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UPPER EXTREMITY FUNCTION IN LONG TERM PARAPLEGIA AND IMPLICATIONS FOR INDEPENDENCE

by

Wendy E. Pentland MEd. BScOT(C)

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ABSTRACT

The intent of this study was to describe the effects of long term paraplegia and wheelchair use on upper limb function. Bilateral upper extremity isokinetic and grip strength, pain, and active range of motion were compared in 52 men with paraplegia (mean age 44 years; mean duration of spinal cord injury (SCI) 17 years) and 52 age and activity-level matched able-bodied men. The impact of upper limb pain on activities of daily living (ADL) performance was examined in the paraplegic sample. Strength was not significantly different between the two samples except for bilateral shoulder flexion (able-bodied stronger) and bilateral elbow extension (paraplegia stronger). Strength changed similarly with age in the two groups. The effect of duration of SCI on strength, excluding age, was significant for grip strength only. Duration of paraplegia and activity-level were better predictors of strength than age in 9 of 14 muscle groups, whereas in the able-bodied, age was the best strength predictor. Limited bilateral shoulder internal rotation and non-dominant external rotation were associated with paraplegia. Upper limb pain in the past week was associated with paraplegia (shoulder $p<.001$; elbow $p<.001$; wrist/hand $p<.001$). Reported pain prevalences for the paraplegic sample were; shoulder 39%, elbow 31%, wrist/hand 40%. The paraplegic subjects' pain intensity ratings revealed them to be experiencing mild to moderate levels of upper limb pain.

Shoulder pain was associated with duration of injury, exclusive of age ($p<.05$). Measurement of the impact of upper limb pain on 18 activities of daily living (ADL) tasks revealed pain to be experienced by the majority of subjects with paraplegia (mobility tasks 60%; self-care tasks 58%; general activities tasks 60%). However, only 23-35% had made changes in their routines, and 6-16% had sought assistance with ADL due to upper limb pain. When age was excluded, it appeared that duration of SCI was more associated with pain during ADL, but this was significant only for pain during self-care tasks. The tasks most reported to cause upper limb pain were work/school, sleep, wheelchair transfers, outdoor wheeling, and driving. These results suggest that preventative and management steps are required to ensure continued independence and quality of life in this group over time. The effect of duration of SCI suggests that limitations in upper limb function may be seen in this population at relatively young ages.

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INTRODUCTION

Traumatic paraplegia results in lower extremity sensory and motor impairment to various degrees, but implies normal function in the upper extremities. Persons with paraplegia who are required to use a wheelchair are therefore expected to achieve high levels of independence (Trombly, 1990; Pedretti & Zoltan 1990). Acquired paraplegia is an injury most common in young men (Stover & Fine, 1986). As the life expectancy of those with paraplegia now approximates that of able-bodied persons (Bedbrook, 1985), the spinal cord injured can anticipate many years of wheelchair use and heavy stresses on their upper limbs.

A few investigators have examined the prevalence and possible causes of upper limb pain in wheelchair and crutch-users, but their samples have included a mixture of diagnoses, mobility methods, and gender. To date, no study has compared these pain prevalence rates with those in the able-bodied population. Nor has any investigation examined changes in upper limb function (strength and flexibility) other than pain, in the long-term mobility-aid user, or its impact on their ability to continue performing activities of daily living (ADL).

As persons with paraplegia are beginning to live into old age, results of the interaction of long-term disability and aging are becoming apparent (Corbett, 1987; Trieschmann, 1987: Eisenberg and Tierney, 1985). Existing literature identifies age-related changes in the musculoskeletal system in the able-bodied, including declines in strength and flexibility (Rice, 1991; Vandervoort, Hayes, and Belanger, 1986; Murray, Gore, Gardner, and Mollinger, 1985). At the same time there is a large body of research that suggests that continued use and moderate stress of the muscles and joints have a positive effect on strength and tissue and joint integrity, and can in fact delay age related deterioration. However, the occupational overuse literature suggests that repetitive movements or stresses to which the musculoskeletal system is unaccustomed, can result in tissue microtrauma, with associated pain and loss of function (Miller & Topliss, 1988; Weislander, Norbach, Gothe, and Juhlin, 1989).

The ability of persons with paraplegia to remain independent rests primarily in the integrity of the upper extremities. Any limitations in upper extremity function will jeopardize these persons' ability to perform ADL tasks and their quality of life, and will impact on health care costs. It is not clear whether over many years, the upper limb would adapt to a weight-bearing role, or whether years of wheelchair use will precipitate pain and weakness that in turn will adversely affect independence.

A description of the changes in upper limb function in persons with paraplegia, relative to an able-bodied reference cohort, will suggest whether or not there is a need for specific interventions and attention to the management and prevention of musculo-skeletal problems in the upper extremities of persons with paraplegia. This could include attention to techniques of activities of daily living performance, upper extremity fitness and conditioning, sprain and strain management in the wheelchair user, and improved ergonomic design of the wheelchair user's environment and equipment. This type of information would also assist in planning for this group as they age.

With this in mind, the study was designed to answer the following questions:

1. Are there differences in upper extremity (UE) muscle strength, pain, and flexibility at the shoulder and elbow, between persons with short term (less than 15 years) and persons with long term (greater than or equal to 15 years) paraplegia?

2. Are there differences in upper extremity (UE) muscle strength, pain, and flexibility at the shoulder and elbow, between gender, age, and upper limb activity-level matched able-bodied persons and persons with paraplegia?

3. Do persons with short term and persons with long term paraplegia differ in their reports of the changes that they have had to make in their performance of activities of daily living due to problems in their upper extremities?

4. If there are differences in upper limb strength, pain, shoulder and elbow flexibility, and activities of daily living performance, between persons with short term paraplegia and persons with long term paraplegia, are these differences associated more with chronological age or duration of spinal cord injury?

Based on these questions, it was proposed to investigate the differences in upper limb strength, active range of motion (AROM), and pain prevalence between persons with traumatic paraplegia whose ages and durations of SCI ranged over 40 years, and a matched able-bodied reference cohort. It was also proposed to examine the impact of upper limb function on the paraplegic subjects' performance of specific activities of daily living.

CHAPTER ONE: REVIEW OF THE LITERATURE

1.1 Paraplegia

Complete paraplegia entails the loss of lower extremity motor and sensory function, including autonomic functions such as bowel and bladder control. Paraplegia results from severence of the spinal cord at the thoracic, lumbar, or sacral level (Burke & Murray, 1975). There are numerous possible etiologies including non-traumatic (spina bifida, poliomyelitis, intervertebral disc herniation, embolism, tumor) and traumatic (fall, motor vehicle accident, gunshot wound). The mechanism of spinal cord injury (SCI) in traumatic lesions may be flexion-rotation dislocation or fracture dislocation, compression fracture, hyperextension injury, or open injury (Burke & Murray, 1975). Lesions may be complete, in which case all neurological function caudal to the lesion is lost; or incomplete, with some combination of motor, sensory, and autonomic function preserved. Episodes of muscle spasticity may occur in regions caudal to the injury in 75% of thoracic lesions, and 58% of lumbar lesions (Burke & Murray, 1975). The spasms are thought to be due to reflex muscle activity that can no longer be inhibited by supraspinal impulses from the brain. Those with complete lesions tend to suffer less from spasms than those with incomplete lesions (Burke & Murray, 1975).

As opposed to quadriplegia, where the spinal cord is damaged at the cervical level, subjects with paraplegia have no disturbance of the neurological function of the upper extremities. Depending on their level of lesion they will have impairment of portions of trunk, abdominal, and hip musculature (Bedbrook, 1985). Table 1.1 has been constructed to give an indication of the muscles innervated and functional capabilities in persons with lesions at various levels. The functional abilities outlined assume the paraplegic to be a healthy, athletic male who has no spasticity, decubiti or contractures, and who has developed and maintained sufficient strength and endurance.

Table 1.1 Functional ability in paraplegia.

Lesion Level	Muscles Innervated	Functional Capabilities
T6	Upper intercostals Long muscles of the back	Limited endurance Limited trunk control Independent in self-care and light to moderate housekeeping Independent in wheel-chair transfers Drives with hand controls Can work and do some heavy lifting from sitting
T10	Majority of intercostals Upper abdominal muscles	Limited endurance and trunk control but improved functional ability from T6 Requires wheelchair for mobility
T12	All intercostal and abdominal musculature Minimal hip flexors and adductors	Improved endurance and trunk control Most require wheelchair for mobility Independence possible in self-care, work, and wheelchair sports Independent in all housekeeping if house is wheelchair accessible

(Pedretti & Zoltan, 1990; Trombly, 1989; Jones, 1982)

In the absence of accurate SCI prevalence data, Young, Burns, Bowen, and McCutchen (1982) have estimated that there are 200,000 persons with SCI in the United States. The incidence of parapelgia versus quadriplegia in the U.S. is relatively equal (Stover & Fine, 1986) indicating that there are roughly 100,000 persons with paraplegia. No similar statistics could be located for Australia. However, in Western Australia (population 1.4 million) the incidence rate of paraplegia for 1982-1988 was 96 cases (Royal Perth Rehabilitation Hospital, 1989). In the United States, eighty-two percent of those sustaining SCI are male, and 61% of traumatic SCI occur in the 16-30 year old (mean=29.7 years) age group. Statistics for Western Australia in 1983-88 revealed a similar proportion (62%) of SCI occurred in the 15-35 year old age group (Royal Perth Rehabilitation Hospital, 1989). In previous decades the life expectancy of persons who sustained paraplegia was low. However, with improvements in health care and technology, their life expectancy is approaching that of the able-bodied population (Bedbrook, 1985). Therefore it has not been until recently that the effects of aging superimposed on long term paraplegia and wheelchair use have become apparent.

1.1.1 The Impact of Paraplegia

The impact of complete paraplegia on an individual's lifestyle is marked, causing a dramatic upset in lifestyle and plans (Treischmann, 1988; Spencer, 1989). The vast majority of persons with complete lesions between T1 and L2 will be forced to use a manual wheelchair as their primary method of mobility

(Guttmann, 1976; Trombly, 1989). Therefore, the methods required to complete activities of daily living (ADL) from a wheelchair differ from those techniques employed by the able-bodied person.

Many of these ADL methods are learned during the rehabilitation period, which in 1979 in the United States was 4.25 months for persons with complete paraplegia (Young & Northrup, 1979). During this period, techniques and necessary equipment are problem solved and practiced. There are common techniques of ADL, but they will vary among individuals depending on each person's abilities and the environment where they must function (Schneider, 1990; Pedretti & Zoltan, 1990). However, in all cases, since the legs are paralyzed, the arms are responsible for positioning, lifting, and moving the body weight during activities such as bed mobility; transfers to and from the wheelchair to the bathtub, toilet, bed, and car; dressing; bathing; loading the wheelchair to and from the car; housekeeping tasks; vocational tasks; and sports activities (Pedretti & Zoltan, 1990).

Despite the primary role that the upper extremity plays in independence for a person with paraplegia, there is very little research on the ergonomics and biomechanics of the upper limb during routine wheelchair activities. No empirical research was found that examined the performance of activities of daily living by individuals with paraplegia with respect to frequency, techniques, or usual routines and practices. The arm height of a person seated in a wheelchair is approximately 20 inches lower than that of the able-bodied (Diffrient, Tilley, Bardagjy, 1974). In order to function in environments designed for the arm height of the average able-bodied person, those with paraplegia who use wheelchairs must employ shoulder elevation and abduction (Diffrient, Tilley, Bardagjy, 1974). Work in these positions places greater demands on the shoulder than when it is working in a neutral posture (Newberg, 1987; Nasca, Salter, Weil, 1984).

Standards are available to construct accessible and ergonomically designed environments for the wheelchair user (Diffrient, Tilley, Bardagjy, 1974). However, the costs will depend on the extent of the changes required, and not all wheelchair users have sufficient insurance or personal resources to fund these renovations (Royal Perth Rehabilitation Hospital, personal communication, 1989). Wheelchair access in the community and public buildings has improved in recent years, largely due to revisions in building codes that legislate wheelchair accessible design, however, this often applies only to new buildings.

1.1.2 Wheelchair Transfers

Research on the biomechanics, kinematics, and techniques of wheelchair transfers performed by those with paraplegia is scarce. Various transfer methods may be used by these individuals, nevertheless the majority use some variation of the side to side lift (Trombly, 1989). For this lift, the palms are placed to either side of the hips, with the arms slightly abducted. The arm musculature then initiates, lifts, and controls the transfer of body weight across from one surface to the other. As the body weight moves between surfaces the majority is carried by one arm and then the other; for only a brief period is the weight likely evenly distributed between the upper limbs. Lesion level, and hence trunk balance and control, as well as height and different distances from the wheelchair will cause significant variations in technique (Trombly, 1989). No research was found as to the kinematics or muscle groups used by persons with paraplegia for these types of transfer.

Bergstrom, Frankel, Gaber, Haycock, Jones, and Rose (1985) examined the relationship of anthropometric measurements, technique, and ability to transfer in subjects with quadriplegia, but no similar research has been found for those with paraplegia. Bayley, Cochrane, and Sledge (1987) and

Gellman, Chandler, Petrasek, Sie, Adkins, and Waters (1988b) found that the intra-articular pressure in the shoulders and wrists of paraplegic subjects increased significantly during wheelchair transfers, and they suggested that these raised pressures may play a role in the development of shoulder pain and carpal tunnel syndrome (CTS) in this group. Pringle (1984) noted more glenohumeral displacement at the shoulder during weight-bearing in the elderly able-bodied than in a young patient with paraplegia and wondered if this is a typical change with age. He believed that the resulting vascular compression could lead to necrosis of the humeral head (Pringle, 1984).

Transfers also necessitate weight-bearing at the wrist and elbow. Wheelchair transfers are characterized by a high but brief impulse-loading on the upper limbs followed by rest. In addition to bearing weight during transfers, the paraplegic subjects' upper limbs must lift the body off the wheelchair seat periodically throughout the day in order to relieve ischial pressure and prevent decubitus ulcer formation (Merbitz, King, Blieberg, Grip, 1985). Persons who have sustained paraplegia are normally taught to perform these push-ups roughly every 20 minutes, although research has shown that compliance may be well below that rate (Merbitz et al, 1985). While the upper extremity is required to weight-bear during transfers and push-ups, no data as to usual frequncy of transfers were found, and only limited information as to push-up frequency was available. While intra-articular pressure appears to increase in the joints during these tasks, it is difficult to anticipate what frequency of task performance would be sufficient to precipitate pathology or overuse problems.

1.1.3 Wheelchair Propulsion

By far the bulk of the literature available on wheelchair use has focused on wheelchair propulsion, and the majority of this has looked at cardio-pulmonary responses and metabolic energy expenditure, as opposed to the kinematic and biomechanical aspects. Furthermore, many of the investigations used samples of young, male subjects with paraplegia who were elite athletes (Sanderson & Sommer, 1985; Higgs, 1986; Wicks, Oldridge, Cameron, and Jones, 1983) and thus a generalization of the findings to the paraplegic population as a whole is normally inadvisable.

Research has shown that mobility using the traditional manual wheelchair involves greater energy expenditure per unit distance travelled than does walking (Engel & Hildebrandt, 1974; Brattgard, Brimby, and Hook, 1970; Knowlton, Fitzgerald, and Sedlock, 1981) and becomes especially worse over rough terrain (Wolfe, 1978). Even carpet versus hard surfaces indoors has been shown to negatively affect paraplegic subjects' wheeling by decreasing mean velocity 20%, increasing mean oxygen uptake, and increasing energy costs 36-41% (Wolfe, 1978). A number of authors believe that with more attention to ergonomic design, the efficiency of manual wheelchair use could be greatly improved (McLaurin & Brubaker, 1979).

One reason that manual wheeling is seen to be so energy consuming is that it depends on the efforts of a relatively small muscle mass to produce a given power output (Engel & Hildebrandt, 1971; Miles, Critz, Knowlton, 1980). Cerquiglini, Figura, Marchetti, and Ricci (1981) also proposed, following their biomechanical analysis of wheelchair locomotion, that the mixture of isometric and eccentric contractions involved at the wrist and elbows is inefficient. The high demands on the upper limb muscles during wheelchair propulsion may predispose them to muscle fatigue, with subsequent damage and overuse problems in adjoining joint structures.

In the few studies that have examined the biomechanics of wheelchair propulsion, the results must be interpreted with caution since sample sizes were very small; n=6 paraplegic subjects (Cerquiglini et al, 1981), n=3 paraplegic subjects (Sanderson & Sommer, 1985), n=3 paraplegic subjects

(Harburn & Spaulding, 1986). Furthermore, all found low intrasubject variability in push technique, but large intersubject differences, suggesting that it may be very difficult to predict which muscle groups will be active during wheelchair locomotion. Nevertheless, some interesting findings emerged.

At slow and fast speeds of wheelchair propulsion Cerquiglini et al (1981), using electromyographic (EMG) recordings, found that the shoulder flexors delivered the majority of the propulsion power. Whereas Harburn & Spaulding (1986), also using EMG, found pectoralis major and anterior deltoid tended to be active only 0-10%. Both studies agreed that middle and posterior deltoid fibres were active during the majority of pushing. Biceps activity-levels varied between studies and subjects, but seemed to be active in the early phase at a relatively low level. Triceps activity-levels also varied. Triceps appeared to be recruited at the end of the push phase in both propulsion speeds in some subjects (Cerquiglini et al, 1981) and at low levels (Harburn & Spaulding, 1986). Both studies concluded that the shoulder muscles are the principle movers in wheelchair propulsion.

In their observations, Cerquiglini et al (1981) noted that the propulsion patterns became more complex at the higher speed, with the most displacement occurring at the shoulder, including extension to -30^0 at the start of push, and greater shoulder abduction. This is supported by Davis et al (1986) who found that sport appeared to make the largest difference in shoulder flexion and abduction strength in a comparison of elite wheelchair athletes and sedentary wheelchair users.

The relationship of upper extremity isokinetic strength to the ability to initiate wheelchair motion has been found to be greater for elbow extension than shoulder flexion (Tupling, Davis, Pierrynowski, and Shephard, 1986). Kofsky, Shephard, Davis, and Jackson (1985) found that in wheelchair users, high isokinetic strength in the arms was associated with a high VO2 Max more than was static strength. This finding suggests that isokinetic measurements of upper body strength can be an indicator of physical condition in this group and that the development of muscle strength is an important contributor to improved wheelchair mobility.

The results of the studies above suggest that measurement of isokinetic strength in the upper limbs is one important indicator of functional ability in wheelchair users. It appears that shoulder and elbow muscles all contribute in the push phase, with individual variations. Therefore, until more data are available, strength in shoulder flexors, extensors, abductors and elbow flexors and extensors, as well as grip strength, should be measured.

Biomechanical research into other daily activities performed from a wheelchair could not be found. More data are needed as to average frequencies of tasks performance, and the techniques and equipment used. Tasks of interest would be transfers, loading the wheelchair into and out of the car, and average distances wheeled.

1.1.4 Aging With Paraplegia

Today, the life as an individual with paraplegia is very different than in previous decades. Not only has improved health care extended survival time, but the Independent Living Movement, International Year of the Disabled, and Paralympics are but a few of the indicators that there are now many more opportunities for living independently, being employed, and engaging in activities never before considered possible (rock climbing, rowing, airplane flying, motorcycle riding) (Trieschmann, 1988).

The needs of the aging spinal cord injured population are only recently coming to the attention of health care professionals and research funding agencies (Eisenberg & Tierney, 1985). In research and health care, efforts have tended to focus on emergency and acute management of SCI, and now statistics are showing that there are growing numbers of aging SCI requiring medical care. There is, therefore, a need for research that describes the nature and needs of this population so that they can be dealt with appropriately (Eisenberg & Tierney, 1985; Krause & Crewe, 1990).

In the few long term followup studies published on the spinal cord injured, aging has been found to predict length of stay in hospital (Meyers, Branch, Cupples, Lederman, Feltin, and Master, 1989) and to affect activities of daily living (ADL) performance more seriously than in the aging able-bodied (Nakajima & Honda, 1988). Decreased independence and more unmet ADL needs in SCI were associated with more visits to hospital emergency (Meyers et al, 1989), and therefore has implications for both the individual, their family (Nakajima & Honda, 1988), and society. Based on their follow-up of 72 persons with long term SCI (mean duration of SCI= 110 months), Hjeltnes & Jansen (1990) reported that high physical endurance was related to fewer medical complications and greater ADL independence. They advocated regular physical activity to enhance well-being in this population (Hjeltnes and Jansen, 1990).

Wright, Catterall, and Cook (1965) examined subjects with paraplegia and found higher levels than are usual in the general population, of genito-urinary infections, osteoporosis in the feet, persistent edema, digit clubbing, and sacro-iliac joint changes. It has also been suggested that due to the sedentary nature of life in a wheelchair, those with long term paraplegia develop a greater than average percentage of body fat and may be at increased risk of coronary heart disease (Sedlock & Laventure, 1990).

Persons with long term spinal cord injuries have been shown to have an incidence of post-traumatic syringomyelia of 0.3 to 2.3 percent (Watson, 1981; Williams, Terry, Jones, McSweeney, 1981; Barnett & Jousse, 1976). Pain, and sensory and motor changes develop in the upper limbs in those with syringomyelia (Watson, 1981; Rossier, Foo, Shilitto, Naheedy, Sweet, Dyro, Sarkarati, 1981) and this is thought to be related to the formation of cystic cavities in the spinal cord above the lesion level (Williams et al, 1981; Griffiths & McCormick, 1981).

In Japan, paraplegics have been shown to be at greater risk of diseases normally associated with old age including heart disease, diabetes, hypertension, and cerebrovascular accident (CVA) (Nakajima & Honda, 1988). Ohry, Shemesh, and Rozin (1983) hypothesized based on their clinical experience and the literature that chronic spinal cord injured persons (duration greater than 15 years) are prone to premature aging. Their observations were primarily of systemic age changes such as decreased immunity, increased hypertension, atherosclerotic heart disease, and changes in the regulation of body functions.

The spinal cord injured are themselves noticing changes with age and duration of SCI and have reported some of these in their newsletter "Spinal Network". They reported declining energy levels, more frequent bladder infections, increased numbers of pressure sores, more tendonitis and bursitis, more shoulder problems, carpal tunnel syndrome, ulnar nerve syndrome, and arthritis, among other problems (Corbett, 1987). Trieschmann (1987), interviewed persons aging with a variety of disabilities, and found the older spinal cord injured subjects complained of increased fatigue, and shoulder, elbow, and wrist problems. She also found that more musculoskeletal problems were reported by persons with paraplegia, or those with quadriplegia who transferred independently. She suspected that the greater prevalence of problems in the group with paraplegia was secondary to their greater mobility.

Relatively high prevalences of pain and pathology in the upper limbs of long term wheelchair users have been reported by a number of authors (Nichols, Norman, & Ennis, 1979; Gellman, Chandler, Petrasek, Sie, Adkins, Waters, 1988; Gellman, Sie, Waters, 1988; Blankstein, Shmueli, Weingarten, Engel, Ohry, 1985; Bayley, Cochrane & Sledge, 1987; Aljure, Eltorai, Bradley, Lin, Johnson, 1985). However, other than upper limb pain prevalence, and occasionally diagnostic testing, other aspects of upper limb function secondary to long term wheelchair use by persons with paraplegia does not appear to have been examined. These aspects include age and duration of SCI related changes in upper limb strength and flexibility and the impact of upper limb pain on these peoples' ability to continue to perform ADL independently.

1.2 Age-related Changes in the Musculoskeletal System

1.2.1. Changes in Human Muscle Strength with Age

Along with the progressive decline in most body functions, the decrease in human skeletal muscle strength with age has been acknowledged for many years. Quetelet (1835, quoted in Fisher & Birren) found that the back and hand strength of 50-60 year old males and females was remarkably less than that in young adults. The literature does not appear to agree on the age at which strength loss begins, with some researchers reporting a peak in muscle strength at 20-30 years of age followed by a plateau of up to 30 years duration (Larsson, Grimby, and Karlsson, 1979; Petrofsky, Burse, and Lind, 1975); whereas others show a similar age peak but followed by a steady decline (Assmussen, Fruensgaard, and Norgaard, 1975; Burke, Tuttle, Thompson, Janney, and Weber, 1953). Vandervoort et al, (1986) concluded, after reviewing the literature, that relatively small strength losses (less than 20%) occur up to the 6th or 7th decade and that it is only the more rapid decline occurring after that age, that becomes significant clinically.

Studies of strength changes with age have based their conclusions on the measurement of maximum voluntary contractions (MVC) of one or a combination of grip, upper, or lower limb musculature, with the latter two measured both isometrically and isokinetically. The earliest studies measured grip strength. It appears that maximum grip strength peaks at about 25-30 years of age (Burke et al, 1953; Schwartz, Britton, and Thompson, 1928) and has declined by 17.4% to 28% in the 6th to 7th decade in cross-sectional studies of men and women (Sperling, 1980; Asmussen & Heeboll-Neilson, 1961; Burke, Cunningham, Paterson, & Rechnitzer, 1953) and 28% in a longitudinal study conducted by Asmussen et al (1975). After this age most studies report an accelerated loss of strength (McLennan, Hall, Timothy, and Robinson,1980; Burke et al,1953), with Rice (1991) reporting that age is the most important predictor of grip strength in males and females in the 75 to 90 age group. However Aniansson, Sperling, Rundgren, & Lehnberg's (1983) results showed that grip strength did not change significantly between the ages of 70 to 75, and they attributed this to the ongoing training of grip strength inherent in the performance of daily living activities.

Isometric torque (moment) generated by muscles is used functionally in holding, and to maintain stability and posture. Studies evaluating changes in isometric upper and lower limb strength with age are fairly consistent in their reports of strength declines by the 6th or 7th decade. Young, Stokes, and Crowe (1985) found that the quadriceps muscle group in 70 year old males generated on average 39% less isometric torque than did those of men in their 20's. Similarly, in a study of women, Murray, Duthie, Gambert, Sepic, and Mollinger (1985) found isometric quadriceps strength decreased from 24-38% depending on joint position, in young versus 70-86 year olds. In the only study found of age-related strength changes in the shoulder, six muscle groups acting about this joint in 55-66 year old men and women were shown to generate 66-93% of the torque registered by young subjects (Murray, Gore, Gardner, Mollinger,1985). Sperling (1980) evaluated elbow strength in 42 healthy, 70 year old men and women and found elbow flexion, but not extension, to be significantly weaker than in the 20-30 year old group. Studies of isometric elbow strength changes during old age (after 65 years) show that it continues to decline (Pearson & Bassey,1985) and appears to do so more rapidly in both elbow flexors and extensors in men and women (Aniansson et al, 1983).

Movements required for tasks such as walking, wheeling a wheelchair, and transferring to and from a wheelchair, require isokinetic muscle torque to be produced about the joints of the upper and lower limbs. Measurement of isokinetic strength requires relatively sophisticated equipment which has only become available in recent years. No studies of age related changes in the isokinetic strength of upper extremity muscles were found in the literature reviewed. There appears to be agreement among those measuring isokinetic strength changes with age in the lower limbs that there is an age related decline (Johnson, 1982; Murray et al, 1985a; Borges, 1989; Cahalan, Johnson, Liu, and Chao, 1989). In their review, Vandervoort et al (1986) pointed out that studies measuring both isometric and isokinetic torque found isometric torques to be consistently higher for all age groups. This, as well as torque decreasing with increasing velocity, has been reported as a predictable phenomenon in all isokinetic strength testing (Osternig, 1986). The reduced torque at higher velocities is usually attributed to the faster movements depriving the muscle of sufficient time to develop maximum tension. However, there are very few studies which examine the effects of velocity on isokinetic strength with increasing age. Larsson, Grimby, and Karlsson (1979) showed that velocity affected the quadriceps strength of older subjects more than that of younger men, and Aniansson et al (1983) suggested that there appears to be an earlier loss in isokinetic strength with age than isometric strength. In contrast Borges (1989), in a study of the same muscle group, found that velocity affected the two age groups equally. The difference in findings between these studies may be explained in part by differences in the samples and protocols utilized. Further investigations are required before definite conclusions can be drawn.

Some investigators report that the effect of age on skeletal muscle strength varies with gender and among muscle groups. These variations may have an activity-level (Aniansson et al,1983), hormonal (Cauley, Petrini, LaPorte, Sandler, Bayles, Robertson, and Slemenda, 1987), or morphologic (Katch, Katch, and McArdle, 1986) basis, although research is limited and no one explanation has been fully accepted. Clement (1974) reported that in longitudinal studies the rate of decline in strength was less for women than men. Sperling (1980) measured various upper limb functions including strength measures of key grip, transverse volar grip, and isometric elbow flexion in healthy 70 year old men and women. Both groups were significantly weaker in hand grip, but only male elbow flexion strength had declined. She postulated that neither group demonstrated a decline in key grip, because it is used frequently in daily activities at all ages. Murray et al (1985a),1980) examined age related differences in isometric and isokinetic knee muscle strength in men and women and found the difference in mean older and younger womens' strength to be less than that calculated for the men. These studies suggest that age related strength loss may be less for women than for men. However, there are many factors at play and further research is needed before conclusions can be drawn.

Based on differences betweeen age groups in the strength of various muscle groups, it has been reported that in general, age affects upper extremity strength less than it does lower limb strength (Aniansson, 1980). Murray et al (1985b), in studies of shoulder strength, found age and especially gender affected results, however the muscle groups where age-related strength changes were detected differed for men and women. Vandervoort et al (1986) in their review of studies of isometric muscle strength changes with age reported that there was a similar pattern of decline across upper and lower limbs. However, their conclusion was based on a review of fourteen studies of which only five were of the upper limb and of these, four examined grip strength. Until further studies are completed on age-related strength changes in the upper limb, it remains unclear as to whether or not patterns of strength loss vary by anatomical location. Variations observed in the age-related strength loss among different muscle groups could have a morphological basis since relative fibre type content of muscles is known to differ according to muscle function (Katch et al, 1986), and in turn there is evidence that certain fibre types are more affected by age than others (Klitgaard, Ausoni, and Damiani, 1989). These variations may also be a function of patterns of use and disuse associated with aging such that the elderly become less mobile but continue to perform activities of daily living (ADL), whereby the lower limbs are used less but upper limb activity-levels are more or less maintained (Aninasson et al, 1983; Agre, Pierce, Raab, McAdams, and Grimby, 1988).

The knowledge that muscle remains able to be trained throughout life cannot be overlooked in studies of age-related strength changes. This would mean that variations in activity-levels in the sample will affect results, and it raises the question of whether age-related strength losses can be prevented or reversed with exercise programs. The strength trainability of old versus young muscle has been studied by a number of investigators. While the elderly do appear to be able to gain strength with muscle training, this ability has been found to be less than in younger subjects in elbow flexors (Moritani & DeVries,1980), elbow extensors (Hettinger,1958), and knee flexors and extensors (Liemohn,1975). Kauffman (1985) trained abductor digiti minimi in young (mean age 22.6 years) and old (mean age 69.2 years) women and found both groups made equal strength gains. However he questioned whether the old group was old enough to have undergone age related muscle changes at the time of the study. Agre et al (1988) trained women aged 63-88 years isokinetically for 25 weeks in shoulder, elbow, and knee strength, and found improvement in four of the six exercised muscle groups. This suggests that at least some of the strength loss with aging may be related more to a sedentary lifestyle and that this loss can be reversed with exercise (Larsson,1980; Cauley et al,1987). The adaptability of elderly muscle to increased activity has been attributed to increased recruitment of motor units (Grimby,1988), hypertrophy (Moritani & DeVries,1980), and an increase in fast twitch fibre area and relative number of fast twitch fibres (Grimby,1988).

Performance of activities of daily living requires adequate levels of muscle strength and endurance. Declines in strength have been shown to be correlated with declines in independent functioning and ability to complete daily tasks in the elderly (Aniansson, Rundgren, Sperling, 1980; Jernigan, 1981) and in individuals with longterm poliomyelitis (Cosgrove & Alexander, 1987). Inability to function independently in the spinal cord injured can result in lowered health status, admission to hospital, decreased sense of well-being, increased needs for personal assistance, and greater costs to the individual and society (Meyers et al, 1989).

Methodological considerations in measuring strength changes associated with aging have been discussed by a number of authors. Actual strength performance during testing is influenced by motivational factors as well as the physical capability of the muscle itself (Vandervoort et al, 1986). In the aged these factors could include joint pain, or upper motor neurone lesions, or a limited interest in performing at maximum levels. Vandervoort and McComas (1986) examined the issue of motivation in 69 healthy elderly aged 60-100 years by assessing maximum voluntary contraction (MVC) and then superimposing an electrical pulse of sufficient intensity to induce a maximum muscle twitch. In 80% of subjects no increase in force was evident and in the remaining 20% the increase was only slight. They concluded that the elderly have excellent ability to activate their muscles for assessment purposes. They pointed out however, that MVC values increased markedly over the initial trials, and on this basis advised ensuring that there are sufficient practice trials when strength testing elderly subjects.

The vast majority of studies that assess muscle strength between age groups utilize cross-sectional methodologies. A number of considerations are particularly important when interpreting data generated by measurement of different people at different ages at the same point in time, rather than the same people repeatedly as they age (longitudinally); a technique which is very costly, and often impractical and not feasible. Grimby (1988) and Clement (1974) point out that due to natural selection, those elderly subjects alive at the time of a study are probably the healthier and stronger representatives of their age group. They may also have been better protected than those who died earlier. As a result the mean strength of that age group may be inflated from the true had all members of the age cohort been living and tested. This in turn will tend to underestimate the strength loss due to age.

Another category of factors affecting strength data in cross-sectional studies are the distributions of subject characteristics such as occupation (Clement ,1974), activity-level (Cauley et al,1987), body size (Clement, 1974), and nutrition (Grimby,1988). Occupation and habitual activity levels directly affect muscle training and conditioning and should be considered during sample selection and interpretation of strength results. Petrofsky and Lind (1975) found no significant difference in grip strength in a study of 100 males aged between 22-62 years. However, these results are inconsistent with the vast majority of research in the area and Petrofsky and Lind (1975) believed this to be because all of the subjects utilized in their study had similar jobs in the same machine shop.

Body size has been shown to be positively correlated with strength (Clement, 1974), and since there has been an increase in the average size of humans (Tanner, 1962), cross-sectional studies of strength in subjects separated by as many as 40 to 50 years may exagerate age-related strength losses. Asmussen et al's (1975) longitudinal study of age-related changes in grip strength generated similar results to cross-sectional studies; and they concluded that the effect of body-size differences was only slight. However, they examined grip strength only and significant differences in body size should probably be considered as a factor in cross-sectional studies of age-related strength changes.

1.2.2. Age-Related Myopathic and Neuropathic Changes in Muscle

Skeletal muscle and motorneurons in both humans and animals have been examined in various studies in an attempt to explain the mechanisms of age-related loss of strength. While the results of such investigations have added to our understanding, it is clear that human muscle tissue differs from that of rat, rabbit, guinea-pig, and other animals in a number of important respects (Grimby & Saltin,1983) and results from such studies should be generalized to humans with caution (Larsson,1983). For this reason, this review is restricted to research on age-related changes in human skeletal muscle.

1. Muscle Mass

It is generally accepted that the proportion of lean muscle mass to body tissue declines with age (Allen, Andersen, Langham, 1960; Tzankoff & Norris,1977; Young, Stokes, & Crowe,1985; Vandervoort & McComas,1986) and that this decline is usually greater in women than in men (Steen, Bruce, Isaksson, Levin & Svanborg,1977; Young et al, 1985). This decline has been shown to be roughly equivalent to the loss of strength evident with aging (Grimby, Danneskiold-Samsoe, Hvid, Saltin, 1982). Muscle mass is difficult to measure reliably and a number of methods have been devised. These include extrapolations from skinfold tests, calculation of total body creatinine, and cross-sectional area (CSA) measurements conducted using ultrasound scans. Based on creatinine measurements Grimby and Saltin (1983) estimated that humans lose roughly 1/3 of their total muscle mass throughout the lifespan, and the rate of loss increases with age. Young et al (1985) compared ultrasound scans of the quadriceps in young men (mean age 25 years) and old men (mean age 75 years) as well as in young and old women (Young et al, 1984). They found that the muscle CSA was 25% less in old versus young men, and 33% less in the old versus young women. Studies of the decline in excitable muscle mass with age have focused primarily two possible causes; i.e. loss of muscle fibres and a decrease in muscle fibre size with age.

2. Loss of Muscle Fibres

It is generally accepted that the number of muscle fibres decreases with age. Based on muscle fibre counts in the vastus lateralis of autopsied 19-37 year olds and 70-73 year olds, Lexell, Henriksson-Larson, Winblad, and Sjostrom (1983) estimated that roughly 1/3 to 1/2 of the total number of muscle fibres are lost with aging. Exactly when this loss begins is still under debate. Grimby and Saltin (1983) reported that

Colling-Saltin, in unpublished data from autopsies of the biceps brachii of stillborn infants versus young adults, found that mean fibre number had already decreased by 23% (510,000 to 395,000). In contrast, Sato, Akatsuka, Kito, Tokoro, Tauchi, & Kato (1984) counted muscle fibres in 200 women aged 26-80 years, in surgery for resection of pectoralis major, and found that numbers did not decrease until after the 6th decade, and then fell approximately 25% by the 7th decade. This discrepancy may be explained in part by muscle specific age-related fibre loss in different muscle groups.

3. Decrease in Muscle Fibre Size

Muscle mass may also decrease secondary to shrinkage of individual muscle fibres. Research based on needle biopsies indicates this does occur with age, however it appears that Type II muscle fibres are more predisposed to age related atrophy than Type I fibres (Klitgaard, Ausoni, Damiani,1989; Larsson, Grimby, Karlsson,1979) particularly up to age 60-80 years (Tomonaga,1977; Larsson,1978; Grimby,1988). Skeletal muscle is composed of Type I and Type IIa and Type IIb muscle fibres. Type I, or slow fibres, are used for prolonged muscle work such as posture control. Type II, or fast fibres, are generally used for movements requiring greater strength, speed, or finer control.

There are fewer muscle fibres in a Type II motor unit than in a Type I motor unit. Type II fibres have a more extensive sarcoplasmic reticulum than Type I to enable rapid release and uptake of Ca+ for fast contractions. Based on neurophysiological studies, Brown (1972) and Campbell, McComas and Petito (1973) reported that Type II fibres aged more quickly than their Type I counterparts.

It has been suggested that individual muscles differ in the extent to which their fibre size reduces with age (Grimby and Saltin, 1983; Aniannson, Hedberg, Henning, Grimby, 1986). Jennekens, Tomlinson, and Walton (1971) found more age related changes in proximal than distal muscles. Based on their work, Tomonaga (1977) and Toghi, Shimiau, Iuone, Komeyama, and (1975) have proposed that the lower limbs are more affected by muscle fibre atrophy during aging than the upper limbs. Furthermore, Aniansson et al's (1986) longitudinal study revealed that there were variations in fibre atrophy patterns between vastus lateralis and biceps brachii with age. They caution that single muscle results cannot be used to generalize regarding age related muscle fibre atrophy.

The variation in Type II fibre atrophy with age between the upper and lower limbs may be activity related

(McDonagh, White, Davies,1984) since the elderly continue to use their upper limbs to perform the faster movements associated with activities of daily living, whereas the lower limbs may be used less and less for fast paced mobility. As a result, Type II fibres will be recruited more frequently in the upper than lower limbs. The belief that type II fibre atrophy may be partly activity related is supported by Klitgaard et al's (1989) findings that suggest selective atrophy of Type II fibres can be prevented by strength training (high intensity, low repetition) of vastus lateralis in the elderly.

4. Relative Fibre Type Distribution

Early cross-sectional studies of age-related changes in human skeletal muscle suggested that fibre type distribution altered with age due to a preferential loss of Type II motorneurons and progressive increases in relative Type I fibre population (Larsson, Sjodin, Karlsson,1978). Findings from more recent population studies have not supported these earlier conclusions (Lexell et al,1983; Grimby & Saltin,1983; Sato et al,1984; Aniansson et al, 1986; Klitgaard et al, 1989). It now appears that fibre type distribution remains constant, and any muscle fibre loss (as opposed to fibre atrophy discussed in the previous section) that does occur, is not type specific.

However, studies of this issue are based on very small needle biopsies. Lexell et al (1983) showed that fibre distribution varies throughout a given muscle, suggesting that biopsies from different sites in the same muscle could generate quite different fibre number results, regardless of age.

Fibre type grouping (areas of concentration of one type of muscle fibre) is uncommon in young muscle, but has been reported to increase with age in the elderly in vastus lateralis (Grimby, Danneskold-Samsoe, Hvid, & Saltin 1982; Lexell et al,1983; Aniansson, Grimby, Hedberg, Krotkiewski, 1981). Grimby et al (1982) explained this to be a result of denervation and atrophy of Type II fibres and their subsequent renervation by adjacent Type I motoneurons. Aniansson et al (1981) found evidence of grouping in 30% of 80 year old subjects compared to 4% in 70 year olds. The tendency for increased fibre type grouping with age may be greater in the lower limb than in the upper limb (Nygard & Sanchez, 1982).

A number of studies report findings of decreased Type II fibre area in muscles with age, including a seven year longitudinal study conducted by Aniansson et al (1986). It now seems to be generally accepted that preferential loss of type II muscle fibres does not occur. Observations of decreased Type II area may be attributed to both preferential atrophy of Type II fibres, and their denervation and renervation by Type I motoneurons.

5. Reduced Number of Motor Units

Grimby et al (1982) and Aniansson at al (1981) observed decreased muscle strength in subjects prior to the age of 70, which is prior to the age where extensive preferential atrophy is usually observed. This suggested that additional age related changes might be responsible for strength loss, such as the loss of motor units accompanying aging that was reported by Campbell et al (1973). Research has shown that the number of motoneurons declines with age, but it is not clear why (Brown,1973; Vandervoort & McComas, 1986). In a study of adults aged 20-100 years, Vandervoort & McComas (1986) obtained estimates of losses of over two thirds of the motor units of soleus muscle. They suspected that this loss was responsible for decreases in strength in a number of the older subjects.

6. Increased Motor Unit Size

Stahlberg and Fawcett (1982) found that motor unit area increased with age, suggesting that there is a proportionally larger loss of anterior horn cells than muscle fibres. As a result, the number of motor units decreases, while those that remain increase in size due to reinnervation of adjacent denervated fibres. In a study of the motor unit action potentials (MUAPs) of various upper and lower limb muscles in 20-80 year old subjects, Howard, McGill, & Dorfman (1988) observed increases in duration, amplitude, and complexity of the older subjects' MUAPs. They indicated that this was evidence of increased motor unit size and suggested two mechanisms for the size increase. The first was that there may be a selective loss of small motor units. Another possibility is that motor units expand via denervation-renervation secondary to anterior horn cell loss, or anterior spinal root degeneration, or peripheral motor nerve deterioration.

Control of these larger motor units may present some difficulties. Kamen & DeLuca (1989) noted that recruitment-derecruitment patterns for the same tasks differed between the young and elderly. They observed that for a given task, the elderly demonstrated greater activation of their functional antagonists than did the younger subjects. The authors suggested that this was because the elderly had difficulty grading muscle forces with the larger motor units of their agonists, and the increased antagonist recruitment enabled them to gain better control of the movement.

7. Age-related Changes in Contractile Behaviour

Electromyographic (EMG) studies of voluntary and evoked muscle contractions reveal increases in duration, complexity and amplitude of MUAPs with age in some but not all muscle groups (Hayward, 1977; Howard, McGill, and Dorfman,1988). Increased amplitude suggests increased recruitment of motor units for a given task with age (Jokl, 1984). Hayward (1977) pointed out that their EMG findings indicated partial chronic denervation in some muscle groups (biceps, tibialis anterior) more than others (triceps, vastus lateralis), which could be due to repetitive minor peripheral nerve trauma over the lifespan. It could also be a result of differing age processes in various muscles. Howard et al (1988) also found EMG changes and maximum voluntary contraction (MVC) losses to be the least with age in triceps.

Other commonly observed changes in EMG patterns with age are prolongation of both MUAPs (twitch) and half relaxation times (Davies & White, 1983; Vandervoort & McComas,1986; Klein, Cunningham, Paterson, Taylor,1988; Klitgaard,1989). The prolongation of twitch may indicate that the contractions are the result of a greater proportion of the slower Type I fibres being active, hence possible evidence for the preferential atrophy of Type II fibres (Larsson, 1983; Vandervoort & McComas, 1986). Vandervoort & McComas (1986) suggested that these slower contractions actually mean that old subjects can contract more efficiently since they need lower frequencies of impulses to generate the same amount of torque.

8. Age-related Structural and Metabolic Changes in Muscle

Human skeletal muscle has been examined for changes with aging in various enzyme levels. Larsson, (1978), Grimby & Saltin (1983), and Aniansson et al (1986) concluded that enzyme activity per unit muscle mass is relatively preserved. However, Aniansson et al (1986) did find enzyme levels differed between biceps and vastus lateralis, which may simply reflect the expected differences in relative fibre area. Type I muscle fibres contain more oxidative enzymes whereas Type II muscle fibres have higher concentrations of glycolytic enzymes. In contrast, Klitgaard et al (1989) found that elderly male vastus lateralis muscle contained less Ca-ATPase, indicating age related changes in the sarcoplasmic reticulum. Interestingly, they also studied the effects of strength training and found the elderly strength trained subjects did not show evidence of reduced sarcoplasmic reticulum proteins.

Various age related structural changes have been recorded in human skeletal muscle, although the number of studies is limited. Reductions in mitochondrial volume, but not number, in the interfibrillar space and decreasing volume and number in the sarcolemma of vastus lateralis were observed by Orlander, Keissling, Larsson, Karlsson, and Aniansson,(1978). Tomonaga (1977) examined skeletal muscle biopsies from various locations (upper and lower limb, and trunk) of 60-90 year old men using electron microscopy. He found disorganization of the sarcomere structure, Z-band thinning and streaming, nemaline rod formation, accumulation of lipopigment, nucleii aggregation and deformity, increased mitochondrial counts, thickening of the capillary basement membrane, and fewer and thicker synaptic folds at the motor endplates.

1.2.3. Age-related Changes in Articular Cartilage

To properly examine the effects of age and of the duration of paraplegia on upper limb function and pain, it is necessary to consider the response of articular cartilage to the aging process and to levels of applied stress. Thus, this section begins with a brief review of the structure of normal human articular cartilage. This is followed by a review of the literature on the effects of aging, the impact of mechanical stresses and wear and tear; and of osteoarthritis.

1. The Structure of Articular Cartilage (AC)

Articular cartilage covers the ends of bones in diarthrodial joints to create a smooth and almost frictionless surface for movement and also to absorb shock during compressive loading of joints. It can be expected to perform these functions effectively for about 100 years (Chrisman,1984). This tissue is avascular, anueral, self-lubricating, and self-repairing (Chrisman,1984; Eyanson & Brandt,1984). It is nourished by the synovial fluid that is circulated over it and squeezed into and out of it by the alternate compression and relaxation of the cartilage that takes place during joint movement (Stockwell, 1979; Bullough, 1981). AC contains very few cells (chondrocytes) and a large proportion of extracellular material (Gardner, 1983). This material can be described as a gel reinforced by Type II collagen fibres which provide the tensile strength and constrain the gel (Igarashi & Hyashi, 1980). The cross-linking and bonding within these fibres creates a material so strong that a 1mm fibre can hold a 10kg suspended weight without rupturing (Beyer,1983). The gel is largely composed of proteoglycans which give AC its elastic properties and play a major role in determining its resilience to compression (Roughley & White,1980). Proteoglycans are very hydrophilic such that close to 80% of the total weight of cartilage consists of water (Eyanson & Brandt, 1984). Damage to either the collagen or the proteoglycan constituents will compromise the mechanical properties of this tissue.

2. The Effects of Aging, Mechanical Stresses, and Osteoarthritis

It is generally accepted that on close examination human articular cartilage can be expected to differ in a number of respects between young and old subjects (Chrisman,1984; Roughley,1987), subjects with a history of sedentary versus heavy activity (Murray-Leslie, Lintott, Wright,1977; Klunder, Rud, Hansen,1980), and between healthy and osteoarthritic persons (Cooke, 1985). However, it is not clear as to the extent to which the phenomena of AC aging, wear and tear, and osteoarthritis (OA) are discreet or interactive processes.

Osteoarthritis (OA), often referred to as osteoarthrosis in Europe (Lequesne, 1980), involves progressive cartilage and bony joint degeneration (Cooke, 1985). Radin, Paul, and Rose (1972) asserted that osteoarthritis is a disease of wear and tear. However, Fergusson, (1987) and Cooke (1985) stated that there is no evidence that OA results strictly from overuse, and while mechanical stress and joint trauma can be related to OA, their existence does not mean that the development of OA is inevitable. Peyron (1987) and Chrisman (1984) labelled aging as a risk factor in OA. But others (Eyanson & Brandt,1984; Ferguson,1987; Grushko, Schneiderman, Maroudas,1989) found no indication that OA is due to the senescence of cartilage; indeed they reported very different biochemical and biophysical changes in AC between osteoarthritis and aging. Gilloteaux and Linz (1983) acknowledged that it is difficult to separate the effects of aging from those of excessive use in cartilage. A number of researchers propose that in addition to aging and mechanical stresses, other factors may play a role in the onset of OA. These factors can include genetic, metabolic, hormonal, and immunological influences (Cooke,1985; Eyanson & Brandt, 1984). Fergusson (1987) suggested that there is a variable genetic predisposition to AC breakdown, which is triggered in late life by age and by biomechanical factors. If the cartilage repair process is unable to cope with the damage then osteoarthritis will follow.

In summary, aging, wear and tear, and osteoarthritis are regarded as different processes which interact to various degrees on joint cartilage, depending on the individual, on age and lifestyle, and on the location of the joint. This section will focus on age-related and osteoarthritic changes. In a later section, the literature on wear and tear related changes will be reviewed. Interactions and relationships wil be identified where relevant.

3. Age-related Changes in Articular Cartilage

While articular cartilage can be expected to continue to perform its anti-friction and shock absorption roles in joints until late in life, research has shown that with age, cartilage does undergo definite structural and biochemical changes; some more significant than others. Research indicates that the effects of aging in AC become evident in the third decade, increase slowly until the fifth, and then become rapid such that they are very common in those over seventy years of age (Tonna, 1977; Petersson, 1983; Eyanson & Brandt, 1984;

Peyron,1987). The process appears to proceed at different rates in different joints (Leutert, 1980; Roughley & Mort, 1986).

Gross Changes

Gross changes with age observed in articular cartilage include thinning (Roughley & White, 1980; Bozdech & Horn, 1983), yellowing (Fergusson, 1987), increased calcification (Gilloteaux & Linz, 1983) and decreases in tensile strength in both the superficial and deep layers (Kempson, 1982). Weightman (1976) reported that the fatigue resistance of femoral head cartilage in tension was reduced in the aged, indicating possible deterioration in the biomechanical properties of cartilage with age. Bozdech and Horn (1983) reported finding microscopic surface roughening in specimens of old cartilage. Taylor and Twomey (1986) described similar typical age-related changes in the articular cartilage of zygapophyseal joints of the lumbar spine.

Joint Surface Congruity

It has been shown that the joints of old people become increasingly congruous with age (Bullough,1981) although the cause is not clear (Brandt,1988). The distribution of pressure on the cartilage during load-bearing is affected by the degree of matching, or fit, of the joint surfaces. If the socket is too large, the small area of increased pressure under load will predispose the cartilage to damage. Perfect congruity is undesirable as well because during weight bearing most of the cartilage will not be exposed to the circulation of nourishing synovial fluid. Cartilage nutrition will be further compromised by the loss of incongruity because the alternate squeezing and sucking actions resulting from movement in a slightly incongruous joint are important in the mechanics of synovial fluid circulation. Thus, while increased joint congruity with age will increase joint stability, it may also jeopardize cartilage nutrition and redistribute loads to cartilage areas unaccustomed to stress. This may lead to damage since the cartilage will be poorly prepared to weight-bear in accord with Wolff's law which states that cartilage and bone adapt their structure to the functional demands placed on them (Puranen, Ala-Ketola, Peltokallio, Saarela,1975).

Biochemical Changes

While there is some inconsistency in the literature, the majority of authors reviewed reported that human cartilage cell count decreases with age (Stockwell,1979; Leutert, 1980; Chrisman,1984; Peyron,1987). This is likely to interfere with the cartilage's capacity to repair itself.

Conflicting results have been reported as to whether AC cell mitosis decreases with age (Crelin, 1960; Igarashi & Hayashi,1980).

Research is available that examines age changes in the Type II collagen component of AC, although it is limited by the difficulty of obtaining pure Type II collagen specimens (Brandt & Fife, 1986). Leutert (1980) studied cartilage from the femoral heads of subjects between birth and 80 years and found that collagen degenerated with age, and there was a reduction in the proportion of elastic fibres. This may have been related to the loss of water from cartilage which occurs with age and Brandt and Fife's (1986) reports of increased mechanical in older collagen fibrils. A number of authors observed reorienting of the collagen substructures with age including larger diameter fibres and widened spaces between them (Leutert, 1980; Kempson, 1982). Igarashi and Hyashi (1980) report finding Type I collagen in older AC but they acknowledged that this may not have been strictly an age-related change since environmental influences (e.g calcium levels) could have played a role. Articular cartilage derives the majority of its tensile strength from collagen and there appear to be some changes associated with aging that may reduce its ability in that regard.

Proteoglycan components of articular cartilage change throughout life; largely as a result of synthesis in earlier years, with degradative proteolytic changes predominating in later life (Chrisman, 1984; Roughley, 1987) After studies of AC from subjects ranging fetal to elderly, Roughley and White (1980) reported that the older specimens demonstrated decreased proteoglycan concentrations and size. Brandt and Fife (1986) also reported size changes in the form of shortened proteoglycan structures in aged cartilage. A decrease with age in the capacity of cartilage to hold water (proteoglycan hydration) has been reported (Bozdech & Horn, 1983; Brandt & Fife, 1986; Fergusson, 1987), although there may be an initial increase in hydration accompanying histological deterioration which causes swelling that can deform the collagen network (Chrisman, 1984). The functional implications of these changes may relate to a reduction in the elasticity of articular cartilage and in its ability to offer resiliency, to withstand compressive forces, and to protect the underlying subchondral bone.

