discomfort. However, this conclusion must be viewed with caution because the violation of sphericity for the strength data must be considered. The increases in strength based on the multivariate statistical analyses may be due to chance error. On the other hand, the mean scores for changes in strength from baseline to three and six weeks did show substantial increase in strength for all muscle groups. This latter aspect of the analysis supports the premise that strength was increased from exercise training, but the violation in sphericity must always be considered in this conclusion.

The results in this study regarding localized discomfort did not statistically distinguish between the types of exercise protocols, flexion or extension type exercises. Nor was there a distinction between the two exercise intensities used, 50% or 100% of maximum intensity. All the intervention groups had a dramatic drop in discomfort. However, it was noted that the 50%
flexor group had the greatest drop in discomfort over the six-week exercise training period, dropping from 54.5 mm to 4.8 mm on the visual analog scale.

Exercise appears to be an effective intervention, however the optimum type of exercise or exercise intensity was not statistically determined in this study. It may be easier to see the differences between the groups if the groups were more homogeneous or by using one intensity of exercise level for each of the two exercise types, flexion and extension.

Threats to Internal Validity

Internal validity allows the investigator to assess if the design takes into account a clear casual relationship and if the control exists of all other possible contributing extraneous variables (Black, 1999). Internal validity refers to the degree to which it can be inferred that the observed effects are true and the findings can be shown to result from the effects of the independent variable (Cook & Campbell, 1979; Polit & Hungler, 1995). Six threats to internal validity will be discussed. A description of the six threats to internal validity will first be presented, followed by a discussion of the effects of these threats in this study.

Testing

Testing is a threat when an effect might be due to the number of times a person is tested (Cook & Campbell, 1979; Polit & Hungler, 1995). Familiarity with the test can affect the dependent variable when the subject is repeatedly evaluated.

Instrumentation

Instrumentation refers to the measuring tools in the study. This is a threat when the effect on the dependent variable may be due to a change in measuring instruments between data collection days (Cook & Campbell, 1979; Polit & Hungler, 1995).
A mechanical failure of the strength testing equipment occurred in this study on the first data collection day for 18 subjects. These subjects were dropped from the analysis for strength testing. Perhaps inclusion of these individuals would have produced more significant differences.

Selection

Selection is concerned with the subjects in the groups being substantially different at the onset of the study. This is a threat when an effect may be due to the difference between the kinds of people in the experimental groups (Cook & Campbell, 1979; Polit & Hungler, 1995).

In this study the mean baseline strength of the workers in each group was statistically different for three of the six muscle groups. The biceps, extensors, and pinch grip revealed a difference between the groups. However, all the groups had significant increases in muscle strength during the study period except the control group. When the subjects in the groups are substantially different on a key measure this must be considered as a threat to internal validity.

Mortality

This is a threat when an effect may be due to the different kinds of people that dropped out of the study than those remaining in the study (Cook & Campbell, 1979; Polit & Hungler, 1995). With this threat the experimental groups at the later data collections points could be different than the earlier or baseline data collection point. This was the case with the global health survey taken at the onset of the study. All subjects entering the study declared at least 20 mm of discomfort on the visual analog scale. Therefore all subjects had some discomfort. However, the mean physical composite scores on the global health assessment of those dropping out of the study were higher than those remaining in the study. This indicates a higher level of physical functioning and lower discomfort level for those that dropped from the study. This may
indicate that those who dropped from the study were different than those who remained. It is important to note that the subject dropouts were across all five groups, so the proportions of the groups were not substantially affected. Even with the groups having approximately the same composition, this may be a threat to internal validity.

A second threat to internal validity with respect to mortality occurred with those subjects whose strength data was excluded due to the mechanical failure of the testing equipment. It is not known if these subjects would have altered the outcome of strength results in this study.

Estimating Threats to Internal Validity in This Study

Randomization of subjects removes many of the threats to internal validity. With random assignment of subjects to treatment and control groups, each group is similarly constituted on the average, removing selection and maturation threats (Cook & Campbell, 1979; Polit & Hungler, 1995). However, in the case of this study, the initial mean strength measure on three muscle groups was statistically different. More importantly, the control group was stronger on five of the six muscle groups. This opens this study to the possibility that there was selection bias for the subjects.

The groups included in the analysis experienced the same testing equipment and instruments, removing the threats of testing and instrumentation. The subjects tested with faulty strength testing equipment were excluded from that part of the analysis.

Finally, the eight male and two female subjects who dropped out of the study were in all different the treatment groups. However, even if there were treatment-related differences in who drops out of the group, this is interpretable as a consequence of the treatment. However, in this case, there was evidence that those dropping out of the study were at higher levels of subjective
physical functioning, and experienced less discomfort. This is a threat to internal validity and is a limitation of this study.

Random assignment to treatment and control groups is usually the most effective approach of managing the threats to internal validity (Polit & Hungler, 1995). Randomization produces a canceling out of individual variations. The repeated measures design also helps cancel out individual variation, as the same person is measured more than once over a period of time. However, some threats to internal validity may be an issue in this study. It is important to note that although some threats to internal validity may exist, the subject remained equally distributed within the groups.

**Threats to External Validity**

External validity ensures that both the study’s samples and conditions under which the study is carried out are representative of the population and situations to which the results are applied (Black, 1999). It is the extent to which study findings can be generalized to the population (Cook & Campbell, 1979; Polit & Hungler, 1995). Campbell and Stanley (1963) outlined the threats to external validity and have identified three areas of concern.

**Interaction of Selection and Treatment**

This threat concerns the type of people that were entered into the study. The question here is can the results of this study be generalized beyond the group used to establish the initial relationship (Campbell & Stanley, 1963).

The study’s sample was similar to the ethnic composition of the Cincinnati population, with slightly greater ethnic representation. The greater Cincinnati area reports approximately 11 percent African Americans, and the research study had 17 percent (Who we are, 1991). Likewise, Cincinnati has approximately one percent Hispanic and Asian Americans, and the
study had six percent. However, these statistics are difficult to interpret. Those working in industry are a subculture of the population of Cincinnati, and it is not known if the ethnic composition is similar.

Although the prevalence of CTDs by race has not been clearly reported in the literature, one study noted that the greatest percentage of subjects with CTDs in the study was of Caucasian descent. In a study by Tanaka et al. (1995) more Caucasian subject had carpal tunnel syndrome than all other races. In the present study, approximately 75 percent of subjects were Caucasians.

Another consideration is the gender apportions. The literature shows conflicting proportions in the prevalence of males and females developing CTDs. Most of the literature centers on the prevalence of carpal tunnel syndrome. Studies have shown that the prevalence of carpal tunnel syndrome was higher in women than men (Harber et al., 1992). Likewise, in a study by Franklin (1991) the prevalence of carpal tunnel syndrome in the general population has been reported to be 3:1 for women to men. However, this same study showed that women and men had an almost equal ratio in the occupational arena (1.1:1).

Other studies have found similar findings. Armstrong (1986) found that overall women had the highest prevalence. However, when women and men were compared on the same jobs, the prevalence was equal. It is thought that carpal tunnel syndrome appear higher in women due to the over representation of women in repetitive motion type jobs (Latko et al., 1999; Park et al., 1992).

Although there is either sparse or conflicting information regarding the prevalence of CTDs by gender, this study used the data present in the literature regarding carpal tunnel syndrome. This study used approximately equal numbers of both genders (33 females and 35 males).
The final consideration for the interaction of selection and treatment as a threat for external validity is the means for subject selection. Since workers volunteered for the study, those subjects entered in the study may be different from those who did not volunteer. Campbell and Stanley (1963) suggested the way to reduce this threat is to make entrance and participation into the study as convenient as possible. The management of each of the three plants (companies) gave their support for this study. This allowed the workers to use company time to both do their exercises and take the time away from their job for data collection. This is important for the workers as their own personal time was not used and they are getting paid for their exercise time.

Convenience for participation in this study was also enhanced by the willingness of the researcher to come to the plants based on the worker and company’s schedule. A regular schedule was established with the company and individual worker so the least disruption of the production process or worker’s schedule occurred. The researcher was also in the each plant for both shifts so as to allow an equal opportunity for all workers to participate in the study without disruption.