To summarize, in contrast to aging muscle, age-related changes in articular cartilage appear as early as the age of thirty, but they proceed slowly until after the fifth decade when they become greatly accelerated. The observed gross and biomechanical cartilage changes with age would likely increase friction within the joint during movement, possibly causing further damage, and thus reduce the ability of AC to protect subchondral bone during loading. However, more research into the nature and extent of the functional implications of these changes is needed. Age associated flattening of joint structure congruity may affect old cartilage directly by applying unusual load stresses, or indirectly by inhibiting synovial fluid flow and thus compromising cartilage nutrition. Roughley (1986) suggested that the cartilage aging process is probably unaffected by joint biomechanics or nutrition unless either is extremely abnormal.

4. Osteoarthritis (OA)

Osteoarthritis is a progressive deterioration of articular cartilage, normally limited to the weight-bearing joints (Eyanson & Brandt, 1984; Cooke,1985). It is known to accelerate with age and Brandt & Fife (1986) reported prevalence rates of 25% and 30% in men and women in the 45-64 year age group, with increases to 58% and 65% in those over 65 years. Mild to moderate synovitis may occur, which is believed to be secondary to irritation from the products of cartilage breakdown. Subsequently, cartilage softening and fibrillation (fissuring) are seen (Hough, 1983). The disease commonly presents with a deep, aching pain that is aggravated by activity and relieved by rest. Joint stiffness may occur after periods of immobility, but can be loosened with brief activity. Bone on bone crepitus is a primary symptom (Eyanson & Brandt,1984). Morphological and biochemical studies of OA reveal it to involve quite different processes than degeneration, including increases in cellular activity and repair (Solokoff, 1983; Howell,1985)

In descending order, the joints most commonly affected in the general population are the knee, hip, first carpometacarpal, first metatarsal, and the joints of the cervical and lumbar spine. Unless there has been previous joint trauma, it is considered unusual to find OA in the metacarpophalangeal joints, shoulders, elbows, wrists, or ankles (Eyanson and Brandt,1984), although these prevalences increase after the sixth decade (Gardner,1983). Peterson (1983) found that OA in the glenohumeral joint was rare in the general population until after 60 years of age.

The cause(s) of osteoathritis are still subject to considerable debate, and as discussed earlier, a variety of etiological factors, including age (Fergusson,1987), mechanical wear and tear (Radin, 1976), congenital, and biochemical or anatomical abnormalities, metabolic (Huskinsson, Dieppe, Tucker, Canell, 1979), and hormonal influences (Cooke,1985) have been put forth. Cooke (1985) suggested that the mechanical basis for OA results from the interaction of the forces generated due to joint alignment, geometry, and laxity, as well as motor control and sensory feedback during joint motion. Some authors refer to two types of osteoarthritis; primary and reactive, and propose that it is previously traumatized joints that are at risk of developing reactive OA (Gardner,1983).

A number of investigations have attempted to assess the influence of mechanical wear and tear in the development of OA by comparing prevalences in various occupational and athletic groups. The evidence is conflicting, and may relate to confounding variables such as age, methodological variations, differences in diagnostic criteria, and subject selection methods. Radiographic studies of habitual long distance runners over age 50 revealed no increased predisposition to OA in the hip (Lane, Bloch, Wood, Fries,1987; Puranen et al, 1975). Worcester and Green (1968) found no relationhip between occupation and acromioclavicular osteoarthritis diagnossd in 83 subjects. In a rather unusual study, Waldron and Cox (1989) excavated 968 skeletons buried between 1729 and 1869 in east London and examined them for evidence of OA. Occupational histories were obtained and the majority were weavers. The authors were looking for a relationship between occupation and OA in various joints, but they found none. Two studies that did report a relationship between past activities and prevalence of osteoarthritis found that dentists had a higher rate of shoulder OA than farmers (Katevuo, Aitasalo, Lehtinen, & Pietila,1985) and footballers were inclined to develop OA in their knees (Klunder, Rud, Hansen 1980). A particular type of mechanical stress that appears more likely to precipitate osteoarthritis than repetitive work or awkward work postures, is that which is accompanied by vibration (Sikorski, Molan, and Askin,1989). Sixty-seven foundry workers using vibration tools were compared with heavy manual labourers. The exposed subjects had increased radiographic evidence of osteoarthritis in the elbows and wrists (Bovenzi, Fiorito, and Volpe,1987).

1.2.4. Age-related Changes in Bone

In this section, both age-related changes in bone and osteopenia/osteoporosis will be discussed. Bone mass is usually at its maximum between 20 and 30 years of age (Duncan & Parfitt, 1984). Skeletal mass then begins to decrease with age; usually by similar amounts in all bones (Duncan & Parfitt, 1984). A decrease in bone mass may be termed osteopenia. However, osteopenia is a broad entity, and in addition to occurring with increased age, it may also be associated with osteoporosis, osteomalacia, endocrinopathies, and marrow-packing disorders (Lane & Vigorita, 1983).

1. Osteoporosis and Osteopenia

Age-related osteopenia is due to a disturbance in bone turnover rates caused by a disruption in the balance between bone resorption and bone formation (Melton & Riggs, 1986). Osteoporosis is a metabolic bone disorder primarily affecting the elderly that results in a loss of bone mass, increasing bone fragility, and lowered capacity to tolerate strain before fracturing (Gilloteaux & Linz, 1983). A prevalence rate for those over 60 years has been reported to be as high as 30% in women and 15% in men (Gilloteaux & Linz, 1983). Osteoporosis differs from age-related bone change primarily in the quantity of bone reduction; the former resulting in pathologically greater bone changes (Duncan & Parfitt, (1984). Osteoporosis is often defined as a reduction in bone mass accompanied by fracture following minimal trauma (Melton & Riggs, 1986). However, Stevenson and Whitehead (1982) caution against the use of fractures as diagnostic criteria for osteoporosis because pathologically accelerated bone loss of up to 30% may have occurred for years before any fractures became apparent. They prefer instead, to focus on bone mass only, and diagnose osteoporosis in cases where bone mass is less than that expected for age and gender (Steveson & Whitehead, 1982).

Men and women lose bone at a rate of about 1% per year after middle-age, however women undergo accelerated bone loss during the years following menopause (Dequeker, 1975; Stevenson & Whitehead; 1982; Melton & Riggs, 1986). General age-related changes in the structure and physiology of bone include changes in the periosteum such as alterations in its surface, decreases in cell and mitochondria number and cell reproduction, fewer intact osteoblasts (bone-forming cells), and more lysosomes and autophagic bodies (Tonna 1974,1978). Changes in the endosteum occur later with approximately 25% being resorbed by the seventh decade (Jowsey, 1960). The end results of these and other changes include diminishing bone density, cortical thickness, and diameter of trabeculae (Kohn,1978), mineralization, and increasing porosity (Currey,1979).

Osteoporosis results from a variety of factors, often in combination, including initial bone density, nutrition, and disuse (Melton and Riggs,1986). Other factors that may be associated with osteoporosis are specific disease conditions, surgical procedures, and medications (Melton and Riggs, 1986). Osteoporosis is particularly common in the lumbar and thoracic spine, and the distal radius and ulna (Sartoris and Resnick,1986; Jowsey, 1984). It is rare to find osteoporotic radiographic changes in the elbow or shoulder (Sartoris and Resnick,1986). More common radiographically than OA glenohumeral damage, is rotator cuff degeneration and subacromial spur formation causing impingement and rotator cuff tear during arm elevation (Sartoris & Resnick, 1986). Conversely, Sartoris and Resnick (1986) found OA radiographic changes in the acromioclavicular and sternoclavicular joints of most elderly subjects, and noted that sternoclavicular OA changes begin to increase as early as the third decade.

2. Age-related Changes in the Physical Properties of Bone

Changes in the physical properties of bone begin in the thirties and include increased brittleness (Kohn, 1978) and decreased tensile strength (Duncan & Parfitt, 1984). Currey (1979) performed impact tests on male and female human femur specimens and found that over the lifespan there is a three-fold drop in its energy absorbing capacity. This change renders it more vulnerable to fracture. They also showed that this age-related decrease in absorption capacity is greater than the decline in static strength, and elasticity. In another study changes with age in femur and tibia mechanical properties (tension, compression, shear/torsion) were tested on male and female specimens between 21-86 years (Burstein, Reilly & Martens, 1976). They found that at any given age, all mechanical properties were greater in the tibial bones, with no significant differences observed between males and females. The greatest changes appeared to have occurred in the fifth decade, however the age changes in the tibia were found to be less than in the femur. There was a decrease noted in all mechanical properties, with declines in total strain before failure (32%:tibia), 42%:femur) being the most noticeable. Aging bones do appear to become more vulnerable to fracture, however the response to age of different bones appears to vary. The authors postulated that these differences could be due to varying tissue compositions, cell turnover rates, or load stresses (Burstein et al,1976).

3. Osteoporosis and Paraplegia

Radiographic evidence of osteoporosis, primarily in the limbs below the lesion level, has been observed in persons 2-6 months post spinal cord injury (Hendrix, 1981). The fundamental cause is not known, however two likely factors are a) disuse, and b) disturbance in the bone resorption-reformation balance secondary to vascular alterations due to damage to the autonomic nervous system (Chantraine, 1978; Hendrix,1981). Numerous studies have shown that bone stress, such as that resulting from gravity and muscle actions during physical activity, can delay or prevent bone loss (Eriksen,1982; Smith & Raab, 1984, Smith, Smith, Ensign & Shea, 1984; Pocock, Eisman, Gwinn, Sambrook, Kelly, Freund, Yeates, 1989). Heavier upper limb use by those with paraplegia might afford them some protection from the acromioclavicular and sternoclavicular osteoporotic changes, seen as early as the third decade in the able-bodied (Sartoris & Resnick, 1986). Some studies of persons with long term paraplegia have found this group to be at increased risk of diseases normally associated with old age, including diabetes, atherosclerotic heart disease, and decreased immunity (Nakajima & Honda, 1988; Ohry, Shemesh, Rozin, 1983).

The factors causing these diseases earlier in those with paraplegia than in the general population may also have an effect on endocrinological function and bone metabolism.

1.2.5. Age-Related Changes in Tendons and Ligaments

Tendons and ligaments are made up of Type I collagen; whereas articular cartilage consists of Type II collagen. Since collagen is phylogenetically old, with a slow metabolic rate of turnover leaving it exposed for long periods to metabolic and environmental effects, it is particularly vulnerable to aging (Klein & Rajan, 1984). Changes with age observed in human tendons and ligaments include increases in diameter and proximity of collagen fibrils (Pahlke, 1954), fewer reducible cross-links (Bailey, Robins, & Balian, 1974), decreases in the capillary blood supply to tendons resulting in slower healing (Rothman & Parke, 1965), stiffening secondary to increased cross-linking, with subsequent weakening due to increased collagenase activity (Bailey et al, 1974), and calcification at proximal bony attachments due to marrow creeping into the tendon through small fissures in the thinning bone cortex (Shephard,1987). Thus, with increasing age collagenous structures lose flexibility and resilience, are less able to tolerate unusual stresses, and are slower to heal following microtrauma (Hall, 1976).

Studies of age-related changes in upper limb joint flexibility are limited and are based on cross-sectional data.

Boone and Azen (1979) evaluated various ranges of joint mobility in two groups of males aged 19 years or less and aged 20-54 years. They found significant differences for shoulder flexion, extension, internal and external rotation, and elbow flexion. However, in none of these movements was the average difference between the two groups more than 10^0. Murray, Gore, Gardner, and Mollinger (1985) compared shoulder range of motion (flexion, extension, abduction, internal and external rotation) between 10 young men (mean age 31 years) and 10 older men (mean age 62 years). The only significant differences were found for flexion and external rotation (Murray et al, 1985). Age-related changes in active range of motion (AROM) in older subjects was studied by Walker, Sue, Miles-Elkousy, Ford & Trevelyan (1984) in 15 young-old (age range 60-69 years) and 15 old-old (age range 75-84 years). No significant differences in upper limb joint ranges between the two groups was found. The authors did however, report that the mean ranges of motion of their combined sample (age 60 years or over) for some joints were lower than the American Academy of Orthopedic Surgeons (AAOS) (1965) guidelines. This was most notable in the lower extremity in men, however, the mens' shoulder extension scores were, on average, 19^0 less than the AAOS (1965) norms. Overall, they found that for 22 of 25 movements tested, the older men generated, on average, 9^0 of motion less than the averages stated in the AAOS (1965) handbook (Walker et al, 1984). Based on their findings, Walker et al (1984) recommended that a separate set of AROM norms be developed for persons over 60 years of age.

1.3. Overuse in the Musculoskeletal System

In this section, musculoskeletal overuse is discussed under the following headings:

1.3.1. Introduction
1.3.2. Definition of Overuse
1.3.3. Causes of Overuse
1.3.4. Prevention of Overuse
1.3.5. Methodological Considerations for Research into the Area
1.3.6. Overuse in Muscle, Bone, Cartilage and Tendons and Ligaments
1.3.7. Overuse in the Shoulder
1.3.8. Overuse in the Elbow
1.3.9. Overuse in the Wrist and Hand.

1.3.1. Introduction

The nature, mechanisms, and prevalence of excessive use of the musculoskeletal system have been studied in various populations including athletes (Micheli, 1986; Maughan & Miller, 1983; Newburg, 1987; Bollen, 1988; Lehman, 1988; Winge, Jorgensen, Nielsen, 1989), musicians (Fry, 1986a, 1986b, 1987), various occupations (Westerling & Jonsson, 1980; Bjelle, Hagberg, and Michaelsson, 1981; Silverstein, Fine, and Armstrong, 1987; Hagberg & Wegman, 1987; Miller & Topliss, 1988; Weislander, et al,1989; Ohlsson, Attewell, and Skerfing, 1989) and wheelchair users (Ferrara & Davis, 1990; Curtis & Dillon, 1985; Aljure, Eltorai, Bradley, Lin, and Johnson, 1985; Blankstein, Shmueli, Weingarten, Engel, and Ohry, 1985; Bayley, Cochran, and Sledge, 1987). The athletic literature contains a number of studies of overuse of the lower extremity. However, in keeping with the subject of the present study, this discussion will focus primarily on investigations into overuse in the upper limbs.

The area of musculoskeletal insult secondary to excessive use has received increased attention in recent years in a number of fields including occupational health and safety, community health and epidemiology, medicine and allied health, and sports medicine. As a result, the research focii and methodologies vary tremendously and make the body of literature as a whole very difficult to generalize from. Research and discussion in the area has tended either to examine by anatomic location, specific diagnoses that are considered to have resulted from wear and tear (carpal tunnel syndrome: Weislander, et al, 1989; rotator cuff tendon impingement: Hawkins & Kennedy, 1980); or to investigate overuse in the upper limb more broadly using more inclusive, vague terminology, such as cumulative trauma disorder (CTD), repetitive strain injury (RSI), or occupational cervicobrachial disease (OCD). In those studies examining specific diagnoses, interpretation is complicated by a lack of agreement among investigators as to the diagnostic criteria for conditions such as tendonitis and tenosynovitis (Waldron, 1987) or swimmer's shoulder (Ciullo, 1986). Studies of the broader categories such as CTD, RSI, and OCD, are particularly characterized by variable definitions and struggles to reach agreement on criteria, etiology, pathology, diagnostic labels, and in fact whether a condition such as RSI exists as a separate entity at all (McDermott, 1986; Dennett & Fry, 1988; Brooks, 1989). The purpose of this section is to review those aspects of the literature on musculoskeletal wear and tear and overuse that will aid in understanding possible predisposing factors, mechanisms, and symptoms of overuse in the upper limbs of the wheelchair using person with paraplegia.

1.3.2. Definition of Overuse

Musculoskeletal overuse results from repetitive trauma that in itself is not detrimental, but if it persists at a rate or intensity that exceeds the body's ability to respond adequately, then injury will result (Post, 1988). In addition to musculoskeletal wear (which may occur in tendons, ligaments, articular cartilage, and bones), nerves and neurovascular complexes may manifest overuse symptoms from, for example, stretching or compression (Putz-Anderson, 1988).

Musculoskeletal disorders of an overuse nature pertaining to clerks and scribes were discussed as long ago as

1700 by Ramazzini. Interest has increased in recent years, probably for a multitude of reasons. Two of those frequently offered are that the actual incidence of overuse injuries has grown due to the general population's greater involvement in sport (Polisson, 1986), and the increased mechanization of jobs resulting in repetitive and faster work tasks (Putz-Anderson, 1988), coupled with an aging workforce (Putz-Anderson, 1988). Although greater numbers of persons have become involved in a variety of wheelchair sports, only one study was found that examined the prevalence of overuse in wheelchair athletes (Curtis & Dillon, 1985).

1.3.3. Causes of Overuse

Excessive use includes repeated compression, stretching, or friction and can result in progressive tissue damage and deterioration. Factors that have been found to be associated with upper limb overuse problems have been divided into intrinsic and extrinsic (MacLean, 1984) or occupational and non-occupational categories (Armstrong, Fine, Radwin, Silverstein, 1987). Intrinsic or non-occupational factors include gender, age, congenital defects, tissue variations, and pre-existing disease. Extrinsic or occupational factors include sport or job task, technique, repetitive exertions, mechanical insults, awkward postures due to work station design, equipment or method (Punnett, 1987), vibration (Weislander et al, 1989), and duration and intensity of activity (Fry, 1986a), Bjelle et al 1987). Little information is available as to the number or nature of repetitions that various parts of the body can adequately cope with before damage occurs. Some studies have attempted to show that specific types of movements can lead to overuse. Two examples suggest that overuse tendon conditions are more common in those who work intensely with their hands (Punnett, 1987; Weislander et al, 1989; Ohlsson et al, 1989) and that shoulder disorders are more common in those whose work or sport demands repeated or statically elevated arm postures (Hawkins & Kennedy, 1980; Bjelle et al, 1984; Polisson,1986).

1.3.4. Prevention and Management of Overuse Injuries

Improved identification of predisposing variables and greater clinical experience has allowed researchers and clinicians to make better and more comprehensive recommendations regarding the prevention and management of overuse problems. The sooner treatment is begun, the more effective it will be and the better the likelihood of complete recovery (Post, 1988). However, the onset of conditions caused by overuse is usually insidious, and knowledge of early warning signs is important.

Rest is usually identified as the most effective form of treatment. This is not necessarily complete rest, unless the injury is very serious, but may refer to the selective rest of the affected part, while maintaining condition in other body areas (Micheli, 1986; Larkins, 1984; Post, 1988). Other treatments identified include ice, stretching, anti-inflammatory medications, cautious use of steroid injections, and surgery (Richardson, Jobe, Collins, 1980). Steroids should be used judiciously since they weaken the area for up to three weeks (MacLean, 1984).

Silverstein, Armstrong, Longmate, and Woody (1988) evaluated the effects of a one year on-the-job exercise program in reducing postural discomfort scores in assembly plant workers. The results failed to demonstrate the program's effectiveness. While this outcome appears to cast doubt on the benefits of exercise for postural relief, it may suggest that an exercise program is more or less wasted unless attention is also paid to on-the-job ergonomics, posture, and work-station design.

Various preventative measures have been identified in an effort to reduce the risk of overuse injuries. Most of these emphasize adequate physical condition for the task and the use of correct techniques of performing the task or skill. Preventative measures include warm-up and stretching before the activity (MacLean, 1984, Bradfonbrener, 1990), attention to skill and technique (MacLean, 1984; An & Bejjani, 1990; Fry, 1987a); Bradfonbrener, 1990), conditioning for both strength and flexibility and sensible progression of conditioning (Post, 1988; Bradfonbrener, 1990; Press & Wiesner, 1990), and ergonomic tool and work station design (Punnett, 1987; Grant, 1987; Armstrong, Fine, Goldstein, Lifshitz, Silverstein, 1987; Waldron, 1987). Attention to these factors is important in the management as well as the prevention of injuries due to excessive use.

1.3.5. Methodological Considerations for the Investigation of Overuse

A variety of methodologies have been used to study overuse pathologies secondary to various sports and occupations. Questionnaires have been administered to numerous high risk groups to elicit descriptive data such as prevalence of pain, location of discomfort, date of onset, treatment sought, treatment effectiveness, effect of the pain on performance, and ergonomic characteristics of the activity in marathon runners (Maugh & Miller, 1983), distance cyclists (Weiss, 1985), rock climbers (Bollen, 1988), wheelchair athletes (Curtis & Dillon, 1985), elite tennis players (Winge et al, 1989), assembly line packers (Maeda, Harada, Takamatsu, 1980), hospital workers (Punnett, 1987), chicken processing workers (Buckle, 1987), retail salespeople (Buckle, 1987), and secretaries, (Linton & Kamwendo, 1989). This is a particularly useful method for initial investigation into an area as it helps to establish whether or not a problem exists, the general nature of the problem, and can often point out directions for subsequent investigations. Questionnaires are subject to characteristic problems including achieving acceptable return rates, item misinterpretation, recall bias, and the fact that they only provide the subject's assessment of the situation.

Other methods have been used by researchers in an attempt to discern associations between overuse problems and possible predisposing variables. The latter have included occupational job titles, age, gender, or specific characteristics of task performance such as frequency, duration, intensity, and ergonomic, biomechanical, and kinesiological factors. One method used has been to select subjects already diagnosed with overuse type upper limb pain (case control method) and to assess them further for trends in anticipated high risk variables. Usually a combination of the following factors are assessed; underlying rheumatologic disease, congenital anomalies, anthropometric features, and ergonomic stresses associated with the job (Bjelle et al,1979,1981;

Weislander et al, 1989). In some studies the subjects were brought in for clinical investigations and interviews (Bjelle et al, 1979, 1981, 1984), or interviewed over the telephone (Weislander et al, 1989). In three of the above studies, referent groups were used (Bjelle et al, 1979, 1984; Weislander,1989).

Most common are studies that attempt to establish both prevalence and risk factors by selecting subjects who perform job tasks that have a known or suspected association with the development of upper extremity overuse problems (retrospective cohort and cross-sectional designs). Prevalence of upper limb overuse injuries or pain is then established by the use of a form of screening questionnaire, (Maeda, Harada, Takamatsu, 1980; Christensen, 1986; Ohlsson et al, 1989; Linton & Kamwendo, 1989), interview (Westerling & Jonsson, 1980), radiographs (Hagberg & Wegman, 1987), or interview plus clinical examination (Luopajarvi, Kuorinka, Virolainen, Holmberg, 1979; Punnett, 1987; Ryan & Bampton, 1988). Clinical examinations have usually taken the form of a screening protocol developed by the investigators, based on the presence of indicators such as pain, tenderness, weakness, fatigue, and or sensory changes. No reliability or validity data have been reported for these clinical examinations in any of the studies located. In the majority of such studies, prevalence was measured as the number of subjects with upper limb symptoms (pain, numbness, weakness, etc.) by anatomical location. Only rarely did investigators attempt to make specific diagnoses (Luopajarvi et al, 1979).

In previous studies, once prevalence was established, there was an assessment of variables believed to be related to the development of overuse such as subject age, gender, duration of employment and ergonomic characteristics of their job tasks. This data was gathered using questionnaires (Maeda et al, 1980; Punnett, 1987; Ryan & Bampton,1988; Ohlsson et al, 1989; Linton & Kamwendo, 1989), interview (Westerling & Jonsson,1980; Sallstrom & Schmidt, 1984), EMG (Christensen, 1986), or video analysis (Silverstein et al, 1987). Referent groups seem to have been used only rarely in this latter type of study (Luopajarvi et al, 1979; Ohlsson et al, 1989).

All of these studies follow a form of cross-sectional, case-control, or retrospective cohort design. They therefore need to be interpreted carefully since there is no longitudinal dimension to the exposure variables related to job demands, and these may have changed over time. Carefully selected unexposed referent groups, or even disease rates in the general population, were rarely used for comparison and would have strengthened the interpretation of the findings (Kelsey, Thompson, Evans, 1986). A common problem in comparison of the effects of exposure versus non-exposure in occupational groups is the healthy-worker effect where those workers who are less fit or who have already developed a job related illness have left that job by the time of subject selection (Kelsey et al, 1986). Thus the prevalence rate of overuse for those remaining will be lower and will appear to underestimate the risk associated with that job. This suggests that to study the effects of wheelchair use on the arms in paraplegia, a comparison group must be selected that has a similar history of upper limb exposure to other activity, but which differs in that they are not wheelchair users or persons with paraplegia.

In retrospective cohort designs, subjects are selected on the basis of exposure. Therefore this method is particularly useful for exposures of low prevalence (Kelsey, et al, 1986), such as paraplegic wheelchair users. In these studies, the measure of exposure becomes very critical. Some studies measure exposure as either exposed or not exposed. But a more refined measurement that includes for example, duration of exposure, will give more information as to the relationship between the disease and the exposure variable (Kelsey et al, 1986). In retrospective cohort studies, the reliability and validity of the measure of exposure becomes critical. In a number of the studies reviewed this measure is not reported in sufficient detail to properly evaluate reliability and validity.

In many of the studies reviewed, current exposure appears to have been used and this may not reflect the history of exposure leading up to the development of overuse symptoms (Kelsey et al, 1986). Where exposure is permanent (gender, genetic factors, geographical factors), the validity and reliability of measures of that exposure are more favoured (Kelsey et al, 1986). In the present study, paraplegia resulting in wheelchair use can be considered as permanent exposure. Measurement of exposure can be made more direct by including, for example, interviews of subjects regarding their lifestyle and then classifying them by activity-level (Kelsy et al, 1986).

In reviewing the studies of overuse, it is unusual to see the outcome variable measured as a specific diagnosis. Those that did (Luopajarvi et al, 1979), developed their own criteria for each diagnosis based on a review of the literature and on clinical experience. No reports of the validity of these outcome variables were included. The use of the prevalence of discomfort or pain is more commonly measured. The most likely reason that diagnostic categories are not used in the epidemiological investigation of musculoskeletal diseases may be that the International Classification of Diseases (ICD) is always slightly out-dated (Wickstrom, 1982). It is not until newly discovered diseases are sufficiently acknowledged and understood, that they will appear in the ICD (Wickstrom, 1982).

Musculoskeletal diseases secondary to overuse have received more attention recently as a result of increased technology in the workplace and growing involvement of the general population in sport and fitness and the ICD is not yet well developed in this area (Wickstrom, 1982). Furthermore, the ICD was originally designed for clinical diagnosis and treatment, rather than for research classification purposes. As Wickstrom, (1982) pointed out, and as is evident from the controversy in the literature (Waris et al, 1979; Fry,1989; Brooks,1989) there are no accepted methods or criteria for the diagnosis of various overuse conditions as there are for conditions such as angina pectoris, chronic bronchitis, or electrocardiograph interpretation. While in future, analysis by diagnosis would be helpful, until universal criteria are established it would seem that diagnoses should be used with caution. Ideally, a number of aspects of the discomfort could be measured, and quantified where possible, including intensity of pain, location, muscle strength, range of motion, impact on performance, duration of exposure, and intensity of exposure.

Pain or discomfort is an essential variable in the assessment of musculoskeletal overuse since it, along with weakness, is most likely the factor which most interferes with task performance and consequently affects the quality of life. When measuring pain it is important to establish whether the subject has any reason to report inaccurately (e.g. to exaggerate or underestimate the pain) (Westerling & Jonsson, 1980). Pain is a multidimensional phenomenon in humans (Duncan, Bushnell, Lavigne,1989) that is modulated by the conscious and subconscious as well as many other factors including cultural and personal incentives (Miller & Topliss, 1988). Pain can be measured as an individual's perception of the pain itself (location, duration, intensity) or behaviourally (whether treatment was sought, degree to which the pain limits activity) (McDowell & Newell, 1987). Both parameters are useful; the former assists in understanding the nature of the pain and can be used to generate and test future hypotheses related to causality.

There is some controversy in the literature as to whether or not the measurement of pain behaviour is more objective than subjects' verbal reports, or whether both must be recognized as having subjective components (Fordyce, 1988). Studies in the overuse musculoskeletal literature which report on pain tend to focus on subjects' perceptions of their pain (Maeda et al, 1980; Westerling & Jonsson, 1980; Sallstrom & Schmidt, 1984; Weiss, 1985; Punnett, 1987) rather than on its impact on performance (Maugh & Miller, 1983; Miller & Topliss, 1988). Quality of pain is variable secondary to a number of factors including medication, fatigue and anxiety, and the performance of activities that exacerbate it or distract the individual from the pain (McDowell & Newell, 1987). Pain related to musculoskeletal overuse may vary for these and for other reasons and come and go over a long period of time. Therefore subjects may have difficulty in accurately remembering their pain enough to give a valid and reliable description; this is referred to as recall bias.

Not all of the studies reviewed clearly indicated the period of recall which they used when asking subjects to describe their pain. In those that did, the time periods varied widely. Subjects were asked whether they experienced "pain on most days of one month or more in the past year (Punnett, 1987); "pain in the previous few weeks" (Maeda et al, 1980); "pain in the past seven days" (Ohlsson et al, 1989); "pain in the last twelve months" (Ohlsson et al, 1989); "pain occurring on more than twenty occasions or lasting more than one week in the previous year" (Silverstein et al, 1987; Armstrong et al,1987); "pain present at the time of the questionnaire" (Buckle, 1987); and "pain present for six months or longer" (Miller & Topliss, 1988). To measure pain prevalence however, subjects can recall pain which they currently have or significant upper extremity pain experienced within the past year (Ohlsson et al, 1989).

In the study of upper limb pain secondary to overuse, it should be considered that referred cervical pain is an often overlooked cause of upper limb pain (Cailliet, 1966; Miller & Topliss,1988). In order to eliminate upper extremity pain caused by cervical disturbances, Miller & Topliss (1988) recorded only those reports of arm pain that had more peripheral than axial features and that if there were axial features they were described as radiating from a distal centre in the upper limb.

1.3.6. Overuse in Muscle, Bone, Articular Cartilage, and Tendons and Ligaments

Overuse in Muscle

Muscle fibres do adapt to exercise, and must be stressed if they are to achieve this adaptation (Katch, Katch & McArdle, 1986). The fibres will adapt differently depending on whether the training stimulus is for strength or for endurance. However, if the stress is so great that too many fibres are damaged (microtrauma) or there is not sufficient time for restoration of energy stores and removal of lactic acid, then muscle strain ensues (Hagberg, 1982, Micheli, 1986). In a discussion of shoulder muscle symptoms and disorders, Hagberg

(1982) classified muscle strain into three categories: immediate, delayed, and prolonged (chronic). Each of these categories is summarized below.

Symptoms of immediate muscle strain are usually experienced during or immediately following the application of a stimulus. It can be caused by sudden overload resulting in muscle, and possibly tendon, rupture. It may also result from ischaemia associated with the raised intramuscular pressures that occur during even relatively moderate sustained contractions. Lack of muscle perfusion allows metabolites to accumulate, inhibiting muscle performance and causing increasing discomfort. Intermittent rests, as brief as 2 seconds, can reduce the likelihood of ischaemic strain (Hagberg, 1982).

Subjects with delayed muscle strain will experience muscle soreness for 1 to 3 days following the stressful event. Hagberg (1982) noted that no single etiology for exercise-induced pain has been accepted. He suggested four possible mechanisms. These are ultrastructural ruptures within the muscle tissue, inflamed tendons, long lasting effects from activity-related muscle ischaemia, or pain from energy depletion as demands exceed metabolic supply. It has been shown that even constant low-grade muscle contractions can result in energy depletion (Hagberg, 1982).

Prolonged muscle strain can continue for months or years. It may be manifest as degenerative tendinitis secondary to impaired circulation and nutrient supplies (e.g. compressed supraspinatus tendon in those who work with elevated arms), chronic myalgia triggered by hypoxic lesions resulting from muscle contraction induced ischaemia, or reactive tendinitis/myalgia following a viral infection in the muscle or muscle damage from overexertion.

Overuse in Bone

It is generally accepted that bone-modelling is positively affected by mechanical loading and physical activity (Eriksen, 1982; Smith & Raab, 1984). These stresses are only beneficial within certain limits; beyond which pain and stress or fatigue fractures can occur. (Margulies, Simkin, Leichter, Bivas, Steinberg, Giladi, Stein, Kashtan, Milgrom, 1986; Micheli, 1986). There is very little information in the literature that defines "sufficient" versus "excessive" levels of activity which determines appropriate rates of progression of physical activity so as to increase bone density, without stress fracture. These limits are likely influenced by the extent of the load, number of repetitions, the condition of the bone, and the age of the inidividual (Margulies et al, 1986; Micheli, 1986).

Reports of the effects of various levels of activity on bone density exist for a) heavy activity over many years; b) moderate activity over a few months; c) intense activity over a few months. Studies of athletes and heavy manual labourers revealed higher than average bone mass in the loaded limbs (Nilsson & Westlin, 1971; Skrobak-Kaczinski & Andersen, 1974). It may be assumed that these individuals progressed gradually to their habitual level of activity and then maintained it at a relatively constant level for many years. Conversely, in a study of the effect of participation in a short-term moderate training program on bone mineral density in previously sedentary subjects, no significant gains in lower extremity bone density were observed (Dalen, Nils, Olsson, 1974). However, when 268 young men were subjected to a 14 week intense physical activity program, the effects of bone overuse became evident. While the group that were able to complete the course without injury did demonstrate increases in bone density, close to 40% had to drop out due to stress fractures (Margulies et al, 1986).

The majority of investigations into bone overuse (stress fractures) appear to focus on the lower-extremity

(Micheli,1986; Margulies et al, 1986). This is presumably because the weight-bearing role of the lower-limbs in the able-bodied population predisposes this region to overuse more so than the upper limbs. Micheli (1986) pointed out that stress fractures can be very difficult to diagnose, even radiographically, however it should be suspected in any persistent activity-related pain.

Effects of Mechanical Stress and Overuse on Articular Cartilage

While moderate stress is clearly beneficial and essential for healthy cartilage, excessive mechanical stress, particularly compressive loading, can cause cartilage wear and damage, and major bone or joint trauma can lead to a form of secondary postraumatic osteoarthritis (Howell,1985). Aging also results in changes in cartilage, but it is difficult to separate the effects of normal aging and excessive use on AC (Gilloteaux & Linz, 1983) and no studies were found that specifically investigated the independent effects of the two on cartilage changes. This may be partly due to difficulty acquiring subjects for such studies since severe cartilage damage can occur without symptoms (Goodfellow & Bullough, 1967).

As was discussed in the earlier sections on muscle and bone, moderate stress is essential to ensure tissue viability, nutrition, and growth. AC, being relatively avascular and required to absorb high and variable loads, may rely heavily on periodic moderate stress to regulate its cellular metabolic rate and pump the nutritive synovial fluid into and out of the tissue. However, this stress is only a beneficial stimulus if it occurs within certain limits. Excessive or too little stress on tissues will have a negative effect (Hargens & Akeson, 1986).

Periodic moderate stress or loading resulting from joint movement is generally accepted as beneficial to AC (Stockwell, 1979; Hargens & Akeson, 1986; Salter, 1989), particularly for the enhancement of nutrition and metabolic activity and the acceleration of healing (Frank, Akeson, Woo, Amiel, Coutts, 1984; Salter, 1989). Adult AC receives its nutrition almost exclusively via synovial fluid permeation of its surface (Stockwell, 1979). The synovial fluid passes into and out of the various layers of AC via various proposed actions, including passive diffusion (Maroudas, 1973); fluid pressure-volume relationships resulting from cartilage compression and decompression under load, causing a mechanical pumping action (Ekholm, 1955; Hargens & Akeson, 1986) and convection secondary to the hydrostatic pressure gradients resulting from joint motion (Levick,1984). Based on their review of tissue nutrition, Hargens and Akeson (1986) concluded that diffusion may be sufficient for the transport of smaller molecules, but it is slow, and it becomes very difficult for the larger molecules found in synovial fluid. It appears to be generally accepted that the most important mechanism of AC nutrition is convection of synovial fluid through the cartilage layers. Joint motion is important in AC nutrition since it both facilitates the convection flows and stirs and mixes the synovial solute, thereby preventing stagnation (Stockwell,1979).

Localized cartilage damage is most often attributed to wear and tear (Goodfellow & Bullough, 1967). In response to repeated microtrauma the cartilage first softens, then progressively splits, and can eventually thin down to bone (Micheli, 1986). Forces that have a wear and tear effect on cartilage include concentrated areas of pressure from weight-bearing and large shearing forces, and while AC is fairly resistant to rubbing, it is vulnerable to repetitive impulse loading (Ekholm, 1956; Radin & Paul, 1971).

A number of studies were found that attempted to determine the effects of specific types of stress on joint cartilage. Goodfellow and Bullough (1967) looked at the effects of age and joint biomechanics on AC wear and tear using necroscopic examination of the radio-humeral and radio-ulnar cartilages from 28 subjects ranging in age from 18-89 years. The radio-ulnar cartilage showed very little degeneration at all ages, whereas the radio-humeral began to degenerate from an early age. When the joint biomechanics were analyzed, the authors saw that the radio-ulnar joint surfaces are almost constantly in contact during movement, whereas in the radio-humeral there are areas of no contact, moderate contact, and heavy stress (Goodfellow & Bullough, 1967). In contrast to the radio-ulnar joint, the radio-humeral cartilage surfaces undergo movement in two directions; flexion-extension gliding, and pronation-supination spinning. On referring to the areas of cartilage damage, it appeared that the areas of constant contact were well maintained, the non-stressed areas softened, and the heavily used areas degenerated. The authors also pointed out that since the radio-humeral joint both flexes-extends and pronates-supinates, any damage in terms of grooves or roughening of one surface would severely damage the other in a scrubbing manner (Goodfellow & Bullough, 1967).

Gardner (1983) studied the effects of repeated impact loading of cartilage in rabbits by subjecting their knee joints to loads of 1.5 times their body weight, 40/minute, 20-40 times per day. Bone stiffening began to occur within one week and this is known to increase the risk of cartilage trauma during compressive stresses. On experimental application of direct impact or shearing forces, Armstrong, Schoonbeck, Moss, and Mow (1980) found that cartilage split through to the deep layers and subsequently degenerated. Chrisman, Ladenbauer-Bellis, and Panjabi (1981) applied forces to the knee that were just less than those required to induce fracture. They noted increased synthesis of arachidonic acid, which is a normal precursor of cartilage degeneration. While these results suggest that excessive stress leads to cartilage damage, the nature of the stresses is rather high in intensity and administered over a relatively short period of time.

It has also been suggested by a number of authors that mechanical stresses secondary to joint malalignment or malformations, due for example to trauma, muscle tear, or ligament damage, are likely to increase the risk of cartilage damage through high forces, redistribution of stresses to unaccustomed areas, or abnormally directed forces (Cooke, 1985; Peyron,1987; Ferguson, 1987). Although cartilage adapts to normal demands, it may not adjust to unusual stresses.

Age related changes to the joints may in and of themselves add additional wear and tear or mechanical stresses to cartilage. These changes include cartilage thinning (Roughley & White, 1980) so that there is less available to absorb habitual forces, thereby possibly increasing the risk for later degeneration. Flattening of joint contours with age (Bullough, 1981) has been discussed, as has the possibility that the resulting redistribution of forces to previously unloaded, and thus softened, cartilage may render it more likely to break down. Fergusson (1987) has suggested that the small fractures in subchondral bone, due to wear and tear after years of use, result in stiffening of the bone. This interferes with its customary role in assisting cartilage as a shock absorber, and thus in turn, places a greater compressive load on the aging cartilage.

It appears clear that excessive forces or sustained pressure (Salter & Field, 1960) can damage cartilage, however it has also been shown that complete absence of stress is detrimental as well and results in softening and a greater risk of damage from occasional load-bearing (Ryder, 1973; Palmorski & Brandt, 1981) Immobilization also has negative effects since it reduces circulation of the synovial fluid which is cartilage's sole source of nutrition (Salter & Field,1960).

Overuse in Tendons and Ligaments

Both tendons and ligaments are susceptible to wear and tear. Ligaments can be torn due to overstretching or to excessive or repetitive use (Putz-Anderson, 1988). Damaged tendons and ligaments are less effective as joint stabilizers. This permits greater play during joint movement or stress, thus risking further tendon and ligament tearing or stretching. Tendons may be placed under tension by muscles, or compression and shear from nearby bones and ligaments, and they respond to these stresses by deforming. The response of tendons to chronic loads has received minimal attention in the literature (Armstrong, Fine, Goldstein, Lifshitz, & Silverstein, 1987). Goldstein, Armstrong, Chaffin and Matthews (1987) examined the reaction to loads of 12 post mortem flexor digitorum profundus tendons (ages 55-72), and found that cumulative tendon deformation occurred after less than 9 seconds rest between 1 second loadings. Tendons may respond to overuse by becoming rough, by fraying or tearing, and developing irritation and inflammation in their sheaths or adjacent bursae. If there is extreme excessive use, such as 1500-2000 repetitions of a movement per hour, as is sometimes seen during sport or occupational tasks, the synovial sheath may become swollen and pain will develop due to the tension exerted by the increased secretion of synovial fluid and tissue exudate (Putz-Anderson, 1988). Tendon overuse syndromes have been given a variety of diagnostic labels including tendonitis, true tendinitis, peritendinitis crepitans, and tenosynovitis. However, depending on the author concerned, the pathologies described for any one of these labels may vary considerably (Waris, Kuorinka, Kurppa, Luopajarvi, Virolainen, Pesonen, Nummi, Kukkonen,1979; Waldron, 1987; Putz-Anderson,1988).

An examination of the studies which consider the independent effects of age and overuse on tendons and ligaments, leads to the conclusion that while both have the potential for considerable pain and discomfort for the individuals involved, the effects of the two in combination would be profound.

1.3.7. Overuse in the Shoulder

The shoulder is the most mobile joint in the body (Kapandji, 1982; Warwick & Williams, 1973). Its design allows the hand to access most areas of the body (Kapandji,1982), and permits placement, control, and operation of the hand within the visual workspace (Peat, 1986, Kelley, 1971; Kapandji, 1982). Like the hip, the shoulder is classified as a ball and socket joint (Kapandji, 1982). However, it is much less stable than the hip (Sarrafian, 1983; Kapandji, 1982). The surface of the humeral head is four times that of the concave and shallow glenoid surface and the glenoid labrum does little to deepen the socket (Sarrafian, 1983). Furthermore, the shoulder relies primarily on muscles to hold it together and to resist the constant downward pull of gravity; whereas the hip has greater ligamentous support (Sarrafian, 1983). Loads held in the hand increase this downward displacement pull on the shoulder. Weightbearing activities of the arms compress the joint, which relies solely on the superior joint capsule and coraco-acromial ligament for superior stability (Sarrafian, 1983).

There are many causes of shoulder pain (Neviaser, 1983), and accurate diagnosis requires the careful consideration of a variety of causes. In addition to primary neurological or musculoskeletal damage in the shoulder complex itself, shoulder pain may be referred or be secondary to pathology in the cervical spine, postural disorders, thoracic outlet syndrome, rheumatoid arthritis (Neviaser, 1983), and vascular or somatic disorders (Cailliet, 1966). Accurate diagnosis may require any combination of techniques, including clinical examination, arthrograms, radiographs, and EMG (Post, 1988).

The occupational overuse literature has recognized the complexities of accurate diagnosis of painful conditions affecting the shoulder. Rather than attempting a specific diagnosis, studies examining the prevalence and possible predictors of overuse related shoulder pain frequently use the broader label of "shoulder pain" as the dependent variable (Bjelle et al, 1979; Maeda et al, 1980; Westerling & Jonsson, 1980; Sallstrom & Schmidt, 1984; Ohlsson et al, 1989). Some studies have conducted extensive diagnostic testing of workers with shoulder pain in an attempt to ascertain possible causes other than overuse. Bjelle et al (1979) found that of 20 workers with shoulder pain, three could be attributed to inflammatory rheumatic disease, and no diagnosis could be established for the remaining 17 subjects. In a second study of 20 assembly welders with shoulder-neck pain, Bjelle et al (1981) found the cause in 7 was probably congenital malformation or musculoskeletal disease, and in the remaining 13 the pain could only be attributed to increased shoulder workloads. In 1984, Bjelle et al did a similar study of 40 workers, and found the shoulder-neck pain complaints in 10 had medical origins, whereas the pain in the remaining 30 was attributed to high shoulder workloads and to age. These results suggest that when establishing the prevalence of overuse disorders in a population suspected to be of high risk, it should be anticipated that a percentage will have primary shoulder problems not caused directly by overuse.

In addition to the time and expense associated with thorough diagnostic testing, there is a lack of consensus in the literature as to what constitutes various overuse related musculoskeletal disorders (Waris et al, 1979). While it is beyond the scope of this review to discuss these differences in depth, the recent literature in the area contains a wide variety of diagnostic labels that appear to overlap each other in definition, are used in one country but not in another, and in many cases have only vaguely defined pathology or have listed unknown pathologies (Fry, 1988; McDermott,1986), and are often associated with heated discussion (Brooks, 1989). Examples of these include repetitive strain injury (McDermott, 1986), occupational cervico-brachial disorder (Kvarnstrom & Hallden, 1983), and cumulative trauma disorder (Putz-Anderson, 1988).

Shoulder pain induced by excessive use has been investigated by both occupational health and sports medicine. The main factors precipitating overuse in this joint appear to be: a) rotator cuff compression and muscle fatigue resulting from repetitive or static shoulder elevation (Hawkins & Kennedy, 1980; Neer, 1972; Herberts, Kadefors, Hogfors, Sigholm,1984); b) work posture (Neviaser,1983; Punnett, 1987) and chronological age (Westerling & Jonsson, 1980; Buckle, 1987); and c) compression and ischaemia within the shoulder joint region due to weight-bearing on the shoulder (Pringle, 1987; Bayley, Cochrane & Sledge,1987).

a) Stresses in Shoulder Elevation

Rathburn and McNab (1970) in a frequently quoted study, found that dye injected into the subclavian artery revealed a pattern of avascularity in the supraspinatus tendon vessels when the arm was held in the dependent position. A similar area of avascularity was reported in the tendon of the long head of biceps (Neer, Bigliani, Hawkins, 1977). This avascular area is believed by some to leave the tendon more vulnerable to degeneration. However, other studies conclude that the tendons are vulnerable to degeneration secondary to both avascularity and the mechanical factor of repetitive impingement of the tendon on the acromion during shoulder elevation (Hawkins & Kennedy, 1980; Neer, 1972; Herberts, Kadefors, Hogfors, Sigholm, 1984; Richardson et al, 1980). Tendon compression during arm elevation was further implicated as a cause of tendon wear in a study by Nasca, Salter, and Weil (1984) that used 60 cadavers to verify contact pressure areas in the subacromial joint during shoulder abduction. By 45^0 of abduction there was evidence of compression of subscapularis, supraspinatus, and some of infraspinatus, and by 90^0 of abduction there was compression of all four rotator cuff tendons. Based on studies of both cadaveric material and ergonomic analysis of the tasks of workers and athletes complaining of shoulder pain, it appears that work with the arms elevated or abducted puts stress on the shoulder muscle-tendon units, predisposing them to damage (Richardson et al, 1980; Codman, 1934; Post, 1983; Nasca et al, 1984; Bjelle et al, 1979; Polisson, 1976; Newberg, 1987; Herberts & Kadefors, 1976; Peat & Grahame, 1977).

In addition to rotator cuff compression, activities involving repetitive or static arm elevation have been shown to cause muscle fatigue in supraspinatus and trapezius muscles more than do more varied activities, even if the varied tasks are heavier (Herberts & Kadefors, 1976; Hagberg, 1981; Malmqvist, Ekholm, Lindstrom, Petersen, Ortengren, 1981; Kvarnstrom, 1983;

Bjelle et al, 1981; Hagberg & Wegman, 1987). This muscle fatigue can lead to prolonged shoulder pain due to degenerative tendinitis, chronic myalgia or reactive tendinitis/myalgia, lasting months or years (Hagberg, 1982).

The forces borne by the glenohumeral joint during elevation activities is often underestimated. Poppen and Walker (1978) calculated the resultant forces at 90^0 abduction to be .89 times body weight. Furthermore, probably due to the mechanical disadvantage of the muscles responsible for abduction, Herberts et al (1984) found supraspinatus and infraspinatus to be particularly sensitive to the mass of items held in the hand when the shoulder is elevated.

No literature was found that examined the patterns of upper extremity movement during functional tasks performed by persons in a wheelchair. The arm height of an individual in a wheelchair is approximately 45 centimetres lower than that of the average able-bodied person (Diffrient, Tilley, & Bardagjy, 1974). In order for these individuals to function in environments designed according to the anthropometrics of the average able-bodied person, the wheelchair user will have to perform tasks with their arms in elevation.

b) Work Posture and Chronological Age

Other factors that appear to be associated with the development of overuse shoulder pain are work posture and chronological age. Neviaser (1983) wrote that shoulder pain in desk workers is commonly caused by the static posture of a slouched upper back and rounded shoulders. It worsens with prolonged sitting and is characterized by pain over the spine of the scapula and point tenderness over its superior medial border (Neviaser, 1983). In addition to repetitive or static arm elevation and shoulder load, awkward work postures due to poor workstation design and layout were identified in the literature as precipitating overuse shoulder pain (Sallstrom & Schmidt, 1984, Punnett, 1987). No research was found as to the relationship of longterm wheelchair use, sitting posture, and the development of shoulder pain in persons with paraplegia.

Increasing age and longer duration of employment also appeared to be associated with the development of shoulder pain (Buckle, 1987) particularly in occupations already known to be at higher risk for development of shoulder pain (Westerling & Jonsson, 1980; Ohlsson et al, 1989; Bjelle et al, 1979). Westerling & Jonsson (1980) suggested that age and employment duration may interact, since older age is often associated with more years of employment in a physically demanding job. Bateman

(1972) reported that the peak incidence of non-traumatic, non-inflammatory shoulder pain has been shown to be during the 5th and 6th decades. This may illustrate the interaction of age and employment in predisposing persons to shoulder pain just prior to retirement.

In an effort to establish the prevalence of shoulder disease in those over seventy years of age, Chard and Hazelman (1987) investigated shoulder disorders (excluding rheumatoid arthritis, referred shoulder pain and inflammatory arthropathy). They found a prevalence of 21/100 of shoulder disorders. Surprisingly, only three of these had sought medical attention, while the majority of the 21 indicated their shoulder pain was interfering with their performance of their ADL. This suggests that use of the case control method would underestimate the prevalence of shoulder pain in older subjects. This is further supported by Waldron's (1987) findings that workers did not report shoulder pain or seek treatment for fear of losing their jobs.

Age and duration of disability, hence duration of wheelchair use, may be important factors related to the development of shoulder pain in paraplegics. The research available suggests that in older subjects, shoulder pain may be interfering with ADL tasks. Chard and Hazelman's (1987) research also suggests that in the case of shoulder pain, the common epidemiological technique of measuring prevalence as the number of persons seeking treatment may generate gross underestimates.

c) Shoulder Joint Compression

The effects of non-traumatic weight-bearing, and repeated compression on the shoulder have not received much attention in the literature. This may be because this activity is not common in industry or most sports, other than gymnastics. Pringle (1984) presented case histories of older women suddenly forced to use crutches or walkers who subsequently developed asceptic necrosis of the humeral head. Pringle (1984) postulated that this was caused by the compression of the main arterial humeral blood supply as the humerus was displaced upward in the glenoid fossa on weight-bearing. However, he suspected that this humeral displacement on weight-bearing might be more common in the elderly, since radiographs of a young man with parapelgia lifting his body weight on extended arms during a transfer revealed no change in the glenohumeral relationship.

Early studies that investigated upper limb pain secondary to long term mobility aid use were based on questionnaires (Nichols, Norman, & Ennis, 1979) and interviews (Blankstein, Shmueli & Weingarten, 1985; Gellman, Sie, & Waters, 1988a)) administered to n=517, n=50, and n=85 long term crutch and wheelchair using subjects respectively. They showed that these individuals are predisposed to developing upper extremity problems, particularly in the shoulders. However, there are large discrepancies in the reported prevalence of upper limb pain. These differences are very likely to be a reflection of the heterogeneity of the samples used, which also makes the results difficult to compare. The samples vary in age, gender, duration of injury, diagnosis or lesion level, and method of mobility. These are all potential prognostic variables in the study of the development of overuse related musculoskeletal degeneration in the upper limbs.

Bayley, Cochran, and Sledge (1987) used a more comprehensive two phase method to study the prevalence and patterns of shoulder problems in 94 spinal cord injured wheelchair using persons (gender not specified) including subjects with low cervical lesions. They first asked subjects to perform a wheelchair to bed transfer. Those who reported shoulder pain (30%) during the transfer were subsequently assessed using plain radiographs and arthrograms. The three most common diagnoses were impingement with subacromial bursitis (24%), rotator cuff tear (16%), and avascular necrosis (5%).

Average times of onset for these conditions ranged from 12 - 19 years post SCI. The authors noted that the majority of the problems were soft tissue rather than bone related. In their sample, pain on transfer was more likely to be experienced by higher lesion subjects. They found no significant difference in duration of SCI between those with or without shoulder pain. Unlike the previous studies, Bayley et al (1987) only selected wheelchair users, however, their definition of paraplegia is unclear since the sample included low cervical lesions. Upper limb function is already altered in these subjects and their methods of performing activities of daily living (ADL), and often their overall activity-levels, differ from persons with paraplegia who have neurologically intact upper limbs. This in turn creates different stresses on the arms and the two groups would be better studied separately.

Wylie and Chakera (1988) examined the problem of shoulder degeneration in the spinal cord injured from yet another perspective. As part of a larger investigation of joint abnormalities, they reviewed routine radiographs to assess shoulder degeneration in 38 subjects with SCI of greater than 20 years duration. The sample included a mixture of gender and lesion levels (33% cervical) but no information was provided as to subjects' usual mobility or transfer methods. There was radiographic evidence of early degeneration at the shoulder in

18% and moderate to severe degeneration in 13% of the sample studied. Degeneration was not examined with respect to age, duration of injury, or lesion levels but pathology was more common in less active subjects. Based on these findings the authors suggested that activity appears to have a protective effect on the shoulder joint. Another explanation might be that previously active wheelchair users had reduced their activity level secondary to shoulder problems. Wylie and Chakera's (1988) results are difficult to compare with Bayley et al's (1987) due to the lack of information about their samples with respect to age, duration, lesion level, and criteria for radiographic evaluation.