Although an effort was made to make participation convenient for the workers, entrance into the study was voluntary. It is possible that those who volunteer or remain in studies may not represent the population of workers doing repetitive motion tasks. Generalizing these results to workers in other occupational settings must be considered.

Interaction of Setting and Treatment

This threat to external validity addresses the setting that the study takes place. The setting of the study may have influenced the results of the study, which prevents generalization of these results to other settings (Campbell & Stanley, 1963). It is beneficial to replicate studies in
various setting to compare results. If the setting varies, but the results of the study do not, external validity improves. This study used three different types of industries and the results were similar in all three. Two of the plants had the addition of considerable force (heavy metal fabrication and foundry), whereas one plant did not (meat packing). This lends some support that the results can be generalized across groups of workers doing repetitive motion tasks.

To increase the confidence in the generalizability of these results, it is important to replicate this study in several other occupational environments. Future replication of this study in various other industries will further strengthen the findings in this study. For example, the three sites used in this study were very physically intensive. Repeating this study in occupations that are less physically intensive could broaden the generalizability of this study.

Interaction of History and Treatment

This interaction type threat to external validity is concerned with the time the study takes place and if this time can be generalized to other time periods (Campbell & Stanley, 1963). This was a concern with this study. In this study data were collected three times during a six-week period. During this time, subjects can be pulled from their regular jobs to another job that has different physical demands. This is a problem especially if the job switch was around the time or on the day of data collection. In this study, one subject was in this situation of being pulled to another job the week of and including data collection day for her three-week assessment. She reported more discomfort in the three-week assessment than was reported at baseline, and stated that the temporary job was physically difficult. However, she only did the temporary job for one week, and when she was assessed at the six-week point for discomfort, she had levels below her baseline measure. This did not disrupt the study’s results in that the six-week data point reflected this subject’s discomfort in her usual and customary job.
Another related issue with respect to history concerns the past working history of the workers in the study. The job history was assessed for the current job of the subjects. The number of years working at this plant was determined. However, the past job history was not taken because of the difficulty assessing the ergonomic exposure of past positions.

Nonoccupational exposure was also not factored into the subject’s exposure to repetitive motion. Because CTDs are cumulative, past exposures are relevant in determining current cumulative exposure. This is a limitation of this study.

Estimating Threats to External Validity in This Study

There are three issues to be discussed for the threats to external validity. The first is that volunteers are being used. Even though the management of the plants and the researcher are making it very convenient to participate in the study, those that volunteer may be different than those that do not.

Generalizability to workers outside this study population may be limited to workers with physical discomfort. The physical composite score on the general health survey for subject dropping out of the study and those remaining were vastly different. The baseline mean physical composite scores for all 85 subjects entered in the study was an 83. However, following the drop of 15 subjects from the study, the mean physical composite score was 48. The mean mental composite score on the general health survey remained approximately the same after the drop of subjects. The high initial mean physical composite score is indicative of a physically healthy group. The drop of 35 points with the loss of subjects indicates that those remaining in the study were physically less healthy on a subjective measure. This may show that those in the study are selectively biased towards workers with greater physical symptoms. The generalizability to all workers doing repetitive motion tasks may be limited.
A second limitation of this study is the inability to determine cumulative ergonomic exposure to repetitive motion from past occupations. This becomes important when making a profile of the worker in this study.

Finally, generalizing to other occupational settings outside the three plants will be difficult. Replication of this study in different occupational settings such as for transcriptionists would improve the generalizability of the results.

Implications for Nursing

The results of this study have implications for theory, nursing practice, and nursing research. A discussion of these will be presented.