Bayley et al (1987) also examined the etiology of shoulder problems in wheelchair users. They suspected that intra-articular pressure increased greatly in the shoulder during wheelchair transfers. Intra-articular shoulder joint pressures were measured in 5 pain-free spinal cord injured subjects. Pressures in the joints at rest ranged from 40-80 mmHg. During the weight bearing phase of transfers it increased up to 280 mmHg. The authors believed that this stress on the joint contributes to the development of shoulder problems in wheelchair-users.

1.3.8. Overuse in the Elbow

In contrast to the shoulder, the elbow joint is naturally stable due to the structure of its articulation (Morrey & An, 1983). This joint is classified as a hinge joint with three articulations: olecranon-trochlear (humero-ulnar), radio-capitellar (radio-humeral), and proximal radio-ulnar (Schwab, Bennett, Woods, Tullos, 1980). A major source of elbow joint stability is the articulation between the trochlear notch of the olecranon and the trochlea of the humerus (Schwab et al, 1980; Morrey & An, 1983). The medial aspect of the elbow is better supported than the lateral aspect, and in fact, valgus stresses are more common than varus stress (Schwab et al, 1980). Daily activities requiring lifting and excessive loads, such as hammering and throwing, have been shown to involve not only flexion and extension stresses, but significant valgus forces (Tullos, Schwab, Bennett, Woods, 1981). Valgus stresses are counteracted by the flexor forearm mass, the medial collateral ligament, the anterior capsule, and the bony articulations (Schwab et al, 1980; Morrey & An, 1983). Varus stability is maintained primarily by the anterior capsule and joint articulations, with minimal contribution from the radial collateral ligament (Morrey & An, 1983). Depending on the position of the elbow, the proportion that each of the aforementioned structures contributed to varus and valgus stability was found to shift (Morrey & An, 1983).

A large number of investigations into occupationally related overuse, use dependent variables such as occupational cervico-brachial disorder or chronic upper extremity pain (Maeda et al, 1980; Sallstrom & Schmidt,1984; Miller & Topliss, 1988). Definitions of these syndromes vary but the pathology may occur anywhere in the upper limb (Maeda et al, 1980; Kvarnstrom, 1983; Sallstrom & Schmidt 1984). Since authors in these studies do not report specific locations of pain it is, unfortunately, difficult to extract information on overuse in any one joint in particular from many of these investigations.

a) Lateral Epicondylitis

Lateral epicondylitis is usually attributed to overload of the wrist extensors, causing pain and inflammation of the origin of extensor carpi radialis brevis, which may involve microscopic rupture, tearing, and tendon repair with immature tissue (Polisson, 1986; Newberg, 1987). Overuse and poor muscle condition are usual causes and lateral epicondylitis becomes more common after middle age as tissue resiliency declines (Cabrera & McCue, 1986). It may also be precipitated by lateral epicondyle trauma or poor alignment of wrist joint surfaces (Snijders, Volkers, Michelse, and Vleeming 1987). This disorder causes pain that increases with grasping, weakened grip, and tenderness distal and anterior to the lateral epicondyle. It results from overloading of the tendinous portion of the extensor muscle-tendon unit and is common in activities such as tennis, throwing (Cabrera & McCue, 1986) and food packers (Luopajarvi et al, 1979). Actions that have been implicated in its development include the extreme pronation and wrist flexion occurring during the deceleration phase of throwing, which place traction stresses on the lateral epicondyle (Cabrera & McCue, 1986); repetitive grasping coupled with finger extension and wrist movements at rates of up to 25,000/workday (Luopajarvi et al, 1979); repeated stresses on the wrist extensors as they resist wrist flexion during power grip and pinch (Snijders et al, 1987); and muscle imbalance resulting from the naturally stronger wrist flexors being further strengthened, relative to the extensors, by most activities (Norris, 1987).

b) Medial Epicondylitis

Medial epicondylitis is usually characterized by pain and tenderness over the area, made worse by resisted wrist flexion and pronation (Cabrera & McCue,1986). It is due to overloading of the wrist flexor group causing stress of the flexor carpi radialis or pronator teres insertions on the epicondyle (Polisson, 1986). This stress may result from the marked elbow valgus moment occurring repetitively during throwing (Cabrera & McCue, 1986). This same moment can also chronically irritate the ulnar collateral ligaments during sports such as javelin, baseball pitching, or golf (Cabrera & McCue,1986).

c) Median Nerve Entrapment (Pronator Syndrome)

The entrapment of the median nerve as it courses between the two heads of pronator teres has been called pronator syndrome (Koppel, 1958). It has been noted to occur in those whose job tasks involve repetitive pronation and is believed to be due to compression either by the hypertrophied pronator group or other structures in the area (Nakano, 1978). Symptoms include pronator teres and proximal thenar eminence tenderness, and possible weakness in those hand muscles supplied by the median nerve (Donaldson, 1978).

d) Cartilage Wear

As was discussed in the section on changes in articular cartilage with age and overuse, Goodfellow and Bullough's (1967) dissections of 28 cadaveric elbows suggested that the radio-humeral joint undergoes far more changes with age (and presumably more years of use) than does the humero-ulnar joint. The authors believed this to be partly a result of the quality of the movements that occur at these joints. The radio-ulnar cartilages slide back and forth in a linear path, whereas the humeral-ulnar joint both pronate-supinates and flex-extends causing its surfaces to both spin and slide. This combination of movements means that any irregularities in the cartilage surfaces will effectively scrub and grind the opposite surface (Goodfellow & Bullough, 1967).

e) Compression Overuse

In their review of non-osseous athletic injuries of the lower arm, Cabrera and McCue (1986) only briefly described elbow compression injuries. They refer to a common mechanical injury caused by radio-capitellar joint compression in a valgus position, which can lead to bone degeneration or degenerative arthritis. It is not clear from their remarks whether this injury results from one incident (i.e trauma) or repetitive overuse. Weight-bearing and elbow joint compression occurs during gymnastics. In a review of common elbow injuries in gymnastics (Hotchkiss, 1990), the author indicated that the injuries are generally due to falls from heights or tumbling. Hotchkiss (1990) reported that osteochondritis dessicans of the humeral capitellum is seen in female gymnasts. Its incidence increases from the age of 10 years onward. The extent of damage to the radiocapitellar joint is an important consideration in the decision as to whether to continue in competition (Hotchkiss, 1990).

A number of investigations have examined the transmission of forces through the elbow joint for various positions of flexion and extension, and under a variety of loads (Amis, Dowson, Wright, 1980; Goel, Singh, Bijlani, 1982; Morrey & Stormont, 1988). Amis et al (1980) used a mathematical model to determine isometric flexion and extension forces at the elbow. They found that there are compressive forces at both the humero-radial and humero-ulnar joints during strenuous activities, and concluded that the elbow cannot be considered a non-weight-bearing joint (Amis et al, 1980). Halls and Travill (1964) attempted to discern the distribution of loads within the elbow when a compressive force is applied to the joint in full extension. They found the load was transmitted to the humerus by the radius and ulna in a ratio of 57:43 respectively (Halls & Travill, 1964). Morrey and Stormont (1988) used cadaveric specimens to examine force transmission under active conditions through the radius only, under various muscle loads. They found that the greatest force was transmitted through the radius to the humerus when the elbow was extended, that this force decreased as flexion increased, and that the force was always greater in pronation than supination (Morrey & Stormont, 1988). In contrast Goel, Singh, and Bijlani (1982) applied no external loads and reported no radio-humeral contact in full elbow extension, but increased contact with increased flexion. No descriptions were found of elbow mechanics during the weight-bearing phases of wheelchair use.

f) Wheelchair Related Elbow Overuse

Schaefer and Proffer (1989) in their discussion of sports medicine for the wheelchair athlete, suggested that poor wheelchair pushing technique could precipitate overuse injuries in the wrist and elbow. No reports were found of the prevalence of epicondylitis or pronator teres syndrome in paraplegics or wheelchair users in general. The lack of information on the biomechanics of the upper limb during wheelchair tasks makes it difficult to predict whether overuse might occur about this joint. In a study examining upper limb pain in ambulation aid users of at least five years duration, 32% complained of elbow pain (Blankstein, Shmueli, and Weingarten, 1985). However it is difficult to generalize from these results since the sample included both crutch and wheelchair users. Due to the different stresses on the upper limbs that result from the two mobility methods, these two groups would be better studied separately.

1.3.9. Overuse in the Wrist and Hand

The wrist has been referred to as the most complex joint in the body due to its articular geometry and multiple radio-carpal and intercarpal joint systems (Mayfield, 1980, 1984). This design allows the hand to combine dorso-palmar flexion and radial and ulnar deviation (Kauer, 1986). The evolution of the structure of the human wrist from that found in lower primates has allowed the development of the hand as a prehensile instrument. This brachiation has been achieved by the replacement of the ulno-carpal articulation with the ligamentous and cartilaginous triangular fibrocartilage complex (TFCC) which suspends the distal radius and carpus from the distal ulna (Palmer & Werner, 1981). The loads borne by the wrist during daily living activities have not been established, but Brand, Beach, and Thompson (1981) calculated the potential tension producing forces of the forearm musculature to be approximately 500 kilograms. The distribution of loads on the forearm in a neutral position has been shown to be roughly 82% through the radius and 18% through the ulna (Palmer & Werner, 1981; Palmer, 1987).

The articulations of the wrist have little inherent stability. Carpal joint stability is maintained primarily by ligaments (Kauer & deLange, 1987). Studies of ligament strengths in the wrist have revealed the weakest link between the carpus and the forearm to be on the radial aspect, with the weakest ligament being the radial collateral ligament (Mayfield, 1980, 1984). Distal radio-ulnar joint stability is provided primarily by the TFCC (Palmer & Werner,1981; Dell,1987; Palmer, 1987). The TFCC also acts as a cushion for the radial carpus (Palmer & Werner, 1981), stabilizes the ulno-carpal joint, and transmits forces across the wrist to the distal ulna (Dell,1987).

Damage to the TFCC will alter the distribution of loads through the forearm; placing stress on other structures, and may result in damage and wrist pain (Dell, 1987; Palmer, 1987). Ulnar wrist pain can be difficult to diagnose and complaints of discomfort in the distal radio-ulnar joint region have been referred to as the "low back pain of the upper extremity" (Palmer, 1987). Differential diagnoses include distal radial ulnar joint arthritis, radio-carpal arthritis, distal radial carpal joint dislocation, medial column carpal instability, extensor carpi ulnaris subluxation, ulno-carpal impaction, and TFCC wear or perforation (Palmer, 1987). Degenerative perforation of the TFCC is more common than traumatic tears (Palmer, 1987). Mikic (1978) found that by the third decade, 40% of subjects had age-related perforations in the articular disc of the TFCC, and by the seventh decade the proportion had increased to 53%.

A normal wrist will not usually develop arthritis (Watson & Brenner, 1985). But if the ligamentous supports are disrupted, the joint becomes at risk of arthritis since the resulting abnormal joint alignments and forces will damage articular cartilage (Watson & Brenner, 1985). Watson & Brenner (1984) identified degenerative arthritis in 210 of 4000 wrist radiographs. Of these, the most common was arthritis (55%), and disrupted articular alignment between the scaphoid, lunate, and radius. This is a painful and debilitating condition and has been labelled the SLAC wrist (scapholunate advanced collapse) (Watson & Brenner,1985; Watson & Ballet, 1984). Degenerative arthritis at the wrist usually begins at the scapho-radial articulation; probably because this joint plays a primary role in wrist function (Watson & Ballet,1984). The second most common (26%) pattern of degenerative arthritic changes was observed between the scaphoid, trapezium, and trapezoid (Watson & Brenner, 1985).

Studies of the effects of overuse on the wrist and hand focus on the prevalence and possible causes of median nerve entrapment in the carpal tunnel, tendon disorders, and degenerative disorders including degeneration of the triangular fibrocartilage and various patterns of arthritis. Waldron (1987) indicated that tenosynovitis in the hand and wrist is second only to dermatitis as the most common industrial disease in Britain, however reports of prevalence rates vary from 1% to 50% (Silverstein, Fine & Armstrong, 1986).

Job tasks reported to be associated with carpal tunnel syndrome (CTS) and tendon disorders in the wrist include high repetition manual tasks more than high force tasks (Armstrong, Fine, Redman, Silverstein, 1987a)); and the combined effects of high speed, extra movements, static work, and hand overstrain (Luopajarvi et al, 1979). Tasks involving both high repetition and high force appeared to increase the risk of CTS and tendon disorders by over five times that of either factor inidividually (Armstrong et al, 1987a)). Hand and wrist postures were not found to be significantly associated with the development of CTS. Vibration caused by holding vibrating tools or machinery appears to increase the risk of CTS and wrist tendon pathology (Armstrong et al 1987a); Weislander et al, 1989). Vibration is known to facilitate muscle contraction (Hagbarth & Eklund, 1965), which can predispose the muscle to fatigue. During long periods of vibration, workers have reported feelings of decreased sensation in the hand and compensate by increasing their grip force by up to twice their baseline

(Westling & Johansson, 1984). This can cause muscle-tendon fatigue and strain and may contribute to overuse disorders. Compression of the ulnar nerve and associated numbness and parasthesias have been reported in cyclists after long periods of weight-bearing of the upper trunk through the palms on the handlebars (Weiss, 1985).

There are five principle studies that examine wrist and hand problems which appear as secondary to longterm use of either wheelchair or crutches (Aljure et al, 1985; Blankstein, et al, 1985; Tun & Upton, 1987; Gellman, Chandler, Petrasek, Sie, Adkins, and Waters, 1988a); Davidoff, Werner & Waring, 1991). All but one (Tun & Upton, 1987) showed an increasing incidence of hand and wrist pain and pathology, ranging from 48 to 63 percent of the subjects examined. Hand problems which appear as secondary to longterm use of either wheelchair or crutches were studied by Blankstein et al (1985). They examined 50 (48 male, 2 female) subjects who had used crutches or a wheelchair for at least five years. Mean age and cause of disabilities were not reported. Results of wrist and hand clinical and radiographic assessments were compared with age and gender matched controls. More degenerative arthritis was found in the disabled than the control group. Pathology was located primarily at the trapezio-metacarpal and radio-scaphoid joint and prevalence tended to decrease toward the ulnar aspect of the wrist. Hand pain was reported by 48%, elbow pain by 32%, while 19% indicated that they had shoulder pain.

Aljure et al (1985) investigated the prevalence of carpal tunnel syndrome (CTS) and ulnar nerve disease in 47 males with paraplegia (average age 47.8 years). Subjects' methods of mobility were not described. The authors hypothesized that over time the manual activity associated with paraplegic subjects' performance of ADL results in a greater incidence of CTS and ulnar nerve disease. CTS was diagnosed in 63% of subjects and 40% showed evidence of ulnar nerve neuropathy. Prevalence of CTS increased with duration of SCI from 30% in those injured 1 - 10 years, to 54% in those injured 11 - 30 years, to 90% in those injured over 31 years. Based on these findings the authors recommended median and ulnar nerve testing within five years of SCI so that preventative and management steps can be taken. In contrast, Tun and Upton (1987) tested 240 median and ulnar nerves in subjects with paraplegia and found only 23% had abnormal conduction times. The prevalence of abnormal conduction times did not appear to be associated with either age or duration of SCI (Tun & Upton, 1987). They also reported that 44% of those with abnormal conduction times were asymptomatic. Davidoff et al (1991), using a clearly described protocol, found that 67% of n=31 subjects with paraplegia (mean age= 38 years; mean duration of SCI = 10 years) had electrodiagnostic evidence of either or both of median or ulnar neuropathies. However they found no association between the prevalence of mononeuropathy and age or duration of SCI.

The effects of raised pressures on internal wrist structures secondary to weight-bearing was also studied by Gellman et al (1988b)). They attempted to determine to what extent increased carpal tunnel pressure or repetitive median nerve trauma precipitated carpal tunnel syndrome in persons with paraplegia. Invasive testing was conducted to compare pressure in the carpal tunnels of 8 symptomatic and 10 asymptomatic subjects during various wrist movements. Those with CTS had greater carpal tunnel pressure than the asymptomatic group during neutral and flexed wrist postures and when lifting the body weight onto the hands, but no tests for significance were reported. The authors concluded that CTS occurs in those with paraplegia as a result of repetitive trauma from wheelchair use and ischaemia secondary to repetitive rather than chronic increases in pressure in the carpal tunnel.

1.4. Review of Measurement Systems

1.4.1. Isokinetic Strength Measurement

Isokinetic dynamometers are used by rehabilitation clinicians and researchers to objectively measure isometric and isokinetic muscle strength. In isokinetic strength testing the speed of limb movement is held constant (Hinson, Smith, & Funk, 1979) throughout the arc of motion, thus converting the increased muscle force generated at various points in the range to resistance, rather than to acceleration, as would occur in a gravity loaded system such as weight-lifting (Moffroid, Whipple, Hofkosh, Lowman, Thistle, 1969). This theoretically allows the muscle to be loaded to its maximum capacity throughout the range (Hislop & Perrine, 1967), whereas muscles tested isometrically can only reflect maximal loading in the one position (Thistle, Hislop, Moffroid, Lowman, 1967). Moffroid (1969) who was involved with research into early developments of the isokinetic concept of exercise, explained that isokinetic muscle work is like a series of successive maximum isometric contractions at each point in the range.

Isokinetic strength testing offers a number of advantages over isotonic strength measurement. Firstly, considerable skill and balance are required to use weights normally associated with isotonic testing methods, and inexperienced subjects may have difficulty or be at risk of injury to muscles and joints secondary to their efforts to control the load (Lander, Bates, Sawhill, & Hamill, 1983; Osternig, 1986). Isokinetic methods are regarded as safer, particularly for subjects who may have pre-existing pain, because there is no need to control the load, and if the subject reduces contraction for any reason, the machine responds immediately by reducing the resistance.

Secondly, unlike isometric strength, which measures strength at only one point in the range, isokinetic strength reflects the muscle's maximum capacity at each point in the range by resisting and measuring the various moments that muscles can produce as biomechanical and physiological variables change throughout the range (Rothstein, Delitto, Sinacore, & Rose, 1983). In an isotonic muscle contraction the resistance load remains constant, but since the resistance moment arm changes through the movement arc, the actual resistance to the muscle changes, being greatest at the extremes of range (Hislop & Perrine, 1967). Similarly, there are changes in the skeletal lever system as it becomes mechanically most efficient in mid-range and the contractile capacity of the muscle alters according to the length tension relationship (Rothstein et al, 1983). As a result, in isotonic strength testing the overall work done by the muscle is at less than maximum capacity because it can only be loaded to what the muscle is capable of at the weakest point in the range (Thistle et al, 1967), whereas in isokinetics the resistance encountered by the musculature is a product of the force applied to the machine at that point in the range.

The KIN-COM, or "kinetic communicator", is a relatively new dynamometer, and at the time of the study, was the only one on the market capable of measuring eccentric contractions isokinetically. The mechanical reliability of the KIN/COM has been established by Farrell and Richards (1986) using an Apple II microcomputer controlled external system to simulate a human user and measure force, lever arm position, and lever arm velocity. The KIN/COM was tested in eccentric and concentric modes at speeds of 30^0/s, 60^0/s, 90^0/s 120^0/s, 180^0/s, and 210^0/s using two levels of force defined as between 100-120 N and 270-300 N. Data were analyzed according to Safrit (1976). Inter-trial reliability coefficients for speed and applied force were RI(1,5)= 0.990 and RI(1,5)= 0.948 respectively. The error in force betweeen the KIN/COM and the external transducer was less than 1% of the transducer value. There was less than 10^0/s difference between speeds as measured by the two systems. Based on this data the authors concluded that the KIN/COM is acceptably accurate for most research requirements.

Exercise Reliability of the KIN-COM

The majority of studies evaluating reliability of human isokinetic strength data generated by the KIN/COM have been based on knee strength testing protocols (Hanten & Ramberg, 1988; Harding et al, 1988; Snow & Johnson, 1988; Tredinnick & Duncan, 1988; Wessel, Mattison, Luongo, & Isherwood, 1988). At the time of development of the isokinetic protocol for this study, Griffen's (1987) work on elbow testing was the only study found that examined reliability of the KIN/COM for use with the upper extremity.

Harding, Black, Bruulsema, Maxwell, and Stratford, (1988) examined test-retest reliability of knee flexor-extensor strength of fourteen women using a reciprocal (flexion followed by extension) test protocol on the KIN/COM. Reliability coefficients were high for peak torque and average torque for both inter-repetition (range 0.984 to 0.993) and inter-occasion (range 0.939 to 0.957). Coefficients for reliability were not as high for peak torque angle between occasions (range 0.631 to 0.822) These results support the use of the more efficient reciprocal testing protocol and indicate that reliable measures of peak and average torque can be obtained at the knee.

Tredinnick and Duncan (1988), also focusing on the knee, demonstrated high inter-test reliability for concentric peak torque and work at 60^0/s and 120^0/s (Intraclass correlation co-efficients ICC range .85 to .97), and medium reliability for 180^0/s (ICC= .75). Eccentric peak torque and work were moderately reliable at 120^0/s and 180^0/s (ICC range .72 to .86) but poor for 60^0/s (ICC .47 and .68 respectively). The authors used a specific test protocol and included a practice session two days prior to initial testing. They proposed that the variability in 60^0/s eccentric peak torque resulted from force oscillations that occurred during contractions.

Wessel et al (1988) examined KIN/COM test-retest reliability of concentric and eccentric knee work measurements at a slow and fast speed. The intraclass correlation coefficients ranged from a low of .85 for 180^0/s eccentric contractions in session 1 to a high of .966 in session 2 for 60^0/s concentric contractions. The authors reported that the second session tended to be more reliable than the first, and based on this recommended a practice session. However ICC's were not given to indicate how much more reliable session 2 actually was. They also found that concentric tests were more reliable than eccentric, and low velocities more reliable than fast.

Snow and Johnson (1988) evaluated the reliability of peak torque concentric and eccentric measurements at the knee with the KIN/COM at velocities of 30^0/s and 180^0/s. No information as to protocol was supplied. Test-retest reliability was high for both types of contraction and at both velocities (ICC range .93 to .97), which conflicts with Trednnick and Duncan's results. Highgenboten, Jackson, and Meske (1988) obtained a reliability coefficient of r>.88 for average concentric and eccentric knee muscle 50^0/s torque on the KIN/COM. They did not give specific reliability coefficients for the various tests nor did they include a detailed description of the protocol followed.

Griffen (1987) assessed the reliability of concentric and eccentric elbow peak torques at 30^0/s and 120^0/s on the KIN/COM by re-testing 20 women after a 30 minute rest interval. ICC's between both concentric speeds and the slow eccentric ranged from .80 to .83 but was only .72 for the 120^0/s eccentric tests. The author deemed all reliability results as unacceptable as they did not reach at least .90.

Griffen (1987) attributed the lack of reliability to poor stabilization, lack of familiarity with the testing process, and subject fatigue.

A review of exercise reliability studies performed on the KIN/COM indicates that in general, reliable test results can be expected, particularly for slower concentric contractions, but that data based on eccentric contractions at the higher velocities should be interpreted carefully. Close examination of these studies reveals a wide variety of factors are considered, and often dealt with quite differently, by researchers when planning isokinetic testing protocols. The literature relating to some of these factors is reviewed below.

The Validity of Isokinetic Strength Measurements

Validity is the extent to which a measurement measured the characteristic it is intended to measure (McMillan & Schumacher, 1984). Reliable results can include systematic errors in validity. Inherent in valid measurement of isokinetic muscle torque is accurate location and maintenance of alignment of joint axis with machine rotation axis, skeletal lever arm and machine lever arm, as well as subject positioning that isolates those muscles under study from assistive contraction in neighbouring muscles (Osternig, 1986). No studies were found that specifically assessed the validity of isokinetic measurements using the KIN/COM.

Nosse (1982) suggested that method of stabilizing the subject during testing is the most important factor affecting muscle torque generated on the Cybex isokinetic dynamometer. Once the joint axis and skeletal lever arm are aligned with those of the dynamometer, adequate stabilization is necessary to ensure alignment is constant throughout the test movement. Poor stabilization can adversely affect the validity of torque measurements in two ways. Firstly, since a contracting muscle pulls equally on its origin and insertion (Daniels and Worthingham, 1980) an isokinetic contraction about an unstabilized joint will very likely result in body part movement that shifts the joint axis out of alignment with that of the machine, at least temporarily, thus introducing error into the torque calculations. Secondly, if a joint is poorly stabilized during contraction, other muscle groups will assist, particularly on maximal effort (Nosse, 1982). Thus measurements obtained will reflect synergistic strength rather than that of the muscle group under study.

Various researchers have explored the effects of different methods of stabilization on isokinetic torque output.

Mendler (1967) and Richard and Currier (1977) found that isometric torque generated by the knee was greatest with maximal stabilization. Hart, Stobbe, and Till (1984) found similar results with knee isometric and isokinetic concentric contractions on the Cybex II. Hanten and Ramberg (1988) investigated the effect of stabilization on quadriceps femoris isokinetic torque with the KIN/COM at seven different speeds both concentrically and eccentrically. Their data revealed that maximum versus minimum stabilization did not significantly affect torque values. They concluded that minimum stabilization is sufficient for maximum strength testing of quadriceps using the KIN/COM. However it is important to note that for both maximum and minimum stabilization methods, all subjects in their study were permitted to self-stabilize by gripping the sides of the testing bench. This may have confounded Hanten and Ramburg's (1988) results since the upper extremity may in fact be a significant stabilizer. Due to anatomical variations, effects of stabilization on torque readings at one joint cannot be generalized to test protocols designed for movements at other joints (Rothstein, 1986).

Minimal equipment is available with the KIN/COM for stabilization during upper extremity testing and limited instruction is provided in the manual. Studies in the literature reporting results of upper extremity testing with the KIN/COM give minimal information as to how they positioned and stabilized subjects (Ng & Kramer, 1988; MacDonald, Alexander, Frejuk, & Johnson, 1988; Ellenbecker, Davies, & Rowinski, 1988). Griffen (1987) used the KIN/COM to assess differences in elbow concentric, eccentric, and isometric peak torque at four velocities. She found only poor to fair test-retest reliability and attributed this in part to poor stabilization. No strapping was used and only manual stabilization over the acromial region (subject in supine) was used to limit shoulder girdle movement. Since some joints in the body do not have one discreet or constant axis of rotation, Strauss (1989) suggests testing in a range where the axis remains relatively constant, and watching for any sliding of the resistance pad on the limb as this may indicate that the joint axis is not correctly aligned with that of the dynamometer.

Pre-loading and Gravity Correction

The KIN/COM has options for management of two force variables during testing; the weight of the limb due to gravity and pre-loaded resistance. The weight of the limb due to gravity will resist torque generated during anti-gravity movements and will assist during gravity assisted movements.

This effect can be removed by the software if desired as long as the limb weight option is followed prior to testing. Winter, Wells, and Orr (1981) investigated the effects of gravity on the work done by the quadriceps and hamstrings at various speeds on the Cybex. Errors in work measurements that were not corrected for gravity were up to 43% for knee extension and 510% for knee flexion. The amount of error varied inversely to the force of the contraction.

The second force variable that can be adjusted on the KIN/COM is the amount of force (Newtons) that the muscle must generate before movement of the lever arm can occur. This is called pre-loading and is particularly useful when measuring average torque since an optimal pre-load would ideally have the muscle working close to its maximum at that point in the range at which data recording begins (Strauss, 1989). The default pre-load setting in the KIN-COM software is 20N, whereas the shoulder extensors of some subjects are capable of generating over 100N (gravity corrected) at 0^0 of the shoulder extension (Pentland, unpublished). Pre-loads set too low will generate data that underestimate the average torque potential of the muscle.

There is only limited attention to pre-loading in the literature; most likely because the KIN/COM is the only isokinetic dynamometer with this option. Piette, Richards, and Filion (1986) tested quadriceps strength in five men and investigated the effects of pre-loading 0%, 50%, and 100% of maximum static strength (determined at 90^0 knee flexion) on curves generated at 30^0/s and 180^0/s. In comparison with the non pre-loaded results they noted an increased amplitude in the early part of the pre-loaded curves and at the fast speed there was a shift in peak torque angle closer to that found at 0^0/s and 30^0/s. They suggested this shift was due to Wickiewicz's (1984) observations that the time necessary for a muscle to develop peak tension is constant. Therefore without pre-loading at the faster speeds, the limb has passed through more range by the time it has a chance to develop maximum tension, and so it appears to peak later. By increasing torque readings in the early part of the curve, pre-loading would therefore avoid under-representation of average torque.

Only two studies were found that mention pre-loads in their protocol description. Griffen (1987), in a study of elbow flexors using the KIN/COM stated that the pre-load was set to 20N for all subjects. Tredinnick and Duncan (1988) arbitrarily set the pre-load for knee extensors at 50N during the warm-up cycles and then increased it to 150N for all subjects to minimize force oscillations that they found tended to occur in eccentric contractions.

Strauss (1989) stated that the choice of optimal pre-load has not been defined, and until guidelines are available, the pre-load should be set at a level that permits generation of the expected strength curve. This can be achieved by gradually adjusting the pre-load for each subject during warm-up contractions.

Isokinetic Velocity

The KIN/COM is capable of testing concentric and eccentric strength at velocities ranging from 0^0/s to 210^0/s. All isokinetic testing is based on the assumption that the subject is making a maximum effort (Rothstein et al, 1983). Validity and reliability of the measurements will be compromised if maximum effort is not obtained. It is difficult to assess whether an individual is working to maximum. Testing at two velocities will give an indication of consistency (reliability) since the results of the two speeds should be in agreement (Strauss, 1989).

No study of isokinetic upper limb strength was found that gave a rationale for its selection of velocities.

Griffen (1987), examined differences in concentric, eccentric, and isometric torque of the elbow flexors and selected a range of speeds (0^0/s, 30^0/s, 120^0/s, and 210^0/s). In contrast, Ng (1988) sought to describe similar relationships in the shoulder rotators but tested only at one speed (60^0/s). Ivey, Calhoun, Rusche, & Bierschenk (1985) reported normal shoulder strength values for the Cybex II based on tests conducted at 60^0/s and 180^0/s. Ellenbecker et al (1988) assessed results of concentric versus eccentric training on rotator cuff strength at 60^0/s, 180^0/s, and 210^0/s. MacDonald et al (1988) used the KIN/COM to assess the outcomes of two acromioclavicular treatment methods by evaluating shoulder strength at 50^0/s and 180^0/s.

Only two studies were found that examined the relationship of isokinetic strength to task performance. Miyashita and Kanehisa (1979) studied the relationship of dynamic peak torque to age, sex, running, and swimming performance in 569 school children and 35 swimmers. They tested only at 210^0/s and no rationale for choice of velocity was given. They also found significant correlations between knee extensor torque and running speed in 13-17 yr. olds and between arm pull peak torque and record holding free-style swimmers. However, they indicated that performance of a motor activity is affected by many factors besides strength, notably style and technique (Miyashita & Kanehisa, 1979). Isokinetic dynamometers test at a constant velocity and whether functional tasks are normally performed in this way not clear. While Zajaczkowska (1962) found that with practice, persons learning a lifting skill changed from a variable to constant speed of lifting, the particular speed related to the one task and may have varied between individuals. No research was found that established the normal velocities of movement of the upper limbs during wheelchair tasks.

The literature describes a number of characteristics of fast and slow isokinetic contractions. Sawhill, Bates, Osternig, & Hamill (1982) tested the knee on the Cybex and found that subjects needed significantly more trials before they could produce stable curves at speeds of 200-400^0/s. Osternig (1986) in his review of isokinetic dynamometry literature noted that at the faster speeds greater range is necessary to give the limb time to catch up to the speed of the dynamometer. Thus, short arcs of movement are not appropriate for tests at fast speeds. Faster speeds have also been noted to produce shorter periods of true constant velocity when the knee is tested on the Cybex because they are associated with longer periods of acceleration and deceleration (Osternig, Sawhill, Bates, & Hamill, 1983). The ramped acceleration and pre-loading options on the KIN/COM are designed to reduce the loss due to acceleration and time needed to develop maximum contractile tension. For a given range of motion, muscles must work longer at slow speeds than fast and Osternig (1986) cautions that at the very slow (30^0/s) the physiological variable of muscle fatigue must be considered.

The literature is in virtual complete agreement that as velocity increases, concentric torque and work decreases (Knapik, Wright, Maudsley, Braun, 1983; Osternig, 1986; Tredinnick & Duncan, 1988). This is usually attributed to the knowledge that the muscle requires time to develop maximum tension and the fast speeds mean the maximum appears to occur later in the range. This in turn reduces average readings. Barnes (1975) found peak elbow torque dropped 43% between 60^0/s and 300^0/s and 12% between 60^0/s and 120^0/s.

There are conflicting results as to how eccentric torque and work are affected by velocity. Rogers and Berger (1974), using a Cybex, and Griffen, (1987) using the KIN/COM found that eccentric elbow peak torque increased to a point and then decreased. In Griffen's study it increased from 30^0/s to 120^0/s before declining. Komi (1973) designed his own isokinetic test machine and found that eccentric elbow flexion torque increased with faster velocities. Eloranto and Komi (1980) and Hageman, Gillaspie, & Hill (1988) found no significant differences between hamstring/quadriceps ratios during two speeds of eccentric testing. Walmsley, Pearson, and Stymiest (1986) suggested that the discrepancies in findings in this area are likely due to the variety in protocols and subjects.

Concentric and Eccentric Contractions

There appears to be agreement in the literature that eccentric contractions generate greater torque than concentric contractions at the same speed (Komi & Rusko, 1974; Rogers & Berger; 1974; Ng, 1988). Rogers and Berger (1974) incorporated EMG into their studies and found no significant difference in the levels of motor unit involvement between maximum concentric and eccentric contractions, even though maximum eccentric tension was almost twice concentric. This has been explained as due in part to the knowledge that the sole source of muscle tension in concentric contractions is the contractile elements, whereas in eccentric contractions the simultaneous contraction and lengthening process stretches the non-contractile elements such that these connective tissues become an additional source of tension. Doss and Karpovich (1965) designed their own dynamometer to study relationships between elbow flexor concentric, eccentric, and isometric torque. They found eccentric force to be 39.7% greater than concentric. In separate studies Komi (1973) and Rogers and Berger (1974) found eccentric isokinetic elbow flexor torque to be almost twice concentric torque. Ng & Kramer (1988) examined shoulder rotator strength using the KIN/COM and found eccentric contractions produced significantly larger peak and average torque than concentric contractions. The differing responses of concentric and eccentric contractions to increased velocity of movement has been discussed in the previous section.

Design of the Isokinetic Strength Test Protocol

The intensity and number of warm ups and recorded maximal trials necessary before stable strength curves are achieved has been addressed in reliability studies by a number of investigators. Their results are very difficult to generalize because of the tremendous varieties in equipment, populations, muscle groups tested, and protocols followed. As Rothstein (1986) points out in his discussion of isokinetic dynamometry, studies achieving reliable results can only be generalized to testing of similar subjects, muscle groups, and conditions. In studies of the knee at speeds of 180^{0}/s Johnson and Siegel (1978) concluded that 3 submaximal followed by 3 maximal warm-ups were needed before consistent measures were obtained. Sawhill et al (1982) tested the knee at speeds of 200-400^0/s and found that significantly more trials were needed to achieve stability at 400^0/s. He concluded that on average four trials were needed for consistent data. In contrast, Mawdsley and Knapik (1982) tested the knee at a much slower speed of 30^0/s and based on their results recommended that only one maximum trial needed to be given before achieving stable scores with inexperienced subjects being tested in only one session. Rothstein (1986) suggests that movements at the slower speeds may be easier for subjects to replicate. Osternig (1986) in his review of literature on isokinetic dynamometry concluded that "whether submaximal or maximal warmups are essential to ensure stable measures is still somewhat questionable at this time. It seems prudent to recommend submaximal warm-ups prior to maximal testing in order to reduce the possibility of muscle strain." (p.67-8).

Reciprocal isokinetic test protocols are more time efficient than those using unidirectional movements. Harding et al (1988) examined the reliability of a reciprocal test protocol for the knee on the KIN/COM and achieved high test-retest reliability co-efficients for peak and average torque measures and relatively lower reliability for peak torque angle data. Asmussen & Bonde-Peterson (1974), Cavagna

(1979) and Komi (1986) suggested that concentric contractions are potentiated when preceded by an eccentric contraction and that the degree of potentiation is a function of the elapsed time between the two contractions. To eliminate the effects of this phenomenon, Tredinnick & Duncan (1988) scheduled a 5 second delay between eccentric and concentric work in their test protocol. They achieved high intertest reliability for concentric torque and work at three speeds (60^0/s-180^0/s.) and for eccentric torque and work at all but the slowest speed. Griffen (1987) used a consecutive eccentric/concentric protocol when testing the elbow, and she attributed the unusually low concentric/eccentric ratios in her results to eccentric facilitation of concentric contractions.

The incorporation and duration of muscle recovery periods into isokinetic test protocols is inconsistent in the literature. This variety is not surprising since studies of muscle recovery in the physiology literature tend to examine fatigue induced by long sessions of repeated submaximal contractions (Mundale, 1970), or electrical stimulation (non-voluntary) at submaximal levels in humans over time or supramaximal levels in animals (Piiper & Spiller, 1970; Cooper, Edwards, Gibson, & Stokes, 1988). It is difficult to generalize results from these works to single isokinetic contractions lasting 0.5 to 2 seconds. Piiper and Spiller (1970) studied oxygen debt and high energy phosphate (ATP and creatinine phosphate) resynthesis in the gastrocnemius of the dog. After 7 minutes of supramaximal tetanic stimuli at 20 contractions per minute they found that initial fast oxygen debt repayment was almost complete in two minutes with the subsequent slow phase was completed in 9 minutes. Resynthesis of the high energy phosphates was close to complete in 2 minutes. They acknowledged that recovery will vary between species and with physiological and biochemical characteristics of different muscles, and experimental conditions (Piiper & Spiller, 1970). However they note that the recovery kinematics of resynthesis appear similar between the canine gastrocnemius and human quadriceps.

The number and diversity of variables affecting maximal muscle strength is well recognized and ranges from psychological such as motivation, to biochemical. Deutsch, Kilani, Moustafa, Hamilton, & Hebert (1987) studied the effect of head position on elbow isokinetic torque production. They based their hypothesis on the literature on the asymmetrical tonic neck reflex (ATNR) and the fact that a number of studies have elicited this reflex in healthy adults. The 48 subjects were seated for testing on the Cybex II. Deutsch (1987) and co-workers found that head-neck hyper-extension resulted in some significantly higher average torque readings than head-neck flexion as did some rotation positions. They also found that the influence of the ATNR can be elicited more easily in men than in women. They advised that the influence of head-neck position must be considered in static and dynamic strength tests.

Isokinetic Strength Measurements

The KIN/COM software will calculate peak torque, average torque, and can be used to obtain peak torque angle. Isokinetic torque varies due to an interplay of changes in the length-tension relationship and biomechanical factors. For this reason, a torque value at a specific point represents how these factors interact at that point, and does not give information as to how the muscles function in the remainder of the range (Rothstein, 1983; Knapik et al, 1983) . Thus, if peak torque values are used there is no way to separate out whether the peak at that point is due to the maximum tension in the muscle, or due to an optimum combination of tensile, biomechanical, and length-tension factors (Rothstein, 1983). Kulig et al (1984) in their review of the existing literature on muscle strength curves reported that there was general agreement that the shoulder flexor and extensor muscle groups generate linear strength curves and therefore have no true peak. Average torque is based on the torque generated throughout a specific range of movement and reflects more of the overall capacity of the muscle group.

While theoretically, isokinetic contractions are performed at constant velocities, it is recognized in the literature that there are fluctuations in speed, particularly early on and toward the end of a movement. Based primarily on results obtained from the Cybex, Winter et al (1981), Osternig (1986), and others noted that there are often initial spikes, or impact artifact that may result from the limb acclerating to catch up to the speed of the machine and then being suddenly decelerated by it to match the pre-set speed. To deal with this Gransberg and Knutsson (1983) recommended that isokinetic dynamometers incorporate a feature that would resist acceleration and thereby reduce early torque oscillations as the speed of the limb is gradually accommodated to the speed of the dynamometer. The KIN/COM has this ramping feature but oscillations are still apparent with some subjects and with some movements more than others. Thus, as Osternig (1986), Rothstein et al (1983) and Sapega, Nicholas, Sokolow, & Saraniti (1982) suggested, since these spikes do not accurately represent muscle tension, the period of the movement in which they occur should be removed from the data.

Subjects have been noted to decelerate toward the end of an isokinetic movement (Osternig, 1986; Rothstein, 1983). This may be a protective response or in anticipation of the end of the movement. Rothstein (1983) suggested that both the early period of oscillations and the end phase of deceleration should be eliminated from the data by taking only the readings from a central "window" of the range of motion tested. In his study of knee extensor torque on the Cybex at velocities of 30-120^0/s over 90 degrees of movement, he recorded torques from a central 70 degrees of range (Rothstein, 1983).

1.4.2. Grip Strength Measurement

The measurement of grip strength is frequently used as an indicator of overall strength in fitness testing; as a measurement of progress in rehabilitation, and as an indicator of a client's ability to perform activities of daily living and return to previous employment (Trombly, 1989, Newman, Pearn, Barnes, Young, Kehoe, Newman, 1984; Smith, Nelson, Sadoff, Sadoff, 1989). Many instruments are available to assess grip strength, however, hand dynamometers are the most commonly used (Rothstein, 1985). In his discussion of the validity of hand strength measurements, Rothstein (1985) pointed out that many investigators use the terms grip strength and hand function interchangeably. While grip strength is related to an individual's ability to perform certain tasks, it is only one aspect of hand function (Rothstein, 1985; Agnew & Maas, 1982).

There is limited literature available that reviews the reliability of grip strength measurements in healthy or patient populations (Stratford, Norman, McIntosh,1989; Rothstein, 1985; Mathiowetz, Weber, Volland, Kashman, 1984). Jones (in Rothstein) assessed the reliability of grip strength measurements in children over two consecutive days using an elliptical dynamometer. The maximum values were used in the analysis. The correlation for measurements of right hand grip strength was .915, and the correlation for the left hand was .934. Stratford, Norman, and McIntosh (1989) evaluated the reliability of maximum grip strength measurements, using the Smedley dynamometer, in 35 patients with tennis elbow. They achieved reliability coefficients in excess of .96 when measurements were averaged over multiple test sessions. Mathiowetz et al (1984) used a Jamar Dynamometer to assess the reliability of grip strength measurements in 27 female college students. They calculated correlation coefficients between two separate sessions to be above .862, with the highest coefficient (.883) obtained when the three trials from each session were averaged. Both Stratford et al (1989) and Mathiowetz, Weber, Volland, & Kashman (1984) provide descriptions of the test protocols followed. The available literature suggests that reliable measurements of grip strength can be obtained when a standardized protocol is used. However, reliability studies of strength measurements are valid only for the specific instrument, protocol, and sample tested (Rothstein, 1985).

1.4.3. Active Range of Motion (AROM) Measurement

The universal goniometer is commonly used to measure joint range of motion. Intra-tester accuracy has been shown to be within 3-5^0 (Cole, 1971), and is more reliable than the use of multiple testers (Boone et al, 1979). The average joint ranges published by the American Academy of Orthopedic Surgeons (1965) are commonly used as benchmarks for normal adult ranges of motion (Boone et al, 1979), although some researchers have identified a need for separate norms for some movements in those over 60 years of age (Walker et al, 1984). Table 1.2 presents normal ranges of motion for the shoulder and elbow reported various investigators.

Table 1.2 Normal ranges of motion for the shoulder and elbow

Motion	Constant & Murley (1987)	AAOS* Average Ranges of Joint Motion (1958)	Murray et al (1985) (mean age 31 yr)	Boone et al (1979) (19-56 yr)	Murray et al (1985) (mean age 62 yr)	Walker et al (1984) (60-84 yr)
Shoulder						
Flexion	$151\text{-}180^0$	158^0	170^0	165^0	165^0	155^0
Abduction	$151\text{-}180^0$	170^0	178^0	182^0	178^0	160^0
Int. rotation	hand to T_7	70^0	49^0	67^0	59^0	59^0
Ext. rotation	hand to top of head, elbow held back	90^0	94^0	100^0	82^0	76^0
Elbow flexion	$126\text{-}150^0$	146^0	--	140^0	--	139^0

*= American Academy of Orthopaedic Surgeons

When information as to joint function, as opposed to diagnosis, is desired active range of motion will provide more relevant data than passive range of motion (Constant & Murley, 1987). Constant & Murley (1987) developed an assessment of overall shoulder function that is recommended by Rowe (1988) in his monograph of the shoulder. The instrument is functionally based, uses a numerical scoring system, and has been found to be reliable and sensitive to minor changes in function (Constant & Murley, 1987). The ranges selected as normal agree with those defined in the literature (Table 1.2). Shoulder flexion and abduction range is divided into six categories of 30^0 each, with scores based on maximum active range obtained by the subject (Constant & Murley, 1987). Shoulder rotation range is scored based on the subjects' ability to reach defined anatomical regions with the hand, which require progressively greater degrees of internal or external shoulder rotation.

1.4.4. Pain Measurement and Its Impact on Daily Living Activities

Pain or discomfort is often used as the dependent variable in studies of musculoskeletal injuries or overuse (Bjelle et al, 1981; Christensen, 1986; Punnett, 1987; Buckle, 1987). It is an important variable to examine in these types of conditions since it, along with weakness, is most a factor which can interfere with task performance and affect quality of life (Waldron, 1987). When measuring pain it is important to establish whether the subject has any reason to report inaccurately, for example, to exaggerate or underestimate the pain (Westerling & Jonsson, 1980). Pain is a multidimensional phenomenon in humans (Duncan, Bushnell, Lavigne,1989) that is modulated by the conscious and subconscious as well as many other factors including cultural and personal incentives (Miller & Topliss, 1988). Pain can be measured as an individual's perception of the pain itself (location, duration, intensity) or behaviourally (whether treatment was sought, degree to which the pain limits activity) (McDowell & Newell, 1987). Both parameters are useful; the former assists in understanding the nature of the pain and can be used to generate and test future hypotheses related to causality (McDowell & Newell, 1987).

There is some debate in the literature as to whether or not the measurement of pain behaviour is more objective than verbal reports of pain, or whether both must be recognized as relatively subjective measurements (Fordyce, 1983). Studies in the overuse musculoskeletal literature which report on pain tend to focus on subjects' perceptions of their pain (Weiss, 1985; Maeda et al, 1980; Westerling & Jonsson, 1980; Sallstrom & Schmidt, 1984; Punnett, 1987) rather than on its impact on performance (Maughn & Miller, 1983; Miller & Topliss, 1988). Quality of pain is variable secondary to a number of factors including medication, fatigue and anxiety, and the performance of activities that exacerbate it or distract the individual from the pain (Williams, 1988). Pain related to musculoskeletal overuse may vary for these and for other reasons and thus its presence and intensity may be intermittent over a long period of time. Therefore subjects may have difficulty in accurately remembering their pain enough to give a valid and reliable description. This is referred to as recall bias (McMillan & Schumacher, 1984).

Not all of the studies reviewed clearly indicated the period of recall which they used when asking subjects to describe their pain. In those that did, the time periods varied widely. Subjects were asked whether they experienced "pain on most days of one month or more in the past year (Punnett, 1987); "pain in the previous few weeks" (Maeda et al, 1980); "pain in the past seven days" (Ohlsson et al, 1989); "pain in the last twelve months" (Ohlsson et al, 1989); "pain occurring on more than twenty occasions or lasting more than one week in the previous year" (Silverstein et al, 1987; Armstrong et al,1987); "pain present at the time of the questionnaire" (Buckle, 1987); and "pain present for six months or longer" (Miller & Topliss, 1988). To measure pain prevalence however, subjects can recall pain which they currently have or significant upper extremity pain experienced within the past year (Ohlsson et al, 1989).

Analogue scales have been used to measure subjects' perceptions of the severity of their pain (Huskisson, 1974, 1982; Scott & Huskisson, 1976, 1979; Dixon & Bird, 1981; Downie, Leatham, Rhind, Wright, Branco, Anderson, 1978). Numerous types of scales exist. A numerical rating scale (NRS) requires the subject to select the number from 0 (no pain) to 10 (worst possible pain) that best represents the intensity of their pain (Downie et al,1978). A visual analogue scale (VAS) is a 10 cm vertical or horizontal line on which the subject is asked to make a mark at the point between the two endpoints that best represents the severity of their pain (Downie et al,1978; Dixon & Bird, 1981). Downie et al (1978) and Huskisson (1979) found that subjects required careful instructions prior to using the VAS and often seemed confused by its wide range of choice. McDowell and Newell (1987), after a review of the pain rating scale literature, concluded that a 10 point NRS was a compromise between the crudeness of a 4 point NRS and the lack of structure and long explanation required on first use with a 10 cm VAS.

Changes in behaviour can be used as indicators of pain intensity (McDowell & Newell, 1987), just as behaviour rating scales are used to measure functional disability (Bombardier & Tugwell, 1987). Behavioural measurements of pain include a) limitations in functional performance due to pain (Jette, 1987; b) recording overt behaviour such as facial expressions (McDowell & Newell, 1987); and c) screening, where subject is asked to perform various movements and indicate when pain is elicited (Waris et al, 1979). Of the few studies of upper extremity problems secondary to longterm wheelchair use, the majority measure only whether or not pain exists, its location, and very limited questions as to the nature of the pain (Nichols et al, 1979; Blankstein et al, 1985; Gellman et al, 1988a). The impact of upper limb pain on function is measured in one study (Bayley et al, 1987) but only with respect to its interference with the performance of wheelchair transfers. No studies were located that examine the intensity or overall functional impact of upper limb pain in longterm wheelchair users.

In his review of the measurement of chronic pain, Williams (1988) emphasizes the importance of including the assessment of function in order to develop a complete picture of a subject's pain. This includes the extent to which the pain interferes with productivity and functional tasks (DeJong & Hughes, 1982) as well as mobility and self-care activities. A number of assessment tools have been developed for the measurement of pain and disability. An example is the Sickness Impact Profile (Bergner, Bobbitt, Carter, Gilson, 1981). However, these instruments measure the impact of pain, and do not discriminate between functional limitations caused by pain in specific regions of the body (e.g. low back pain versus shoulder pain in those with paraplegia). Furthermore, the majority of the items are based on activities performed by the able-bodied; thus do not include many of the tasks specific to wheelchair use.

There is a wide assortment of assessments designed to measure individual's ability to perform activities of daily living (ADL). Examples are The Barthel Index (Mahoney & Barthel, 1965), the Katz Index of ADL (Katz, Ford, Moskowitz, Jackson, and Jaffe, 1963), the PULSES Profile (Granger, Albrecht & Hamilton, 1979), and the Functional Status Index (Jette, 1987). There are also numerous tools designed to measure independence and quality of life in the disabled (DeJong & Hughes, 1982; Wood-Dauphinee & Williams, 1987). However, these instruments are intended to measure whether or not an individual can or is performing an activity, but they do not elicit information as to the reasons the activity may be difficult (e.g pain). There were no assessments located that measure the extent to which upper limb pain interferes with the performance of activities of daily living in wheelchair users.

Summary of the Review of Literature

As a background to the examination of upper limb function in longterm paraplegia and impact on performance of ADL, the literature was first reviewed to determine existing information on the impact of paraplegia and wheelchair use on the performance of ADL, and the effects of the aging process on persons with SCI. Research exists to suggest that wheelchair use does stress the upper limbs, and longterm wheelchair users appear to be prone to the development of upper limb pain. But these studies are based on heterogenious samples, which makes generalization of their results difficult. Furthermore, able-bodied reference groups were not used, and parameters of upper limb function such as strength, flexibility, and the ability to perform ADL after years of paraplegia, have not been examined. Existing research into the effects of aging on the musculoskeletal system shows that there is deterioration which accelerates after the sixth decade, and that the extent of some of these effects may be influenced by daily use. There is consensus in the literature that moderate stress of the musculoskeletal system is essential for viability, nutrition, and growth of its component parts. However, the limits beyond which this stress becomes destructive are not clearly defined, and may be influenced by factors such as load, age, and physical condition. The interaction of musculoskeletal aging and overuse, such as might occur in the upper limbs of persons with longterm paraplegia, is not well understood. Methods exist that enable the measurement of a number of parameters of upper limb function (isokinetic strength, grip strength, flexibility, pain, and activities of daily living performance) in order to determine changes over time in upper limb function in persons with paraplegia and in comparison to able-bodied persons.

CHAPTER TWO: MATERIALS AND METHODS

2.1. Materials

The intent of the study was to measure specific aspects of upper limb function (isokinetic and grip strength, active range of motion, pain, and the performance of ADL) in two groups of men; one group with paraplegia, and the other able-bodied. The purpose was to describe how upper limb function changed over time in persons with paraplegia, and whether or not the nature of the changes differed from those in the able-bodied group. The study was conducted at Curtin University of Technology, in Perth, Western Australia. Data collection took place during 1989.

2.1.1. Subjects

The study sample consisted of two subject groups; one consisting of 52 males with paraplegia, and the other comprising 52 able-bodied males.

A. Paraplegic Subjects

Inclusion Criteria for the Subjects with Paraplegia

The subjects with paraplegia were obtained from the medical records of the Spinal Unit at the Royal Perth Rehabilitation Hospital, in Perth, Western Australia. Recruitment procedures are described fully in the Methods section. All of those who met the following criteria, and for whom a current address or phone number could be obtained, were invited to participate:

- complete traumatic paraplegia from T4 to L1 (functional level);
- manual wheelchair had been the primary method of mobility for the duration of the SCI;
- non-institutionalized;
- certified by own physician to be free from medical complications that would affect upper extremity function, but which were unrelated to SCI e.g. rheumatic diseases, ankylosing spondylitis, neurological disorders, syringomyelia;
- had not had an injury to the lower extremity prior to the SCI that required prolonged use of crutches (longer that 4 months);
- the subject's own physician provided medical approval that it was safe for the individual to participate in the study;
- the subject did not receive severe upper extremity trauma at the time of the SCI;
- the subject resided within 100 kilometers of Curtin University;
- the subject's duration of SCI was at least one year so that activities of daily living (ADL) routines and methods had been established, and any minor arm trauma acquired at the time of the accident had resolved.

Table 2.1 contains a breakdown of the paraplegic sample by age-decade and duration of SCI. Table 2.2 contains a breakdown of the sample by lesion-level and age. The young and old age groups were divided at age 45 years since the literature reviewed indicated that age-related musculoskeletal changes would have clearly begun by this time, and furthermore, this age divided the sample into two relatively equal sized groups. Lesion levels have been classified according to the ISMGF classification system. This system is as follows:

Lesion at T1-T5 = Level II (labelled I in this study)

Lesion at T6-T10= Level III (labelled II in this study)

Lesion at T11-L3= Level IV (labelled III in this study).

Table 2.1 Distribution of subjects with paraplegia by age (decades) versus duration of SCI (decades).

	Duration of Injury (years)				
Age	>1.5≤10	>10≤20	>20≤30	>30≤44	Total
<30	8				8
>30≤40	5	6			11
>40≤50	1	5	8		14
>50≤60	2	2	4	5	13
>60		3	1	2	6
Total	16	16	13	7	52

Table 2.2 Distribution of subjects with paraplegia by age and SCI lesion-level.

Lesion Level	Aged <45 years n=28	Aged≥45 years n=24	Total
T_2-T_5	5	5	10
T_6-T_{10}	15	6	21
T_{11}-L_2	8	13	21

B. Classification of Upper Limb Activity-levels

Since the paraplegic and able-bodied persons were being compared to determine possible effects of longterm wheelchair use on the upper limbs, it was important that other than using a wheelchair, the two groups should resemble each other in arm activity-levels as closely as possible. Therefore, the paraplegic subjects' upper limb activity-levels were classified independently of their being in a wheelchair, and this was used as a matching variable in selection of the able-bodied subjects. In this way, the two groups' upper limbs were exposed to similar upper limb stresses, except that the subjects with paraplegia used wheelchairs.

Present upper limb activity-level during the last six months was a matching variable because it would result in a training effect and would influence upper limb strength measurements. Past arm activity was considered since it might influence the development of overuse related problems in the upper limbs. The latter was based on the activity-level of the upper limbs (job, sport, hobby) for the majority of the adult life.

Paraplegic subject data collection preceded able-bodied subject data collection. Information as to paraplegic job, sport and recreation participation was obtained, and on this basis each paraplegic subject's upper extremity activity-level was classified for both present arm activity-level and arm activity-level for the majority of their adult life. Upper limb activity-level was divided into three categories labelled Sedentary, Moderate, and Heavy. The levels were defined as follows:

Sedentary	- Desk job, no sport participation.
Moderate	- Bench work, manual physiotherapist, recreational upper extremity sport (tennis, golf, swimming, basketball, squash) primary responsibility for homemaking and childcare.
Heavy	- Job involving heavy tool use, or tool use at or above chest level, or heavy lifting e.g boilermaker-welder, industrial electrical fitter. Regular heavy upper extremity sport (field events, weight-lifting).

Table 2.3 presents the distribution of paraplegic subjects by age and present upper limb activity-level. The Moderate and Heavy categories were combined due to the small number of subjects in each.

Table 2.3 Distribution of paraplegic sample by age group and upper limb activity-level.

Activity-levels	Aged <45 years (n=28)	Aged≥45 years (n=24)	Total
Sedentary	20	18	38
Moderate/Heavy	8	6	14

C. Able-bodied Subjects

The 52 able-bodied subjects were matched to the paraplegic subjects by gender, age (within 3 years), present upper limb activity level, and past upper limb activity level. The sources of able-bodied subjects included university staff and students and their families, Lion's Clubs, senior citizens' groups, hospital staff, and friends and work colleagues of the subjects with paraplegia.

2.1.2. Demographics and Activity History Questionnaire

This questionnaire (Appendix A) was designed to collect relevant demographic data including the job, sport, and recreation history information that was used to classify subjects' upper limb activity-levels. The questionnaire was administered during an interview with the subject and was completed by the investigator.

2.1.3. Activities of Daily Living History Questionnaire

The purpose of this instrument (Appendix B) was to determine the paraplegic subjects' frequency and techniques of performing specific daily living activities. Each activity was selected on the basis that it involved significant upper extremity work for an individual in a wheelchair and might play a role in the development of overuse related upper extremity problems in longterm paraplegia. Information was sought as to the performance of these activities both now and in the past, since the two might differ secondary to aging, lifestyle, or pain related changes.

2.1.4. Pain Interview Schedule

If the subjects with paraplegia indicated during the interview (Item 12 on the Demographic questionnaire) that they had experienced upper limb problems, pain, weakness, or subjects discomfort since their spinal cord injury, or, in the case of the able-bodied, during adult life, the Pain Interview Schedule (Appendix C) was administered. The purpose of this set of questions was to obtain a description of the history and nature of any upper limb discomforts or problems experienced by the subjects. The McGill Pain Questionnaire (Melzack,1975) was not used because its focus on the psychological dimensions of pain (sensory-discriminative, motivational-affective, and cognitive-evaluative) (Melzack,1973;1975) would not provide all of the information required in this study to thoroughly understand the nature of the upper limb pain experienced by the paraplegic subjects. Examples of needed information not elicited by the McGill Pain Questionnaire are: when the pain first began, what exacerbates it and reduces it, exactly where on the upper limb that the pain occurs, and what types of treatment have been used.

2.1.5. Pain Screening Test

This test (Appendix D) was administered to all subjects by the examiner. It comprised seven test movements designed to screen for pain bilaterally in the following areas: neck, acromio-clavicular joints, impingement, supraspinatus, bicipital tendons, and medial and lateral epicondyles.

2.1.6. Impact of Upper Limb Problems on Activities of Daily Living Performance Questionnaire

The purpose of this questionnaire (Appendix E) was to measure the spinal cord injured subjects' perceptions of the impact of upper extremity problems (e.g. pain stiffness, aching, weakness, fatigue, numbness) on their performance of usual activities of daily living. The questionnaire was designed to be administered by interview and completed by the investigator. The questionnaire content is based on the Barthel Index (Mahoney & Barthel, 1965). The Barthel Index was modified to focus specifically on upper extremity function in activities of daily living relevant to paraplegia. The process of development of the questionnaire is outlined in the Methods section.

2.1.7. Scales to Measure Body Weight

Each subject's body weight was measured in sitting using four scales (Soehnle, West Germany, OZMA Medical, Perth, W. Australia) mounted in a reinforced plywood frame (Figure 2.1) similar to the set-up used by Kofsky, Shephard & Davis (1984). This equipment was wheelchair accessible and enabled body weight to be obtained efficiently without the need for additional wheelchair transfers. This was regarded as important, particularly for the elderly subjects with paraplegia.

2.1.8 Grip Dynamometer

Isometric maximum grip strength was measured bilaterally in kilogram units using a hand held Smedley's Dynamo Meter (Smedley Inc.;Tokyo, Japan) (Figure 2.2). The Smedley model of dynamometer was used because it was available as standard equipment in the Excercise Science Laboratory. It was calibrated using standardized weights, and very high test-retest reliability (n=30) was established prior to data collection. The handgrip was not padded and the space between the palm contact and finger flexion bar was 5 cm. Prior to data collection the dynamometer calibration was checked by placing it in a specially constructed steel frame (Figure 2.3) that had been mounted on the wall, so that selected known weights could then be suspended from the grip meter handbar.

2.1.9. Anthropometric Characteristics

Body segment lengths were measured in centimetres using a flexible plastic measuring tape. A felt-tipped marker pen was used to mark bony landmarks since skin pencils were found to scratch the skin.

2.1.10. Range of Motion

The range of motion section of Constant and Murley's (1987) clinical method of functional assessment of the shoulder was adapted to include the elbow for use in this study (Appendix F). Goniometric measurements were taken using a 12 inch universal goniometer (Figure 2.4) (Rolyan Medical Products, P.O.Box 555, Menomonee Falls, Wi. 53051, USA).

2.1.11. Isokinetic Dynamometry

Isokinetic average torque was measured using the Kinetic Communicator (Kin-Com) Dynamometer (Chattecx Corp., 101 Memorial Drive, PO Box 4287, Chattanooga, TN 37405) (Figure 2.5). The software for data collection was that provided with Kinetic Communicator II, Version 4.0 (Chattecx Corp., Chattanooga, TN., 1987). The small upper extremity cuff that was supplied with the machine was attached to the dynamometer lever arm (Figure 2.6). The equipment used for support, positioning, and stabilization during isokinetic testing is listed below:

1. Hydraulically adjusted padded manipulation therapy table (Figure 2.5),

2. Two sheepskins were secured to the surface of the manipulation therapy table for the paraplegic subjects' skin protection (Figure 2.7).

3. 8 inch (20 cm)medium density foam as a head rest (Figure 2.7),

4. diving weight belt strapping and quick release buckles for strapping of lower extremities and trunk (Figure 2.8),

5. 4 inch (10 cm) medium density foam for skin protection from lower extremity strapping (Figure 2.7),

6. 1 inch (2.5 cm) low density foam for skin protection from arm resistance pad strapping,

7. 4 inch (10 cm) moderate density foam to distribute pressure from the investigator's hands during manual stabilization.

An adapted spirit-level (Figure 2.9) was used to calculate the gravity correction angles.

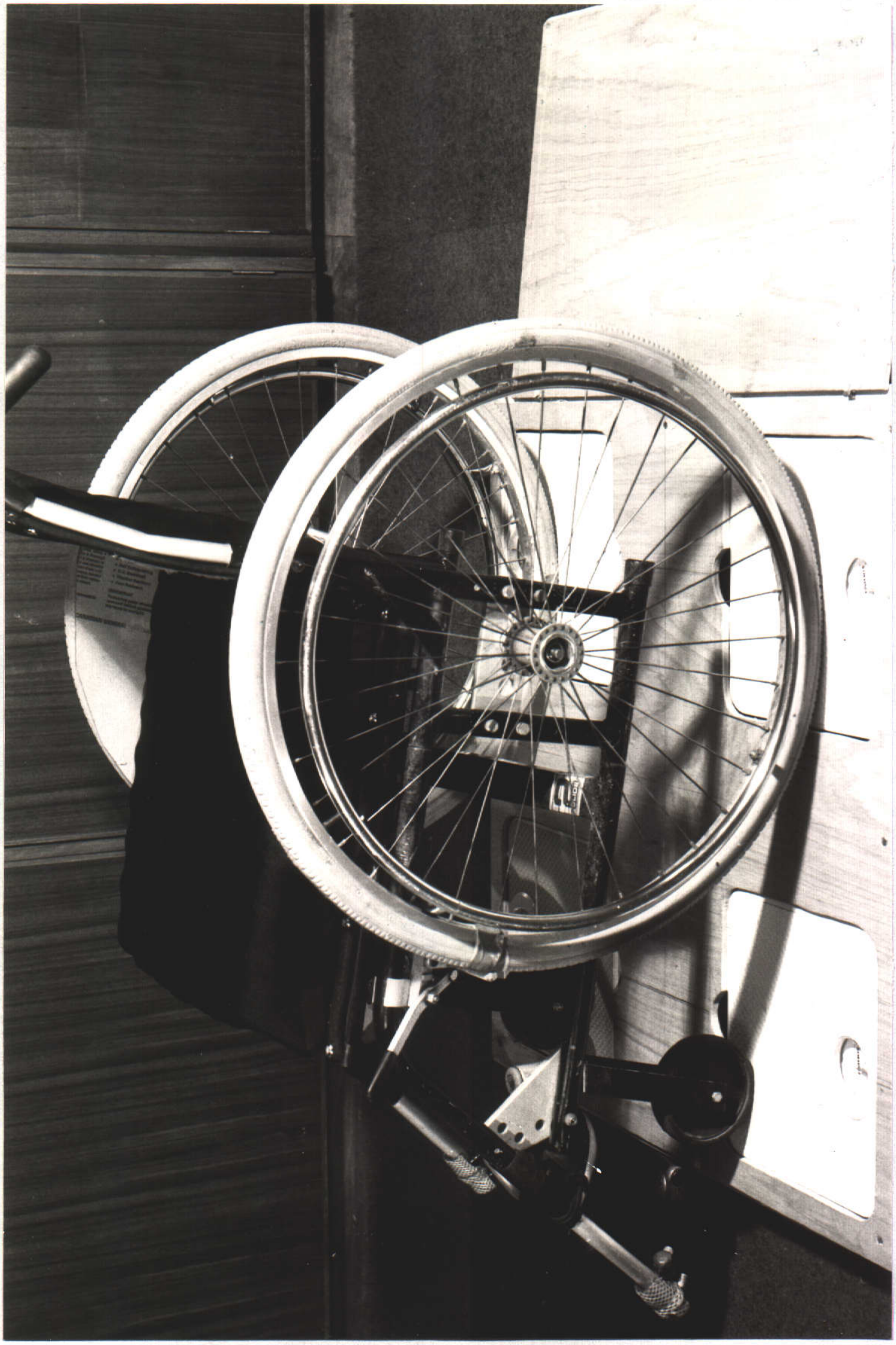


Figure 2.1 Scales to measure body weight while seated in a wheelchair.

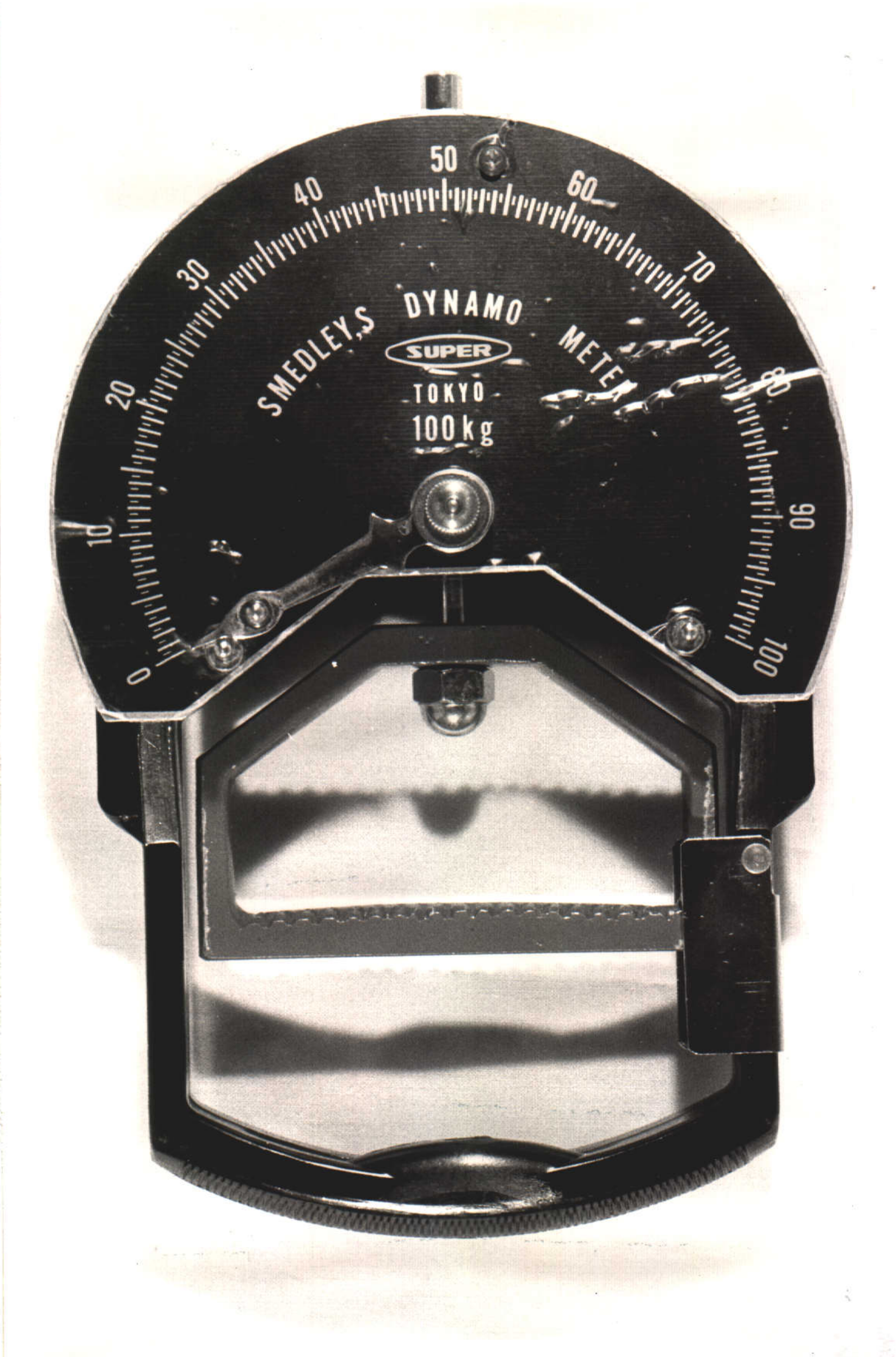


Figure 2.2 Dynamometer to measure maximum isometric grip strength.

Figure 2.3 Steel frame used to mount grip dynamometer to suspend known weights for calibration.

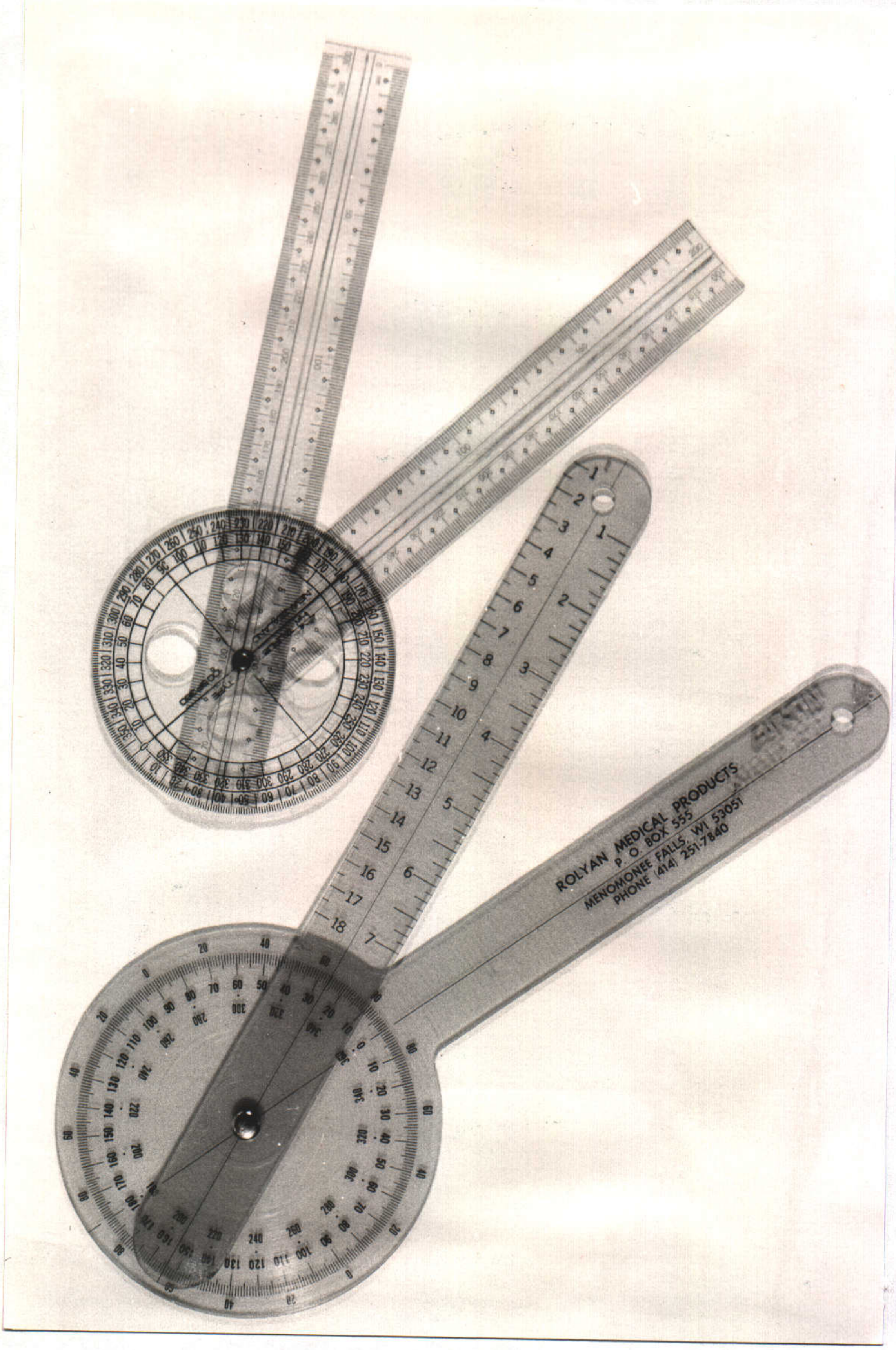


Figure 2.4 Universal goniometer (12 inch/30 cm) used to measure active range of motion.

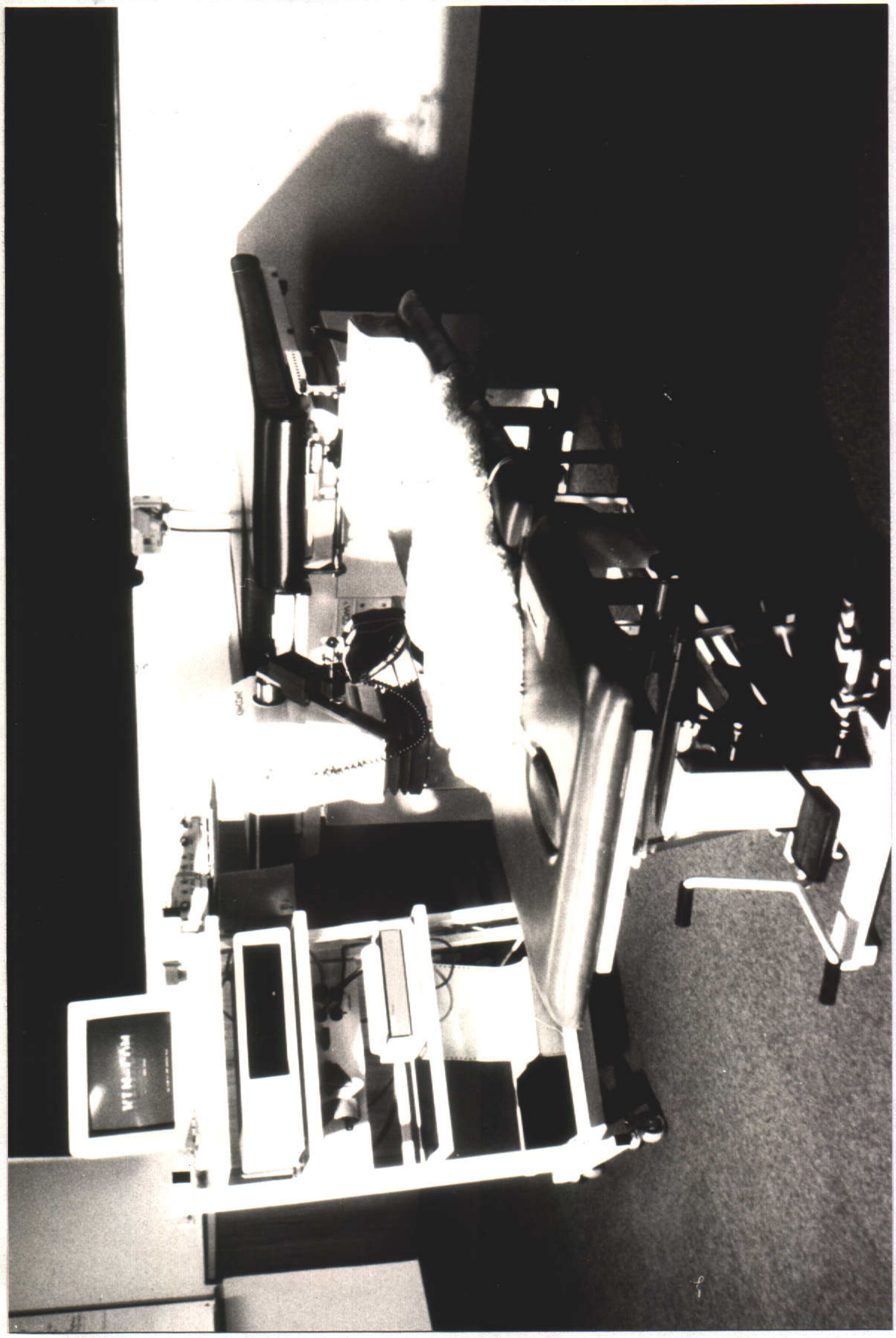


Figure 2.5 KIN-COM isokinetic dynamometer and padded adjustable manipulation therapy table.

Figure 2.6 Upper extremity cuff used in isokinetic strength testing.

Figure 2.7 Sheepskin pad, 8 inch (20 cm) head support foam, and 4 inch (10 cm) foam used to protect the lower extremities during isokinetic testing.

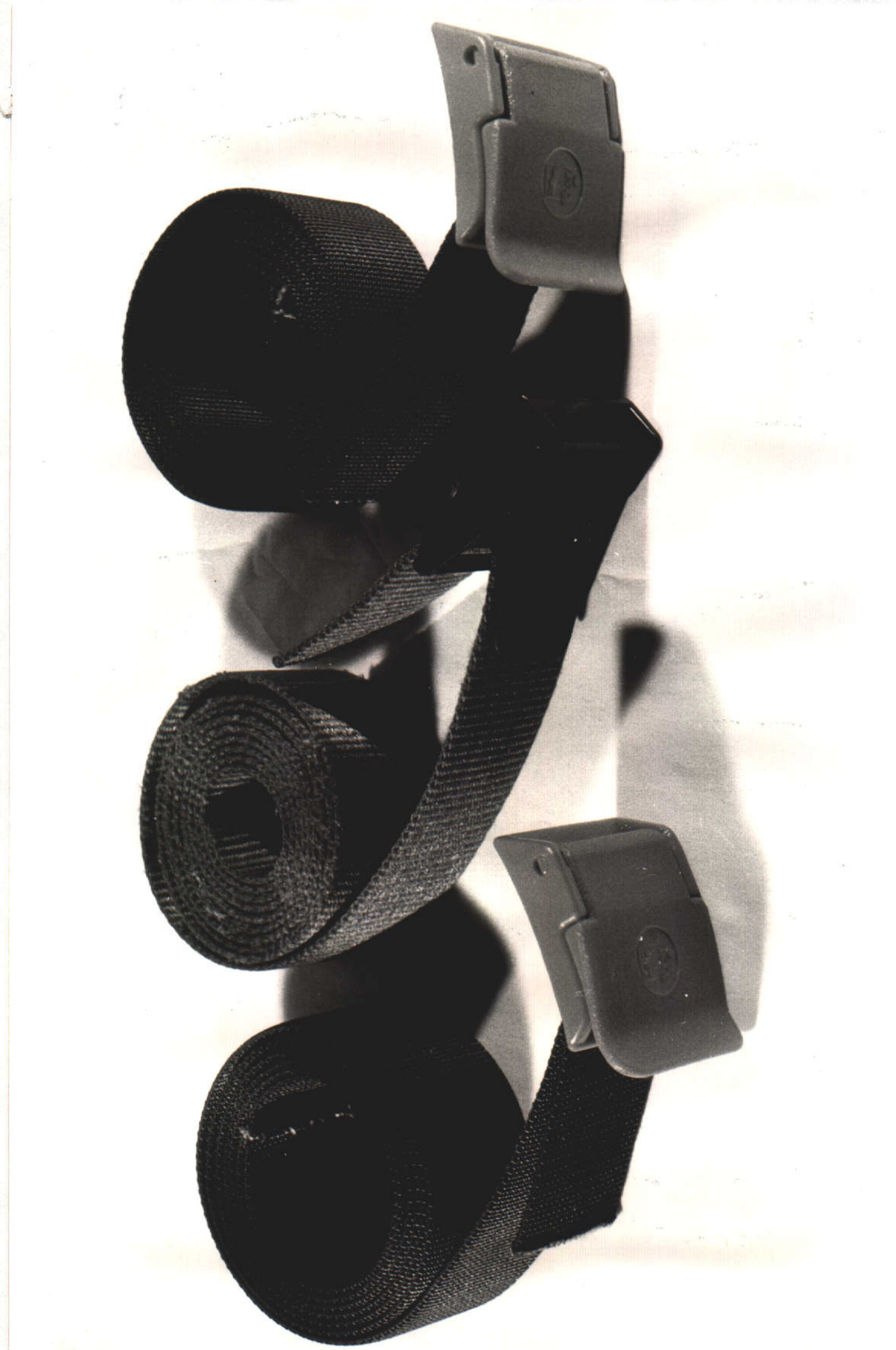


Figure 2.8 Diving belts used to stabilize the subjects during isokinetic testing.

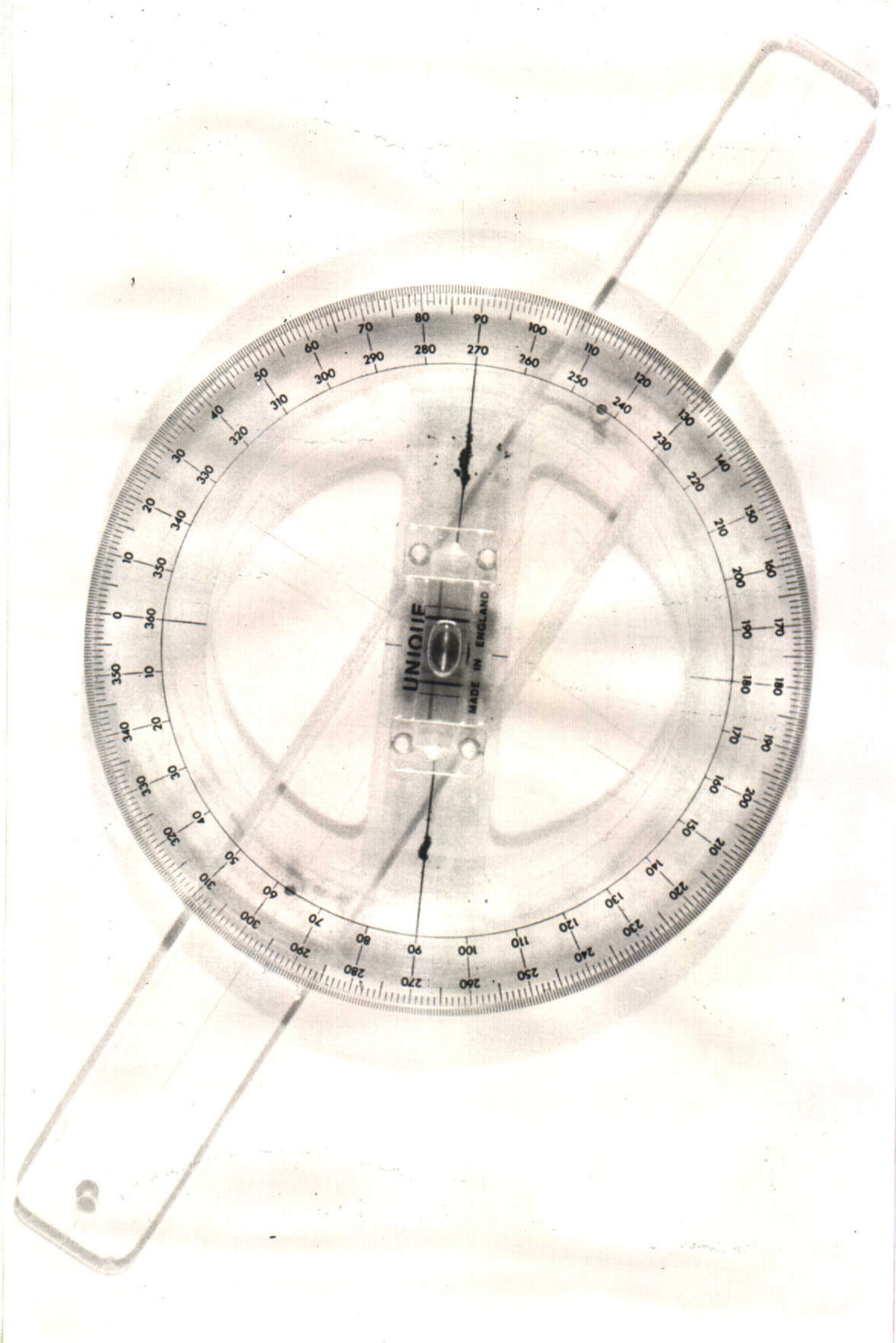


Figure 2.9 Adapted spirit-level used to calculate gravity-correction angles during isokinetic testing.

2.2 METHODS

Data collection for the study proceeded in three distinct phases in the following order; interviews of the subjects with paraplegia in their homes; physical measurements of the paraplegic subjects at the Curtin University School of Physiotherapy Exercise Science Laboratory; and interviews and physical measurements of the able-bodied referent subjects in the Exercise Science Laboratory. The specific measurements taken in each phase are listed in Table 2.4.

Table 2.4 Measurements taken in each phase of the study.

1. Interviews of the Subjects with Paraplegia
   - Demographics and Activity History
   - ADL History
   - Pain Questionnaire
   - Impact of Upper Limb Pain on ADL Questionnaire
2. Physcial Measurements of the Subjects with Paraplegia
   - Anthropometric characteristics
   - Grip strength
   - Active range of motion
   - Pain screening
   - Isokinetic upper limb strength
3. Interviews & Physical Measurements of the Able-bodied Subjects
   - Demographics and Activity History
   - Pain Questionnaire
   - Anthropometric characteristics
   - Grip strength
   - Active range of motion
   - Pain screening
   - Isokinetic upper limb strength

The duration of an interview of a subject with paraplegia (Table 2.4, Phase 1) was approximately 1.5 hours. The duration of a physical measurement (Phase 2) session for a subject with paraplegia was between two to two and a half hours. An interview and physical measurement session with an able-bodied subject (Phase 3) lasted 2.5 to 3.0 hours.

This section will describe the methods of the study in chronological order as per Table 2.4. Each measurement technique will be presented separately, and all aspects related to it will be discussed at that time. This includes the development of the tool, and where relevant, reliability and validity testing, the interview protocols, and scoring. The procedures that were followed to ensure safety and comfort of the subjects during data collection are described.

2.2.1. Pilot Test

Prior to proceeding with the study, a pilot test of the Demographics and Activity History Questionnaire, ADL History, Pain Interview Schedule, Pain Screening Test, Impact of Upper Limb Pain on ADL Questionnaire, and the equipment and protocols to measure active range of motion, grip strength, and isokinetic strength was conducted in November, 1988 at Queen's

University, in Kingston, Canada. The purpose of the pilot test was to evaluate the comprehensiveness and clarity of the questionnaires, and the safety, comfort, feasability, and suitability of the physical measurement protocols for use with both persons in wheelchairs and able-bodied individuals. The methodololgy was submitted to and passed by the Queen's University Faculty of Medicine and School of Rehabilitation Therapy Human Ethics Committees.

Fifteen subjects participated in the pilot test and they are described in Table 2.5. Medical clearance was obtained from each subject's physician. The subjects' informed consent was obtained at the beginning of the assessment session. Each assessment took approximately two hours.

Table 2.5 Description of the subjects used in the pilot test.

Subjects with Paraplegia	Age (yr.)	Gender[1]	Duration of SCI (yr)	Able-bodied Subjects	Age (yr.)	Gender
P1	32	F	32	A1	32	F
P2	32	F	32	A2	33	F
P3	29	F	1.5	A3	30	F
P4	65	M	18	--		
P5	66	M	46	--		
P6	51	M	20	A6	52	M
P7	38	M	13	A7	38	M
P8	35	M	2	A8	36	M
P9	27	M	6	--		

[1] F = female; M= male

The pilot test enabled the evaluation of the instruments and protocol by the investigator, and collection of subject feedback and recommendations. This enabled identification of aspects of the method, equipment, and questionnaires that needed modification or adjustment, as well as an opportunity to problem solve possible solutions.

2.2.2 Method of Paraplegic Subject Selection and Informed Consent for the Study

During the year prior to commencing the study the proposed research was discussed with the Medical Director of the Royal Perth (Rehabilitation) Hospital (RP(R)H), Perth, Western Australia, Mr. Ellis Griffiths. His formal support and authorization for access to the medical records of the Spinal Unit was obtained at that time. These records were subsequently reviewed to identify persons with paraplegia who met the inclusion criteria outlined above. As a result of this review, a list of 78 males with paraplegia was compiled.

The RP(R)H medical records contained current addresses for the majority of these individuals. Telephone numbers and updated addresses were obtained from numerous sources including the telephone directory, Spinal Unit Community Visiting (Silver Chain) Nurses, prospective subjects' families, and other subjects.

Initial contact was made with the paraplegic subjects by mail, and this was followed up with a telephone call. The initial contact consisted of two letters sent together; a covering letter from the Medical Director of the RP(R)H (see Appendix G) and a brief introductory letter from the investigator (Appendix H). The intent of this mailing was to briefly introduce the study and its rationale, to indicate the RP(R)H's approval of the research, and to ask the individual to consider participating as a subject in the study. In instances where the telephone number was unknown and unavailable (n=18) a note was attached to the letter asking the individual to phone in their number to the Curtin Schools of Therapy receptionist, so that they could be contacted.

The introductory mailing to the subjects with paraplegia was followed by a telephone call from the investigator to explain further details of the study and the ask whether the individual was willing to participate. If yes, an appointment time was booked for the investigator to interview the subject in their own home or workplace, whichever was most convenient for the subject.

Of the original list of 78 potential participants, 49 subjects met the inclusion criteria. Table 2.6 lists the reasons for exclusion. In an effort to gain more subjects, the medical records at RP(R)H were reviewed a second time. Following the same process outlined above, a further 3 subjects were identified and agreed to participate.

Table 2.6 Reasons for exclusion of persons with paraplegia from the study sample.

Unable to locate	4
Deceased	3
Refused	4
Current illness	3
Caliper-walking	5
Moved out of state	2
Syringomyelia/rheumatoid arthritis	2
Head injury	1
Other (severe arm trauma at SCI, psychiatric, alcohol abuse, foreign language, severe extraneous pain)	5
Total excluded	29

The able-bodied subjects were identified based on the matching variables (gender, age, past and present upper limb activity-levels). The able-bodied subjects were approached by the investigator in person or by telephone. The purpose and nature of the study was explained. If willing to participate, the subject was questioned regarding the matching variables. If these matched a subject with paraplegia, the able-bodied individual was accepted into the study. An appointment was booked for an assessment within the following three to four weeks.

2.2.3. Ethics Review, Informed Consent, and Medical Clearance for the Paraplegic and Able-bodied Subjects

Prior to commencing data collection, a proposal for the study was submitted to the Ethics Review Committee of the Royal Perth Rehabilitation Hospital, Perth, Western Australia. The proposal was reviewed and accepted (Appendix I).

Informed consent was obtained from all subjects at the outset of their first data collection session with the investigator. Informed consent was obtained during the interview with the paraplegic subjects in their home. The study, the subject's role, and the associated risks and benefits were explained verbally. The subject was then asked to read and sign the consent form (Appendices J and K). The form for the subjects with paraplegia also included a statement indicating that the subject authorized his medical doctor to provide medical clearance to the investigator and to release any information regarding relevant medical conditions necessary to ensure the subject's safety (Appendix L).

2.2.4. Interviews of the Subjects with Paraplegia

Each subject with paraplegia was interviewed in his own home or place of work. During the one to two hour interview, informed consent was obtained and four instruments were administered in the following order:

1. Demographics and Upper Extremity Activity History.
2. Activities of Daily Living History.
3. Pain Questionnaire.
4. Impact of Upper Extremity Problems on Activities of Daily Living Performance.

2.2.5. Demographics and Activity History Questionnaire

As stated in the Materials section, this questionnaire (Appendix A) was designed to collect relevant demographic data as well as job, sport, and recreation history so that each subject's past and present upper extremity activity levels could be determined. During its development, the instrument was reviewed by occupational therapy clinicians and researchers, and was trialled during the pilot test. Necessary modifications were made to content, format, and scoring methods. The questionnaire was administered and completed by the investigator. Paraplegic subjects were asked to respond to all items, whereas only those items with the number underlined were administered to the able-bodied subjects. The rationale for the items is outlined below.

Item 1,2,4,5,6,7: In order to confirm the accuracy of the medical record, paraplegic subjects were asked for their date of birth, date of injury, and level of SCI lesion. Other than for level of lesion, where there was any discrepancy, the subject's report was recorded as fact. The medical record was consulted again to clarify level of lesion. Date of birth and date of SCI were used to calculate duration of SCI and age at the time of SCI.

Item 8: Hand dominance was defined as the hand the subject used for writing. This information was needed as strength data was recorded according to dominant and non-dominant rather than right and left upper limbs.

Item 9: Marital status was categorized as either alone, or with a partner. This information gave direction for later questions regarding the subject's daily household responsibilities and activities.

Item 10: Daily routines were classified into two categories based on whether the subject left the house for a regular activity such as full or part-time work, volunteer work, or school. This information was recorded since the additional upper limb activity associated with outings into the community in a wheelchair might have a relationship with physical findings in the upper limb.

Item 11: A brief description was obtained of any injuries to the neck, shoulders, arms, or hands, that had required medical attention either prior to, at the time of, or since the spinal cord injury (SCI). This screening question was used to ensure that the subject had not received severe upper limb related trauma and to identify less serious upper extremity problems that might influence the subsequent development of overuse or aging related musculoskeletal difficulties.

Item 12: In this sceening question, subjects were questioned as to any incidents of pain, discomfort, numbness, or weakness in their arms (since the SCI in the paraplegic subjects). If these problems had occurred, the Pain Interview was administered.

Item 13: a) Information was gathered as to any medication or other treatment that might alter the subject's pain perception.

b) Paraplegic subjects were questioned as to the presence of lower limb spasticity or severe contractures so that these could be managed appropriately during the transfers and positioning required during the strength testing.

Items 14, 15, and 16: Data from these items was gathered in as much detail as possible. Subjects were asked to list and describe the jobs, sports, and hobbies that they had participated in during their adult life, with a focus on the amount and nature of upper extremity work that each had required. The investigator used this information to classify subjects according to their present and past upper extremity activity-levels, in order that they could be matched with an able-bodied referent. The activity-level categories were described in the Materials section.

2.2.6. Activities of Daily Living (ADL) History

The rationale for the contents of this questionnaire (Appendix B) is based on the assumption that many of the activities performed by an individual in a wheelchair place significant demands on the upper limbs and that high frequencies of performance of the more demanding activities may be associated with upper extremity strength and or the development of overuse problems in the longterm wheelchair and crutch-user (Aljure et al, 1985; Bayley et al, 1987, Gellman et al 1988a, 1988b).

Subjects were asked to estimate how often they performed the activity at the time of the study. They were also asked how often they had performed the task during the majority of the time since their SCI, since frequencies may have changed secondary to lifestyle, aging, or upper limb pain. Hagberg and Michaelson (1981) suggested that musculoskeletal strain is probably an interaction of numerous factors including load, load variation with time, localized muscle fatigue, and duration of strain, and that exposure is the product of quantity x time. The time spent performing ADL tasks that stress the arms is difficult to measure, since unlike an occupational setting, wheelchair users perform a wide variety of different tasks that in themselves are brief, but cumulatively may place significant stress on the upper limbs. For this reason frequency of task performance was measured, rather than exposure time.

The activities of daily living included in the questionnaire were as follows:

Number of transfers per day.
Description of usual transfer technique.
Distance wheeled per day.
Number of times the wheelchair is loaded to and from the car per day.
Number of transfers on and off the floor per week.
Number of transfers to the bottom of the bathtub per week.
Person responsible for the majority of household activities where he lives.

The items were selected based on consultation with persons with paraplegia and rehabilitation clinicians as well as a review of the literature. Individuals with paraplegia, occupational therapists, and physical therapists were asked to indicate those activities normally performed by individuals with paraplegia that they considered to be particularly demanding on the upper limbs. The literature was reviewed to identify positions, movements, and wheelchair activities known to stress upper limb structures. The questionnaire was pilot tested with paraplegic subjects and reviewed by four occupational therapy clinicians and three occupational therapy researchers. Based on their feedback, content and wording were revised to their final form.

The questionnaire was administered and completed by the investigator. Items were scored on a frequency per day or per week basis. Transfers were counted as one per lift, therefore transferring on and off the toilet was equivalent to two transfers.

2.2.7. Pain Interview Schedule

If the subjects with paraplegia or the able-bodied subjects indicated that they had past or present pain in the upper extremities, this interview schedule (Appendix C) was administered. An interview schedule, rather than questionnaire, was used because there was minimal existing research describing upper limb pain in wheelchair users that suggested pertinent questions. The descriptive information obtained in this study could be compiled to describe and compare trends and frequencies of upper limb problems and treatment experiences in this population.

Subjects who indicated that they had had pain in the past week were asked to use a numerical rating scale (NRS) to indicate the intensity of their upper limb pain. This scale ranges from 0 (no pain) to 10 (worst pain possible) (McDowell & Newell, 1987). Use of the NRS was limited to those with pain in the past week in order to reduce recall bias. The numerical rating scale was used instead of a visual analogue scale (VAS) because Downie, Leatham, Rhind, Wright, Branco, &

Anderson (1978) and Huskisson (1979) found that some subjects had difficulties comprehending the VAS. After a review of the pain rating scale literature, McDowell and Newell (1987) indicated that a 10 point NRS is a compromise between the crudeness of a 4 point NRS and the confusingly wide choice possible and long explanation required on first use with a 10 cm VAS. Subjects describing upper limb pain in the past six months were asked to rate its severity using a three point scale (mild, moderate, severe).

The data from the interview was analyzed using frequency counts and was examined for common themes and trends. A form was developed to record and tabulate the results (Appendix M). Questionnaires were identified by number, rather than name, both to protect subject anonymity, and so that the researcher was not biased by the age or duration of a subject when scoring the questionnaire.

2.2.8. Impact of Upper Limb Problems on ADL Performance Questionnaire

The purpose of this questionnaire (Appendix E) was to measure a spinal cord injured person's perceptions of the impact of upper extremity problems (e.g pain, discomfort, aching, stiffness, weakness, tiredness, fatigue, or numbness) on his performance of activities of daily living. The questionnaire was designed to be administered by interview. The researcher conducted all of the interviews and scored all of the questionnaires.

The questionnaire content is based on the Barthel Index (Granger, Albrecht, Hamilton, 1979; Fortinsky, Granger, Seltzer, 1981; McDowell and Newell, 1987). It was modified to focus specifically on upper extremity function in those activities of daily living that are relevant to paraplegic who use wheelchairs. The process of development of the questionnaire included consultation with numerous persons with paraplegia, rehabilitation clinicians who treated persons with paraplegia, and two researchers and two epidemiologists. The questionnaire was pilot tested to identify problems with content and format, and to identify and eliminate items that were poor discriminators.

The questionnaire was scored using a five point Likert scale of frequency indicators; never, rarely, sometimes, usually, always. The questionnaire was divided into three major categories of activities of daily living; self care, mobility, and general activity. For each individual activity or task (e.g car transfers) the same questions were asked. These questions, and their purpose were:

1. Screening question: " Since your spinal cord injury have you usually done x ?"

The purpose of this question was to screen out the subjects who had never done the activity. This question was not asked regarding items that are normally always performed by a healthy person with paraplegia (e.g. feeding, grooming at the sink).

2. Upper extremity problems question: "What percentage of the times that you do x do you have any problems in your arms?".

The purpose of this question was to identify how often upper limb problems were experienced when performing the activity.

4. Change question: "What percentage of the times that you do x, do problems on your arms cause you to change your method, your frequency of doing x, or to use extra equipment or assistive devices to do x ?"

The purpose of this question was to identify how often upper limb pain had caused the individual to make technique changes, OTHER THAN added assistance from another person.

5. Assistance question: "What percentage of the times that you do x have problems in your arms caused you to get help form someone to do x ?".

The purpose of this question was to identify how often assistance was sought with the ADL task due to upper limb problems.

Prior to administration of the questionnaire, the following paragraphs were read to each subject, and the scoring was explained.

"The purpose of this questionnaire is to find out whether the activities you have NORMALLY BEEN DOING SINCE YOUR INJURY have been affected by problems in your arms. When answering please consider whether you have had any problems with your ARMS (SHOULDERS, ELBOWS, WRISTS, HANDS or OUTSIDE THE JOINTS) that have interfered with you carrying out your usual daily activities WITHIN THE LAST SIX MONTHS.

PROBLEMS IN YOUR ARMS might include pain, discomfort, aching, weakness, tiredness, numbness, or stiffness, etc.

Some questions ask whether, due to arm problems, you have "changed your method" of doing a specific activity, for example wheelchair transfers. Changes in method include positioning wheelchair or furniture differently, transferring more to the opposite side than you used to, or doing the transfer less often. In other words you have changed your technique. If you have begun to use assistive devices or equipment because of arm pain, this would be considered a change in method as well. Increasing the amount of assistance you receive from another person does not; as it is considered in the next category. Examples of equipment and assistive devices are sliding transfer board, bath seat, loops sewn into clothing, new bladder routine, hydraulic lift in vehicle, electric wheelchair, changes to clothes or footwear to make them easier to put on.

Finally, some questions ask whether, due to arm problems, you need "more help than you used to" with a specific activity. This means ANY assistance you now receive from another PERSON to do the activity safely, that you did not need previously. This may range from being available in in another room while you bathe in case you fall, to getting out clothes for you to dress in bed in the morning, through to lifting you during a transfer or pushing your wheelchair for you."

The subjects were asked to respond to each item by selecting the category that best represented the percentage of the times that they performed the task that the item applied;

0% (assigned value = 0); 1-24% (assigned value = 1); 25-49% (assigned value = 2); 50-74% (assigned value = 3); 75-100% (assigned value = 4). Using the assigned values, subtotals were then calculated for each type of question in each of the three sections. These subtotals were expressed in percentages based on the sum of the assigned values divided by the maximum possible score for that section. In order to avoid skewing the scores, if a subject did not normally do an activity (e.g transfer into the bathtub), it was not included when calculating the percentage score. This generated scores for the following:

1. Arm pain during mobility.
2. Change in mobility method due to arm pain.
3. Added assistance with mobility due to arm pain.

4. Arm pain during self-care activities.
5. Change in methods of self-care due to arm pain.
6. Added assistance with self-care due to arm pain.

7. Arm pain during general activities.
8. Changes in general activities due to arm pain.
9. Added assistance with general activities due to arm. pain.

2.2.9. Physical Measurements of the Paraplegic and Able-bodied Subjects

The second and third phase of data collection took place in the Exercise Science Laboratory at the Curtin University School of Physiotherapy, where the KIN-COM isokinetic dynamometer is housed. The second phase involved the measurement of the physical parameters of the subjects with paraplegia, and in the third phase the able-bodied subjects were both interviewed and their physical parameters were assessed.

Once medical clearance for the paraplegic subjects was obtained, a two hour assessment session was booked for a time convenient to each subject. The same arrangements were made with the able-bodied subjects, however they completed their own medical clearance at the outset of their session. The start times for the assessment sessions varied from 8am to 7:30 pm and they took place on all seven days of the week.

The sequence of measurement of the physical parameters was:

1. body weight & arm segment lengths;
2. grip strength;
3. range of motion;
4. pain screening assessment;
5. isokinetic strength testing;
6. trunk and body length.

2.2.10. Body Weight

The body weight scales were calibrated and checked for reliability and validity of measurements using standard weights at 50, 60 and 75 kilograms. All subjects were weighed on the day of their strength testing.

a) Weighing of the Subjects with Paraplegia

The paraplegic subjects wheeled into the scales such that each wheel of the wheelchair was in the centre of one scale. Subjects were instructed to put the wheelchair brakes on, look straight ahead, and remain still. The investigator then recorded the weights from each scale and summed them. Later in the session when the subject transferred to the strength testing table, the empty wheelchair plus cushion was weighed and body weight was determined by subtracting this value from the initial overall weight. Body weight was recorded in kilograms (kg). This process is illustrated in Figure 2.10.

b) Weighing of Able-bodied Subjects:

The able-bodied subjects' body weight was calculated using the same method as for the parapelgic subjects. However, instead of using a wheelchair, the able-bodied subjects sat in a 3 kg desk chair placed such that each of its legs were in the centre of a scale. The subjects were instructed to position themselves such that each foot rested on a scale. Their weight was determined by subtracting the chair weight from the overall weight.

2.2.11. Grip Strength

Isometric maximum handgrip strength was measured bilaterally in all subjects using a Smedley's grip dynamometer. The dynamometer was calibrated using standard weights at 25 and 50 pounds (lbs). This was accomplished by mounting the dynamometer on the wall in a specially constructed steel frame (Figure 2.3) and suspending the weights from the grip bar.

Subjects were tested in sitting and instructed to grasp the dynamometer, hold the arm fully extended to the side with the shoulder slightly abducted, and the radio-ulnar joints in neutral rotation (Figure 2.11). Subjects were instructed to slowly squeeze on the dynamometer as hard as they could and to stop if any discomfort was experienced. No warm-up was given. Subjects began with the dominant hand. One set consisted of a test of the right hand followed by a test of the left. Each subject completed three sets and a rest of 60 seconds was observed between each set. If the third trial was greater than the previous two, testing was repeated until a peak was recorded.

Figure 2.10 Measurement of body weight of paraplegic subjects while seated in their own wheelchair.