Nursing Theory

The theoretical framework for this study is based on the physiologic model of CTDs developed by the researcher in this study. The theoretical basis for this model was drawn from three disciplines, Biomechanics, Exercise Physiology, and Ergonomics. Concepts from the interplay of these disciplines describe the physiologic development of CTDs. While the theory was derived from other disciplines, nursing has long had an interest in exercise intervention. Health promotion and exercise are core concepts in at least one nursing theory, and implied in another theory (Newman, 1994; Pender, 1982)

In this model, the combination of biomechanical and physiological factors leads to both a transient strain and an increased pressure in the carpal tunnel. The added ergonomic factor of repetitive motion prevents the strain from healing, and ultimately can lead to a persistent increase in pressure in the carpal tunnel. This results in pathological changes in the soft tissues of the upper extremity.
Three hypotheses described earlier were used in this model to describe the pathologic changes that occur from repetitive motion and result in an alteration in physiologic function (Novak & Mackinnon, 1998). The first hypothesis describes the direct pressure on the median nerve. The second hypothesis characterizes the muscular tightness that occurs in the flexor muscles of the upper extremity. The shortened and tightened flexor muscles were discussed in terms of a direct pinching of the nerve in the upper extremity. This hypothesis was also expanded to describe the inefficiency of the shortened and tightened muscles and how this can lead to premature fatigue. Finally, the third hypothesis espoused an imbalance in the muscles across the joint as the reason pathologic changes occurred in the soft tissues with repetitive motion.

The pathological changes in soft tissues are mediated by individual factors. The individual factors such as diabetes and body mass index affect the vulnerability of the worker to developing CTDs (Nathan & Keniston, 1993). Physiologic alterations occur in the soft tissues that affect the function of the muscles and nerves.

The pathological changes in the soft tissues that develop from doing repetitive motion tasks either directly or indirectly result in a muscular fatigue and discomfort in the upper extremity. Muscular fatigue and discomfort is the center of the model and a significant determinant to the development of CTDs. Fatigue and discomfort reduces the strength of the muscles, which further leads to fatigue.

An intervention that increases muscular strength can directly alter the fatigability of the muscles. Increasing strength will reduce fatigue and discomfort, and according to the model, reduce CTDs.
Increasing muscular strength can result in less or delayed fatigue and discomfort. However, the question remains as to which muscle groups to strengthen. The model in this study provides physiologic reasons that support the strengthening of the flexor group or the extensor group of the upper extremity. This study strengthened both muscular groups and compared the results of this exercise training.

The physiologic model for the development of CTDs designed in this study was supported by these results. The intervention of exercise training increased strength, and discomfort was reduced. The implication of this theoretical model to nursing is that nurses can use this model to guide an exercise protocol to increase strength, decrease discomfort, and reduce CTDs in workers doing repetitive motion tasks.

The area of the model not tested concerns the mediating factors of the workers. Mediating factors are those characteristics of individual workers that determine the vulnerability to developing CTDs from doing repetitive tasks. Although there were some potential mediating factors described in this study such as a positive Phalen and loss of sensation of the fingers, this area of the model was not tested.

Nursing Practice

This study has significant implications for nursing practice. Nurses in the field of Occupational Health must deal with CTD issues if their companies have jobs that entail repetitive tasks. The Occupational Health Nurse (OHN) often initially treats workers with CTDs on-site. The nurse treats workers with ice or heat or non-steroidal anti-inflammant medication. The worker is sent back to the same job after treatment. As symptoms progress and become more persistent, the worker is sent to seek off-site medical care from a physician. The employee
is taken off work for a period of time until the problem resolves. When returning to work the employee often transitions into their regular job by doing a less physically demanding job.

As an alternative to treating existing CTDs, the OHN can institute an exercise program for those workers at risk for developing CTDs. Exercise is recognized as a nursing intervention (McCloskey & Bulechek, 2000). This study provides a scientific basis to implement such a program based on the physiologic model developed in this study. Instituting an on-site exercise training program would be a beneficial nursing intervention for the company and the individual worker.

The optimum way to start an exercise intervention program is to do a classroom session of the employees to inform them of the importance of participating in the exercise training. The next factor is to integrate the exercise program within the employees’ workday, providing the necessary time, equipment, and space to do the exercises. The nurse should also have a qualified consultant to address exercise prescription, exercise adaptation, and injury related questions. The final factor is to provide an open forum between the workers and the nurse regarding the positive and adverse effects of the exercise training.

Recommendations for Research

There are six important implications for nursing research. The first is to repeat this study with more homogeneous sample. Using workers that were similar in strength, either very strong or very weak would accomplish this. It may also be helpful to use companies with similar manufacturing processes. The more homogeneous groups may allow the difference in the intervention groups to be seen.

The second recommendation would be to repeat this study using only two intervention groups (extension exercise and flexion exercise), using a single exercise intensity. This would
serve to narrow the dependent variable when testing for strength so that the changes in this variable may be more apparent. It may also be helpful to reduce the number of muscles tested for the same reason, testing only three muscle groups (forearm flexors, forearm extensors, and handgrip). These three muscle groups are most directly affected by the exercise intervention.

The third recommendation is to replicate this study, but adapt the exercise training to train both the flexor and extensor muscles. This study found that exercise, both flexion and extension, leads to increased strength, and a decrease in localized discomfort. Combining the two types of exercise may show results that are even more dramatic. Two comparison exercise groups could be added that include only stretching of the upper extremity and one that does both stretching and flexion and extension exercises.

The forth recommendation for nursing research is to replicate this study using the premise espoused in the physiological model for developing CTDs, but use another type of exercise instrument to work the same muscle groups. For example, an exercise rubber band can be used to exercise train both the flexor and extensor muscle groups. Using another means to exercise the muscle groups supports the physiologic model without the attachment to a specific exercise protocol.

The fifth recommendation is to replicate this study with subjects having higher physical function as assessed using the Short Form –36 General Health Assessment. In this study, the 15 subjects who dropped out of the study had higher physical composite scores (pcs) than those remaining in the study. The question remains if these subjects were substantially different from those remaining in the study. It is recommended to replicate the study with the same requirements for the level of discomfort on the visual analog scale (i.e., 20-mm), but require a pcs score of greater than 65 for inclusion into the study.
The sixth recommendation is to repeat this study, but include an assessment and analysis of the effect of mediating factors from the individual workers. Those factors most associated with CTDs are body mass index, wrist size or ratio, smoking, and drinking (Nathan, 1993). In this way the physiologic model developed for this study can be further tested.

Conclusion

The increase in strength and decrease in discomfort supported the theoretical model espoused in this research study. Exercise training increases strength, which then decreases fatigue and the sensation of localized discomfort. However, the type or intensity of exercise most effective in increasing strength and decreasing discomfort was not borne out in this study. Several recommendations for future research were presented that may assist in delineating the optimum type and intensity of exercise training for those at risk for developing CTDs.
References


control musculoskeletal symptoms? Journal of Occupational Medicine, 30(12), 922-927.


Worksafe Australia. (1986). RSI training package. Canberra, Australia, AGPS.


Appendices

Appendix A

Strength Testing Equipment
Hanoun Medical, Inc.
Strength testing equipment

Hanoun Medical
12 Ashwarren Rd.
Downsview, ON.
M3J126
Canada
1-800-461-6888
1-416-398-9108
Appendix B

Job Analyses

Company: Meat Packing

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Company: Heavy Metal Fabricating

### Job: Track Mobile Operator

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### Job: Assembly/Drill Operator

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### Job: Welder/Grinder

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## Job: Shakeout/Pour off

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Appendix C

Note to treating physician requesting consent to enter patient in this research study

JoAnn Randolph  
307 Oxford Ave.  
Terrace Park, Ohio, 45174  
831-5018  
831-1935 (fax)

September 11, 1998

Dear Physician,
I am writing you in regards to your patient___________________________________________.
I am an Occupational Health nurse who has worked in the Cincinnati area for 16 years. I have a masters 
in exercise science, and I am currently attending the University of Cincinnati in pursuit of my PhD 
degree in Occupational Health Nursing. My research interest is the conservative management and 
prevention of cumulative trauma disorder. I am presently involved in a study that uses exercise training 
to reduce the localized discomfort from doing repetitive tasks. Your patient will either be doing flexion 
or extension exercises of the shoulder, arm, and hand.