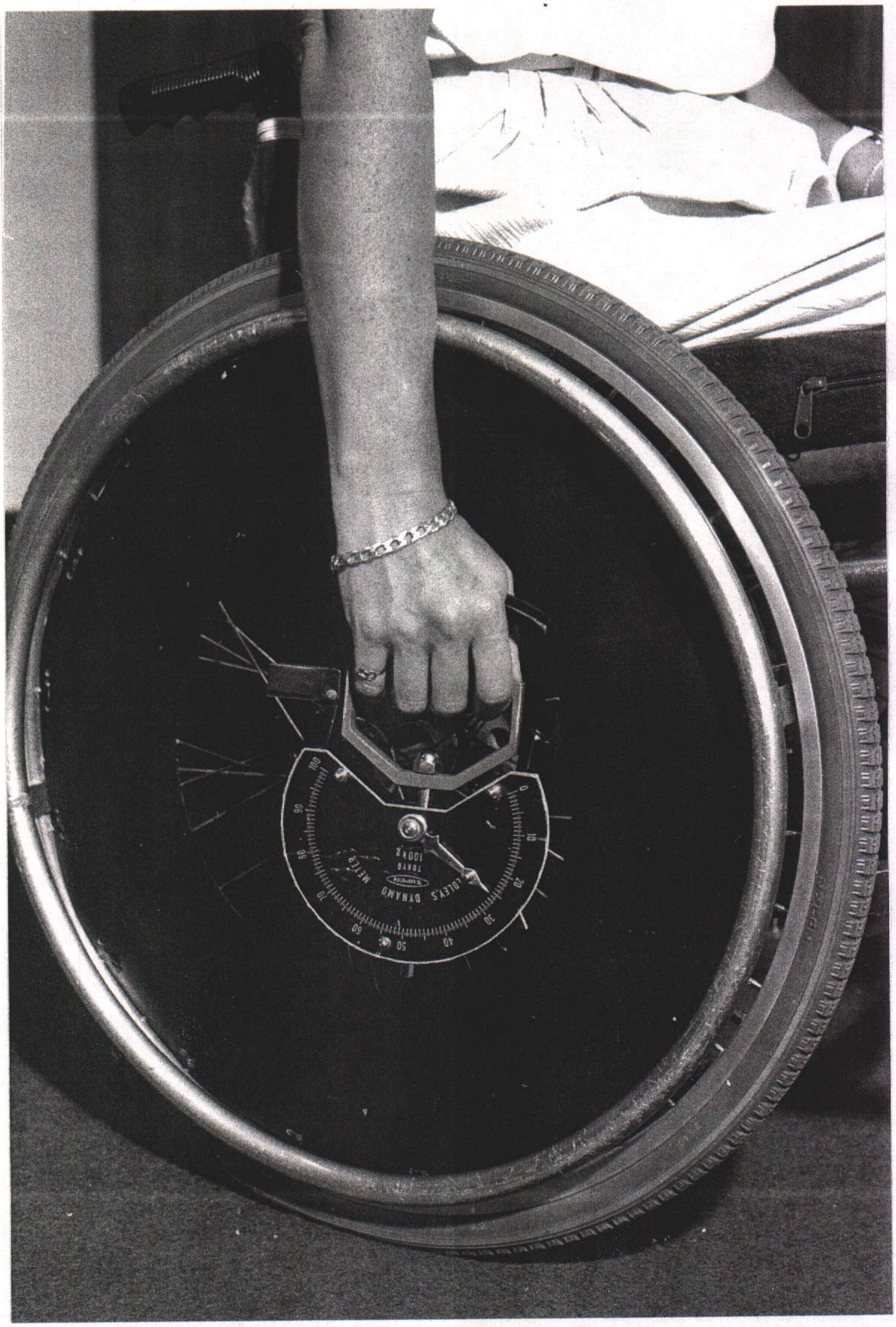


Figure 2.11 Method of measuring maximum isometric grip strength.

2.2.12. Range of Motion

Active range of motion of the shoulders and elbows was measured according to a clinical method of functional assessment of the shoulder (Appendix F) developed by Constant and Murley (1987) and recommended by Rowe (1988) in his text on the medical care and management of shoulder disorders. Following the same format, a category was developed for evaluation of elbow flexion range of motion.

Constant and Murley's (1987) method of assessing active range of motion (AROM) was selected because its measurement of composite movements of internal and external rotation gave a more sensitive overall indication of the functional aspects of these movements, its measurement of loss of range by 10 degree increments would detect functionally significant losses of AROM, and the assessment was time efficient.

The assessment was conducted with the subject in sitting. Subjects were asked to shoulder flex, extend, and abduct, and elbow flex as fully as was comfortably possible. The available range of motion was measured using a 12" universal goniometer, according to the method described by the American Academy of Orthopaedic Surgeons (1965). The movements for internal and external rotation of the shoulder were demonstrated by the investigator, who then stood behind the subject to observe them performing the movement (Figure 2.12). Subjects were asked to indicate the location of any discomfort.

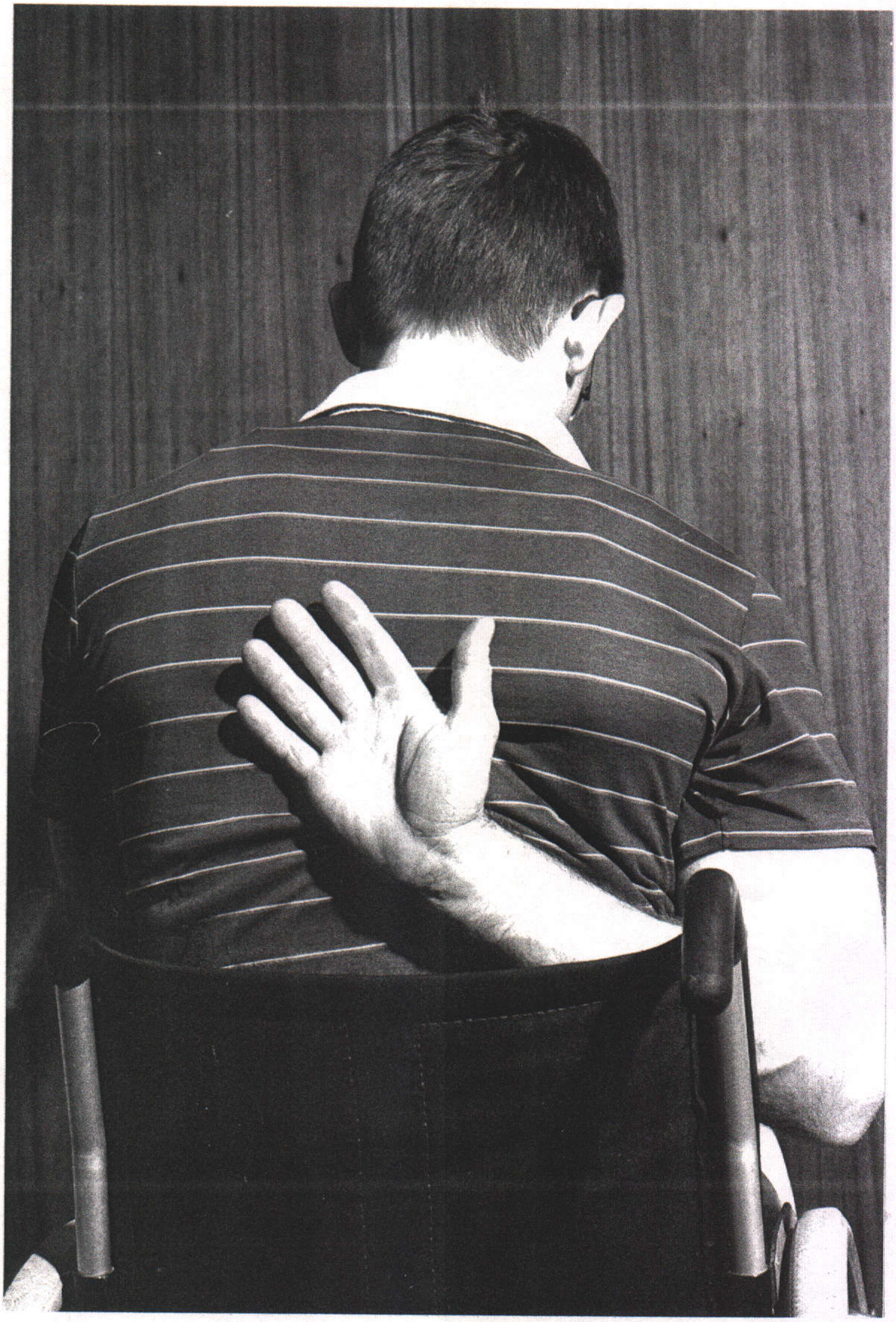


Figure 2.12 Method of measuring shoulder internal rotation range of motion.

2.2.13. Pain Screening Assessment

A brief screening for upper limb pain was developed and conducted on all subjects (Appendix D). Its purpose was to provide a quick, easily administered manual clinical test for pain in areas of the upper limb that were seen as high risk for overuse in wheelchair users. These were selected based on a review of the literature. The screening was intended as a preliminary check to identify movements that could elicit or aggravate pain during the isokinetic testing. It was also conducted because the investigator noticed that during the interviews, some of the subjects with paraplegia appeared to minimize their upper limb pain, or had changed their ADL techniques to avoid the pain. The screening then was used to ensure subject safety during subsequent strength testing and to confirm earlier pain reports.

The protocol was based in part on the work of Waris et al (1979) who developed an epidemiological screening of occupational neck and upper limb disorders. They based their methods on an extensive review of the literature of the diagnostic criteria for eight upper limb disorders that have a known or anticipated relationship to occupational overuse. The final list of overuse problems screened for in this study was based on further review of the literature to determine possible upper extremity changes secondary to long term wheelchair use by persons with paraplegia, and analysis of wheelchair activities to determine movements and stress patterns in the upper limbs that might put joints and tissues at risk of excessive wear.

The screening was conducted with the subject seated. Active forward and lateral neck flexion were assessed. Reduced range and complaints of pain or marked stiffness in the neck were considered positive signs. The acromio-clavicular joint was tested for pain and tenderness by having the subject fold his arms across his chest and the examiner then applied manual pressure directly downward through the superior aspect of the joint. Impingement of the long head of biceps and supraspinatus were tested for by first having the subject abduct the arm with the palm pronated. Secondly, the subject was instructed to abduct the arm to 45 degrees and hold that position while the investigator applied an internal rotation force for 10 seconds by grasping the elbow joint. A third test was used (Roy, 1983) where the subject assumed a posture with the elbow flexed and pronated, and the shoulder internally rotated and flexed to 90^0. From this position the elbow was stabilized and the examiner brought the forearm rapidly downward. This forced the arm into maximal internal rotation, bringing the humerus sharply up against the inferior aspect of the acromion. Pain in the region of the coraco-acromial arch was considered positive. Bicipital tendinitis was tested for using Speed's test since MaGee (1987) suggested that it is more effective than Yergason's test because Speed's test involves bone moving over tendon. For this test the investigator resisted the subject's attempts to shoulder flex with the forearm supinated and the elbow fully extended. Tenderness in the bicipital groove was considered a positive sign.

Medial and lateral epicondylitis were tested for first by resisted wrist flexion and extension. Pain over the common extensor or flexor origins, respectively, was considered a positive sign. If this was negative, the origins were palpated for pain or marked tenderness.

It is important to note that positive results on the pain screening test were not considered in any way as diagnostic of a particular condition. They were intended only to test for discomfort that might indicate overuse in that region, as a basis for comparison between able-bodied and paraplegic groups, and as a safety measure prior to conducting maximum strength testing.

2.2.14. Segment Lengths

Bilateral upper extremity segment lengths and body length were measured since body size has been shown to influence muscle strength (Clement,1974). Winter (1979) suggested using the gleno-humeral and elbow axes as landmarks for measurement of upper limb segment lengths. It was decided, however, that the use of bony prominences would be more reliable. Subjects remained seated. The upper limb segments measured were the lengths from the process of the acromion to the lateral epicondyle, and lateral epicondyle to the ulnar styloid. The landmarks were located, marked with a felt pen, and then distances were measured in centimetres (cms) with a vinyl measuring tape.

All trunk and body length measurements were taken in supine, since the paraplegic subjects were unable to stand. Trunk height was recorded as the distance between the lateral edge of the process of the acromion and the lateral aspect of the iliac crest. The latter was found to be more easily located than the greater trochanter. Body length was recorded as trunk height plus the distance between the lateral aspect of the iliac crest and the lateral malleolus.

2.2.15. Isokinetic Strength Testing

Isokinetic average torque was measured using the KIN-COM dynamometer and the KIN-COM software Version 4.0 (Chattecx Co.,1987). Prior to proceeding, a separate study (n=30) was conducted to establish the test-retest reliability of the isokinetic test protocol (Appendix N). The protocol had to be designed specifically for this study in order that the paraplegic subjects could access the isokinetic dynamometry equipment comfortably and safely.

For the average torque calculations the software was used to edit out 10 degrees from either end of the ranges tested. The resulting values were termed selected average torque. The rationale for this step was based on evidence of oscillations at the extremes of the test ranges, and work by Osternig (1986) and Rothstein (1983) among others, using dynamometers other than the KinCom, that suggested that the impact, oscillatory acceleration, and deceleration phenomena that often occur at the extremes of range may not be termed true isokinetic movement.

Positioning and Stabilization

Subjects were tested in lying on a hydraulically adjusted manipulation therapy table, which is referred to here as the test table. The upper limb cuff attachment was used for all tests. Additional foam was placed beneath the cuff strap as subjects had complained of discomfort during preliminary trials. Standardized stabilization methods were followed for each test using 5cm nylon strapping and 5cm thickness medium density foam. For subject comfort, the examiner applied manual stabilization through a piece of 5cm foam. A universal goniometer and adapted spirit-level goniometer were used for anatomical referencing and gravity calculations.

The sequence of testing was:

1. concentric shoulder flexion/extension; 2. eccentric/concentric shoulder adduction; and 3. concentric elbow flexion/extension.

Subjects were tested in supine or side-lying and the head was supported with 10cm thickness foam. Joint axes were first located by palpation, marked, and aligned with the axis of rotation of the machine. The axis was then checked by securing the limb to the cuff on the actuator arm, moving it passively and actively through the test range, and observing for any migration of the cuff on the limb. Cuff movement represented axis misalignment and the necessary adjustments were made. Subjects were not permitted to self-stabilize by grabbing the table with the non-dominant hand; nor were they allowed to look at the screen during contractions. For all testing the examiner stood by the subject's dominant shoulder, between the subject and the head of the Kin-Com. This was the best position for manual stabilization and observation of trick or extraneous body movements, and yet allowed ready access to the keyboard and screen.

a) Concentric Shoulder Flexion and Extension

In order to achieve the test range of motion (ROM) of -25^0 to 125^0 for shoulder flexion/extension subjects were positioned in supine lying close to the edge of the test table such that their dominant shoulder and arm were unsupported by the test table. They were then strapped snugly across the chest, above the knees, and across the ankles. Pelvic strapping was not used as it caused discomfort to obese and paraplegic subjects. The limb was weighed with the glenohumeral joint at 0^0 flexion and rotation, and the elbow flexed to 90^0 (Figure 2.13). In order to keep the effects of gravity constant and to ensure smooth movement patterns, subjects were instructed to maintain the elbow flexed to 90^0 and the forearm supinated, and to avoid internal or external rotation during all shoulder tests. No manual stabilization was applied during shoulder flexion tests. During extension the shoulder was stabilized anteriorly to prevent shoulder girdle movement (Figure 2.14).

b) Concentric and Eccentric Shoulder Adduction

Concentric and eccentric shoulder adduction were tested between 10^0-90^0 with the subject in side-lying (Figure 2.15). Initial alignment was based on the sagittal glenohumeral axis, with subsequent adjustments made based on any observed sliding of the cuff along the upper arm during adduction. Chest, hip, and ankle strapping were applied. Limb weight was calculated at 25^0 of abduction, with the elbow flexed to 90^0. Subjects were instructed to maintain the elbow at 90^0 during testing. During both eccentric and concentric movements manual stabilization was applied by wedging the examiner's forearm between the Kin-Com bench and immediately proximal to the superior aspect of the subject's acromio-clavicular joint (Figure 2.16).

c) Concentric Elbow Flexion and Extension

Concentric elbow flexion/extension was tested between 35^0 and 130^0, with the subject in supine, the head on the Kin-Com bench, and body on the test table. The subject's head was supported with a piece of 10cm foam. Subjects were instructed to maintain 0^0 neck rotation during testing since work published by Deutsch, Kilani, Moustafa, Hamilton, and Hebert (1987) suggested that head-neck position can influence elbow torque production in adult subjects. The lower limbs were strapped above the knees and at the ankles. The dominant upper arm was secured to the table using a strap placed over the distal section, under the trunk and non-dominant arm, and secured under the table (Figure 2.17). A fourth strap was placed across the chest and shoulder girdles, and around and under the table. Limb weight was calculated with the elbow flexed to 45^0. During warm-up trials, subjects were asked to choose the most comfortable forearm pronation-supination position and then use it consistently during testing. Manual stabilization was provided over the anterior aspect of the shoulder joint during elbow flexion and extension. Subjects were instructed to "plant" the elbow joint into the table before commencing extension, and to ensure that the elbow did not lift off the table during the test. Additional manual stabilization was applied to the upper arm strap if the elbow axis still tended to shift.

Figure 2.13 Use of adapted spirit-level goniometer to calculate angles for gravity-correction for shoulder flexion and extension isokinetic testing.

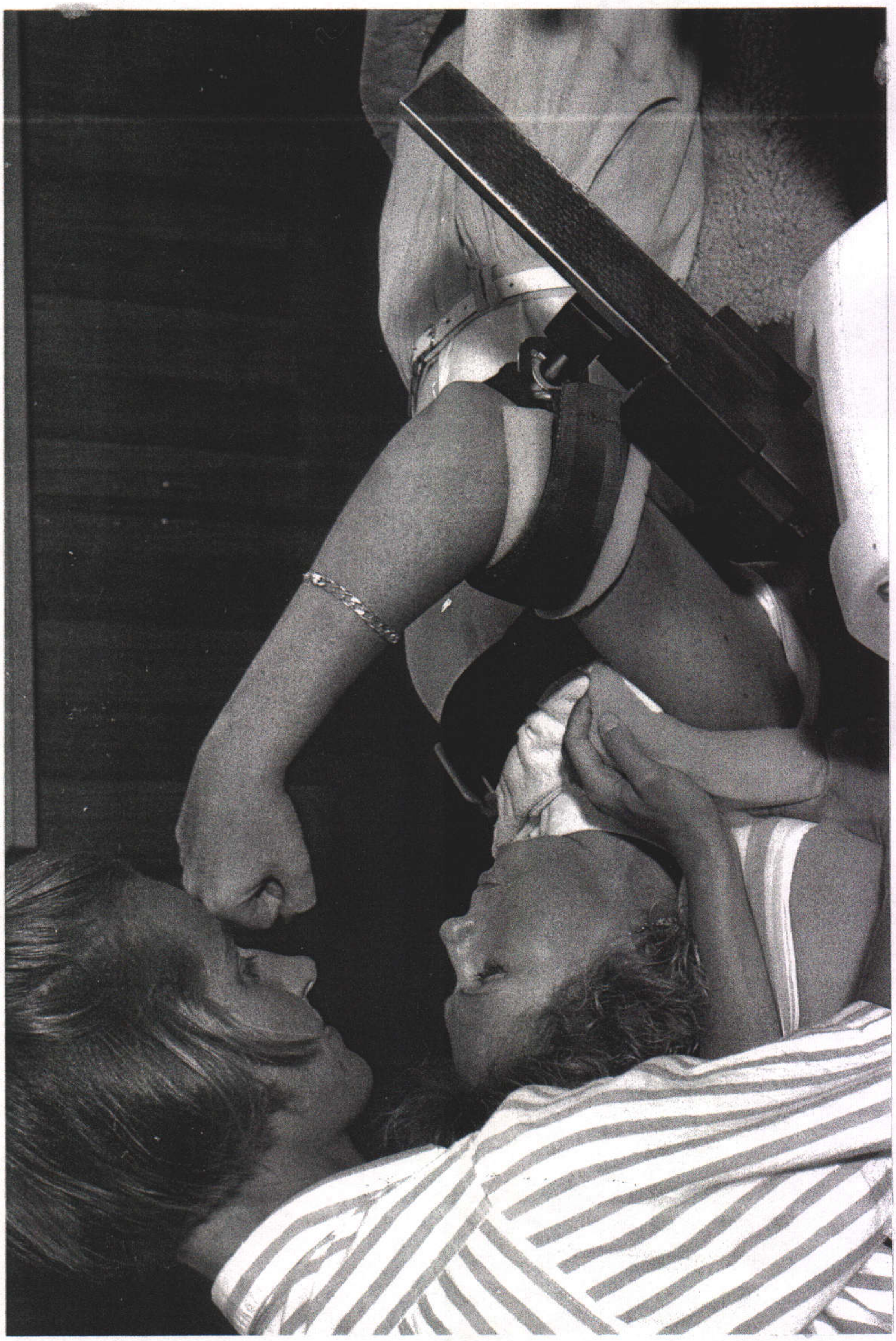


Figure 2.14 Position and stabilization for the assessment of concentric shoulder flexion and extension isokinetic torque.

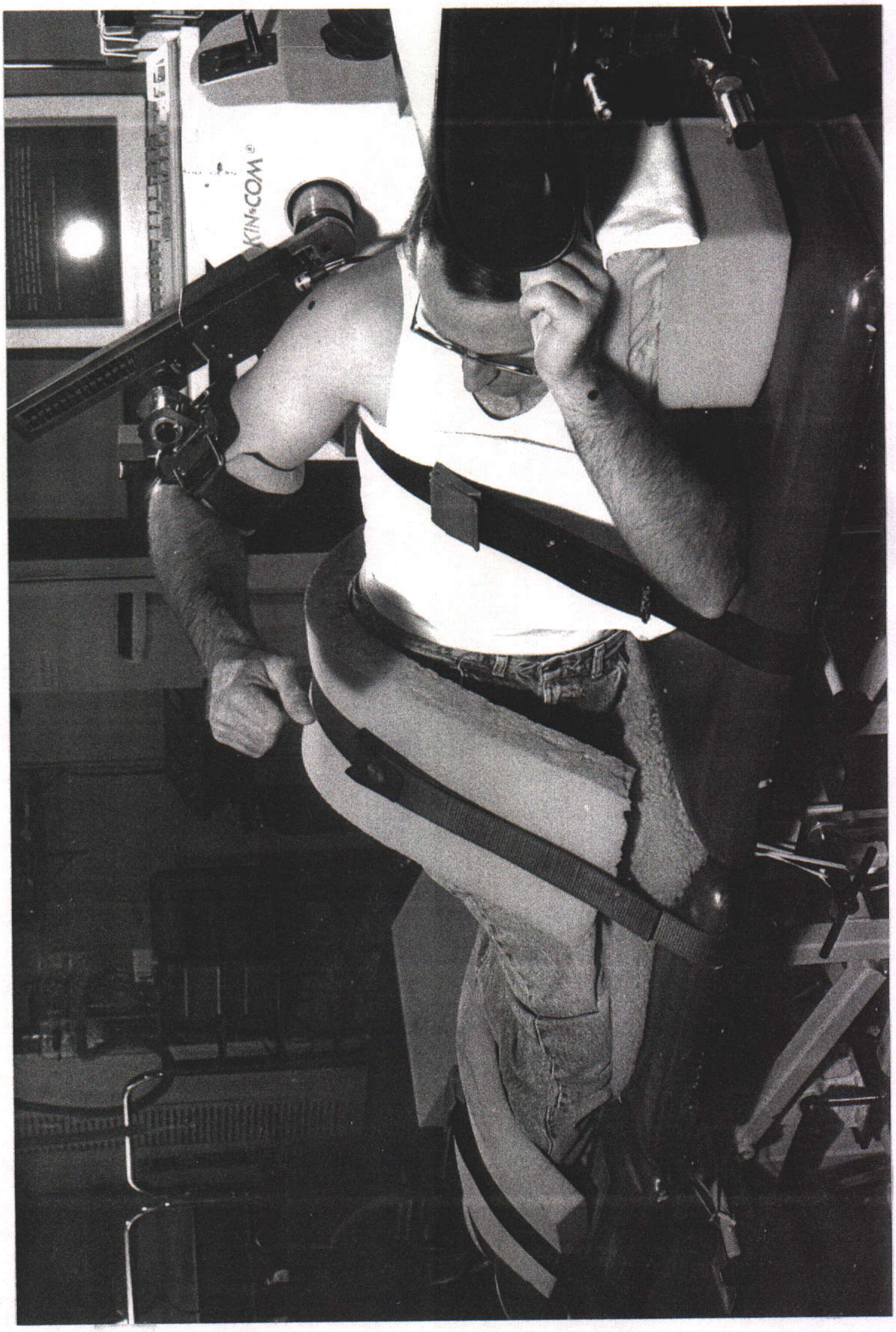


Figure 2.15 Positioning and stabilization for the assessment of concentric and eccentric shoulder adduction isokinetic torque.

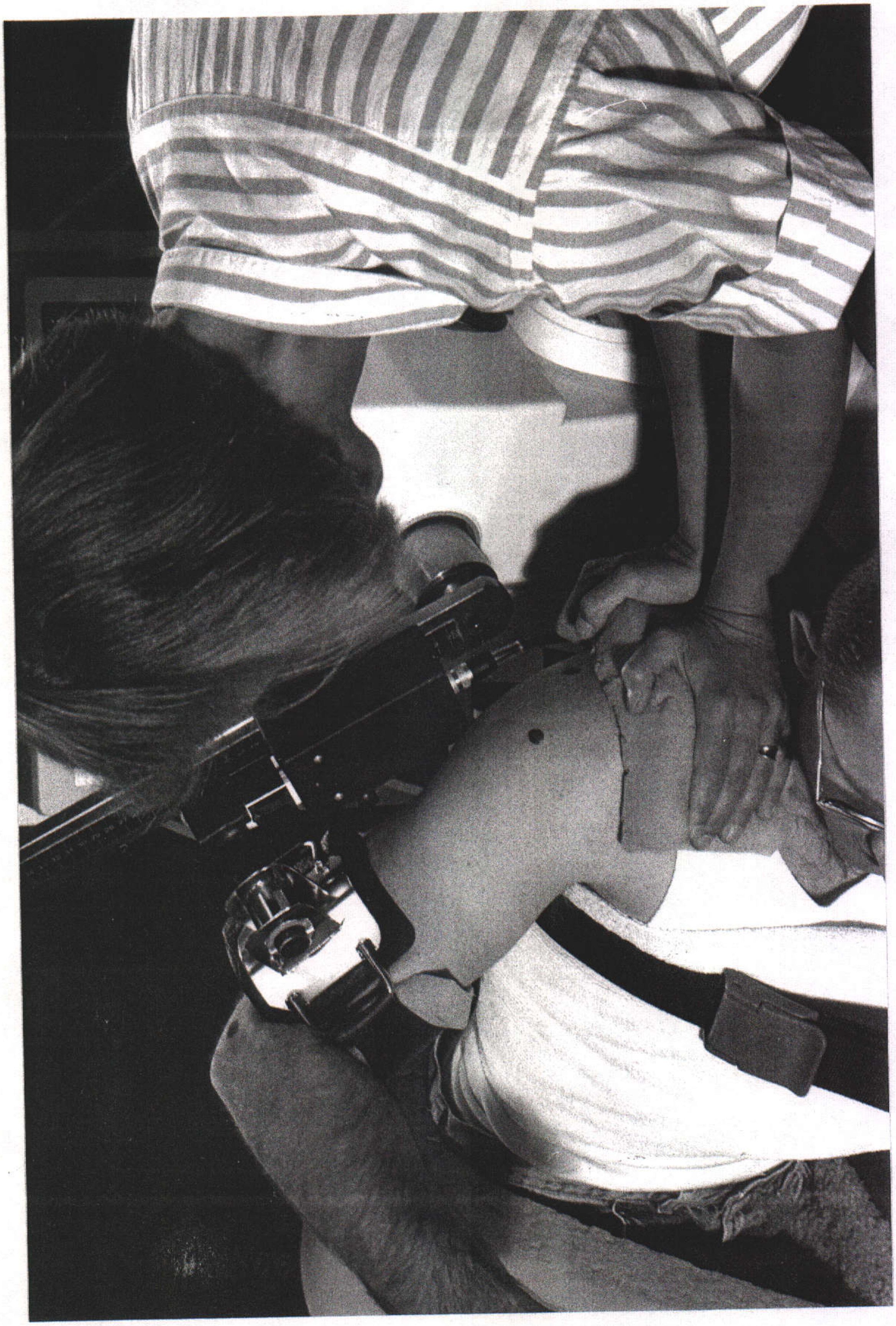


Figure 2.16 Manual stabilization technique used during the measurement of concentric and eccentric shoulder adduction.

Figure 2.17 Positioning and stabilization for the assessment of concentric elbow flexion and extension isokinetic torque.

Isokinetic Strength Test Protocol

Each test was conducted at 60^0/second and 120^0/second. All movements were tested reciprocally with a 5 second pause between concentric actions. A 30 second pause was observed between eccentric and concentric adduction to allow muscle recovery, and because work by Komi (1986) suggested that eccentric contractions potentiate subsequent concentric contractions and this effect is inversely proportional to the time allowed between efforts. Verbal encouragement was not used, however subjects were given feedback if movements were performed incorrectly.

The sequence of testing for each movement was:

Warm-up: 4 submaximal contractions, 1 maximal contraction,
Rest : 45 seconds,
Test : 5-6 maximal contractions at 60^0/s,
Rest : 1 minute,
Test : 5-6 maximal contractions at 120^0/s,
Rest : 5 minutes (set up for next movement).

Thirty second rests were given between each maximal test contraction. This time was selected based on the duration of the muscle action to allow adequate recovery time for the energy systems utilised and the number of efforts required. Trials judged to be unacceptable due to extraneous body movement or poor stabilization were repeated. Curves were selected based on conformity with anticipated shape, absence of oscillations, and height. Reproducible curves were sought and averaged (using the software) when obtained. If not obtained, the best effort was recorded.

2.2.16. Statistical Analysis

In this section the statistical procedures used in the analysis are described for the data concerning a) demographic information; b) isokinetic strength; c) range of motion; and d) upper limb pain. Statistical analyses were performed using the Statistical Analysis System, Version 5.0; and the Statistical Package for the Social Sciences, Versions 3.1 and 4.0. For all tests, alpha was set at .05.

a) Demographic Data

Comparison of the Paraplegic and Able-bodied Subjects

The paired t-test was used to test for weight and height differences between the paraplegic and able-bodied groups. In order to confirm the matching for age of paraplegic and able-bodied subjects, the paired t-test was used to test for a difference in age between the two groups. The paraplegic and able-bodied samples were tested for differences in marital and employment status using the McNemar test of association for binary data with paired samples, since these variables might be related to lifestyle practices and be of interest in the discussion of possible differences in upper limb function between the two groups. Since all of the upper limb strength data was grouped according to dominance rather than right versus left limb, the McNemar test of association was used to compare the proportions of the spinal cord injured and able-bodied subjects that were right and left dominant.

Demographic and Anthropometric Characteristics of the Subjects with Paraplegia

The ranges of chronological age and duration of spinal cord injury (SCI) were described. Pearson's correlations were performed in order to identify any interaction between the age and duration of injury, as this would be an important factor to consider in subsequent analysis of the dependent variables. The age and duration of SCI distribution of the paraplegic sample was tabulated according to the subgroups frequently used in subsequent statistical analyses. These subgroups were defined as follows:

Young: aged less than 45 years

Old : aged 45 years or more

Short term: less than 15 years since date of SCI

Long term : 15 years or more since date of SCI

A second more detailed distribution was constructed using cross-tabulations according to decade of age and duration duration of injury.

The t-test for independent samples was used to test for differences in body height, weight, age, and duration of injury between young and old paraplegic subjects, and between the short and long duration of paraplegia subjects. Cross-tabulations were constructed and the chi-squared test was used to test for any associations between the subjects' SCI lesion level or upper limb activity-level and chronological age or duration of SCI.

Young and old and short term and long term SCI subjects were tested for differences in their frequencies of performing various daily tasks involving upper limb weight-bearing, using the t-test for independent samples and the Fisher's exact test of association for a 2x2 contingency table with small expected frequencies. It was believed important to identify these types of differences since daily activity practices could be related to upper extremity stresses and conditioning, and might help to understand any differences between the groups in upper limb strength, range of motion, or pain.

Demographic and Anthropometric Data for the Able-bodied Subjects

The independent samples t-test was used to compare height, body weight, and age between the young and old subgroups of able-bodied subjects.

b) Upper Limb Strength Data Analysis

In order to determine whether or not separate analyses were required for each limb and each of the two isokinetic velocities tested, Pearson's correlation co-efficients were generated for the isokinetic strength data between the 60^0/second and 120^0/second velocities for both the paraplegic and able-bodied subjects, and between the dominant and non-dominant limbs for the paraplegics. A correlation was considered acceptable for averaging if $r \geq .85$.

Differences in upper limb mean isokinetic average torque were tested between the paraplegic sample and the able-bodied sample using Paired t-tests. Described below are further analyses conducted to examine the effects of age on upper limb strength in the able-bodied subjects, and of both age and duration of spinal cord injury on upper limb strength in the paraplegic sample.

Effect of Chronological Age on Upper Limb Strength

A number of techniques were employed in order to determine whether or not paraplegic and able-bodied persons' upper limb strength responds differently to advancing age. The independent samples t-test was not used to compare differences in strength between young and old subjects in each sample because it would mask any trends or curves of mean strength changes with age. Instead, scatterplots of changes in strength with age were constructed, and means and standard deviations of strength at each age decade were plotted as histograms in bar graph format for both paraplegic and able-bodied subjects.

Linear regression was used to determine the ability of age to predict strength in paraplegic sample and in the able-bodied sample. The Standard Error of the difference (SE_C) in strength-age regression slopes between the paraplegic (SE_P)

and able-bodied (SE_A) subjects was calculated in order to identify differences in rates of change in strength between the two groups. The following formula was used:

$$\frac{(SE_A)^2 + (SE_P)^2}{2} = SE_C$$

Since for 95% of the time this difference can be expected to be within two SE_C of zero, then if SE_C is greater than 2, the slopes would not be assumed to be the same, and thus the rates of change with age of upper limb strength between paraplegic and able-bodied persons would not be assumed to be the same. But this method did not take advantage of the paired data, and therefore it was decided to use paired tests instead. Therefore, in order to examine whether or not paraplegic upper limb strength changed differently with age than did that of the able-bodied, the paired data was used to construct a plot of able-bodied upper limb strength (considered as the reference for "normal" strength for this study) minus the strength of paraplegic subjects at the same age against paraplegic age, for each muscle group tested. Linear regression was then performed to see if paraplegic subject age (independent variable) predicted the difference between able-bodied and paraplegic subject upper limb strength (dependent variable).

Effect of Duration of SCI on Upper Limb Strength

In order to establish whether or not the differences in paraplegic and able-bodied upper limb strength appear to be affected by duration of SCI, short and long term paraplegic subjects were compared with age-matched able-bodied subjects using the paired t-test. Since paraplegic subject age and duration of SCI were shown to correlate (r=.68), examination of the effect of duration of SCI on paraplegic upper limb strength required that age be removed as a covariate. This was achieved by assuming the isokinetic and grip strength scores of the able-bodied sample to represent age-normal values. The corresponding scores of the paraplegic subjects were then subtracted from those of their age-matched able-bodied counterparts. The resultant value of this new variable represented the difference from normal of the paraplegic subjects' average torque and grip strength at a given age. These data were then plotted against duration of SCI to determine if the difference between paraplegic subjects' strength and normal strength changed as duration of spinal cord injury increased. Linear regression was then performed using able-bodied subject strength minus paraplegic subject strength as the dependent variable and duration of SCI as the independent variable, in order to see whether duration of SCI predicted the difference in strength between able-bodied subjects and those with parapelgia.

Predictors of Upper Limb Strength

Stepwise regression/Max R (SAS) was used with the paraplegic subjects' data to determine which of age, duration of SCI, lesion level, and upper limb activity-level best predicted upper limb strength. The same test was used with the able-bodied subjects' data to determine which of age or upper limb activity-level is the better upper limb strength predictor in that sample. The models selected were those where @< .05, or the model producing the lowest alpha.

c) Active Range of Motion (AROM) Data Analysis

Frequency tabulations of paraplegic and able-bodied subjects' range of motion scores revealed a near binary distribution with the large majority in both groups scoring normal (a score of 10) and the remaining having slightly less than normal AROM (a score of 8 or 6). Due to the lack of scores in the 0 to 4 range, the range of motion data was transformed to binary data; normal and less than normal AROM. The McNemar test for binary data with a paired sample was used to test whether or not reduced ROM is associated more with paraplegic or able-bodied persons.

The Effect of Age on Active Range of Motion

The effect of age on shoulder and elbow AROM was examined first by dividing the paraplegic and able-bodied subjects into two groups by age. One group was designated as Young and comprised those aged less than 45 years. The remaining subjects were aged 45 years or older were placed in the second group which was designated as Old. The McNemar test was used to determine if reduced AROM was associated with either paraplegia or able-bodied subjects when they are less than 45 years of age, and the test was repeated on those aged 45 years or older to see if the association changed with increased age. Secondly, the Fisher's Exact test (1 tailed) for small expected frequencies, was performed in order to test whether or not reduced shoulder or elbow AROM in paraplegic or able-bodied subjects was associated with age.

The paraplegic sample did not generate enough duration of SCI, lesion level, and activity-level matched pairs with contrasting ages, to allow statistical analysis. Therefore, in order to examine the effect of age on AROM, exclusive of the effect of duration of SCI, as many pairs as possible were matched for duration of SCI within 5 years (range of the difference = 2 months-4.3 years), lesion level (within 4 vertebral levels), and present activity-level (the same), but who differed in age by at least 12 years (range of the difference = 12-35 years). The AROM results of the nine matched pairs found were then examined, using visual analysis and the McNemar test, for trends in AROM loss with increased duration of injury.

The Effect of Duration of SCI on Active Range of Motion

In order to examine the effect of duration of spinal cord injury on shoulder and elbow AROM, the Fisher's Exact test (1 tailed) was used with the AROM data from a group of subjects with short duration paraplegia and one with long duration paraplegia. Eventhough duration of SCI was known to correlate with age in this sample ($r=.68$), the results of this test could be compared to the results of the same test performed with age as the independent variable. To examine the effects of duration of injury on range of motion in another way, a second approach was used. The parapelgic sample did not generate enough age, lesion-level, and activity-level matched pairs for statistical analysis of the effect of duration of SCI on AROM, exclusive of age. Therefore, as many pairs as possible were matched for age (within 5 years), lesion level (within 4 vertebral levels), and present upper limb activity-level (the same), but with durations of SCI at least 10 years apart. The AROM results of the seven matched pairs were then examined using visual analysis and the McNemar test, for trends in AROM loss with increased duration of injury.

Predictors of Upper Limb Active Range of Motion

A log linear model could be fitted to the AROM data for the purpose of identification of the best predictor (age, duration, lesion level, or activity-level) of AROM in paraplegic subjects; and which of age, or activity level best predicted AROM in able-bodied subjects. However, due to the limited numbers of subjects with restricted AROM, there was insufficient data, and p had insufficient variance to proceed with the log linear model.

d) Pain Data Analysis

Upper extremity pain in the paraplegic and able-bodied samples was examined using a) the Pain Screening Assessment; b) the Pain Interview Schedule; and c) the Impact of Upper Limb Pain on Activities of Daily Living (ADL)

Questionnaire. This section describes the procedures followed to analyze the data collected using each of these instruments.

Analysis of the Pain Screening Assessment Data.

The frequencies of paraplegic and able-bodied subjects who scored positive on each item of this screening test were tabulated and compared using bar graphs. Associations between positive scores and either the paraplegic or able-bodied subjects were tested using the McNemar test.

The influence of age on the screening test scores was examined from three aspects. First, the paraplegic and able-bodied samples were divided into young (aged less than 45 years) and old (aged 45 years or older) age groups. Then, McNemar tests were used on each age group, to test for any associations between pain on the screening assessment items and either the paraplegic or able-bodied subjects. Secondly, the Fisher's Exact Test (1 tailed) for 2x2 tables with small expected frequencies was used to test whether or not pain on each item was associated with age group within either the paraplegic or able-bodied sample. Thirdly, since age and duration of SCI correlated in this sample ($r=.68$), the effect of age, excluding duration of injury, was examined using the same nine pairs used for the AROM analysis. As described earlier, these pairs differed in age by at least 12 years (range of the difference = 12-35 years), and were matched for duration of spinal cord injury within 5 years (range of the difference = 2 months-4.3 years), lesion level (within 4 vertebral levels), and present activity-level (the same). Their pain screening assessment scores were tabulated and inspected for trends in upper limb pain associated with age. The McNemar test was used to test for any association between age, excluding duration, and upper limb pain.

The effect of duration of spinal cord injury on the pain screening test scores was examined first using the Fisher's Exact test of association between pain prevalence and short term (injured less than 15 years) or long term (injured 15 years or longer) duration of paraplegia. Since age was known to correlate with duration of injury in this sample ($r=.68$), the influence of duration of injury on the screening assessment scores was also examined with age excluded. This was accomplished by using the data from the seven age-matched, duration of SCI contrasted pairs utilized in the AROM analysis. The scores of the pairs were tabulated and compared for trends, using visual analysis, and associations were tested using the McNemar test.

Analysis of the Pain Interview Data

For analysis, the data from these interviews was categorized according to joint; shoulder, elbow, and wrist/hand. Bar graphs were constructed to compare the frequencies at each joint, of both pain in the past week and pain in the past six months, between the paraplegic and able-bodied samples. McNemar tests were used to determine if any of the reports of pain were more associated with the paraplegic or able-bodied samples.

In order to evaluate the influence of age on the reports of upper limb pain between and within the two samples, three analyses were performed. McNemar tests were conducted on the young age group subjects and again on the old age group subjects, to determine if reports of upper limb pain were more associated with paraplegic or able-bodied persons. Then, chi-squared tests were used to test for any associations between reports of pain in the last week or past six months in the shoulder, elbow or wrist/hand regions, and age group within the paraplegic or able-bodied samples. Finally, any influence of duration of SCI was excluded from the analysis of the effect of age on the paraplegic subjects' reports of upper limb pain by tabulating and inspecting the relevant data from the nine pairs of age contrasted, and duration of SCI, lesion level, and activity-level matched pairs. The McNemar test was used to test for any associations between upper limb pain and age.

The effect of duration of spinal cord injury on reports of upper limb pain was first examined using the chi-squared test of association. Next, in order to exclude age as a covariate of duration of SCI, the data from the interviews of the seven age-matched, duration contrasted pairs of subjects with paraplegia was tabulated and visually analyzed and tested using the McNemar test, for trends in upper limb pain and duration of injury.

The remaining information collected during the interviews was used to describe and identify the differences in the nature of the upper limb pain reported by the paraplegic and able-bodied subjects. First, frequency tabulations of the positive scores were compiled for each item of the interview schedule. To facilitate comparisons, these frequencies were expressed as percentages of the sample (paraplegia n=52; able-bodied n=52) who gave a positive response to each item. Tests of association were then performed between the paraplegic and able-bodied groups' frequencies of positive responses for each item, using the McNemar Test for binary data with paired samples. Bar graphs were constructed to summarize and compare the frequency distributions of the two samples' perceived pain intensity ratings.

Analysis of the Impact of Upper Limb Pain on ADL Questionnaire Data.

This questionnaire was administered to those subjects with paraplegia in order to examine the impact of upper limb pain on three categories of activities of daily living (ADL) tasks: mobility, self-care, and general activities. The impact of upper limb pain on each category of activity was examined from three aspects; a) the prevalence of upper limb pain when performing the tasks; b) the proportion of the tasks where the subject had had to change his method or technique of performing the task due to upper limb pain; and c) the proportion of the tasks where assistance had been sought due to upper limb pain. Thus, the nine items of data used in the analysis were:

1. The proportion (%) of mobility task events where upper limb pain was experienced.
2. The proportion (%) of mobility task events where method changes were made due to upper limb pain.
3. The proportion (%) of mobility tasks events where assistance was sought due to upper limb pain.

4. The proportion (%) of self-care task events where upper limb pain was experienced.

5. The proportion (%) of self-care task events where method changes were made due to upper limb pain.

6. The proportion (%) of self-care tasks events where assistance was sought due to upper limb pain.

7. The proportion (%) of general activities task events where upper limb pain was experienced.

8. The proportion (%) of general activities task events where method changes were made due to upper limb pain.

9. The proportion (%) of general activities tasks events where assistance was sought due to upper limb pain.

The scores were expressed in percentages and these represented the paraplegic subjects' estimates of the number of times in 100 that they performed the tasks (events) that resulted in upper limb pain; or that method changes were made due to this pain; or that assistance was sought due to the pain. The analysis was conducted using the same five categories of percentages used in the questionnaire. These were; 0%, 1-24%, 25-49%, 50-74%, and 75-100% of the times the tasks were performed.

The analysis was conducted in three stages. First, the frequency distributions of the scores for the paraplegic subjects (n=52) were examined for each of the nine variables. Then, a number of techniques were used to examine the effects of age and duration of spinal cord injury on upper limb pain during ADL. Bar graphs were used to compare the frequency distributions of the scores between the young (aged <45 years) and old (aged ≥45 years) age groups, and between the short duration (injured <15 years) and long duration (injured ≥15 years) of SCI groups.

Visual inspection of the bar graphs revealed that the scores were not normally distributed, and that a large proportion of the scores were in the 0% category. Therefore, the scores were converted to binary data by retaining the category of 0% (i.e. never having upper limb pain; making changes in ADL method, or seeking assistance), and summing the remaining (1-25%, 26-50%, 51-75%, 76-100%) categories into one. Using this transformation, Fisher's Exact tests (1 tailed) for 2x2 tables with small expected frequencies were then used to test for any associations between upper limb pain during ADL, method changes, or assistance sought, and age or duration of injury in paraplegia. The relationship between the occurrence of upper limb pain during specific activities of daily living and age and duration of spinal cord injury was also examined using the

Fisher's Exact test (1 tailed).

Then, since chronological age and duration of spinal cord injury correlated in this sample (r=.68), the effects of each exclusive of the other, on upper limb pain during ADL, were examined using matched pairs. That is, when examining the effect of age on the development of upper limb pain, duration of SCI was excluded by using pairs of subjects that had been matched for duration of SCI (as well as lesion level and activity-level). When examining the effect of duration of SCI, the pairs were matched for age (as well as lesion level and activity-level). These were the same pairs used for the AROM analysis. Their ADL scores were tabulated and inspected for trends relating to age or duration.

Finally, the binary data transformation was used to calculate and rank, by frequency, the ADL activities where the paraplegics most often reported experiencing upper limb pain.

CHAPTER THREE: RESULTS

The data were analyzed in order to answer the study questions. The results are presented under the following headings:

3.1 Demographic Information.

3.2 Upper Limb Strength.

3.3 Upper Limb Range of Motion.

3.4 Upper Limb Pain.

3.5 The Impact of Upper Limb Pain on Activities of Daily Living Performance in Paraplegia.

In all tables in this chapter, S is used to highlight a p-value that is significant at the .05 level.

3.1. Demographic Information

3.1.1. Comparison of the Paraplegic and Able-bodied Subjects

The paraplegic and able-bodied subjects were tested for differences in age, body weight, and height using paired t-tests (Tables 3.1, 3.2, and 3.3). There were no significant differences in age between the two samples as a whole, or between the paired subgroups of young (less than 45 years of age) or old (greater than 45 years of age) paraplegic and able-bodied subjects. This was to be expected since chronological age was one of the matching variables.

Heights were similar between all groups tested. There was a significant difference in body weight between the two samples when all of the paraplegic and able-bodied subjects were compared (Table 3.1). The able-bodied were, on average, 6.2 kilograms heavier than the paraplegic subjects. When the two samples were compared by age group (Tables 3.2 and 3.3), the able-bodied subjects were significantly heavier in both young and old age. This probably is a reflection of lower limb muscle atrophy in the paraplegic subjects.

Table 3.4 illustrates the differences between the paraplegic and able-bodied samples with respect to marital status, employment status, and hand dominance. Unemployment was shown to be associated with the paraplegic subjects ($p < .0001$). No difference in activity-levels between the two samples was anticipated, as this was a matching variable.

Table 3.1. Age, body weight, and height comparisons of paraplegic and able-bodied subjects.

	Paraplegic* (n=52)	Able-bodied (n=52)	P-value
Age (yr)	44.3 (12)	44.1 (12)	.62
Body weight (kg)	71.4 (12)	77.6 (10)	.005 S
Height (cm)	147.5 (7)	148.7 (6)	.31

*= mean (±1 S.D.).
S = significant at the .05 level.

Table 3.2. Age, body weight, and height comparisons of paraplegic and able-bodied subjects younger than 45 years of age (n=28 pairs).

	Paraplegic*	Able-bodied	P-value
Age (yr)	35.1 (7)	34.3 (7)	.49
Body weight (kg)	70.4 (12)	75.9 (11)	.04 S
Height in (cm)	146.4 (7)	147.8 (6)	.31

* = mean (±1 S.D.).
S = significant at the .05 level

Table 3.3. Age, body weight, and height comparisons of paraplegic and able-bodied subjects aged 45 years or older (n=24 pairs).

	Paraplegic*	Able-bodied	P-value	
Age (yr)	54.9 (6)	54.6 (6)	.96	
Body weight (kg)	72.5 (13)	79.4 (10)	.05	S
Height (cm)	148.8 (8)	149.6 (6)	.71	

* = mean (± 1 S.D.)

Table 3.4. Comparison of hand dominance, marital status, and job status of the paraplegic and able-bodied subjects (McNemar test; n=52 pairs).

	Paraplegic	Able-bodied	P-value	
Single	23	14		
Married	29	38	.11	
Employed	29	48		
Unemployed	23	4	.0001	S
Right Dominant	48	48		
Left Dominant	4	4	1.000	

S = significant at the .05 level

3.1.2. Comparison of the Paraplegic Subjects by Age Group, Duration of Injury, Level of Lesion, and Activity Level

The paraplegic subjects ranged in age from 21.8 to 72.7 years (Table 3.5) with an average age ($\pm$1 S.D) of 44.3 (12) years. The subjects with paraplegia had sustained their spinal cord injuries between 1.2 and 44.7 years previously. As a group, they had been injured for an average ($\pm$1 S.D.) of 17.4 (11) years. The Pearson's correlation co-efficient for age and duration of SCI in this sample was r=.68.

Table 3.5 Age and duration of SCI in paraplegic subjects (n=52).

	Range	Mean ($\pm$1 S.D.)
Age (years)	21.8 - 71.7	44.3 (12)
Duration of SCI (yrs)	1.2 - 44.7	17.4 (11)

Correlation of Age & Duration of SCI: r =.68

Table 3.6 presents a distribution of the paraplegic sample by age and duration of SCI, using the subgroups that were frequently used for analysis in this study. These subgroups are as follows:

Young - less than 45 years of age
Old - greater than or equal to 45 years of age
Short duration - SCI for less than 15 years
Long duration - SCI for 15 years or longer

The sample broke down relatively equally into the two age groups (Young n=28; Old n=24). There were 40% more subjects in the Long duration group (n=32) than in the Short duration group (n=20). Inspection of Table 3.6 reveals that the largest category is that made up of subjects who were 45 years or older and injured for more than 15 years. Only four subjects were 45 years or older and injured less than 15 years.

Table 3.6. Distribution of the paraplegic subjects by subgroups of young and old versus short and long duration of spinal cord injury.

	Short Duration (<15 years)	Long Duration ($\geq$15 years)	Total
Young (<45 years)	16	12	28
Old ($\geq$45 years)	4	20	24
Total	20	32	52

Table 3.7 was constructed to obtain a more detailed distribution of paraplegic subjects by age versus duration of SCI. Decades were used as the units of age and duration of SCI. The subjects' ages were distributed relatively evenly across the 4th, 5th, and 6th decades, with fewer in the 3rd and 7th or over decades. The distribution of subjects by duration of SCI was also relatively even until >30 years where there were only 7 subjects. The overall distribution shows an expected positive relationship between age and duration of spinal cord injury, with few to no subjects falling into both the younger age and longer duration categories.

Table 3.7. Distribution of the paraplegic subjects by age (decades) versus duration of SCI (decades).

	Duration of Injury (years)				
Age	>1.5≤10	>10≤20	>20≤30	<30≥44	Total
>20≤30	8				8
>30≤40	5	6			11
>40≤50	1	5	8		14
>50≤60	2	2	4	5	13
>60		3	1	2	6
Total	16	16	13	7	52

Independent samples t-tests were used to compare young and old paraplegic subjects for body weight, height, duration of SCI, and age (Table 3.8). No significant differences were found for body weight or height. The average age difference (19.8 years) between the two groups was, as expected, significantly different. The average difference in duration of SCI between the two age groups was also significant (11.9 years). Similar findings resulted when the same variables were compared between subjects with short <15 years) and long (>15 years) duration paraplegia (Table 3.9). Based on this, and the established correlation between age and duration of SCI in this sample (r=.68), specific steps were followed in subsequent analyses in order to gain a better understanding of the discreet effects of these two independent variables on the dependent variables under study.

Table 3.8. Comparison of body weight, height, duration of injury, and age, between paraplegic subjects aged less than 45 years (n=27) and 45 years or older (n=25).

	<45 Years (Mean $\pm$1 S.D.)	$\geq$45 Years	P-value
Body weight (kg)	70.4 (12)	72.5 (13)	.54
Height (cm)	146.4 (7)	148.7 (8)	.25
Duration of SCI (yr)	11.9 (8)	23.8 (10)	.0001 S
Age (yr)	35.1 (7)	54.9 (7)	.0001 S

S=significant at the .05 level

Table 3.9. Comparison of body weight, height, duration of SCI, and age, between paraplegic subjects injured less than 15 years (n=20) and 15 years or more (n=32).

	<15 Years (Mean $\pm$1 S.D.)	$\geq$15 Years	P-value
Body weight (kg)	67.6 (12.6)	73.8 (11.6)	.07
Height (cm)	146.5 (7.8)	148.1 (6.9)	.44
Duration of SCI (yr)	6.0 (4.3)	24.5 (7.2)	.0001 S
Age (yr)	34.6 (10.3)	50.3 (8.9)	.0001 S

S = significant at the .05 level

The paraplegic sample was further described by age in Table 3.10, and by duration of SCI in Table 3.11. The International Stoke Mandeville Games Federation (ISMGF) (Jackson & Fredrickson, 1979) classification was used to classify spinal cord lesion levels into three groups. The level of spinal cord lesion was not shown to be associated with age group (Table 3.10) or duration of injury (Table 3.11). From Table 3.10, it is evident that equal numbers of subjects (n=21 or 40%) were injured at the T_6-T_{10} and T_{11}-L_2 levels. Fewer (n=10 or 19%) were injured between T_2 and T_5. In the young paraplegic group, the majority (54%) were injured at the T_6-T_{10} level, whereas in the older group, the majority (54%) had lower lesions in the T_{11}-L_2 region. The distribution of levels of injury by duration revealed the largest proportion (n=10 or 50%) of short term subjects to be injured at the T_6-T_{10} level, whereas the largest proportion (n=14 or 44%) of the long term subjects were injured at the T_{11}-L_2 levels.

Tabulation of the paraplegic subjects' activity-levels during the last six months revealed similar distributions for the young and old age groups (Table 3.10) and short term and long term duration groups (Table 3.11). The majority of the paraplegic sample (n=38 or 73%) reported a sedentary lifestyle during the six months preceeding data collection.

Table 3.10. Distribution of the paraplegic subjects' lesion levels and activity levels by age group.

	Age Group			
	<45 years n=28	≥45 years n=24	Total	P value
Lesion Levels				
T_2-T_5	5 (18)*	5 (21)	10	
T_6-T_{10}	15 (54)	6 (25)	21	
T_{11}-L_2	8 (29)	13 (54)	21	.09
Activity Levels				
Sedentary	20 (71)	18 (75)	38	
Moderate/Heavy	8 (29)	6 (25)	14	.77

*percent

Table 3.11. Distribution of paraplegic subjects' lesion levels and activity levels by duration of SCI.

	Duration of SCI		Total	P value
	<15 years n=20	≥15 years n=32		
Lesion Levels				
T_2-T_5	3 (15)*	7 (22)	10	
T_6-T_{10}	10 (50)	11 (34)	21	
T_{11}-L_2	7 (35)	14 (44)	21	.53
Activity Levels				
Sedentary	13 (65)	25 (78)	38	
Moderate/Heavy	7 (35)	7 (22)	14	.29

* = percent

Differences in wheelchair transfer routines between young and old, and short and long duration paraplegic subjects were compared using the independent samples t-test (Tables 3.12 and 3.13). The overall number of transfers performed per day did not differ between age groups or duration groups. During the six months prior to the study, the young paraplegic subjects transferred more often than the older subjects to and from the car each day (p =.002) and between the wheelchair and the floor (p =.02). In contrast, for this same time period, there was no difference between the frequencies that the short and long term paraplegic subjects performed these two tasks. But, prior to the past six months, the long term paraplegic subjects had transferred more often to and from the car ($p = .03$) and between the wheelchair and the floor ($p = .04$) than the short term paraplegic subjects.

The Fisher's Exact test was used to determine if there were any associations between paraplegic subject age or duration of SCI and usual wheeling distances or household task performance (Tables 3.12 and 3.13). Both age and duration groups' practices for these variables were similar, except that the older paraplegic group was less likely to have sole or shared responsibility for the performance of household tasks, but instead, to report that these were performed by another person ($p = .03$).

Table 3.12. Comparison of the young and old paraplegic subjects' usual activities of daily living practices.

Activity	Paraplegics Aged 45 Years or Less* (n=28)	Paraplegics Aged 45 Years or More* (n=24)	P-value
# Transfers/day in past six months	15.0 (6)	14.6 (10)	.87
# Transfers/day prior to past six months	14.8 (6)	18.9 (13)	.16
# Loading wheelchair to & from car/day in past six months	5.1 (4)	1.9 (4)	.002 S
# Loading wheelchair to & from car/day prior to past six months	6.3 (6)	6.9 (10)	.78
# Transfers in & out of bathtub/week in past six months	0.0 (0)	0.6 (2)	.08
# Transfers in & out of bathtub/week prior to past six months	0.4 (2)	0.6 (2)	.63
# Transfers on & off floor/week in past six months	0.8 (2)	0.0 (0)	.02 S
# Transfers on & off floor/week prior to past six months	1.8 (4)	2.5 (5)	.54
Usual wheeling distance in past six months:			
Mainly indoors	14	17	
Indoors & outdoors & sport	14	7	.11
Usual wheeling distance prior to past six months:			
Mainly indoors	13	10	
Indoors & outdoors & sport	15	14	.48
Who performed the majority of household tasks in the past six months:			
Self or shared	14	5	
Other	14	19	.03 S
Who performed the majority of household tasks prior to past six months:			
Self or shared	12	5	
Other	16	19	.08

* Mean $\pm$1 S.D.
S= significant at the .05 level

Table 3.13. Comparisons of the long and short duration of injury paraplegic subjects' usual activities of daily living practices.

Activity	Short Duration 15 Years or Less* (n=20)	Long Duration 15 Years or More* (n=32)	P-value
# Transfers/day in past six months	15.6 (7)	14.4 (9)	.61
# Transfers/day prior to past six months	15.2 (7)	17.6 (12)	.36
# Loading wheelchair to & from car/day in past six months	4.5 (4)	3.1 (4)	.26
# Loading wheelchair to & from car/day prior to past six months	4.1 (4)	8.1 (9)	.03 S
# Transfers in & out of bathtub/week in past six months	0.0 (0)	0.5 (2)	.21
# Transfers in & out of bathtub/week prior to past six months	0.2 (1)	0.7 (2)	.16
# Transfers on & off floor/week in past six months	.95 (2)	0.1 (0)	.08
# Transfers on & off floor/week prior to past six months	.8 (2)	2.9 (5)	.04 S
Usual wheeling distance in past six months:			
Mainly indoors	11	20	
Indoors & outdoors & sport	9	12	.40
Usual wheeling distance prior to past six months:			
Mainly indoors	12	11	
Indoors & outdoors & sport	8	21	.06
Who performed the majority of household tasks in the past six months:			
Self or shared	7	12	
Other	13	20	.54
Who performed the majority of household tasks prior to past six months:			
Self or shared	5	12	
Other	15	20	.27

* = Mean (±1 S.D.)

S = significant at the .05 level

3.1.3. Comparison of Able-bodied Subjects by Age Group

Table 3.14 presents the results of two-sample t-tests conducted to compare height, weight, and age between the young and old able-bodied subjects. The results indicate that there was no significant difference between the two groups for either height or body weight. Table 3.8 revealed similar relationships between these two variables in the paraplegic sample. As expected, the age difference between the young and old able-bodied age groups (mean difference = 20.2 years) was statistically significant (p=.0001).

Table 3.14. Comparison of body weight, height, and age between able-bodied subjects less than 45 years (n=27) and 45 years or older (n=25).

	<45 Years*	≥45 Years	P-value	
Body weight (kg)	75.9 (11.3)	79.4 (9.9)	.23	
Height (cm)	147.8 (6.2)	149.6 (6.2)	.29	
Age (yr)	34.4 (6.9)	54.6 (6.3)	.0001	S

* = mean (±1 SD)
S= significant at the .05 level

3.2. Upper Limb Strength

Introduction

The results pertaining to the examination of upper limb strength are presented in four sections. Section 3.2.1 provides a descriptive overview of the upper limb isokinetic and grip strength results including velocity and dominant and non-dominant limb correlations. The section also documents the strength comparisons between the paraplegic and able-bodied samples, both in their entirety and for "young" and "old" age groups. Section 3.2.2 is a compilation of the results of the analyses pertaining to the effects of age on paraplegic and able-bodied subjects' strength. Section 3.2.3 presents the results of the analyses of changes in paraplegic subject upper limb strength as duration of spinal cord injury increased. And finally, Section 3.2.4 contains the results of the analyses designed to determine which of selected variables best predicted upper limb strength in the paraplegic and able-bodied samples.

3.2.1. Results of Correlations and Inter-group Comparisons of Upper Limb Strength

Table 3.15 contains the Pearson product-moment correlation coefficients between the dominant and non-dominant upper limbs of the paraplegic subjects, at both isokinetic velocities for the movements tested, and for maximum grip strength. The range of r was .53-.76. The best correlations occurred for elbow extension (r=.76) and grip strength (r=.70). The lowest correlations were between the dominant and non-dominant shoulder extensors at both velocities (at 60^0/sec r=.53; at 120^0/sec. r=.55). Based on these results, for all subjects, the strength data for the dominant and non-dominant upper limbs was analyzed separately.

Table 3.15. Correlations of isokinetic average torque between dominant and non-dominant upper limbs in the paraplegic sample (n=52).

Test Movement:	SF60*	SF120	SE60	SE120	EF60	EF120	EE60	EE120	ADC60	ADC120	ADE60	ADE120	GRIP
Correlation co-efficient	.62	.65	.53	.55	.60	.69	.76	.76	.65	.66	.65	.66	.70

* SF60=shoulder flexion at 60^0/second, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

Pearson product-moment correlations were performed between the scores for the 60^{0}/second and 120^{0}/second velocities for both the paraplegic and able-bodied subjects, in order to determine if the two velocities required separate analysis. Table 3.16 reveals the correlations for the sample with paraplegia to be greater than r=.91 for all movements completed, except for eccentric shoulder adduction, where r=.77. The correlations generated for the able-bodied data are found in Table 3.17, and show that nine of the twelve muscle groups tested had inter-velocity correlations of r>.93. The inter-velocity correlation for concentric shoulder adduction was r=.78. Since the large majority of movements tested generated inter-velocity correlations of r>.90, and the two lowest correlations were r>.77, it was decided that all subsequent analyses of the isokinetic average torque data would be performed using the average of the two isokinetic velocities.

Table 3.16. Correlations between isokinetic average torque at 60^0/second and 120^0/second in the paraplegic sample (n=52).

Test Movement	DSF*	DSE	DEF	DEE	DADC	DADE	NSF	NSE	NEF	NEE	NADC	NADE
Correlation co-efficient	.97	.95	.96	.95	.96	.93	.91	.94	.91	.94	.95	.77

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

Table 3.17. Correlations between isokinetic average torque at 60^0/second and 120^0/second in the able-bodied sample (n=52).

Test Movement	DSF*	DSE	DEF	DEE	DADC	DADE	NSF	NSE	NEF	NEE	NADC	NADE
Correlation co-efficient	.94	.93	.99	.97	.78	.86	.94	.97	.96	.96	.94	.86

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

When the paired t-test was used to compare upper limb strength between all paraplegic and all able-bodied subjects (Table 3.18), the results indicated that the differences between the two samples for shoulder flexion and elbow extension bilaterally, were between 16-18% and were statistically significant. For shoulder flexion, the able-bodied subjects generated on average 18% greater average torque in the dominant limb, and 16% greater average torque in the non-dominant limb, than did the paraplegic subjects. In contrast, the average torque produced by the paraplegic sample for elbow extension was greater, on average, than that produced by the able-bodied subjects by 18% on the dominant side and 17% on the non-dominant side. For all other isokinetic tests and maximum grip strength, the differences were not statistically significant.

Table 3.18. Comparison of upper limb strength between in all paraplegic and able-bodied subjects using the paired t-test (n=52 pairs). @=.05

	Paraplegic mean (1 SD) (nm)*	Able-bodied mean (1 SD) (nm)	P-value	
DSF**	42.4(12)	50.1(10)	.001	S
NSF	39.5(8)	45.7(10)	.0003	S
DSE	44.6(12)	47.9(10)	.162	
NSE	43.9(10)	47.0(12)	.173	
DEF	48.9(10)	45.9(11)	.085	
NEF	45.1(9)	43.5(10)	.395	
DEE	40.5(10)	34.3(8)	.0004	S
NEE	42.3(9)	36.0(8)	.0003	S
DADC	51.9(13)	55.8(14)	.131	
NADC	52.9(13)	55.2(12)	.310	
DADE	96.6(24)	103.0(26)	.219	
NADE	93.7(23)	96.8(20)	.429	
DGRIP	53.3(9)	50.4(8)	.089	
NGRIP	48.4(8)	47.2(8)	.519	

* = newton-metres ** D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow
extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric. S=significant.

In order to examine more closely the differences between the upper limb strength of the paraplegic and able-bodied samples, each sample was subdivided by age into two groups, and compared. The results of the comparisons of those subjects aged less than 45 years are shown in Table 3.19. Table 3.20 contains the results of the comparison for those aged 45 years or more. The results in the two tables suggest that, in both age groups, the able-bodied subjects produced statistically significantly greater average torque in the non-dominant shoulder flexors (young age group = 11% greater average torque; old age group = 21% greater average torque) than did the paraplegic subjects. In the older group, the able-bodied subjects also produced more average torque (33%) than the paraplegic subjects in dominant shoulder flexion.

Table 3.19. Comparison of upper limb strength between young (age < 45 years) paraplegic and young able-bodied subjects using paired t-test (n=28 pairs).

	Paraplegic mean (1 SD) (nm)*	Able-bodied mean (1 SD) (nm)	P-value	
DSF**	47.3(11)	51.1(9)	.174	
NSF	42.7(7)	47.6(9)	.029	S
DSE	47.9(12)	48.6(11)	.703	
NSE	45.7(10)	49.5(13)	.235	
DEF	52.3(10)	48.7(11)	.112	
NEF	48.4(9)	45.5(9)	.256	
DEE	42.7(9)	35.1(9)	.0009	S
NEE	44.9(9)	35.9(8)	.0001	S
DADC	55.6(12)	59.1(13)	.263	
NADC	56.0(14)	57.5(1)	.645	
DADE	102.4(20)	107.9(23)	.406	
NADE	97.4(25)	99.9(21)	.663	
DGRIP	58.4(5)	51.3(7)	.0003	S
NGRIP	51.4(7)	48.4(9)	.234	

* = newton-metres ** =Dominant, N=Non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

Table 3.20. Comparison of upper limb strength between old paraplegic and old able-bodied subjects using the paired t-test (n=24 pairs).

	Paraplegic mean (1 SD) (nm)*	Able-bodied mean (1 SD) (nm)	P-value
DSF**	36.8(10)	49.0(12)	.002 S
NSF	35.8(8)	43.5(11)	.005 S
DSE	41.4(12)	47.1(11)	.102
NSE	41.9(9)	44.1(11)	.500
DEF	44.9(9)	42.9(10)	.420
NEF	41.3(9)	41.2(9)	.956
DEE	37.9(9)	33.5(8)	.096
NEE	39.1(8)	36.2(8)	.224
DADC	47.8(13)	51.8(14)	.321
NADC	49.4(11)	52.6(12)	.324
DADE	89.8(27)	97.4(29)	.375
NADE	89.4(21)	93.1(18)	.470
DGRIP	47.3(8)	49.4(9)	.448
NGRIP	44.9(7)	45.9(7)	.656

* = newton-metres ** D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

When strength was compared by age group (Tables 3.19 and 3.20), the advantage demonstrated by the paraplegic subjects in bilateral elbow extensor average torque in the entire samples comparisons (Table 3.18), disappeared in those aged 45 years or older. But the young paraplegic subjects yielded, on average, statistically significantly more elbow extensor torque than the same aged able-bodied subjects in the dominant (22% greater) and non-dominant (25% greater) limbs. There was no difference in dominant grip strength between the paraplegic and able-bodied subjects aged 45 years and over. But, in those aged less than 45 years those with paraplegia were, on average, 14% stronger in dominant maximum grip strength.

In summary, when the entire paraplegic and able-bodied samples were compared, significant differences in strength were found for four out of fourteen muscle groups tested. The able-bodied subjects were stronger in shoulder flexion bilaterally, and the paraplegic subjects had stronger elbow extensors bilaterally. When the samples were subdivided by age group and the comparisons were repeated, the young able-bodied were stronger in non-dominant shoulder flexion and the young paraplegic subjects had stronger elbow extensors bilaterally, and stronger non-dominant grip. In the older age group, the paraplegic group's advantage in elbow extension and non-dominant grip disappeared, but the able-bodied group continued to demonstrate stronger shoulder flexion bilaterally. The significant differences in muscle strength between the subject groups ranged from 14-33%.

3.2.2. Changes in Paraplegic and Able-bodied Upper Limb Strength with Age

Scatterplots of age versus average torque for each movement tested for the paraplegic and able-bodied samples revealed that strength remained constant through to the fifth or sixth decade, with subsequent gradual declines in the years following. It was difficult to determine from the scattergrams the ages at which peak average torque and grip strength occurred.

Therefore, the data was examined further by constructing histograms, of the average strength scores for each variable by age decade, for both samples. The graphs for the paraplegic and able-bodied subjects are presented beside each other, to facilitate visual comparison (Figures 3.1 to 3.7). The sample sizes for each age group were: 20-29 = 8; 30-39 = 11; 40-49 = 14; 50-59 = 13; 60-74 = 6. While it should be remembered that the average scores for each decade are those of different individuals, and are not repeated measures, some trends emerged. In both the paraplegic and able-bodied samples, the declines in strength by decade appeared to be gradual with some slight variations among muscle groups.

Table 3.21 documents the decades in which the peak scores occurred. On examination of Figures 3.1 to 3.7 and Table 3.21, the most noticeable difference in strength trends with age between the two groups was the location of the peak average torque scores. In all but three muscle groups (bilateral shoulder flexion; non-dominant shoulder eccentric adduction), the paraplegic subjects' peak average torque readings occurred in the 30 to 39 year age group. Whereas, the peak in average torque for the able-bodied subjects occurred in the 20 to 29 year age group, except for the dominant shoulder extensor muscle group, where the highest scores were constant across the 3rd and 4th decades. Peaks in maximum grip strength occurred in the 4th decade for the able-bodied subjects. Peak maximum grip strength for the paraplegic subjects was fairly constant across the 3rd and 4th decades.

Table 3.21 also presents the percentage differences between the peak strength scores, (including the decade in which the peak occurred), and the strength scores in the 60 years and older age group for both the paraplegic and able-bodied samples. Both samples showed similar declines with age in the bilateral shoulder flexor muscle groups and in grip strength. In all remaining muscle groups, the strength difference between the peak and that of those aged 60 or over ranged from 1.7 (dominant shoulder concentric adductors) to 3.7 (non-dominant shoulder extensors) times greater in the able-bodied, than in the paraplegic sample. The difference in average torque between peak and old age in the eccentric shoulder adductors of the able-bodied was close to three times greater than that in the paraplegic sample. In the remaining muscle groups, the differences in strength of the able-bodied between peak and those aged 60 years or more were close to twice those documented in the paraplegic subjects.

Figure 3.1: Mean shoulder flexor average torque (± 1 S.D.) by age decade of paraplegic subjects (n=52) versus able bodied subjects (n=52).

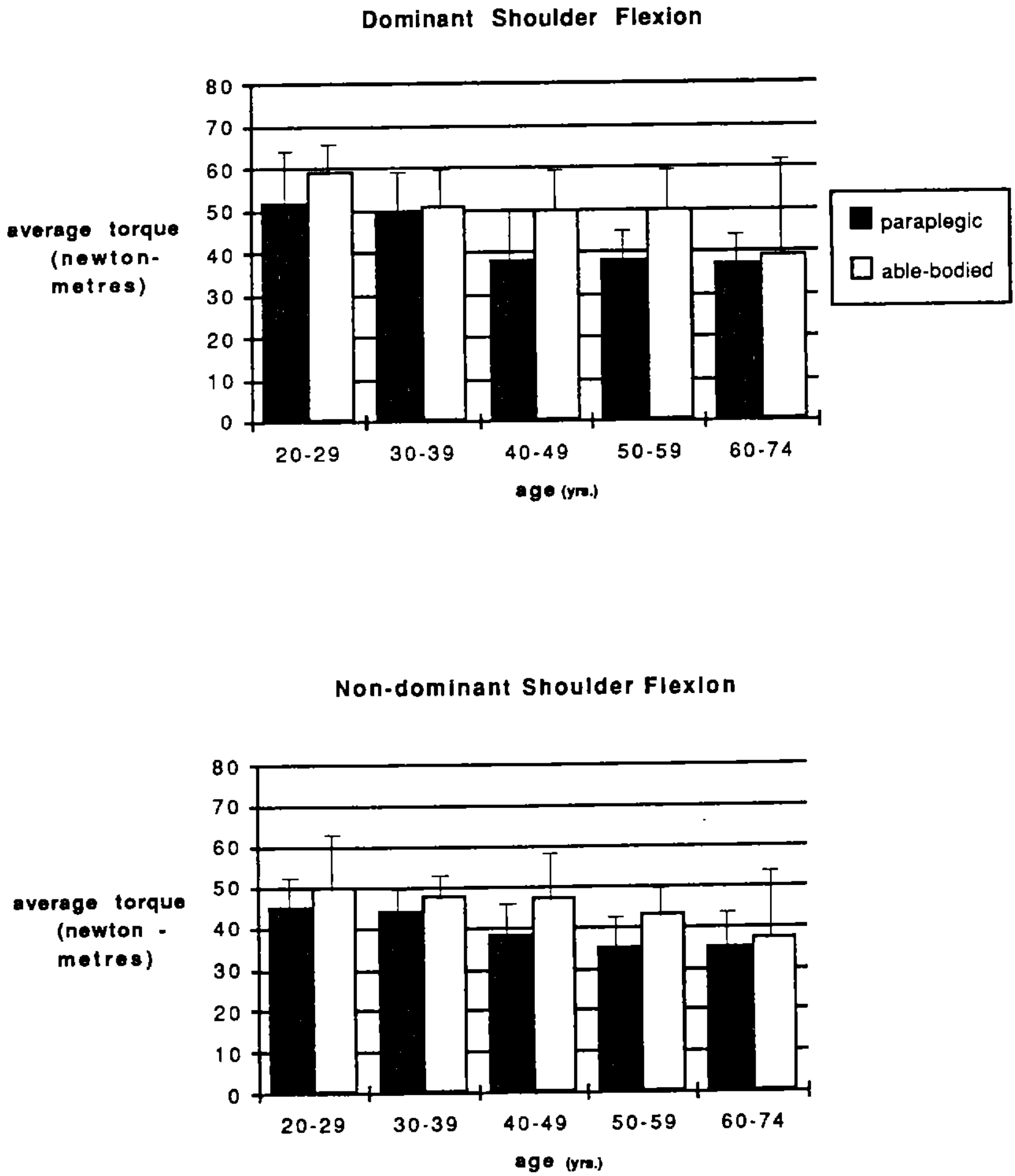
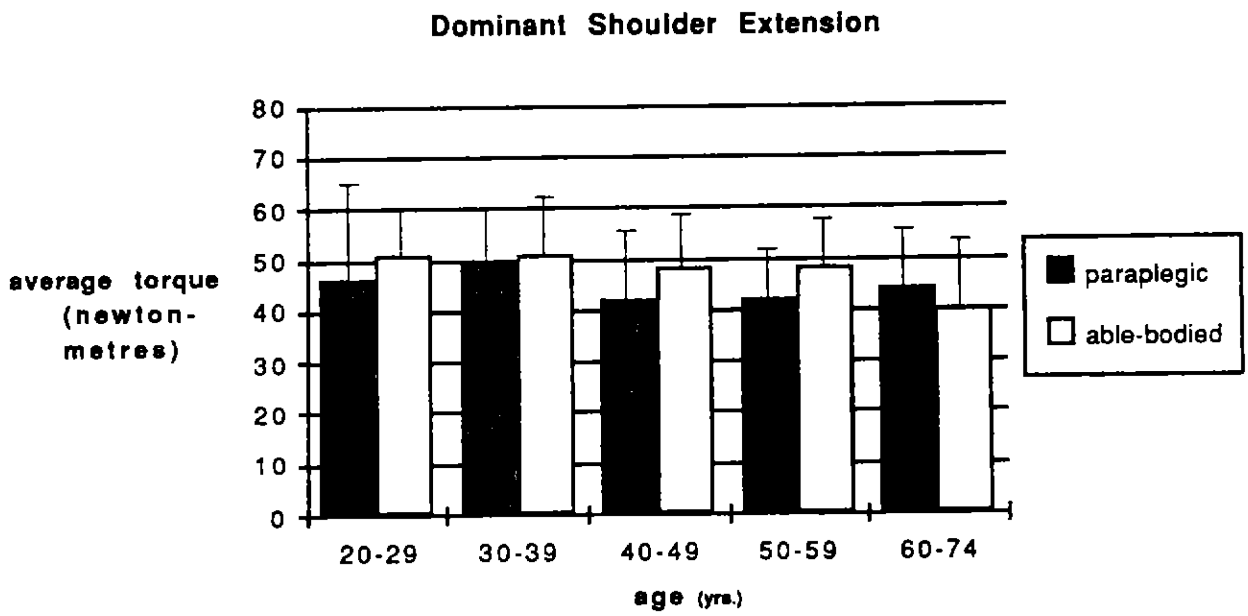


Figure 3.2: Mean shoulder extensor average torque (± 1 S.D.) by age decade of paraplegic subjects (n=52) versus able-bodied subjects (n=52).



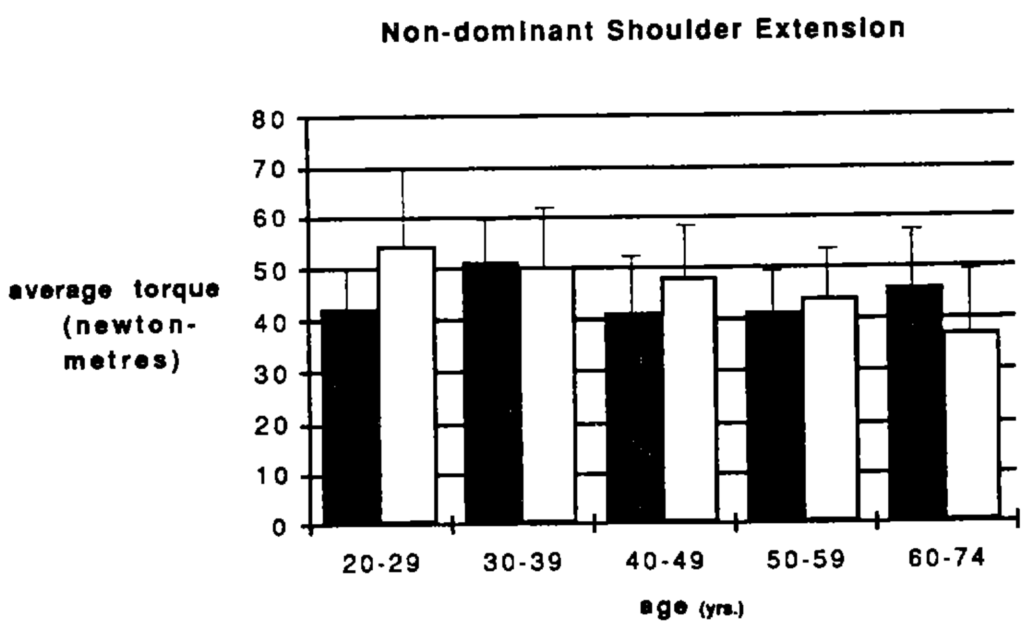
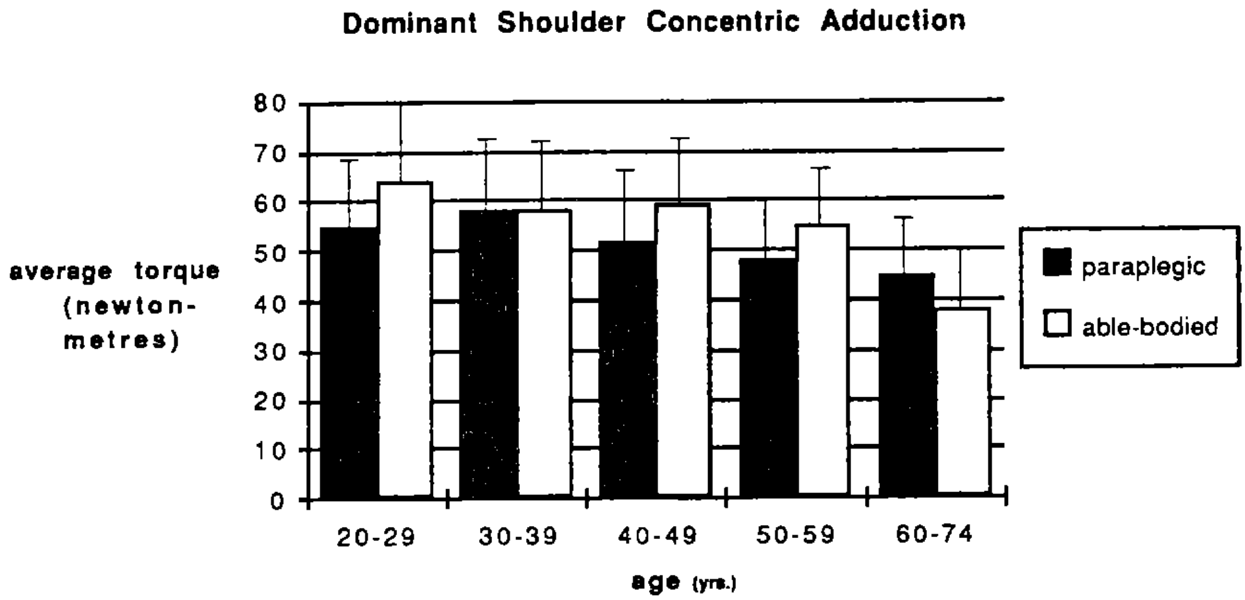


Figure 3.3: Shoulder concentric adduction average torque (± 1 S.D.) by age decade of paraplegic subjects (n=52) versus able-bodied subjects (n=52).



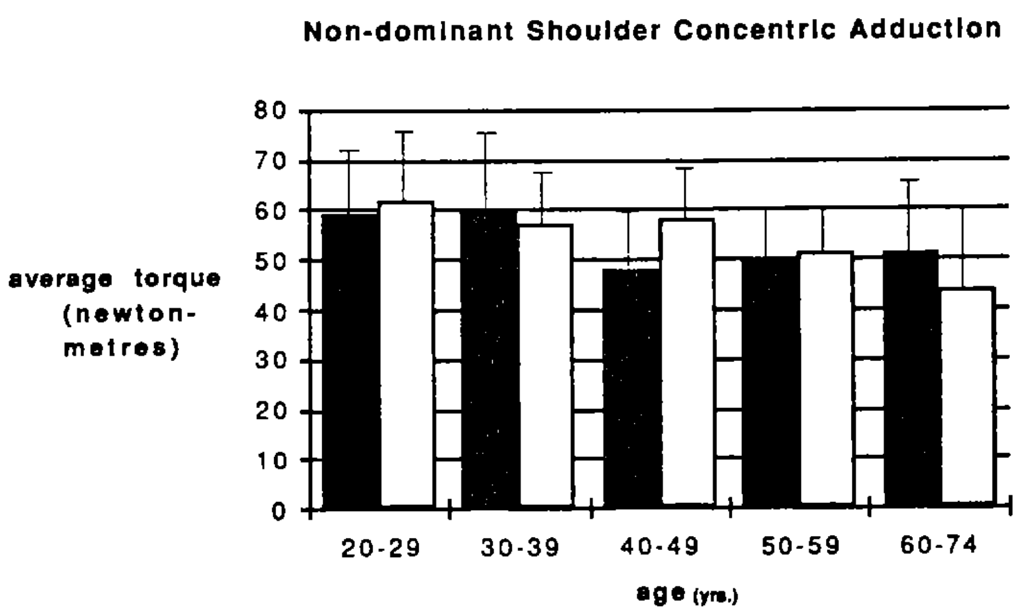
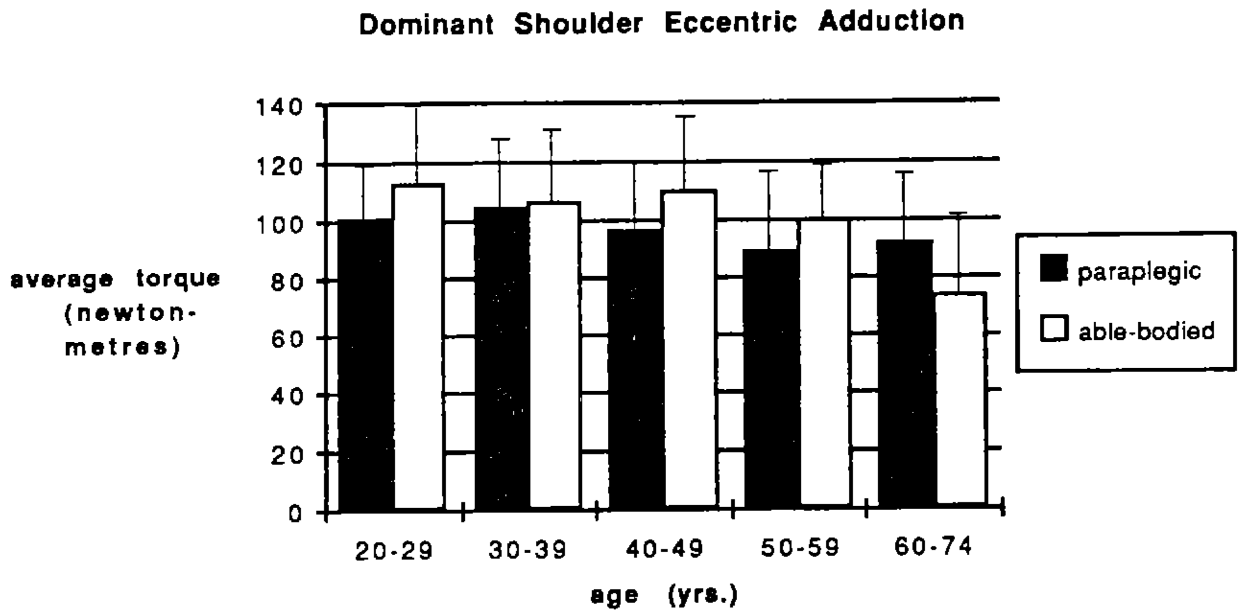


Figure 3.4: Shoulder eccentric adduction average torque (± 1 S.D.) by age decade of paraplegic subjects (n=52) versus able-bodied subjects (n=52).



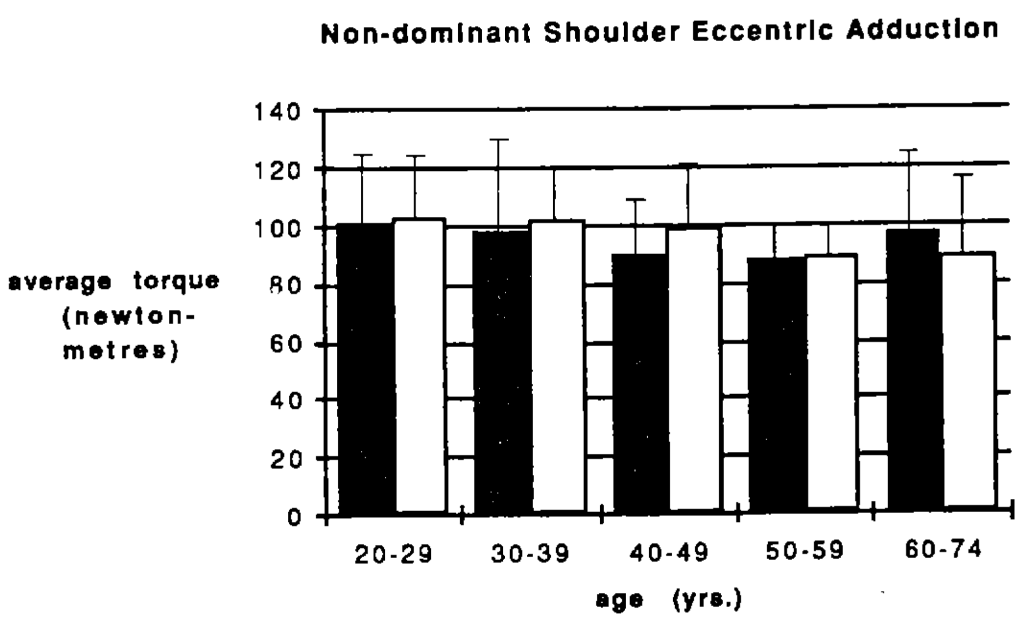


Figure 3.5: Elbow flexion average torque (± 1 S.D.) by age decade of paraplegic subjects (n=52) versus able-bodied subjects (n=52).

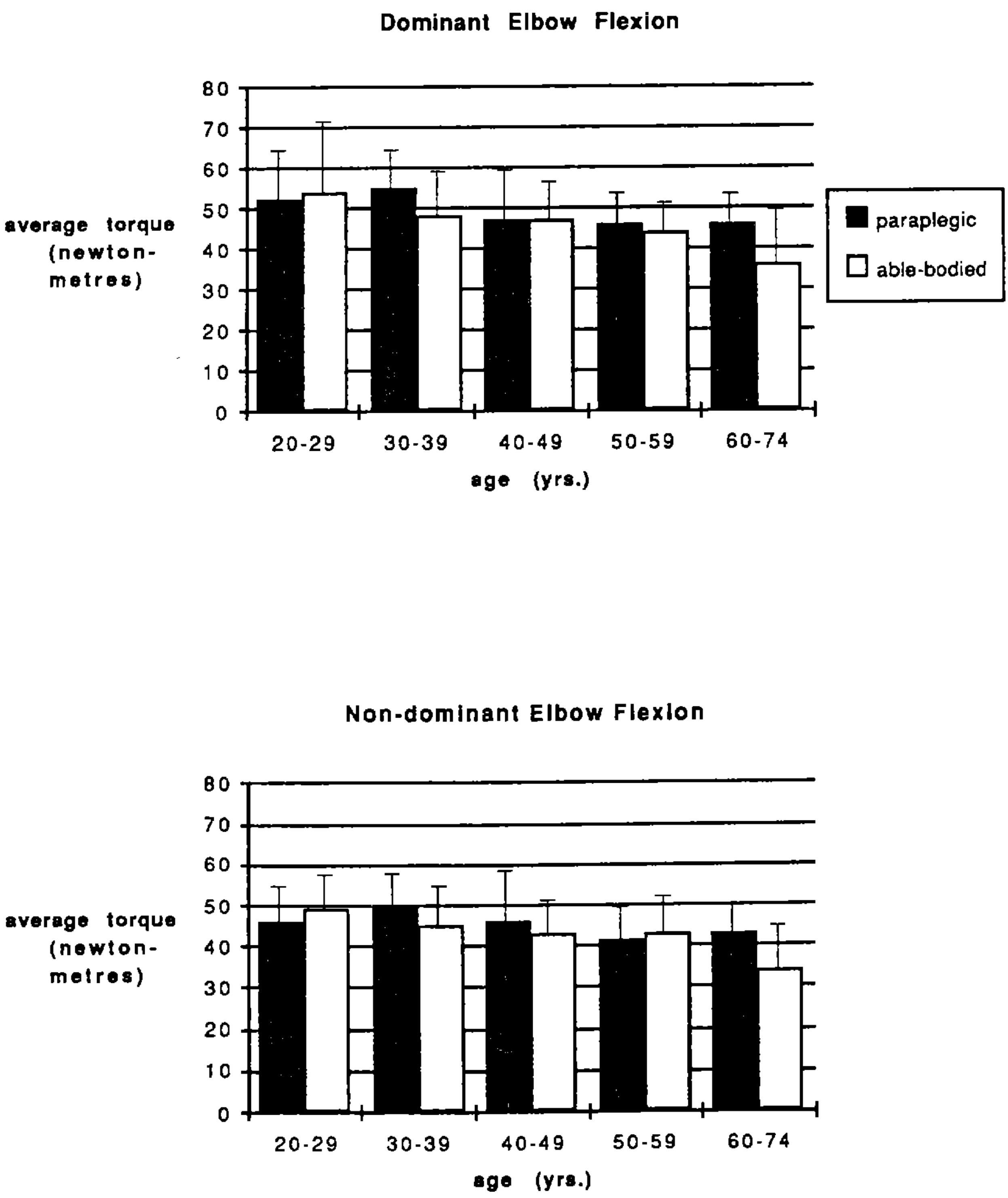
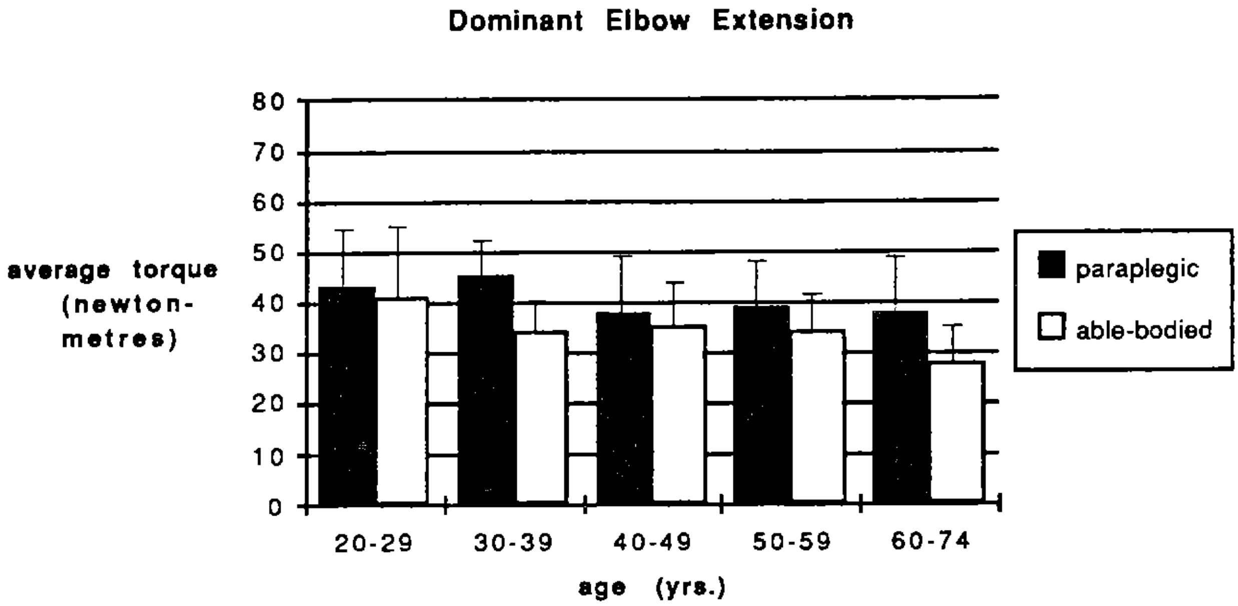


Figure 3.6: Elbow extension average torque (± 1 S.D.) by age decade of paraplegic subjects (n=52) versus able-bodied subjects (n=52).



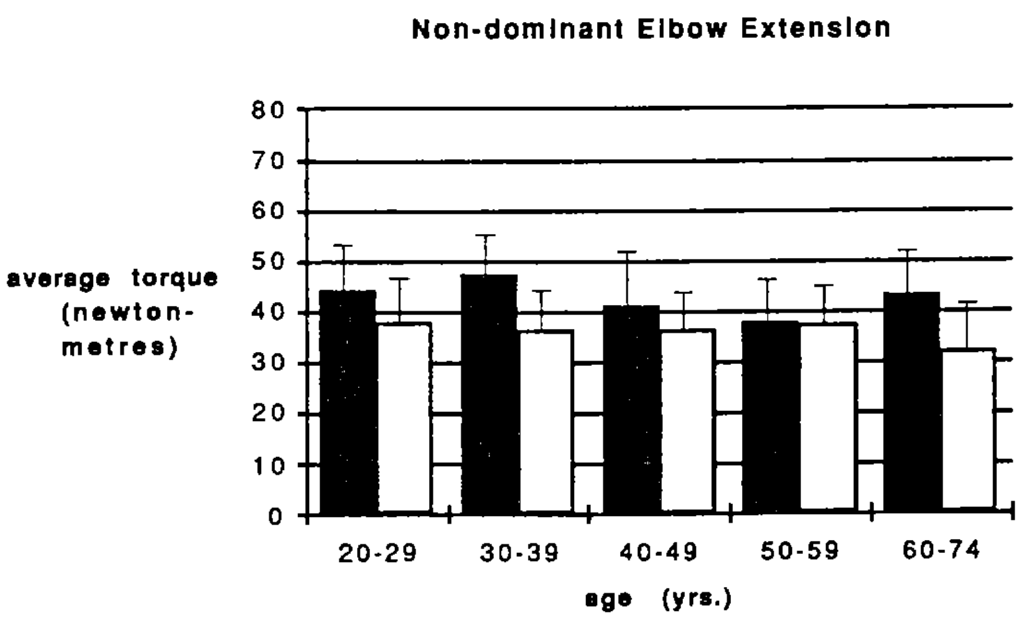
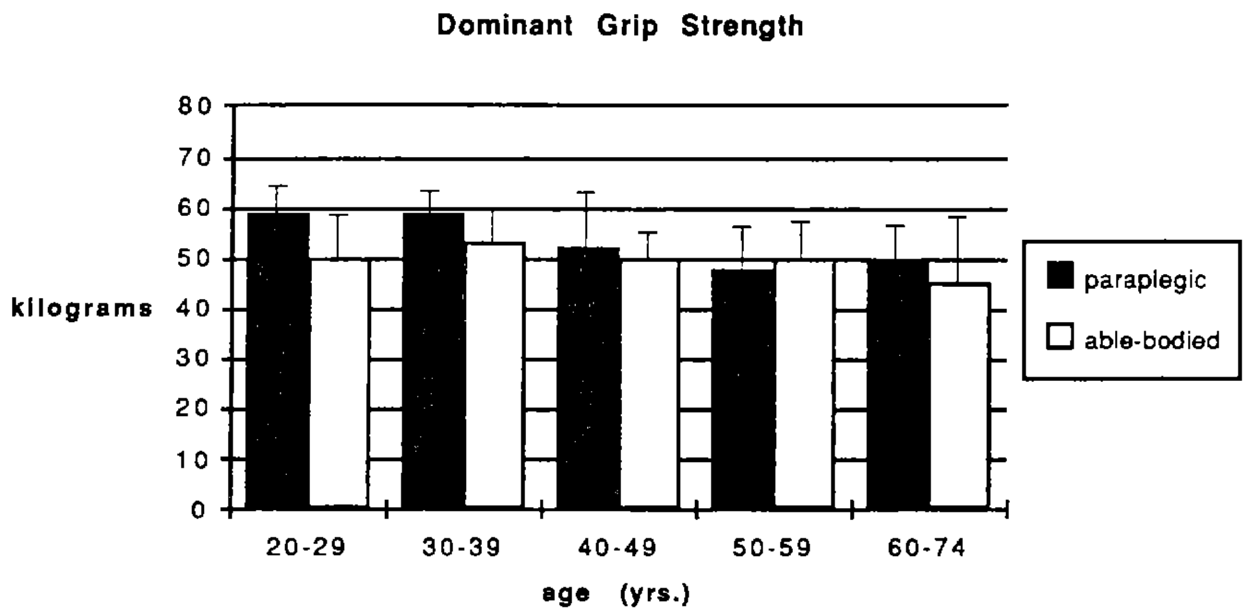


Figure 3.7: Maximum isometric grip strength (± 1 S.D.) by age decade of paraplegic subjects (n=52) versus able-bodied subjects (n=52).



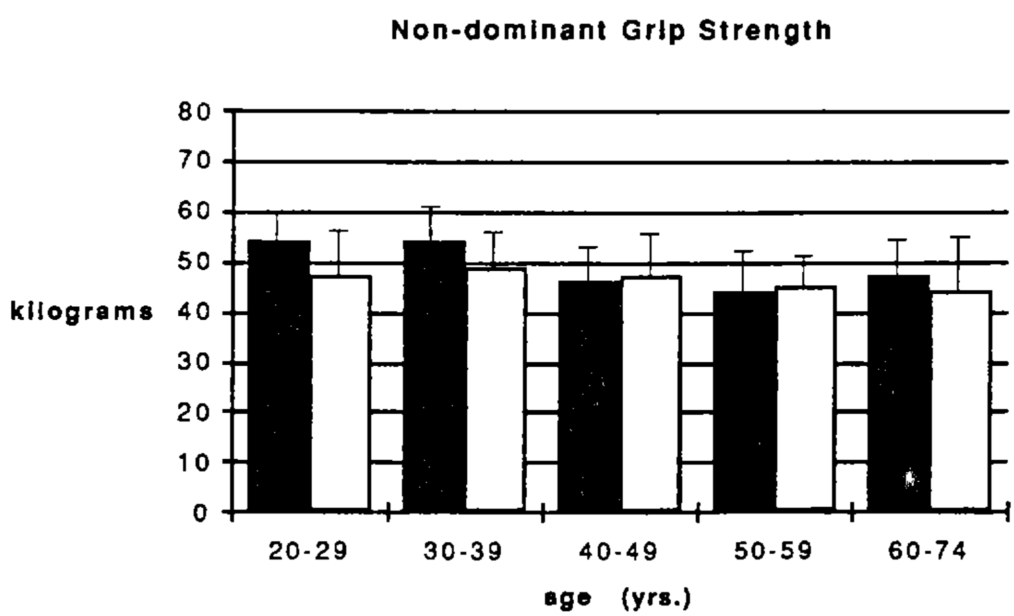


Table 3.21. Comparison of decrease from peak strength to strength in the over 60 age group for paraplegic and able-bodied subjects.

	Paraplegic Strength		Able-bodied Strength		
	Age Decade of Peak Strength	Percent decline from Peak to 60+yrs.	Age Decade of Peak Strength	Percent decline from Peak to 60+yrs	Ratio of Decline Para:Able
DSF*	3	29	3	35	.83
NSF	3	29	3	26	1.12
DSE	4	11	3	22	.51
NSE	4	9	3	32	.28
DEF	4	17	3	33	.50
NEF	4	15	3	30	.49
DEE	4	14	3	32	.43
NEE	4	8	3	17	.47
DADC	4	24	3	41	.58
NADC	4	15	3	29	.51
DADE	4	13	3	35	.36
NADE	3	4	3	13	.31
DGRIP	4	16	4	16	.99
NGRIP	3	13	4	10	1.28

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

Linear regression was then performed on the paraplegic (Table 3.22) and able-bodied (Table 3.23) subjects' strength data to determine whether or not age was a predictor of upper limb strength. As might be expected from the bar graphs in Figures 3.1 to 3.7, the regression analyses showed a decline in strength with age for both groups. However, even in those muscle groups where the ability of age to predict this decline was statistically significant, the prediction effect was weak (significant slopes ranged from -.001 to -.123).

Age was found to significantly predict declines in isokinetic average torque in both paraplegic and able-bodied persons for bilateral shoulder flexion, bilateral elbow flexion, and dominant shoulder concentric adduction. Age did not have a significant effect on average torque production in the remaining muscle groups in the subjects with paraplegia. However, for the able-bodied sample, it did appear to weakly predict strength declines bilaterally for the concentric and eccentric shoulder adductor muscle groups and the non-dominant shoulder extensor musculature. For the able-bodied subjects, the only muscle groups where age was not a significant predictor of strength were the elbow extensors bilaterally and the dominant shoulder extensors. The predictive effect of age on grip strength was statistically significant bilaterally for the paraplegic subjects, but significance was not attained for the predictive effect of age on able-bodied persons' maximum grip strength.

Table 3.22. Linear regression to determine whether or not age predicts upper limb muscle strength in subjects with parapelgia (n=52). @=.05

	Y Intercept	Slope	P-value
DSF*	60.53	-.034	.0019 S
NSF	53.33	-.026	.0005 S
DSE	50.89	-.012	.319
NSE	46.57	-.005	.607
DEF	60.15	-.021	.026 S
NEF	54.66	-.018	.048 S
DEE	47.83	-.014	.114
NEE	48.72	-.012	.173
DADC	66.63	-.028	.024 S
NADC	64.93	-.023	.072
DADE	116.24	-.037	.113
NADE	106.85	-.025	.268
DGRIP	68.89	-.030	.0002 S
NGRIP	60.59	-.123	.002 S

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

Table 3.23. Linear regression to determine whether age predicts upper limb muscle strength in able-bodied subjects (n=52). @=.05

	Y Intercept	Slope	P-value
DSF*	64.4	-.027	.009 S
NSF	60.6	-.028	.006 S
DSE	55.97	-.016	.140
NSE	60.02	-.026	.027 S
DEF	62.2	-.03	.004 S
NEF	56.83	-.025	.007 S
DEE	42.69	-.016	.053
NEE	40.54	-.008	.299
DADC	77.84	-.041	.002 S
NADC	72.11	-.001	.006 S
DADE	132.74	-.056	.028 S
NADE	119.10	-.041	.035 S
DGRIP	57.86	-.014	.072
NGRIP	53.35	-.011	.156

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

In order to examine whether or not the difference in upper limb strength between the paraplegic and able-bodied subjects changed as the paraplegic subjects aged, the strength scores of the paraplegic subjects were subtracted from those of their age-matched able-bodied counterparts, and the resulting difference was then plotted against paraplegic subject age. Examination of the scattergrams revealed them to be random, and linear regression analysis was subsequently performed to confirm this. Table 3.24 contains the results of the regression analysis for each movement tested. No statistically significant results were found; suggesting that the difference between paraplegic and able-bodied persons' strength does not change as the paraplegic subjects age.

Table 3.24. Linear regression to determine whether paraplegic subject age predicts the difference in strength between the paraplegic and able-bodied samples (n=52 pairs). @=.05.

	Y Intercept	Slope	P-value
ZDSF*	3.49	.008	.62
ZDSE	3.54	-.001	.94
ZDEF	0.52	.007	.58
ZDEE	-6.54	.0004	.97
ZDADC	9.41	-.012	.54
ZDADE	15.72	-.018	.63
ZDGRIP	-12.75	.019	.11
ZNSF	6.03	.0003	.98
ZNSE	14.10	-.021	.18
ZNEF	0.88	-.004	.71
ZNEE	-10.08	.007	.52
ZNADC	5.47	-.006	.68
ZNADE	7.83	-.009	.78
ZNGRIP	-8.84	.015	.18

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric. Z=Able-bodied subject strength value minus paraplegic subject strength value.