I have obtained permission from the Institutional Review board of the University of Cincinnati Medical 
Center and the Veterans Administration Hospital. Participation in the study entails completing six weeks 
of exercise five times per week. Exercises will take from approximately 5 minutes per day. Data 
collection will consist of a limited upper extremity physical exam, measuring localized discomfort using 
a pencil and paper survey, and strength measurements of the upper extremity. A medical history and 
symptom survey will also be conducted.

Attached you will find a form that you can complete and return to me in the stamped and addressed 
envelope. If you have any questions, or would like a full copy of the proposal please contact me. I do 
appreciate your consideration of this request.
Sincerely,
JoAnn K. Randolph, PhDc, M.S., R.N.
Permission to Recruit Patients

Please sign and complete the attached form regarding participation of your patients in the study "Comparing resistance exercise training to tendon gliding exercises for reducing localized discomfort and increasing strength in workers at risk for developing carpal tunnel syndrome" conducted by JoAnn Randolph, PhDc, M.S., R.N.

_____ Yes, you may recruit my patient,_______________________________________

_____ No, you may not recruit my patients for your study.

_____ I would like more information about the study before I make a decision regarding recruiting my patients.

__________________________________
Name (please print)

_______________________________________________
Signature Date

Use this space for any specific requests or comments concerning the study.

__________________________________

_________________________________________

_________________________________________

_________________________________________

This form may be faxed to JoAnn Randolph at (513) 831-1935
Appendix D

Medical History Form

Time of assessment: ________ (Military Time): Pre-shift ___ Post-shift _______
Name: __________________________ Phone: __________________ Sex: male/ female
DOB: _____ age____ Wrist size: ___ cm. Height:_______ Weight:_______ BMI____
B/P:_________ Pulse:____________ Resp:__________(taken after 5 minutes of sitting)
Dominant hand: Right / Left Study hand: Right / Left
Assessment of extremity:
Deformities________________________________________________________
Scars________________ Other_______________________________________

Range of Motion with goniometer:
Wrist: Flexion____ Extension___ Radial dev. ___ Ulnar dev.____
Phalen sign_______ Semmes-Weinstein: 2nd digit___________ 5th digit________
Job title:_________________________ Job description:____________________
________________________________________________________________________
In your job how often do you….

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Company______________________ Contact person________________ Phone_______
Employed # hours per week________ Self employed____ Yes No
Duration of current job:________________________
Last job if occurred within one year________________________________________
Have you had a…….
Worker’s comp claim to upper extremity yes no date__ Explain________
Surgery to your extremity yes no date__
Explain________________________
Carpal tunnel surgery to study hand yes no date____
Non-study hand yes no date____
Injury to your neck yes no date__ Explain_______
Injury to your shoulder yes no date__ Explain_______
Injury to your elbow yes no date__ Explain___________
Injury to your arm, wrist, or hand  yes  no  date  Explain

Diabetes  yes  no (shots, pills, diet, or none)
Thyroid disease  yes  no (medication:__________________)
Cardiovascular disease  yes  no  Date of Dx_______
   Explain___________________________________________________________
Cardiovascular medicine  yes  no  Medication________________________
Are you currently under a doctor’s care for:
  • Cardiovascular disease  yes  no  
    Explain___________________________________________________________
    Doctor_______________________ phone______________________________
  • Upper extremity problems  yes  no  
    Explain___________________________________________________________
    Doctor_______________________ phone______________________________
  • Other____________________________ yes  no  
    Explain___________________________________________________________
    Doctor_______________________ phone______________________________
  • Are you taking any medications  yes  no

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PRN meds

Are you currently pregnant  yes  no
Have you been pregnant in last 6 months  yes  no
Do you smoke more than 2 cigarettes per week  yes  no
   # years smoking____ # packs per day______ pack year history______
Have you ever smoked  yes  no
   How long since you quit_______ days/ months/years
Do you drink more than 2 drinks per day  yes  no
Have you ever done so for more than 6 months  yes  no
   How long since you quit_______ days/months/years
Appendix E

Eight Subscales of the SF-36 General Healthy Survey

Physical Functioning
Role Physical
Bodily Pain
General health
Vitality
Social Functioning
Role Emotional
Mental Health