In conclusion, the effect of age on strength was examined in paraplegic and able-bodied persons aged 21 to 74 years. Histograms of average strength by decade revealed that in both the paraplegic and able-bodied subjects the strength declines with age were gradual, and that there was a plateau in average torque until the fifth or sixth decade. The predictive effect of age on declining strength was statistically significant for the paraplegic subjects for bilateral shoulder and elbow flexor average torque, and dominant concentric shoulder adductor average torque, as well as for maximum grip strength. In the able-bodied group, age predicted isokinetic strength in all muscle groups tested except elbow extension bilaterally, and dominant shoulder extension. Age did not predict maximum grip strength in the able-bodied sample.

3.2.3. Changes in Upper Limb Strength with Increasing Duration of Paraplegia

Table 3.25 shows that when the paired t-test was used to compare persons having sustained paraplegia less than 15 years previously (mean age [1 SD] = 34.6 [10] years) with able-bodied persons of the same age, the average torque generated by the two groups did not differ significantly except for dominant grip strength and non-dominant elbow extension. In these instances those with paraplegia were stronger than the able-bodied subjects. In the non-dominant elbow extensor muscle group, the paraplegic subjects generated, on average, 17% more average isokinetic torque than did their same aged able-bodied counterparts. The short duration paraplegic subjects' maximum dominant grip strength was an average of 11% greater than that of the same able-bodied group.

Table 3.25. Comparison of upper limb strength between short duration (injured for less than 15 years) paraplegic subjects and matched able-bodied persons (n=20 pairs) @=.05.

	Paraplegic strength (nm)* mean (1 SD)	Able-bodied strength (nm) mean (1 SD)	P-value	
DSF**	48.0(11)	52.8(8)	.21	
NSF	43.4(7)	48.2(9)	.05	
DSE	47.9(13)	48.7(9)	.86	
NSE	46.3(9)	48.9(13)	.47	
DEF	52.5(11)	47.7(12)	.05	
NEF	46.8(8)	45.3(10)	.55	
DEE	45.2(11)	41.7(8)	.19	
NEE	42.6(8)	36.4(8)	.02	S
DADC	54.3(13)	58.1(13)	.36	
NADC	57.8(14)	58.3(12)	.91	
DADE	99.3(21)	105.4(22)	.41	
NADE	97.7(28)	97.8(18)	.97	
DGRIP	57.2(7)	51.5(7)	.03	S
NGRIP	51.9(7)	47.3(7)	.09	

* = newton-metres
** D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

The results of the same comparisons between persons who have had paraplegia for 15 years or longer (mean age [± 1 S.D.] = 50.3 [9]years) and same aged able-bodied subjects (Table 3.26) revealed more statistically significant dissimilarities in isokinetic average torque scores between the two groups. The paraplegic sample continued to dominate in non-dominant elbow extension (17% greater), and in this group, were also stronger in dominant elbow extension (16% greater). Unlike the short duration of SCI sample, the paraplegic subjects in the long duration group did not have significantly greater maximum grip strength than their able-bodied counterparts. In the comparison of long duration of SCI subjects and matched able-bodied subjects however, the able-bodied subjects, on average, produced significantly greater average torque than the same aged paraplegics in the dominant shoulder flexors (24% greater), non-dominant shoulder flexors (18.9% greater), and in the dominant shoulder extensor muscle group (11.5%).

Table 3.26. Comparison of upper limb strength between persons with paraplegia for 15 years or more and age matched able-bodied subjects (n=32 pairs).

	Paraplegic strength (nm)* mean (1 SD)	Able-bodied strength (nm) mean (1 SD)	P-value	
DSF*	38.9(10)	48.5(11)	.0002	S
NSF	37.0(8)	44.1(10)	.003	S
DSE	42.6(11)	47.5(11)	.01	S
NSE	42.5(10)	45.9(12)	.25	
DEF	46.6(9)	44.9(10)	.59	
NEF	44.1(10)	42.3(9)	.55	
DEE	41.1(8)	41.3(9)	.02	S
NEE	42.0(10)	35.8(8)	.008	S
DADC	50.6(12)	54.3(14)	.24	
NADC	49.9(11)	53.3(11)	.22	
DADE	94.9(26)	101.6(28)	.36	
NADE	91.2(20)	93.8(14)	.28	
DGRIP	50.9(9)	49.8(8)	.62	
NGRIP	46.2(7)	47.2(9)	.63	

*D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

As was described in the Methods chapter, in order to examine the effect of duration of SCI paraplegic subjects' upper limb strength, exclusive of the covariate of age, a new variable was created by subtracting each paraplegic subjects' average torque and grip strength values from those of their age-matched able-bodied counterparts. As the first step in examining whether or not there is a change in the difference between paraplegic strength and normal (able-bodied) strength with increasing duration of SCI, scatterplots were constructed. The difference in strength between able-bodied and paraplegic subjects was placed on the y axis, and duration of paraplegia was placed on the x axis. Inspection of these plots revealed them to be random.

To confirm the findings from the scatterplots, linear regression was performed with the difference in strength between the two groups as the dependent variable, and duration of SCI as the independent variable. The results are shown in Table 3.27. Only in the case of dominant and non-dominant grip strength was the difference from 0 of the slope of the regression line shown to be statistically significant; suggesting that the difference between paraplegic and able-bodied persons' grip strength increased as the duration of paraplegia increased. The negative y intercepts for grip strength indicate that the paraplegic subjects were stronger than the able-bodied group in young age. The slopes of .023 (dominant grip) and .027 (non-dominant grip) indicate that the paraplegic subjects' grip strength decreased only slightly more quickly with time than did the able-bodied. But extrapolation of the slopes indicates that the subjects with paraplegia will maintain their grip strength advantage over the able-bodied within a normal lifetime, exclusive of age. All of the remaining regression slopes in Table 3.27 are positive, and their values are minimal. This suggests that, even though significant results were not obtained, the trends in isokinetic average torque changes may be that duration of SCI predicts the difference in paraplegic upper limb strength from normal only weakly, at best.

Table 3.27. Linear regression to determine whether duration of paraplegia predicts the difference in strength between paraplegic and able-bodied samples (n=52 pairs).

	Y Intercept	Slope	P-value	
ZDSF*	2.83	.023	.18	
ZNSF	3.66	.012	.33	
ZDSE	0.42	.012	.51	
ZNSE	2.23	.003	.84	
ZDEF	-0.49	.009	.48 ZNEF	-3.61
.010	.43			
ZDEE	-7.62	.006	.64	
ZNEE	-8.53	.011	.37	
ZDADC	0.95	.013	.52	
ZNADC	-0.66	.013	.44	
ZDADE	-1.80	.037	.36	
ZNADE	-1.86	.026	.38	
ZDGRIP	-8.37	.023	.02 S	
ZNGRIP	-6.64	.027	.02 S	

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric. Z=Able-bodied subject strength value- paraplegic subject strength value.

3.2.4. The Ability of Selected Variables to Predict Upper Limb Strength in Paraplegic (n=52) and Able-bodied Subjects (n=52).

Table 3.28 lists the results of the stepwise regression procedures performed to determine which of age, duration of spinal cord injury, present upper limb activity-level, or level of lesion best predicted upper limb strength in persons with paraplegia, and which of age and present upper limb activity-level were the best predictors of the same in the able-bodied subjects. For the able-bodied, in all muscle groups except grip strength, age was shown to be a better predictor of strength than activity-level. This effect was not statistically significant for the dominant shoulder extensors.

The paraplegic subjects' results were more diverse. Duration of SCI was a slightly more common best predictor than the other independent variables used. It was identified as the best predictor of strength for non-dominant elbow flexion, elbow extension, and concentric shoulder adduction, as well as for grip strength bilaterally. Four of the five muscle groups where duration was selected as the best strength predictor were on the non-dominant side. As for the able-bodied, age was selected as the best predictor for shoulder flexion bilaterally and dominant concentric shoulder adduction, and was one of two significant predictors of dominant elbow flexion average torque. Present upper limb activity-level reached significance as the best predictor for strength of the dominant shoulder extensors and eccentric adductors, and along with age, was shown to be a best predictor of dominant elbow flexion. Present upper limb activity-level was the best predictor of paraplegic subject dominant elbow extension, but this effect did not reach statistical significance. All instances where present upper limb activity-level best predicted strength were on the dominant side. Lesion level was the least common best predictor of strength for the muscle groups under study. It was selected as the best strength predictor for non-dominant shoulder concentric adduction. Lesion-level was also identified as the best predictor of non-dominant shoulder extension, but the result was not statistically significant.

Table 3.28. Stepwise regression to determine which of age, duration, present upper limb activity-level, or lesion level, best predicts strength in the paraplegic subjects and which of age and present activity-level best predicts strength in the able-bodied subjects.

	Paraplegic Subjects (n=52)		Able-bodied Subjects (n=52)	
Movement	Best Predictor	P-value	Best Predictor	P-value
DSF*	Age	.002 S	Age	.014 S
NSF	Age	.0005 S	Age	.005 S
DSE	Present activity-level	.022 S	Age	.081
NSE	Lesion level	.119	Age	.012 S
DEF	Present activity-level	.016 S	Age	.003 S
	Age	.035 S		
NEF	Duration	.023 S	Age	.007 S
DEE	Present activity-level	.065	Age	.049 S
NEE	Duration	.042 S	Age	.005 S
DADC	Age	.024 S	Age	.002 S
NADC	Duration	.042 S	Age	.005 S
DADE	Present activity-level	.031 S	Age	.018 S
NADE	Lesion level	.043 S	Age	.041 S
DGRIP	Duration	.0001 S	Present activity-level	.014 S
NGRIP	Duration	.0002 S	Present activity-level	.012 S

* D=dominant, N=non-dominant, SF=shoulder flexion, SE= shoulder extension, EF=elbow flexion, EE=elbow extension, ADC=shoulder adduction concentric, ADE=shoulder adduction eccentric.

3.3. Upper Limb Range of Motion

Introduction

The results of the analysis of the active range of motion (AROM) data are presented in three sections. In section 3.3.1 bar graphs are used to illustrate and compare the distributions of the shoulder and elbow AROM scores for both the spinal cord injured and able-bodied samples. The results of tests of association between reduced AROM and either persons with paraplegia or able-bodied persons are also presented. The effect of age on upper limb AROM is examined in section 3.3.2. The results the analysis of the effect of duration of SCI on upper limb AROM are reported in section 3.3.3.

3.3.1. Comparison of the Subjects with Paraplegia and the Able-bodied Subjects

Figures 3.8 to 3.17 illustrate and compare the frequency distributions of the active range of motion scores of the subjects with paraplegia and the able-bodied subjects:

Figure 3.8	dominant shoulder flexion,
Figure 3.9	non-dominant shoulder flexion,
Figure 3.10	dominant shoulder abduction,
Figure 3.11	non-dominant shoulder abduction,
Figure 3.12	dominant shoulder internal rotation,
Figure 3.13	non-dominant shoulder internal rotation,
Figure 3.14	dominant shoulder external rotation,
Figure 3.15	non-dominant shoulder external rotation,
Figure 3.16	dominant elbow flexion,
Figure 3.17	non-dominant elbow flexion.

It was apparent from these distributions that very few subjects in either group suffered from losses in active range of motion for the movements tested, except for the spinal cord injured subjects, who appeared more likely to have reduced AROM in internal rotation bilaterally, and non-dominant external rotation. It was also evident that the extent of the reductions in AROM for all movements tested were distributed unevenly; in that of the six possible scoring categories, no subject in either sample scored in the lowest three categories. For this reason, it was decided to transform the AROM scores to binary data for all subsequent analyses. The two categories used were normal range of motion and below normal range of motion. Using the transformed data, McNemar tests were employed to test for associations between reduced range of motion and either paraplegic or able-bodied subjects. These results are shown in Table 3.29.

Figure 3.8 shows that for dominant shoulder flexion, 94% of the group with paraplegia and 96% of the able-bodied group scored in the normal range category of 151^0-180^0. In each group, 2 subjects, or 4%, scored in the 121^0-150^0 category. One SCI subject scored in the 91^0-120^0 category. For non-dominant shoulder flexion (Figure 3.9), the results in the two samples were similar, with 94% of each sample scoring in the normal AROM category. Of those having less than normal range, 6% of the able-bodied and 4% of the paraplegic subjects, achieved 120^0-150^0 of motion, and one subject with paraplegia scored in the 91^0-120^0 category. The McNemar test results in Table 3.29 confirmed that there was no association between reduced shoulder range of motion and able-bodied or SCI persons (dominant shoulder flexion: p=1.000; non-dominant shoulder flexion: p=1.000).

The distributions of AROM scores for dominant and non-dominant shoulder abduction (Figures 3.10 and 3.11) were similar to those for shoulder flexion. In the dominant limb, 8% of the SCI subjects and 10% of the able-bodied subjects had ranges of less than 150^0 of abduction. Of these, all but one subject with paraplegia scored in the 121^0-150^0 category. On the non-dominant side, 6% of the subjects with paraplegia, and 10% of the able-bodied subjects had reduced active range; with all but one SCI subject scoring in the 121^0-150^0 category. The results of the McNemar tests in Table 3.29 confirmed that there was no association between reduced abduction range and either able-bodied persons or persons with paraplegia (dominant shoulder: $p=1.000$; non-dominant shoulder: $p=.727$).

Figure 3.8: Comparison of frequencies of dominant shoulder flexion range of motion scores of paraplegic (n=52) and able bodied (n=52) subjects.

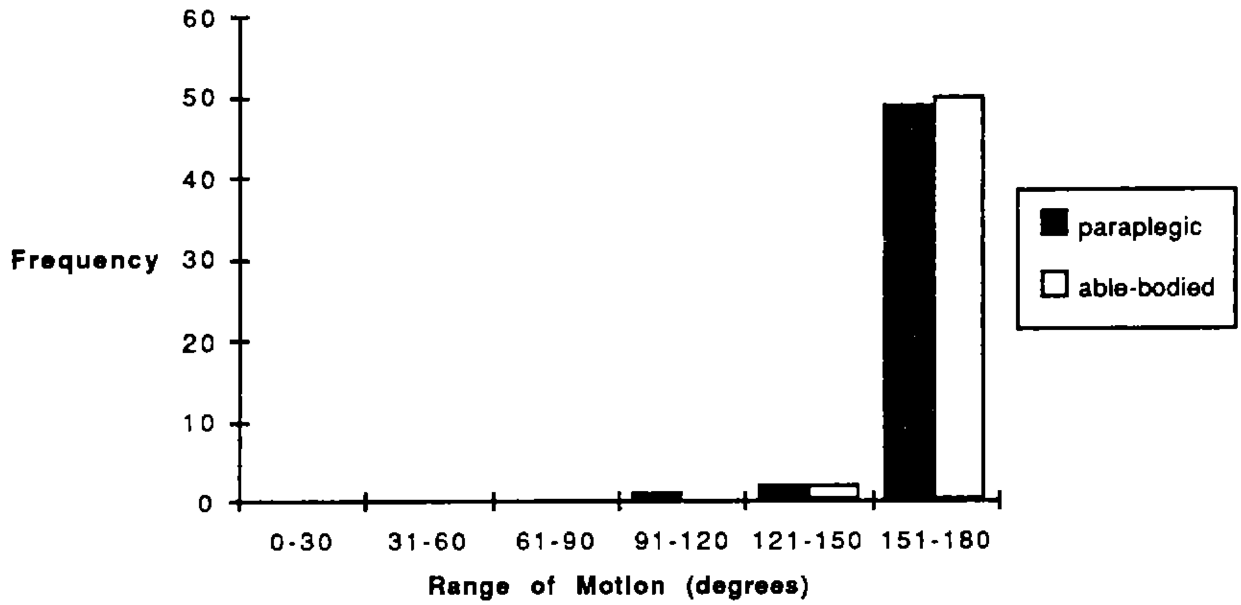


Figure 3.9: Comparison of frequencies of non-dominant shoulder flexion range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.

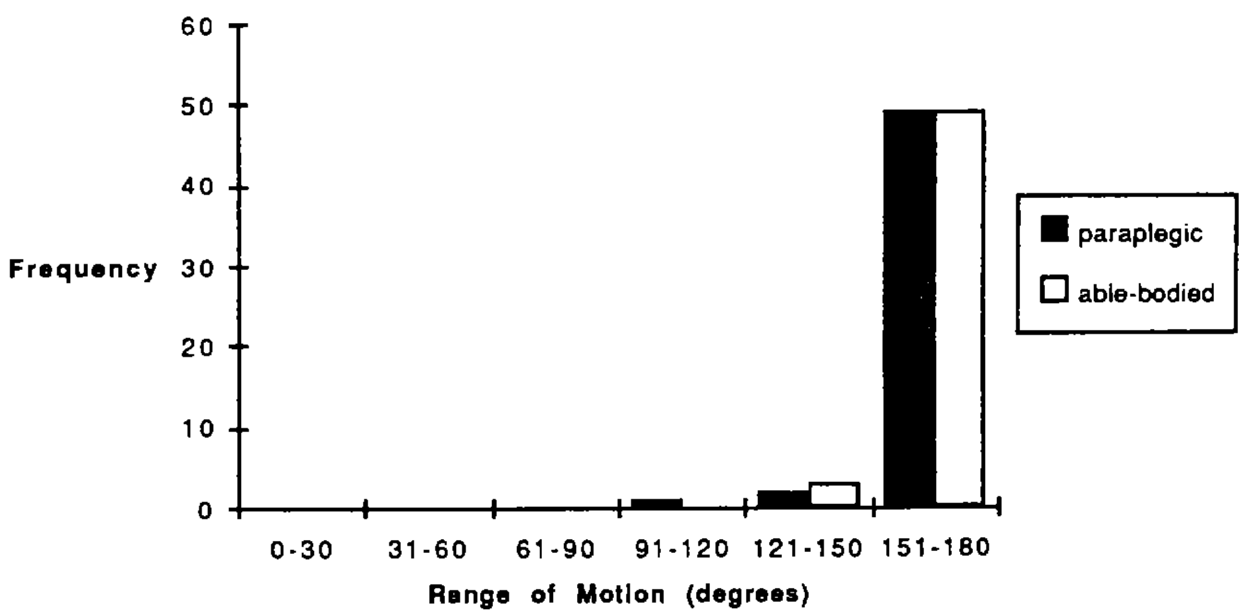


Figure 3.10: Comparison of frequencies of dominant shoulder abduction range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.

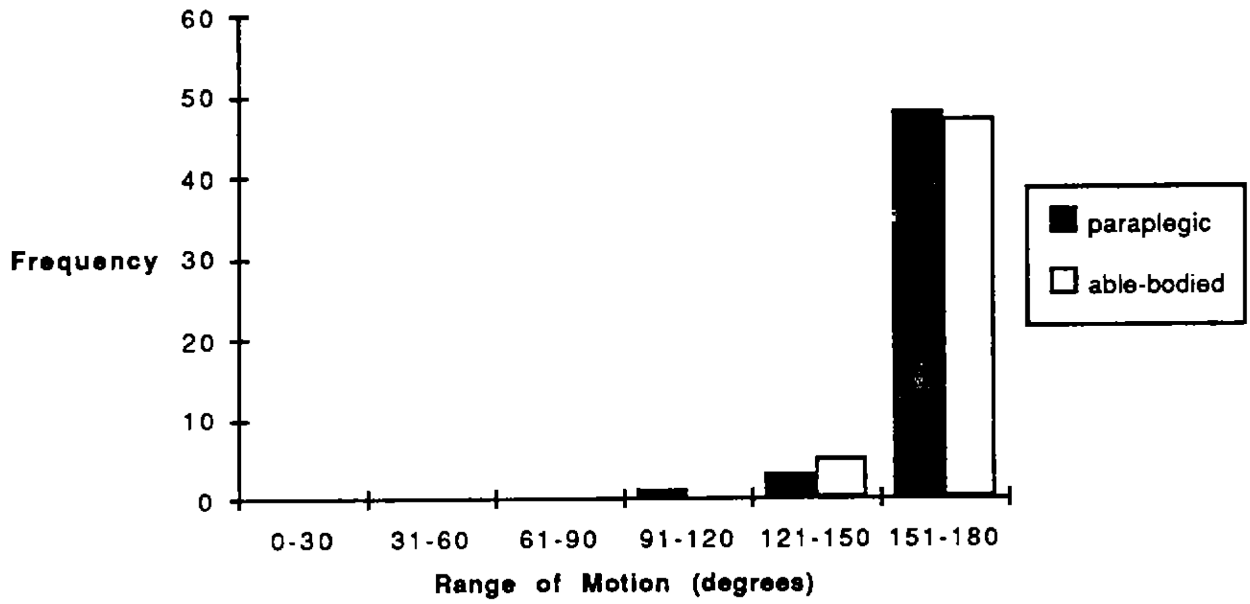
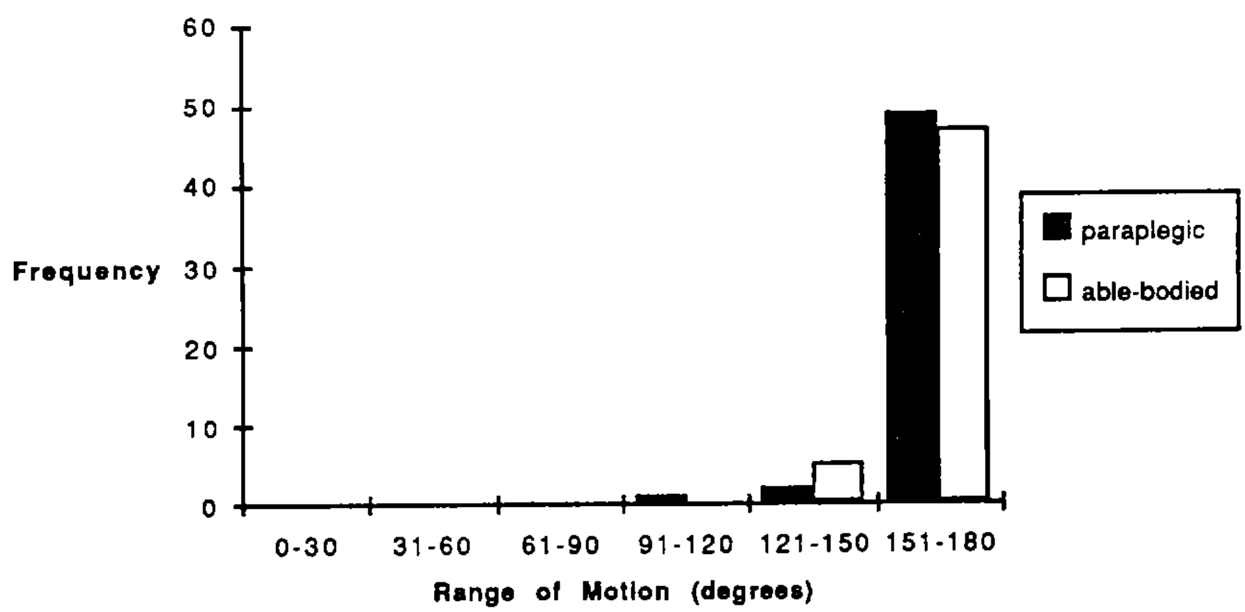


Figure 3.11: Comparison of frequencies of non-dominant shoulder abduction range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.



The distributions of dominant and non-dominant shoulder internal rotation scores revealed the greatest differences between the two subject groups (Figures 3.12 and 3.13). More paraplegic than able-bodied subjects could reach the dorsum of their hand only to the height of the T_{12} vertebral level on their back. Calculation of these numbers in percentages revealed that on the dominant side, below normal internal rotation was found in 33% of the subjects with paraplegia and in 12% of the able-bodied subjects. On the non-dominant side 27% of the paraplegic subjects and 2% of the able-bodied group had reduced range of internal rotation. However, the extent of the reductions for all but one SCI subject were such that they could reach to at least the T_{12} level on the back. The McNemar tests (Table 3.29) revealed a statistically significant association between reduced range of internal shoulder rotation and persons with paraplegia versus those who were able-bodied (dominant side : $p=.013$; non-dominant side: $p=.0005$).

In dominant shoulder external rotation (Figure 3.14) normal range of motion was measured in 92% of the paraplegic subjects and 98% of the able-bodied subjects. The remaining subjects (8% paraplegic; 2% able-bodied) scored one category below normal AROM. The distribution of scores for the able-bodied were the same for each limb. However, in the paraplegic group, restricted external rotation range was found more often on the non-dominant side (21%). Of those persons with paraplegia who had restricted AROM on the non-dominant side, all but one subject scored one category less than normal range. The McNemar tests (Table 3.29) indicated that the SCI subjects were statistically more likely to present with reduced range of external shoulder rotation on the non-dominant side than were the able-bodied subjects of the same age ($p=.006$).

Figure 3.12: Comparison of frequencies of dominant shoulder internal rotation range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.

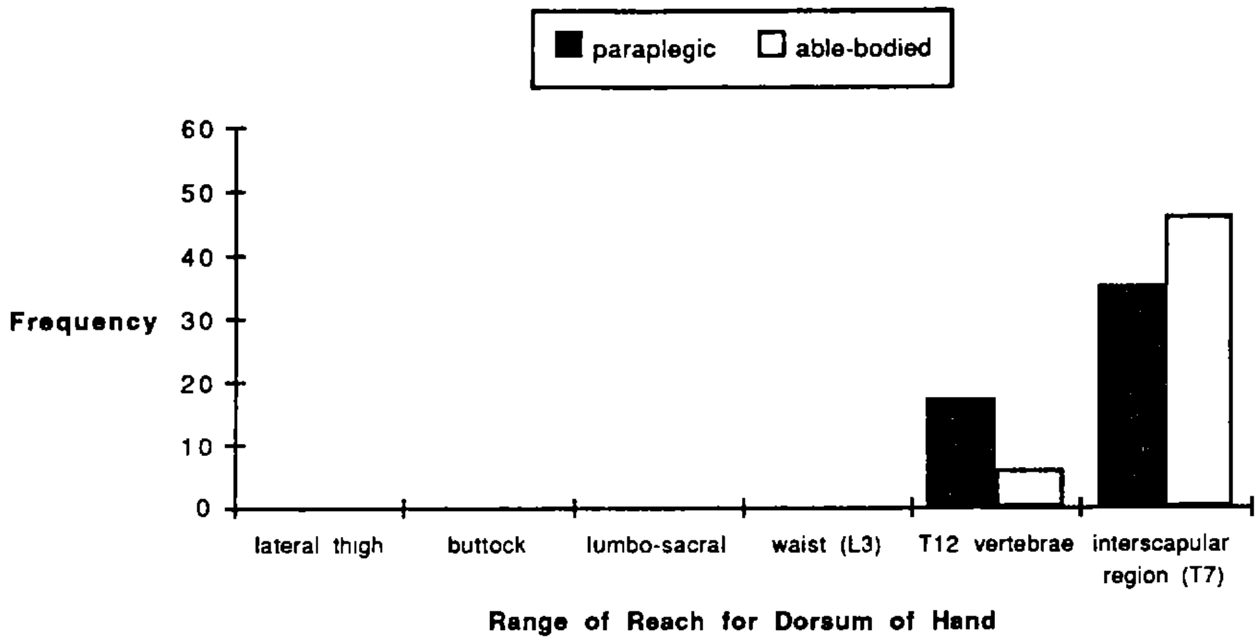


Figure 3.13: Comparison of frequencies of non-dominant shoulder internal rotation range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.

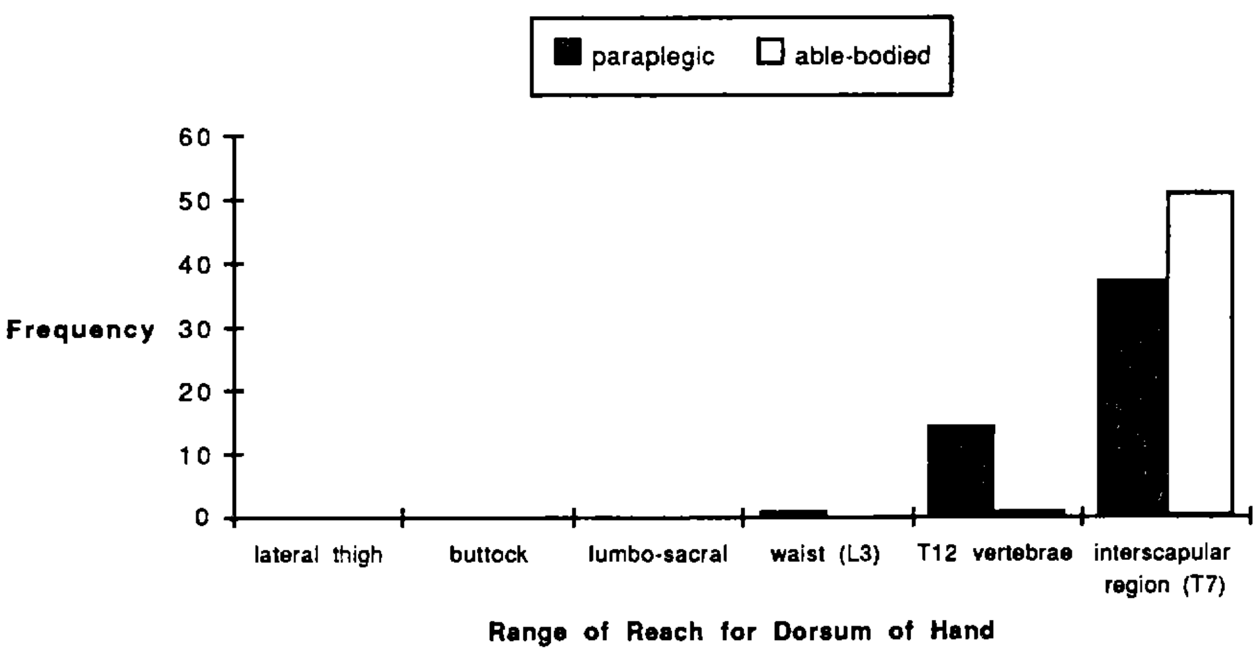
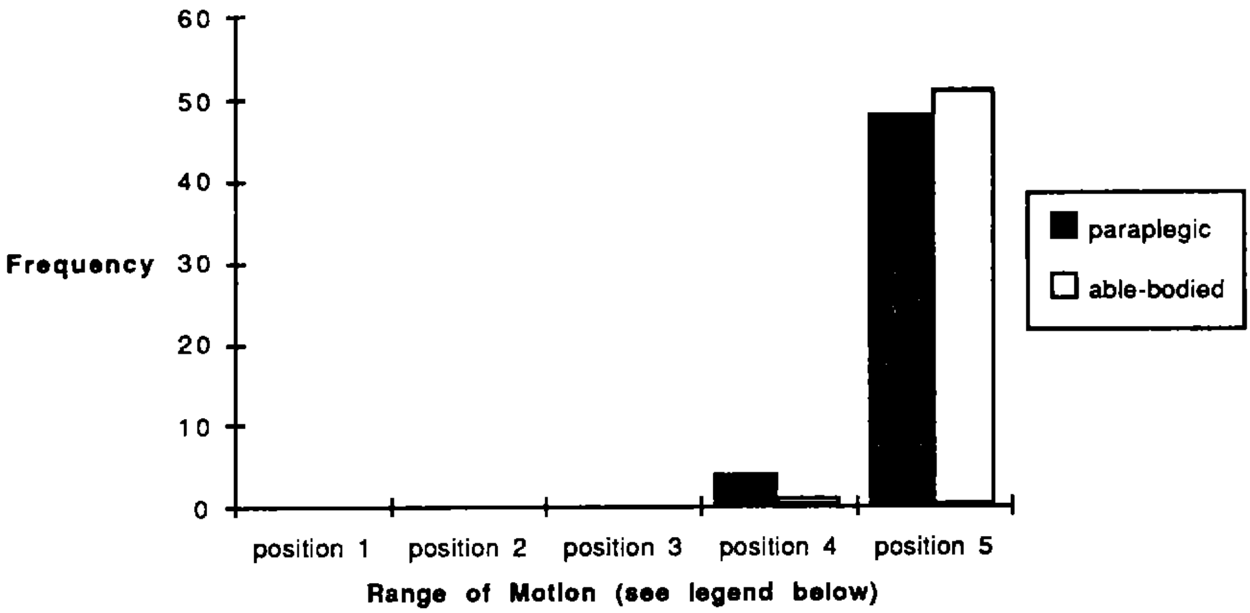
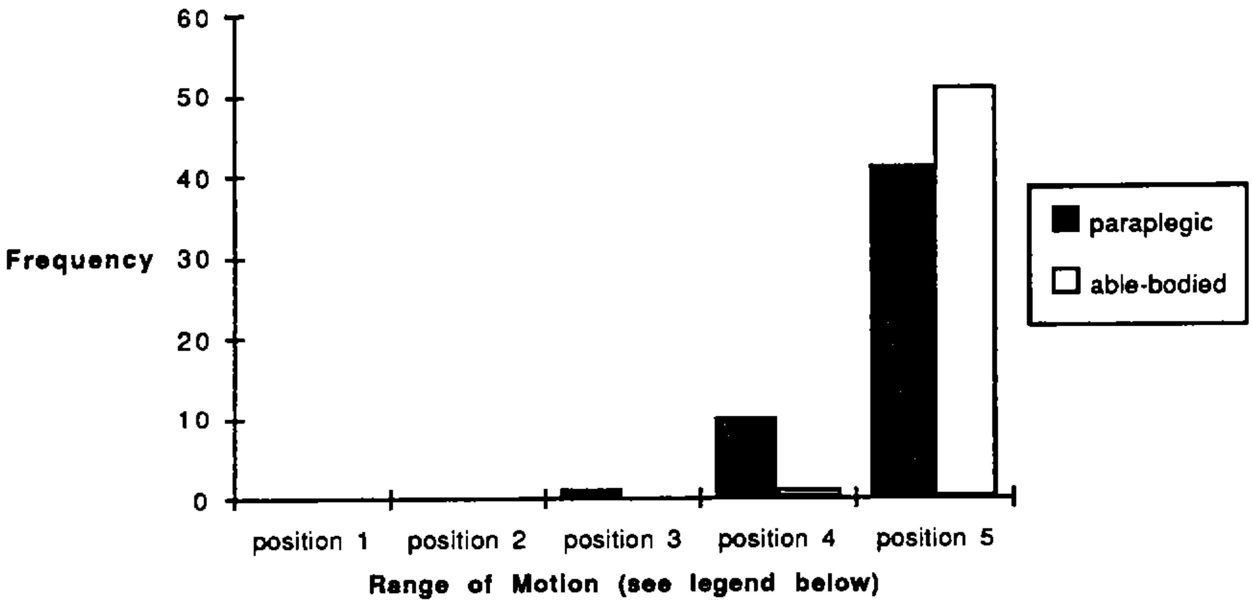


Figure 3.14: Comparison of frequencies of dominant shoulder external rotation range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.



Legend:	1 — hand behind head, elbow forward
	2 — hand behind head, elbow back
	3 — hand on top of head, elbow forward
	4 — hand on top of head, elbow back
	5 — full elevation with hand on top of head elbow held back

Figure 3.15: Comparison of frequencies of non-dominant shoulder external rotation range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.



Legend:	1 — hand behind head, elbow forward
	2 — hand behind head, elbow back
	3 — hand on top of head, elbow forward
	4 — hand on top of head, elbow back
	5 — full elevation with hand on top of head elbow held back

The distributions of AROM scores for elbow flexion (Figures 3.16 and 3.17) were identical for the paraplegic and able-bodied subjects. For both the dominant and non-dominant sides, 98% of the paraplegic subjects and 100% of the able-bodied subjects achieved at least 126^0-150^0 of flexion, which was considered as normal range in this study. One subject with paraplegia scored in the 101^0-125^0 category. The McNemar test results (Table 3.29) confirmed that neither paraplegic nor able-bodied persons are more likely to demonstrate reduced elbow flexion range than same aged individuals in the opposite group.

Figure 3.16: Comparison of frequencies of dominant elbow flexion range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.

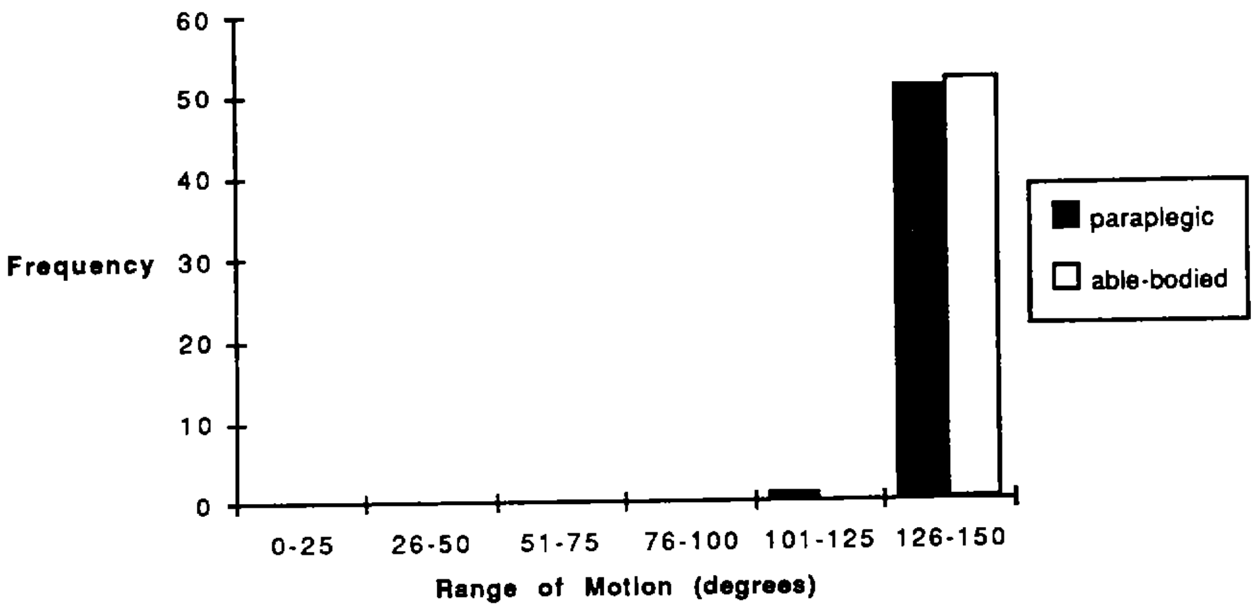


Figure 3.17: Comparison of frequencies of non-dominant elbow flexion range of motion scores of paraplegic (n=52) and able-bodied (n=52) subjects.

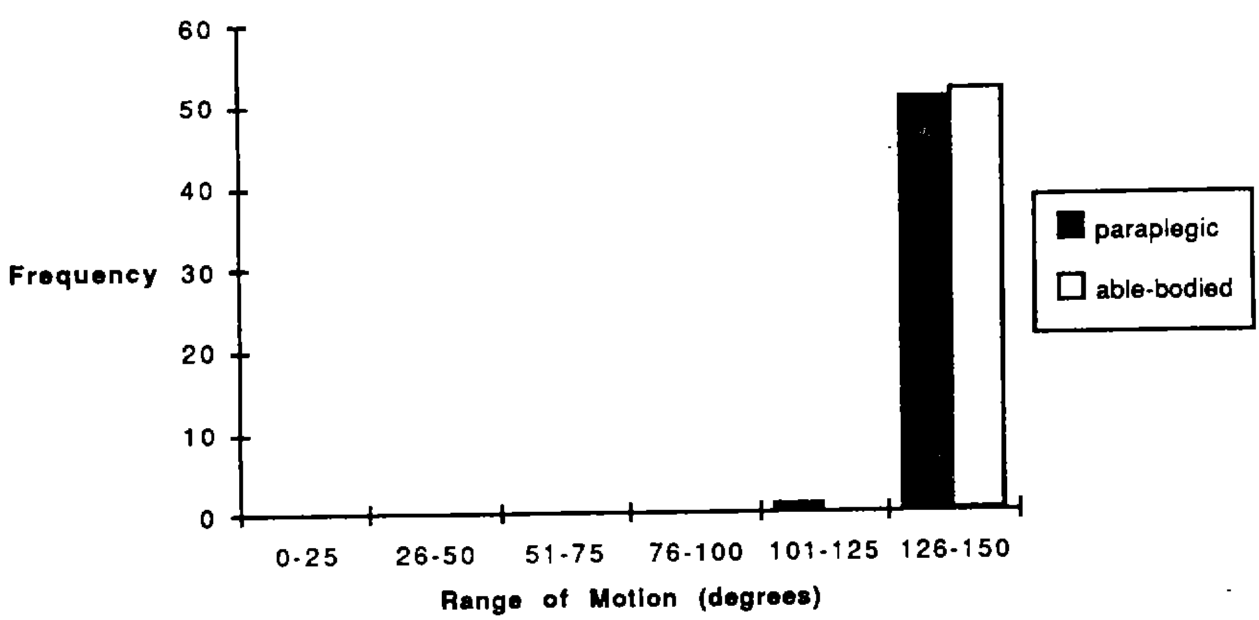


Table 3.29. Results of McNemar tests of whether or not reduced upper limb range of motion is associated with paraplegia (n=52 pairs).

Movement	Paraplegics with Limited AROM	Able-bodied with Limited AROM	P-value
D.* Shoulder flexion	3	2	1.000
N. Shoulder flexion	4	3	1.000
D. Shoulder abduction	4	5	1.000
N. Shoulder abduction	3	5	.73
D. Shoulder internal rotation	17	6	.01 S
N. Shoulder internal rotation	15	1	.0005 S
D. Shoulder external rotation	4	1	.38
N. Shoulder external rotation	11	1	.006 S
D. Elbow flexion	1	0	1.000
N. Elbow flexion	1	0	1.000

* D= dominant; N= non-dominant

3.3.2. The Effect of Age on Shoulder and Elbow Active Range of Motion

When the effect of age on shoulder and elbow AROM was examined using the McNemar test of association with the data from paraplegic and able-bodied persons aged less than 45 years (Table 3.30) versus those aged 45 years or more (Table 3.31), few differences emerged. In the younger group, reduced AROM was statistically significant in its association with paraplegia for non-dominant shoulder internal (p=.02) and external (p=.03) rotation. In those aged 45 years or older (Table 3.31), only reduced non-dominant shoulder internal rotation AROM was associated more with the paraplegic than able-bodied subjects of the same age (p=.04).

Table 3.30. Results of McNemar test of whether or not reduced upper limb range of motion is associated with paraplegic or able-bodied persons aged less than 45 years (n=28 pairs).

Movement	Young Paraplegics with Limited AROM	Young Able-bodied with Limited AROM	P-value
D.* Shoulder flexion	2	0	.50
N. Shoulder flexion	3	1	.63
D. Shoulder abduction	2	2	1.00
N. Shoulder abduction	2	3	1.00
D. Shoulder internal rotation	6	1	.06
N. Shoulder internal rotation	7	0	.02 S
D. Shoulder external rotation	2	0	.50
N. Shoulder external rotation	6	0	.03 S
D. Elbow flexion	0	0	All Normal
N. Elbow flexion	0	0	All Normal

* D= dominant; N.= non-dominant S = significant at the .05 level

Table 3.31. Results of McNemar test of whether or not reduced upper limb range of motion is associated with paraplegic or able-bodied persons aged 45 years or more (n=24 pairs).

Movement	Old Paraplegics with Limited AROM	Old Able-bodied with Limited AROM	P-value
D.* Shoulder flexion	1	2	1.00
N. Shoulder flexion	1	2	1.00
D. Shoulder abduction	2	3	1.00
N. Shoulder abduction	1	2	1.00
D. Shoulder internal rotation	11	5	.15
N. Shoulder internal rotation	8	1	.04 S
D. Shoulder external rotation	2	1	1.00
N. Shoulder external rotation	5	1	.22
D. Elbow flexion	1	0	1.00
N. Elbow flexion	1	0	1.00

* D= dominant; N.= non-dominant

The Fisher's Exact test for small expected frequencies was used to test whether or not reduced AROM was associated with age in paraplegic or able-bodied persons. The results are shown in Tables 3.32 and 3.33, respectively. No statistically significant associations were found between reduced upper limb active range of motion and age in either paraplegic or able-bodied subjects.

Table 3.32. Results of Fisher's Exact test (1-tailed) of whether or not reduced upper limb range of motion is associated with age in paraplegia (n=52).

Movement	Aged <45 years with Limited AROM (n=28)	Aged ≥45 years with Limited AROM (n=24)	P-value
D.* Shoulder flexion	2	1	.56
N. Shoulder flexion	3	1	.37
D. Shoulder abduction	2	2	.63
N. Shoulder abduction	2	1	.56
D. Shoulder internal rotation	6	11	.05
N. Shoulder internal rotation	7	8	.36
D. Shoulder external rotation	2	2	.63
N. Shoulder external rotation	6	5	.62
D. Elbow flexion	0	1	.46
N. Elbow flexion	0	1	.46

* D= dominant; N.= non-dominant

Table 3.33. Results of Fisher's Exact test (1-tailed) of whether or not reduced upper limb range of motion is associated with age in able-bodied persons (n=52).

Movement	Aged <45 years with Limited AROM (n=28)	Aged ≥45 years with Limited AROM (n=24)	P-value
D.* Shoulder flexion	0	2	.33
N. Shoulder flexion	1	2	.47
D. Shoulder abduction	2	3	.46
N. Shoulder abduction	3	2	.54
D. Shoulder internal rotation	1	5	.08
N. Shoulder internal rotation	0	1	.48
D. Shoulder external rotation	0	1	.48
N. Shoulder external rotation	0	1	.48
D. Elbow flexion	0	0	All Normal
N. Elbow flexion	0	0	All Normal

* D= dominant; N.= non-dominant

The effect of age on upper limb AROM in paraplegics, exclusive of duration of SCI, was examined using nine pairs of young and old subjects with paraplegia who differed in age by at least 12 years (range of differences = 12-35 years), but who were matched for duration of SCI, lesion level, and activity-level (Table 3.34). There appeared to be an association between reduced internal shoulder rotation AROM and older age. This association was checked using the McNemar test and found to be statistically significant for the non-dominant limb ($p < .05$). These results show that subjects with paraplegia who are over the age of 45 years, exclusive of their duration of SCI, are more likely to have reduced internal rotation range of motion in the non-dominant shoulder.

Table 3.34. Range of motion scores of duration of SCI, lesion level, and activity-level matched-pairs of young* and old** aged paraplegics (n=9 pairs).

Movement	Paired Scores***	Summary of Pairs' Reduced AROM Scores				
		Neither	Young only	Old only	Both	
Dominant Shoulder Flexion	++ ++ ++ ++ ++ ++ ++ ++ ++	9	0	0	0	
Non-dominant Shoulder Flexion	++ ++ ++ ++ ++ ++ ++ ++ ++	9	0	0	0	
Dominant Shoulder Abduction	++ ++ ++ ++ ++ ++ ++ +- ++	8	0	1	0	
Non-dominant Shoulder Abduction	++ ++ ++ ++ ++ ++ ++ ++ ++	9	0	0	0	
Dominant Internal Rotation	++ +- -- +- ++ +- -+ +- --	2	1	4	0	
Non-dominant Internal Rotation	++ +- +- +- ++ +- -- ++ ++	4	0	4	1	S
Dominant External Rotation	++ ++ -+ ++ ++ ++ ++ ++ ++	8	1	0	0	
Non-dominant External Rotation	++ ++ -- ++ ++ ++ +- ++ ++	7	0	1	1	
Dominant Elbow Flexion	++ ++ ++ ++ ++ ++ ++ ++ ++	9	0	0	0	
Non-dominant Elbow Flexion	++ ++ ++ ++ ++ ++ ++ ++ ++	9	0	0	0	

* Young age = aged less than 45 years. ** Old age = aged 45 years or more.
S =significant at the .05 level.
*** ++ = young and old aged paraplegics had normal AROM.
+- = young paraplegic had normal AROM & old paraplegic had reduced AROM.
-+ = young paraplegic had reduced AROM & old paraplegic had normal AROM.
-- = young and old aged paraplegics had reduced AROM.

3.3.3. The Effect of Duration of Paraplegia on Upper Limb Active Range of Motion

The effect of duration of spinal cord injury on shoulder and elbow active range of motion was examined first using the Fisher's Exact test to compare the AROM scores of subjects who had had paraplegia for less than 15 years (short duration SCI) with subjects who had been injured for 15 years or longer (long duration SCI). The results are shown in Table 3.35. While age is known to correlate with duration of injury in this sample (r=.68), the results in Table 3.35 can be compared with those in Table 3.32 to see if there were noticeable differences in the results when the independent variable was changed from age to duration of SCI. Statistical significance was not achieved for any of the movements tested for an association of reduced AROM with either age or with duration of injury.

Table 3.35. Results of Fisher's Exact tests of whether or not reduced upper limb range of motion is associated with duration of injury in paraplegia (n=52).

Movement	Injured <15 Years (n=20) and now has Limited AROM	Injured ≥15 Years (n=32) and now has Limited AROM	P-value
D.* Shoulder flexion	1	2	.67
N. Shoulder flexion	2	2	.50
D. Shoulder abduction	2	2	.50
N. Shoulder abduction	1	2	.67
D. Shoulder internal rotation	8	9	.28
N. Shoulder internal rotation	5	10	.44
D. Shoulder external rotation	1	3	.49
N. Shoulder external rotation	4	7	.58
D. Elbow flexion	1	0	.39
N. Elbow flexion	1	0	.39

* D= dominant; N.= non-dominant

In order to exclude the possible influence of age when examining the effect of duration of SCI on range of motion, as many pairs of paraplegic subjects as possible who differed in duration of SCI by at least 10 years, were matched for age, lesion level, and activity-level. Their AROM scores were then tabulated and visual analysis and McNemar tests were used to evaluate any possible trends in reduced AROM with duration of SCI. The tabulations are presented in Table 3.36. The sample size was small (n= 7 pairs), and in no one test did the number of pairs where the long rather than short duration of SCI subject having reduced AROM exceed the other by more than one. McNemar tests of association of reduced AROM and duration of SCI were not significant.

Table 3.36 Range of motion scores of age, lesion level, and activity-level matched-pairs of short* and long** duration paraplegics (n=7 pairs).

Movement	Paired Scores***	Summary of Pairs' Reduced AROM Scores: Neither	Short only	Long only	Both
Dominant Shoulder Flexion	++ ++ +- ++ ++ ++ ++	6	0	1	0
Non-dominant Shoulder Flexion	++ ++ +- ++ ++ ++ ++	6	0	1	0
Dominant Shoulder Abduction	++ ++ +- ++ ++ ++ ++	6	0	1	0
Non-dominant Shoulder Abduction	++ ++ +- ++ ++ ++ ++	6	0	1	0
Dominant Internal Rotation	-- -+ ++ ++ -- ++ +-	3	1	1	2
Non-dominant Internal Rotation	-- -+ ++ ++ ++ -+ +-	3	2	1	1
Dominant External Rotation	++ ++ ++ ++ +- -+ ++	5	1	1	0
Non-dominant External Rotation	++ ++ ++ ++ +- -+ ++	5	1	1	0
Dominant Elbow Flexion	++ ++ ++ ++ ++ ++ ++	7	0	0	0
Non-dominant Elbow Flexion	++ ++ ++ ++ ++ ++ ++	7	0	0	0

* Short duration = injured less than 15 years. ** Long duration = injured 15 years or longer.

*** ++ = short and long duration paraplegics had normal AROM.

+- = short duration paraplegic had normal AROM & long duration paraplegic had reduced AROM.

-+ = short duration paraplegic had reduced AROM & long duration paraplegic had normal AROM.

-- = short and long duration paraplegics had reduced AROM.

3.4. Upper Limb Pain

This section reports the results of the Upper Limb Pain Screening Assessment, the Upper Limb Pain Interview, and the questionnaire on the Impact of Upper Limb Pain on the Performance of Activities of Daily Living.

3.4.1. Upper Limb Pain Screening Assessment Results

a) Comparison of Outcomes on the Pain Screening Assessment between the Subjects with Paraplegia and the Able-bodied Subjects

Figures 3.18 and 3.19 contain bar graphs that illustrate and compare, between the paraplegic and able-bodied samples, the prevalences of pain on the pain screening assessment items that were related to the shoulder and elbow regions. More paraplegic than able-bodied subjects scored positive for pain on all of the test items. The most noticeable differences in prevalence between the two groups were, in order of the magnitude of the difference:

1. dominant supraspinatus pain (paraplegic subjects 21% positive: able-bodied 2% positive),

2. neck pain (paraplegic subjects 35% positive: able-bodied 19% positive),

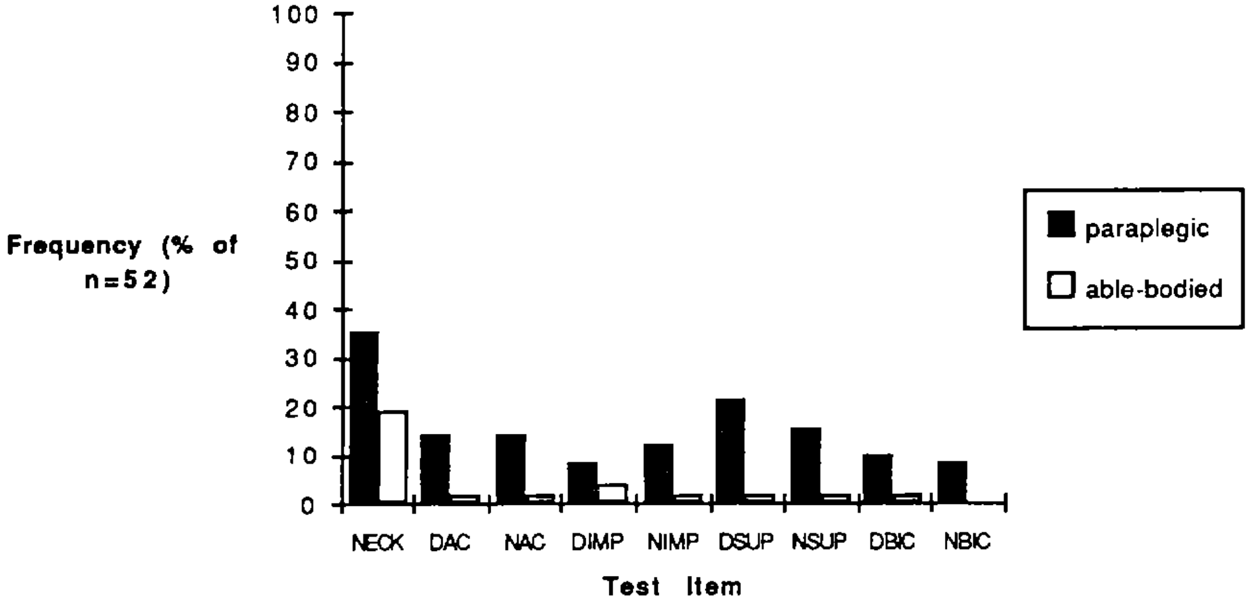
3. non-dominant medial epicondyle pain (paraplegic subjects 15% positive: able-bodied 0% positive),

4. non-dominant supraspinatus pain (paraplegic subjects 15% positive: able-bodied 2% positive), and

5. dominant medial epicondyle pain (paraplegic subjects 14% positive: able-bodied 0% positive). The most similar prevalences between the two groups were found for dominant lateral epicondyle pain (paraplegic subjects 17% positive: able-bodied 15% positive) and dominant impingement pain (paraplegic subjects 8% positive: able-bodied 3% positive).

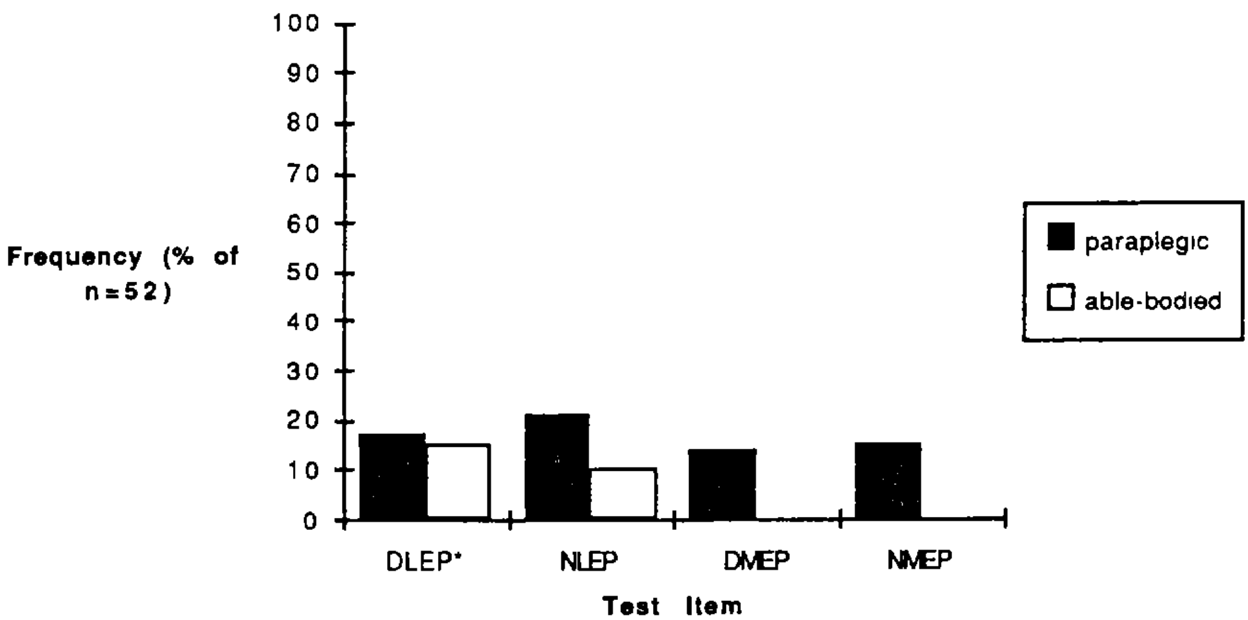
The McNemar test for paired data was then used to test whether or not pain on any of the upper limb pain screening assessment items was more associated with able-bodied subjects or subjects with paraplegia. The test was performed on the entire sample using 52 pairs (Table 3.37). The results revealed statistically significant associations for 4 out of 13 assessment items. Review of the raw data revealed that paraplegia was associated with positive scores on the tests for dominant ($p=.01$) and non-dominant ($p=.04$) supraspinatus tendon pain, and dominant ($p=.02$) and non-dominant ($p=.008$) medial epicondyle pain.

Figure 3.18: Comparison of the paraplegic (n=52) and able-bodied (n=52) groups' prevalences of shoulder region pain on the Pain Screening Assessment.



* DAC/NAC = dominant/non-dominant acromioclavicular pain; DIMP/NIMP = dominant/non-dominant impingement pain; DSUP/NSUP = dominant/non-dominant supraspinatus pain; DBIC/NBIC = dominant/non-dominant bicipital tendon pain.

Figure 3.19: Comparison of the paraplegic (n=52) and able-bodied (n=52) groups' prevalences of elbow region pain on the Pain Screening Assessment.



* DLEP/NLEP = dominant/non-dominant lateral epicondyle pain; DMEP/NMEP = dominant/non-dominant medial epicondyle pain.

Table 3.37 McNemar tests of whether or not positive signs on the Pain Screening Assessment were associated with paraplegic or able-bodied subjects (n=52 pairs).

Location	Paired Results Paraplegic only with Pain	 Able-bodied only with Pain	P-value	
Neck	15	7	.13	
D.**Acromio-clavicular	7	1	.07	
N. Acromio-clavicular	7	1	.07	
D. Impingement	4	1	.38	
N. Impingement	6	1	.13	
D. Supraspinatus	10	1	.01	S (P)
N. Supraspinatus	8	1	.04	S (P)
D. Bicipital tendon	5	1	.22	
N. Bicipital tendon	4	0	.13	
D. Lateral epicondyle	7	7	1.00	
N. Lateral epicondyle	10	4	.18	
D. Medial epicondyle	7	0	.02	S (P)
N. Medial epicondyle	8	0	.01	S (P)

*(P) or (A)= pain associated with paraplegia or able-bodied
**D=dominant arm; N=non-dominant arm.
S=significant at the .05 level

b) The Effect of Age on the Pain Screening Assessment Outcomes

In order to examine whether or not the association between pain on the screening assessment in either of the samples was different in younger or older persons, the McNemar test was performed between the paraplegic and able-bodied pairs aged less than 45 years (Table 3.38), and again between those aged 45 years or more (Table 3.39).

Table 3.38 lists the results of the McNemar tests that were conducted on the pain screening assessment scores of the pairs aged less than 45 years. Statistically significant associations were found for dominant acromioclavicular pain (p=.03), and for non-dominant medial epicondyle pain (p=.02). Review of the data indicated that the associations lay in the direction of paraplegia. In those pairs aged 45 years or more (Table 3.39), dominant supraspinatus tendon pain was significantly associated with one group (p=.03), which the data showed to be those subjects with paraplegia.

The Fisher's Exact test of association (1 tailed) for 2x2 contingency tables with small expected frequencies was then used to test whether or not positive results on the upper limb pain screening assessment items were associated with age group in either the paraplegic (Table 3.40) or able-bodied samples (Table 3.41). Statistically significant associations were not found between any item and age group in the able-bodied sample. In the sample with paraplegia, non-dominant medial epicondyle pain was shown to be associated with the young age group (p=.04).

In order to exclude the possible effects of duration of SCI when examining the influence of age on screening assessment pain, the data from nine pairs of subjects with paraplegia, who were matched for duration of SCI, lesion-level, and activity-level, but who differed in age by at least 12 years (range of the differences = 12-35 years), was tabulated and studied for trends in pain scores (Table 3.42). For individual items, pain was not significantly associated with age (McNemar test). Examination of the overall sum of the number of pairs where only one subject had pain showed that, of 117 instances (13 items x 9 pairs), in 13 instances the young subjects had pain and the old subject did not, while in 11 instances the old paraplegic had pain while the young, but same duration subject did not. This overall sum was not subjected to significance testing due to possible lack of independence between the items. However, the sums, plus the non-significant results of the McNemar tests, suggest that, with duration of SCI excluded, there was no trend from young to old age in paraplegia, in the prevalence of upper limb pain on the screening assessment.

In summary, supraspinatus tendon pain and medial epicondyle pain were associated with the paraplegia. When the paraplegic - able-bodied pairs were subdivided by age group, statistically significant associations were found for 2 out of 13 items in the group aged less than 45 years, and 1 out of 13 items in the group aged 45 years or more. This suggests that there was a slight tendency for the young subjects with paraplegia to have more painful locations in the upper limb than the young able-bodied subjects. And, it suggests that in the older pairs the prevalences of pain between the paraplegic and able-bodied samples were more similar. Pain was not associated with age group for any of the screening assessment items in the able-bodied sample. Only medial epicondyle pain was associated with age group (young) in the parapelgic subjects. When duration of injury was excluded, paraplegic age was not shown to affect the prevalence of pain on the upper limb pain screening assessment.

Table 3.38. Test of whether or not positive signs on the pain screening assessment were associated with paraplegic or able-bodied subjects younger than 45 years (n=28 pairs). (McNemar test).

Location	Paired Results Paraplegic only with Pain	 Able-bodied only with Pain	P-value	
Neck	7	2	.18	
D.**Acromio-clavicular	6	0	.03	S (P)
N. Acromio-clavicular	5	1	.22	
D. Impingement	3	1	.63	
N. Impingement	5	1	.22	
D. Supraspinatus	4	1	.38	
N. Supraspinatus	6	1	.13	
D. Bicipital tendon	2	1	1.00	
N. Bicipital tendon	2	0	.50	
D. Lateral epicondyle	5	5	1.00	
N. Lateral epicondyle	6	3	.51	
D. Medial epicondyle	5	0	.06	
N. Medial epicondyle	7	0	.02	S (P)

q(P) or (A)=pain associated with paraplegic or able-bodied
*D=dominant arm; N=non-dominant arm.

Table 3.39. Test of whether or not positive signs on the pain screening assessment were associated with paraplegic or able-bodied subjects 45 years or older (n=24 pairs); (McNemar test).

Location	Paired Results: Paraplegic only with Pain	Able-bodied only with Pain	P-value
Neck	8	5	.58
D.**Acromio-clavicular	1	1	1.00
N. Acromio-clavicular	2	0	.50
D. Impingement	1	0	1.00
N. Impingement	1	0	1.00
D. Supraspinatus	6	0	.03 S (P)*
N. Supraspinatus	2	0	.50
D. Bicipital tendon	3	0	.25
N. Bicipital tendon	2	0	.50
D. Lateral epicondyle	2	2	1.00
N. Lateral epicondyle	4	1	.38
D. Medial epicondyle	2	0	.50
N. Medial epicondyle	1	0	1.00

**D=dominant arm; N=non-dominant arm.
*(P) = pain associated with paraplegic subjects.
S = significant at the .05 level.

Table 3.40. Test of whether or not positive signs on the pain screening assessment were associated with age in the paraplegic sample (n=52); (Fisher's Exact test 1-tailed).

Location	Age Less Than 45 Years (n=28) & Positive	Age 45 Years or More (n=24) & Positive	P-value	
Neck	9	9	.45	
D.* Acromio-clavicular	6	1	.08	
N. Acromio-clavicular	5	2	.28	
D. Impingement	3	1	.37	
N. Impingement	5	1	.13	
D. Supraspinatus	4	7	.17	
N. Supraspinatus	6	2	.18	
D. Bicipital tendon	2	3	.43	
N. Bicipital tendon	2	2	.63	
D. Lateral epicondyle	5	4	.60	
N. Lateral epicondyle	6	5	.62	
D. Medial epicondyle	5	2	.28	
N. Medial epicondyle	7	1	.04	S

D=dominant arm; N=non-dominant arm.
S=significant at .05 level

Table 3.41. Test of whether or not positive signs on the Pain Screening Assessment were associated with age in the able-bodied sample (n=52); (Fisher's Exact test 1 tailed).

Location	Age Less Than 45 Years (n=28) & Positive	Age 45 Years or Older (n=24) & Positive	P-value
Neck	3	7	.12
D.* Acromio-clavicular	0	1	.48
N. Acromio-clavicular	1	0	.52
D. Impingement	1	1	.74
N. Impingement	1	0	.52
D. Supraspinatus	1	0	.52
N. Supraspinatus	1	0	.52
D. Bicipital tendon	1	0	.52
N. Bicipital tendon	0	0	--
D. Lateral epicondyle	5	3	.39
N. Lateral epicondyle	3	2	.54
D. Medial epicondyle	0	0	--
N. Medial epicondyle	0	0	--

D=dominant arm; N=non-dominant arm.

Table 3.42. Pain Screening Assessment scores of matched pairs (n=9) of young (age <45 years) and old (age $\geq$45 years) subjects with paraplegia.

Location	Paired Scores*	Summary of Pairs' Pain Scores			
		Neither	Young only	Old only	Both
Neck	-+ -- ++ +- -- -+ -+ ++ +-	2	2	3	2
D.** Acromioclavicular	-- -- -- -- -- -- -- -- --	9	0	0	0
N. Acromioclavicular	++ -- -- -- -- -- -- -- +-	7	1	0	1
D. Impingement	-- -- +- -- -- -- -- -- --	8	1	0	0
N. Impingement	-- -- -- -- -- -- -- -- --	9	0	0	0
D. Supraspinatus	-+ -- -- -- -- -- -- -+ ++	6	0	2	1
N. Supraspinatus	+- -- -+ -- -- -- +- -- +-	5	3	1	0
D. Bicipital tendon	-- -- -- -- -- -- -- -- --	9	0	0	0
N. Bicipital tendon	-- -- -- -+ -- -- -- -- --	8	0	1	0
D. Lateral epicondyle	-- -- +- -- -- -- +- -- -+	5	2	1	0
N. Lateral epicondyle	-- -+ -- +- -- -- -- -- --	6	1	1	0
D. Medial epicondyle	-- -- -- -- -- -+ +- -+ --	5	1	2	0
N. Medial epicondyle	-- -- +- +- -- -- -- -- --	6	2	0	0

* ++ = short and long duration paraplegics had pain
+- = short duration paraplegic had pain & long duration paraplegic had no pain
-+ = short duration paraplegic had no pain & long duration paraplegic had pain
-- = short and long duration paraplegics had no pain
** D = dominant; N = non-dominant

c) The Effect of Duration of SCI on Pain Screening Assessment Outcomes

The results of Fishers' Exact tests for each screening assessment item, between pain prevalence and short duration (less than 15 years) or long duration (15 years or more) of spinal cord injury (Table 3.43), revealed no statistically significant associations. In order to exclude the possible effects of age when examining the influence of duration of SCI on screening test pain, the data from seven pairs of age, lesion-level, and activity-level matched subjects, who differed in duration of SCI by at least 10 years, was tabulated and studied for trends in pain scores (Table 3.44). When the McNemar test was used on each item, no significant associations were found between pain and duration of SCI on any one item. However the sample size was small. Inspection of the number of pairs where only one subject had pain showed that, of 91 instances (13 items x 7 pairs), in 6 instances the short term subject had pain and the long term subject did not, while in 21 instances the long term subject had pain while the same aged short term subject did not. Tests were not conducted for the significance of this overall sum of the paired scores on all items due to lack of independence between the items. However, it suggests, that with a larger sample, paired to exclude age, there may be a slightly greater tendency for upper limb pain to be present on the pain screening assessment, in subjects with paraplegia of 15 years or more duration.

Table 3.43. Tests of association of duration of spinal cord injury and pain on the Pain Screening Assessment.

Location	Injured Less Than 15 Years (n=20) & Had Pain	Injured 15 Years or More (n=32) & Had Pain	P-value
Neck	6	12	.40
D.* Acromio-clavicular	3	4	.55
N. Acromio-clavicular	3	4	.55
D. Impingement	1	3	.49
N. Impingement	3	3	.42
D. Supraspinatus	3	8	.31
N. Supraspinatus	3	5	.64
D. Bicipital tendon	1	4	.35
N. Bicipital tendon	1	3	.49
D. Lateral epicondyle	3	6	.52
N. Lateral epicondyle	5	6	.42
w			
D. Medial epicondyle	2	5	.45
N. Medial epicondyle	4	4	.36

D=dominant arm; N=non-dominant arm.

Table 3.44. Pain Screening Assessment scores of matched pairs (n=7) of short (<15 years) and long ($\geq$15 years) duration paraplegia.

Location	Paired Scores*	Summary of Pairs' Pain Scores			
		Neither	Short[1] only	Long[2] only	Both
Neck	-- -- -- -- -- -- --	7	0	0	0
D.** Acromioclavicular	-- +- ++ -- -+ -- +-	3	2	1	1
N. Acromioclavicular	-- -+ -+ -- -- -- --	5	0	2	0
D. Impingement	-- -- -+ -- -+ -- --	5	0	2	0
N. Impingement	-- -- -+ -- -- -- --	6	0	1	0
D. Supraspinatus	-+ -- -+ -+ -- -- +-	3	1	3	0
N. Supraspinatus	-- -+ -+ -- -- -- -+	4	0	3	0
D. Bicipital tendon	-- -+ -+ -- -- -- --	5	0	2	0
N. Bicipital tendon	-- -+ -+ -- -- -- --	5	0	2	0
D. Lateral epicondyle	-- -- ++ +- ++ -- -+	3	1	1	2
N. Lateral epicondyle	+- +- ++ ++ -- -- --	3	2	0	2
D. Medial epicondyle	-- -+ -+ -- -- -- -+	4	0	3	0
N. Medial epicondyle	-- -- -- -- -+ -- --	6	0	1	0

[1] = duration of SCI <15 yrs. [2] = duration of SCI $\geq$15 yrs. * ++ = short and long duration paraplegics had pain

+- = short duration paraplegic had pain & long duration paraplegic had no pain

-+ = short duration paraplegic had no pain & long duration paraplegic had pain

-- = short and long duration paraplegics had no pain ** D = dominant; N = non-dominant

3.4.2. Upper Limb Pain Interview Results

a) Prevalences of Reported Upper Limb Pain in the Paraplegic and Able-bodied Samples

The prevalences of upper limb pain in the shoulder, elbow, and wrist/hand regions for the paraplegic and able-bodied samples were compiled from the interview data and compared using bar graphs and McNemar tests of association.

Figures 3.20 and 3.21 are bar graphs illustrating and comparing the paraplegic and able-bodied subjects' reported prevalence of upper limb pain by anatomical location in the week prior to the interview (Figure 3.20), and in the previous six months, but not including the week prior to the interview (Figure 3.21). The graphs reveal that the subjects with paraplegia had higher reported prevalences of pain than did the able-bodied subjects, for both time periods and for all three anatomical locations.

For the spinal cord injured subjects, the shoulder (39%) and wrist/hand (40%) were the most frequently reported sites of upper limb pain in the past week, followed by the elbow region (31%). It is important to note that this data was collected by subject report, and anatomical locations of pain were recorded as described by the subject. Therefore, for example, pain that was elicited by wrist extension, but was felt over the lateral epicondyle, was recorded as elbow pain. The able-bodied subjects also reported upper limb pain in the past week most often in the wrist/hand and shoulder regions, but the prevalences were lower (shoulder 8%; wrist/hand 8%) than those of the paraplegic sample. No able-bodied subjects reported pain in the elbow region in the past week. Upper limb pain in the past six months was reported most often by the paraplegic subjects in the wrist/hand (60%) and shoulder (58%), and less often in the elbow (39%). In contrast, 14% of the able-bodied subjects reported shoulder pain in the past six months; 13% reported elbow pain; and 9% reported wrist/hand pain in the same time period.

Tests of association between upper limb pain and the paraplegic or able-bodied subjects (Table 3.45) revealed statistically significant associations for reports of pain in the past week at the shoulder ($P<.001$), elbow ($P<.001$), and wrist/hand ($P<.001$). A review of the data revealed the associations to be with paraplegia. Pain in the past six months at the shoulder ($P<.001$) and wrist/hand ($P<.001$) was associated with the paraplegia as well. However, neither sample was more likely to report pain at the elbow during this time period.

Figure 3.20: Comparison of the number of paraplegic (n=52) and able-bodied (n=52) subjects who reported upper limb pain in the past week.

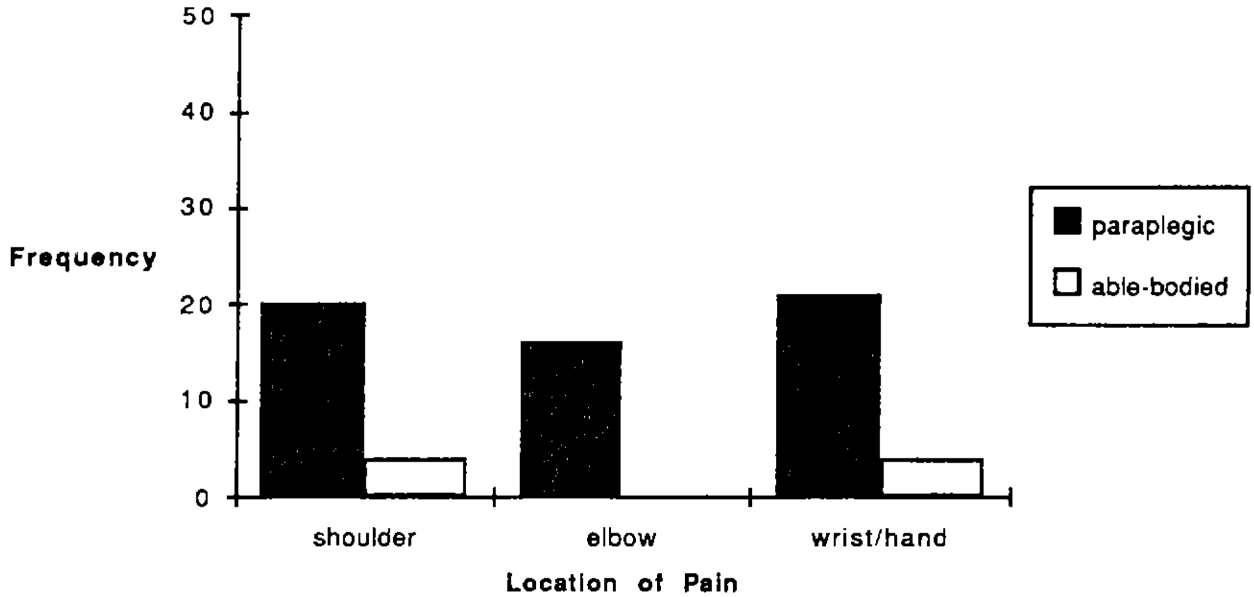


Figure 3.21: Comparison of the number of paraplegic (n=52) and able-bodied (n=52) subjects who reported upper limb pain during the previous six months.

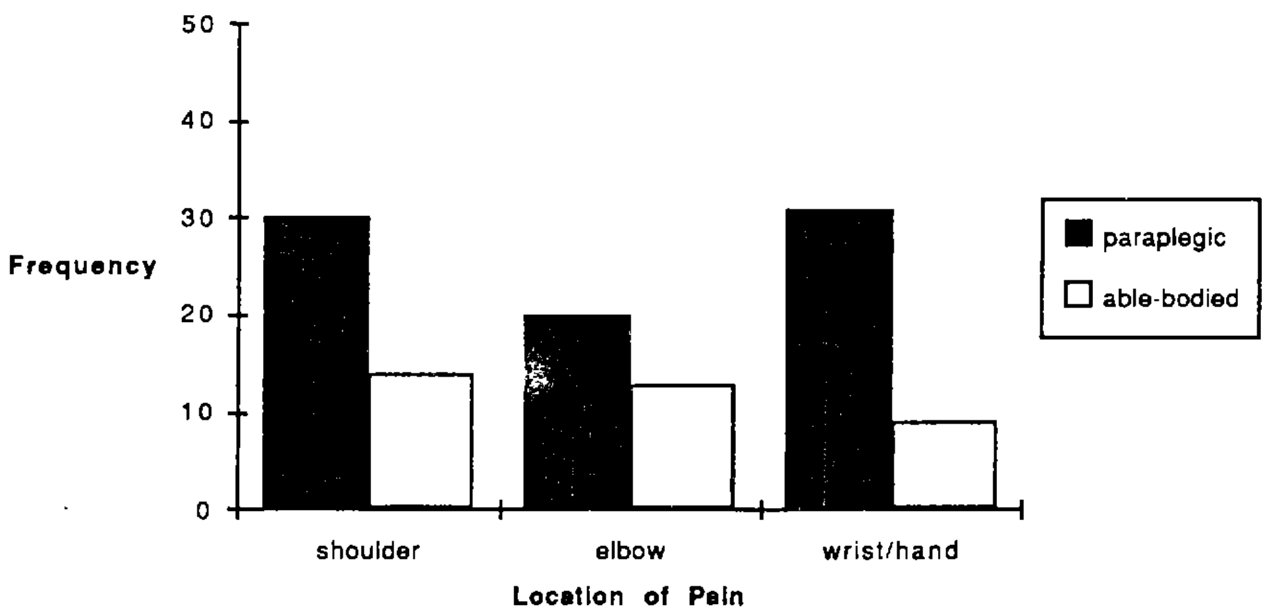


Table 3.45 Tests of association between reports of upper limb pain and paraplegic or able-bodied subjects (n=52 pairs).

Location and Time of Pain	Percent of Paraplegics (n=52) with Pain	Percent of Able-bodied (n=52) with Pain	P-value
Shoulder			
Pain in the past week	39%	8%	<.001 *S
Pain in the past 6 months	58%	27%	<.001 S
Elbow			
Pain in the last week	31%	0%	<.001 S
Pain in the past 6 months	39%	25%	>.05
Wrist/hand			
Pain in the last week	40%	8%	<.001 S
Pain in the past 6 months	60%	17%	<.001 S

*S = significant at the .05 level.

b) The Effect of Age on Reports of Upper Limb Pain

The McNemar test results listed in Table 3.46 shows that in the pairs aged less than 45 years, statistically significant associations were found for pain in the past week in the shoulder, elbow, and wrist/hand regions. Also in the young age group pairs, significant associations were found for pain in the past six months in the shoulder and wrist/hand regions. A review of the data revealed all associations to be with paraplegia. In contrast, in the older pairs, shoulder pain in either the last week or last six months was no more associated with persons with paraplegia or able-bodied persons. This was also true for elbow pain in the past six months. However, elbow pain in the past week and pain in the wrist/hand regions during both time periods did generate statistically significant associations. A review of the data revealed that the pain in these regions was associated with paraplegia.

Reports of pain in the past week at the shoulder, elbow, or wrist/hand, were not associated with young or old age in either the paraplegic or able-bodied groups (Table 3.47). This was also true for pain at these locations in the past six months (Table 3.47).

The effect of age on reports of upper limb pain were studied using duration of SCI-matched pairs in order to exclude any influence of duration of paraplegia (Table 3.48). McNemar tests revealed no significant results for an association between age group (with duration of SCI excluded) and pain at any of the joints during either time period. Tests were not conducted for the significance of the overall sum of the paired scores on all items due to lack of independence between the items. However, the sum of all pairs where only one subject reported pain did confirm the McNemar results. Pain in the past week at the shoulder, elbow, and/or wrist/hand was reported by the young subject only in 5 pairs, and by the old subject only in 7 pairs (total possible = 9 pairs x 3 joints = 27). The sum of the paired scores for pain in the past six months showed that pain was reported by the young subject only in 4 pairs and by the old subject only in 6 pairs (total possible = 27).

In summary, reports of pain in the past week or past six months at the shoulder, elbow, or wrist/hand were not associated with the young or old age groups in either the paraplegic or able-bodied samples. Chronological age, with duration of spinal cord injury excluded, did not appear to predispose the subjects with paraplegia to the development of upper limb pain. In subjects aged less than 45 years, those who had paraplegia were more likely than able-bodied subjects, to report pain in the past week and past six months at the shoulder and wrist/hand, and elbow pain in the past week. In those pairs aged 45 years or more, only wrist/hand pain in both time periods and elbow pain in the past week, were associated more with the spinal cord injured subjects than with the able-bodied subjects.

Table 3.46. Tests of association between reports of pain and paraplegic or able-bodied subjects, in young (n=28 pairs) and old age (n=24 pairs).

Location of Pain	Pairs* Aged <45 Years		Pairs Aged ≥45 Years	
	**Pain in Past Week	Pain in Past 6 Mos.	Pain in Past Week	Pain in Past 6 Mos.
Shoulder	<.01 S	<.01 S	>.05	>.05
Elbow	<.01 S	>.05	<.02 S	>.05
Wrist/Hand	<.01 S	<.01 S	<.01 S	<.01 S

* Pairs= paraplegic and able-bodied subjects matched by gender, age, and activity-level.

** P values

Table 3.47. Tests of association between reports of upper limb pain and young or old age groups, in paraplegic and able-bodied samples (Chi-squared test).

Location of Pain	Pain in the Past Week		Pain in the Past Six Months	
	*Associated with Age in Paraplegia	Associated with Age in Able-bodied	Associated with Age in Paraplegia	Associated with Age in Able-bodied
Shoulder	>.9	>.5	>.25	>.25
Elbow	>.5	None with Pain	>.5	>.1
Wrist/Hand	>.25	>.25	>.1	>.5

*p-value

Table 3.48. Comparison of upper limb pain reports between duration, lesion-level, and activity-level matched young (<45 Years) and old ($\geq$45 Years) aged paraplegics (n=9 pairs).

Location and Time of Pain	*Paired Pain Scores	Summary of Pairs' Reported Pain Scores			
		Neither	Young only	Old only	Both
Shoulder in past week	+- -- ++ -- -+ -- +- -- ++	4	2	1	2
Shoulder in past 6 months	++ -- ++ -- -+ -- +- -- ++	3	1	1	3
Elbow in past week	-+ -- +- +- -- -+ -+ -- --	4	2	3	0
Elbow in past 6 months	-+ -- +- +- -- -+ -+ -- --	4	2	3	0
Wrist/hand in past week	+- -- ++ -+ -+ -- -+ -- --	4	1	3	1
Wrist/hand in past 6 months	+- -- ++ ++ -+ -- ++ -+ ++	2	1	2	4

* ++ = young and old aged subjects with paraplegia had pain
+- = young paraplegic had pain & old aged paraplegic had no pain
-+ = young aged paraplegic had no pain & old aged paraplegic had pain
-- = young and long old aged subjects with paraplegia had no pain

c) The Effect of Duration of Spinal Cord Injury on Reports of Upper Limb Pain

Chi-squared tests were used to determine whether or not reports of upper limb pain in the past week or previous six months were associated with duration of SCI (Table 3.49). No statistically significant associations were found. In order to evaluate the effect of duration of SCI with any possible effects of age removed, as many paraplegic subjects as possible who differed in duration of SCI by at least 10 years, were matched for age, lesion-level, and upper limb activity-level. Their reports of upper limb pain were then tabulated and visual analysis and McNemar tests were used to evaluate any possible trends in reports of upper extremity pain with duration of SCI (Table 3.50). Tests were not conducted for the significance of the overall sum of the paired scores on all items due to lack of independence between the items. McNemar tests for each joint revealed a significant association ($p<.05$) between long duration of SCI and shoulder pain during both time periods. Tabulation of the paired scores suggested an association between long duration of SCI and elbow and wrist/hand pain, but these did not achieve significance. Further testing with larger paired samples is needed to confirm whether or not there is any association between duration of SCI (with age excluded) and elbow and wrist/hand pain.

Table 3.49. Tests of association between reports of upper limb pain and short term (<15 years) or long term (≥15 years) paraplegia (age included in analysis).

Location of Pain	Associated with Duration of Spinal Cord Injury	
	*Pain in the Past Week	Pain in the Past Six Months
Shoulder	>.1	>.9
Elbow	>.1	>.25
Wrist/Hand	>.9	>.75

*p-value

Table 3.50. Comparison of upper limb pain reports between age, lesion-level, and activity-level matched short (<15 years) and long (≥15 years) duration paraplegic subjects (n=7 pairs) (age excluded by pairing).

Location and Time of Pain	*Paired Pain Scores	Summary of Pairs' Reported Pain Scores				
		Neither	Short only	Long only	Both	
Shoulder in past week	-+ -+ -+ -- -+ -- -+	1	0	5	0	S
Shoulder in past 6 months	-+ -+ -+ -+ ++ -- -+	1	0	5	1	S
Elbow in past week	-+ ++ ++ -+ -+ -- +-	1	1	3	2	
Elbow in past 6 months	-+ ++ ++ -+ -+ -- +-	1	1	3	2	
Wrist/hand in past week	-+ -+ -- -- ++ -- --	4	0	2	1	
Wrist/hand in past 6 months	-+ -+ ++ -- ++ -+ ++	1	0	3	3	

* ++ = short and long duration paraplegic subjects had pain
+- = short duration paraplegic had pain & long duration paraplegic had no pain
-+ = short duration paraplegic had no pain & long duration paraplegic had pain
-- = short and long duration paraplegic subjects had no pain
S = significant at the .05 level

d) The Nature of the Upper Limb Pain Reported by the Paraplegic and Able-bodied Subjects

The remaining information collected using the Pain Interview Schedule was analyzed by joint region using frequency tabulations of responses and McNemar tests of association. The frequencies of the subjects' reported pain intensity ratings were compiled in bar graph format to aid intergroup comparisons. All of these results are presented, by joint region, in the following sections.

Pain Reported in the Shoulder Region

Table 3.51 summarizes the shoulder pain interview data and includes the results of McNemar tests for any associations between symptoms and either able-bodied subjects or those with paraplegia. As shown earlier, shoulder pain in the past week ($p<.001$) and previous six months ($p<.001$) was found to be significantly associated with paraplegic subjects more than with able-bodied persons of the same gender, age, and activity-level. Results of the analysis of responses related to the location of shoulder pain revealed no significant association between either group and reports of exclusively dominant limb shoulder pain. But the subjects with paraplegia were more likely than the able-bodied subjects to report non-dominant ($p<.005$) and bilateral ($p<.01$) shoulder pain. Complaints of shoulder pain in the joint, as opposed to in the muscular/non-joint region, were more associated with the paraplegic than able-bodied subjects ($p<.001$).

Examination of the responses related to frequency of shoulder pain revealed the subjects with paraplegia to be more likely to report daily ($p<.01$) shoulder pain than their able-bodied counterparts. Rare or intermittent shoulder pain was not significantly associated with one group more than the other. Shoulder pain intensity was more likely to be described as worst at night by the paraplegic sample than by the able-bodied group ($p<.005$), but no significant association was found between either group for pain described as worst during the day. Of the actions taken by the subjects to deal with the pain, seeking treatment ($p<.005$) and receipt of pain medication ($p<.03$) were associated more with the spinal cord injured subjects than with their matched able-bodied counterparts. Ten percent (10%) of the subject with paraplegia reported taking pain medication at the time of the interview, as opposed to none of the able-bodied subjects. The pain medication was not necessarily being consumed for shoulder pain.

Table 3.51. Summary of paraplegic and able-bodied subjects' pain interview responses regarding the shoulder, and results of McNemar tests of association.

Item	Percent[1] of Paraplegics (n=52) with Positive Response	Percent[1] of Able-bodied (n=52) with Positive Response	P-value	
Pain in last week	39%	8%	<.001	S*
Pain in last six months	58	27	<.001	S
LOCATION: Dominant limb	11.5	17	>.5	
Non-dominant limb	15	0	<.005	S
Bilateral	31	10	<.01	S
Joint	52	17	<.001	S
Muscular/non-joint	6	10	>.75	
FREQUENCY: Rare	10	4	>.25	
Intermittent	31	19	>.25	
Daily	17	4	<.01	S
INTENSITY: Worst at night	19	2	<.005	S
Worst during the day	35	21	>.1	
TREATMENT: Sought treatment	27	6	<.005	S
On pain medication now	10	0	<.025	S

[1] = percentages may not total 100 since for some items, subjects could select more than one answer, or no answer applied to them

*S= significant at the .05 level

Bar graphs illustrating and comparing paraplegic and able-bodied subjects' perceived intensity of shoulder pain experienced in the past week and in the past six months are shown in Figures 3.22 and 3.23 respectively. Figure 3.22 shows that 62% of the paraplegic sample and 92% of the able-bodied sample reported no pain in the shoulders in the week prior to the interview. Pain at an intensity of 1 out of 10 to 3 out of 10 was reported by 11% of the paraplegic subjects and by 6% of the able-bodied subjects. Shoulder pain at an intensity of 4 out of 10 to 6 out of 10 was indicated by 23% of the subjects with paraplegia and by 4% of the able-bodied subjects. No able-bodied persons rated their shoulder pain in the past week as above 6 out of 10, and 4% of the paraplegic subjects reported their shoulder pain at an 8 out of 10 intensity for the same time period.

Figure 3.23 presents the results of subjects' ratings of the intensity of any shoulder pain that they had experienced in the past six months, excluding shoulder pain in the past week. Of the paraplegic subjects (58%) and able-bodied subjects (27%) who indicated that they had had shoulder pain in the past six months, the majority in both groups classified this pain as being of moderate intensity (paraplegia 35%; able-bodied 20%). Fifteen percent (15%) of the paraplegic subjects and 8% of the able-bodied subjects with pain described the intensity as mild. Shoulder pain in the past six months was rated as severe by 8% of the paraplegics but no able-bodied subjects reported having had pain at this intensity.

Figure 3.22: Distribution of the NRS scores for shoulder pain experienced in the past week.

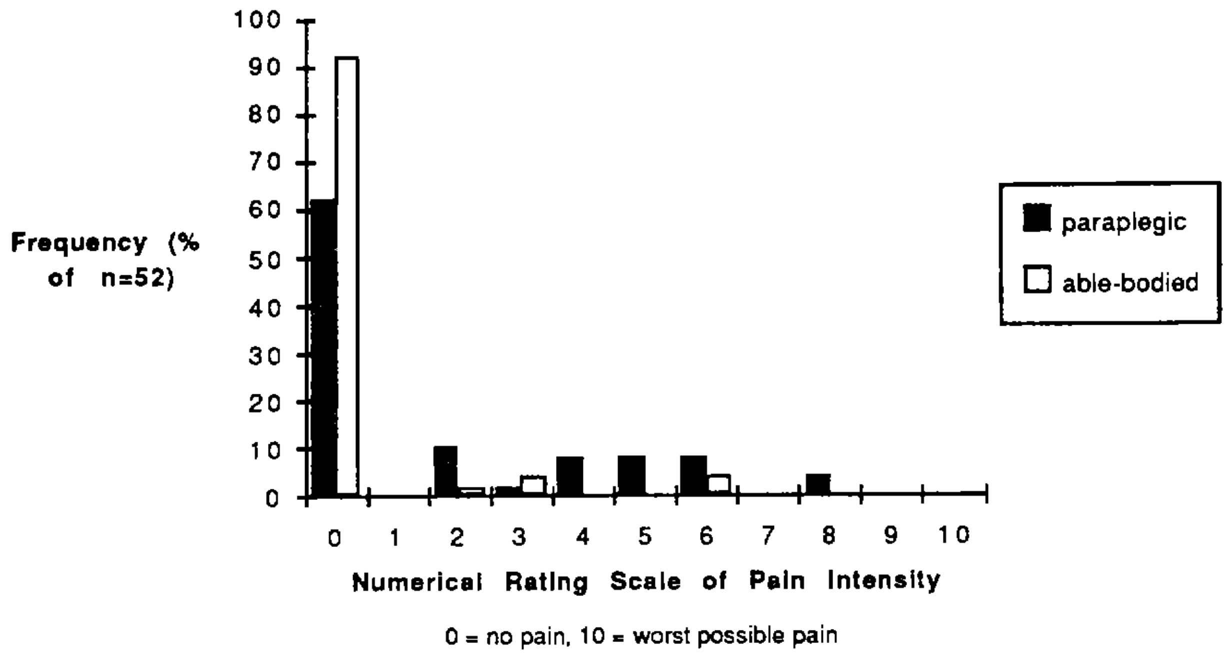
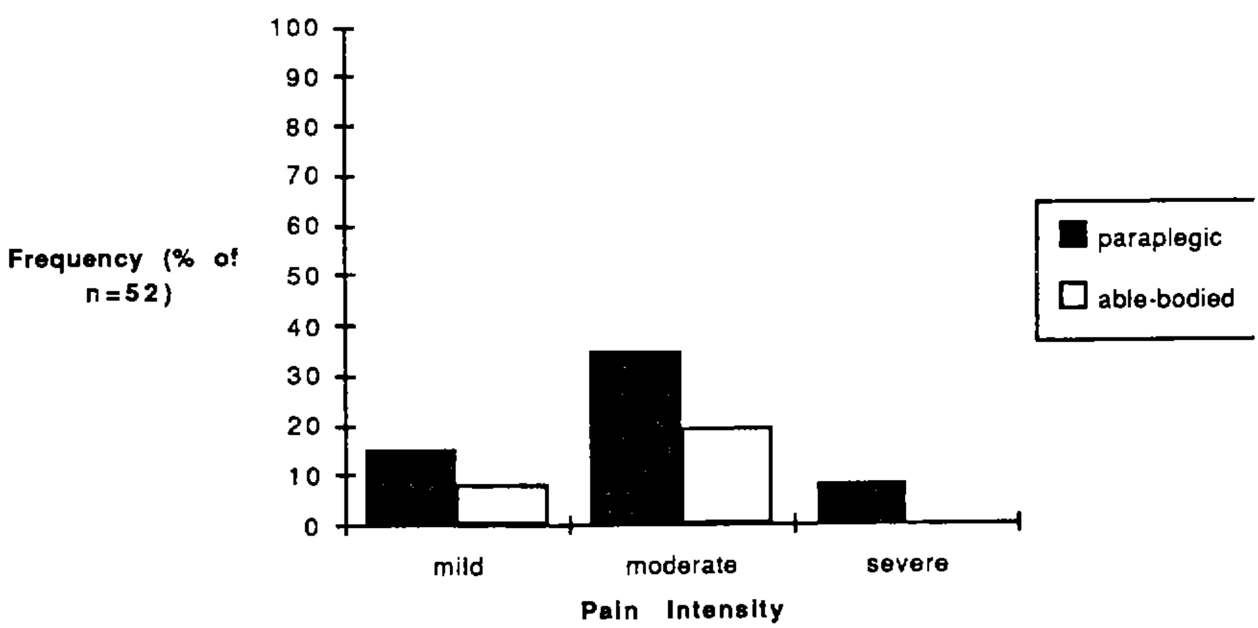


Figure 3.23: Distribution of ratings of shoulder pain experienced in the previous six months.



Pain Reported in the Elbow Region

The pain interview data for the elbow region from both the paraplegic and able-bodied subjects is tabulated in Table 3.52, and the results of the McNemar tests of association are listed. Elbow region pain in the past week was shown to be significantly associated with the paraplegic subjects ($p<.001$). No able-bodied subjects reported experiencing elbow region pain in the week prior to the interview. These results are in contrast with the findings of the pain screening test, where dominant lateral epicondyle pain was elicited in 15% of the able-bodied, and non-dominant lateral epicondyle pain was elicited in 10% of the same group (Figure 3.19). This discrepancy may be explained by the pain screening test method, which scored tenderness on palpation as positive. Subjects with tenderness on palpation may not have had sufficient pathology to have noticed pain during their daily activities. There was no statistically significant association between elbow pain in the past six months and either group.

For the remaining pain characteristics examined (location, frequency, intensity, and treatment), much fewer statistically significant associations between either group were found for elbow pain than for shoulder region pain (Table 3.51). Reports of rare elbow region pain were associated more with the able-bodied than the paraplegic subjects ($p<.05$), but there were no significant associations for either group for intermittent or daily pain. The receipt of treatment for pain in this region was not shown to be associated with one group more than the other. As was found for the shoulder (Table 3.51), the subjects with paraplegia were more likely to be on pain medication at the time of the interview, although the number was small ($n=5$). As stated earlier, the medication was not necessarily specifically for elbow pain.

Table 3.52. Summary of paraplegic and able-bodied subjects' responses to the pain interviews regarding the elbow, and results of McNemar tests of association.

Item	Percent[1] of Paraplegics (n=52) with Positive Response	Percent1 of Able-bodied (n=52) with Positive Response	P-value	
Pain in last week	31%	0%	<.001	S*
Pain in last six months	39	25	>.05	
LOCATION: Dominant limb	10	15	>.25	
Non-dominant limb	12	2	>.05	
Bilateral	17	8	>.1	
Joint	27	23	>.75	
Muscular/Non-joint	8	2	>.1	
FREQUENCY: Rare	0	8	<.05	S
Intermittent	33	17	>.1	
Daily	6	0	>.1	
INTENSITY: Worst at night	6	0	>.05	
Worst during the day	31	21	>.1	
TREATMENT: Sought treatment	15	4	>.05	
On pain medication now	10	0	<.03	S

1 = percentages may not total 100 since for some items, subjects could select more than one answer, or no answer applied to them

*S= significant at the .05 level.

Figure 3.24 presents the frequencies that the subjects selected specific numerical rating scale scores to represent the intensity of their elbow pain in the past week. No pain in the last week in the elbow region was reported by any of the able-bodied (100%) or by 69% of the paraplegic sample. The subjects with paraplegia rated the severity of their elbow pain most often as 1 out of 10 to 3 out of 10 (15%). Ratings of

4 out of 10 to 6 out of 10 were selected by 11% of the paraplegic sample. One spinal cord injured subject (2%) indicated his elbow pain in the past week had been 10 out of 10 in intensity.

Figure 3.25 shows the distributions of ratings of elbow pain experienced by the subjects (paraplegic subjects 39%; able-bodied subjects 25%) during the six months prior to data collection. There are noticeable differences between the two subject groups. The able-bodied subjects reported either mild (12%) or severe (14%) pain. In contrast, the vast majority of the paraplegic subjects with elbow pain rated it as moderate (31%). Relatively few of the sample with paraplegia scored their pain as mild (6%) or severe (4%).

Figure 3.24: Distribution of NRS scores for elbow pain experienced in the past week.

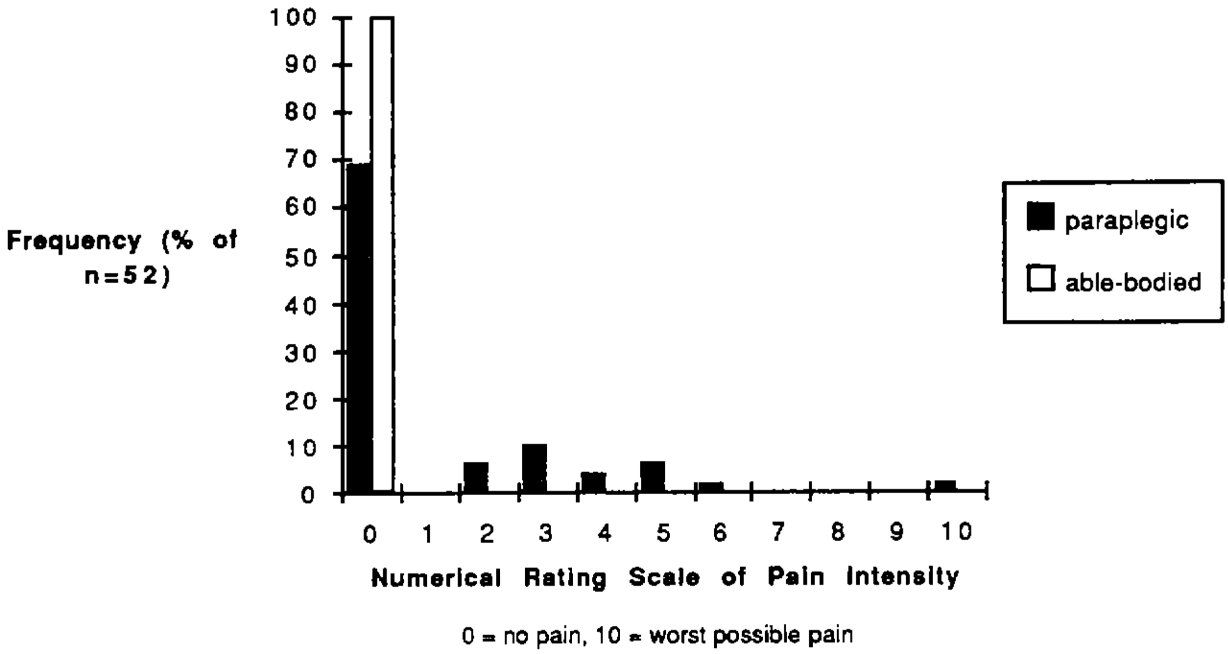
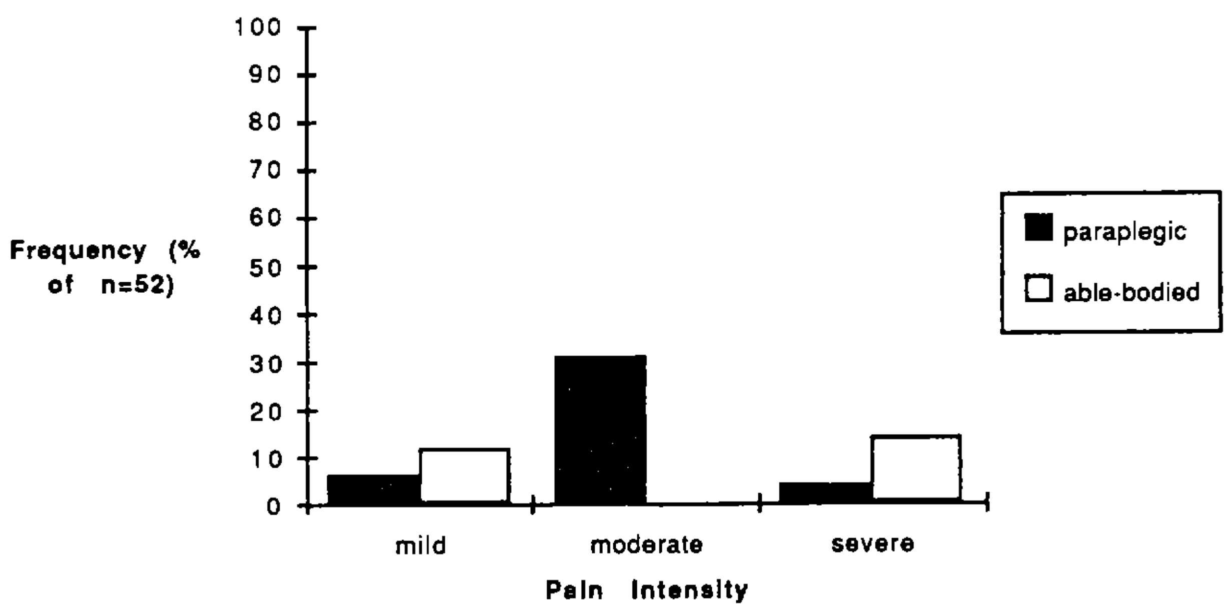


Figure 3.25: Distribution of ratings of elbow pain experienced in the previous six months.



Pain Reported in the Wrist/Hand Region

Wrist/hand region pain experienced in the past week was reported by 40% of the subjects with paraplegic versus 8% of the able-bodied subjects. Wrist or hand pain in the past six months was reported by 60% of the group with paraplegia and by 17% of the able-bodied group. Reports of wrist/hand region pain (Table 3.53) were significantly associated with paraplegia for both the previous week ($p<.001$), and the previous six months ($p<.001$) time periods. Neither group was more likely to report this pain exclusively in one limb more than the other. Complaints of bilateral wrist/hand pain were more associated with the paraplegic subjects ($p<.001$). This group was also more likely to locate their pain in the muscular/non-joint regions than were the able-bodied subjects ($p<.005$).

The subjects with paraplegia described their wrist/hand pain most often as intermittent (44%) versus rare (4%) or daily (12%). Intermittent wrist/hand pain was significantly associated with paraplegia ($p<.001$). Wrist/hand pain that was worst during the day was shown to be associated with paraplegia more than with able-bodied subjects of the same gender, age, and activity-level ($p<.025$). Despite the differences in frequencies of reported wrist/hand pain between the paraplegic and able-bodied subjects, the seeking of treatment for pain in this region was not associated with one group more than the other.

Table 3.53. Summary of paraplegic and able-bodied subjects' responses to the pain interviews regarding the wrist and hand, and results of McNemar tests.

Item	Percent[1] of Paraplegics (n=52) with Positive Response	Percent[1] of Able-bodied (n=52) with Positive Response	P-value
Pain in last week	21	8	<.001 S
Pain in last six months	60	17	<.001 S
LOCATION: Dominant limb	8	6	>.75
Non-dominant limb	4	2	>.5
Bilateral	46	8	<.001 S
Joint	23	8	>.05
Muscular/non-joint	38	8	<.005 S
FREQUENCY: Rare	4	4	>.95
Intermittent	44	12	<.001 S
Daily	12	2	>.05
INTENSITY: Worst at night	13	8	>.25
Worst during the day	37	10	<.025 S
Sought Treatment	13	4	>.05
On pain medication now	10	0	<.025 S

[1] = percentages may not total 100 since for some items, subjects could select more than one answer, or no answer applied to them

S = significant at the .05 level

In Figure 3.26 the distributions of the paraplegic and able-bodied subjects' numerical rating scale scores of perceived pain intensity are presented for wrist/hand pain experienced in the past week. A rating of 0, or no pain was reported by 60% of the paraplegic group and by 83% of the able-bodied group. Ratings of 1 out of 10 to 3 out of 10 were selected most often by those with paraplegia (27%), versus 8% of the able-bodied persons. Ratings of 4 out of 10 to 6 out of 10 were reported by 11% of the spinal cord injured and by 0% of the able-bodied group. One subject with paraplegia (2%) rated his wrist/hand pain as 7 out of 10 in the past week. Figure 3.27 shows that the distributions of ratings of intensity of wrist/hand pain experienced in the past six months were spread relatively evenly between mild (paraplegia 29%; able-bodied 10%) and moderate (paraplegia 27%; able-bodied 8%) in both groups. No subjects in either group reported severe wrist/hand pain in the six months preceeding the interviews.

Figure 3.26: Distribution of the NRS scores for wrist/hand pain experienced in the past week.

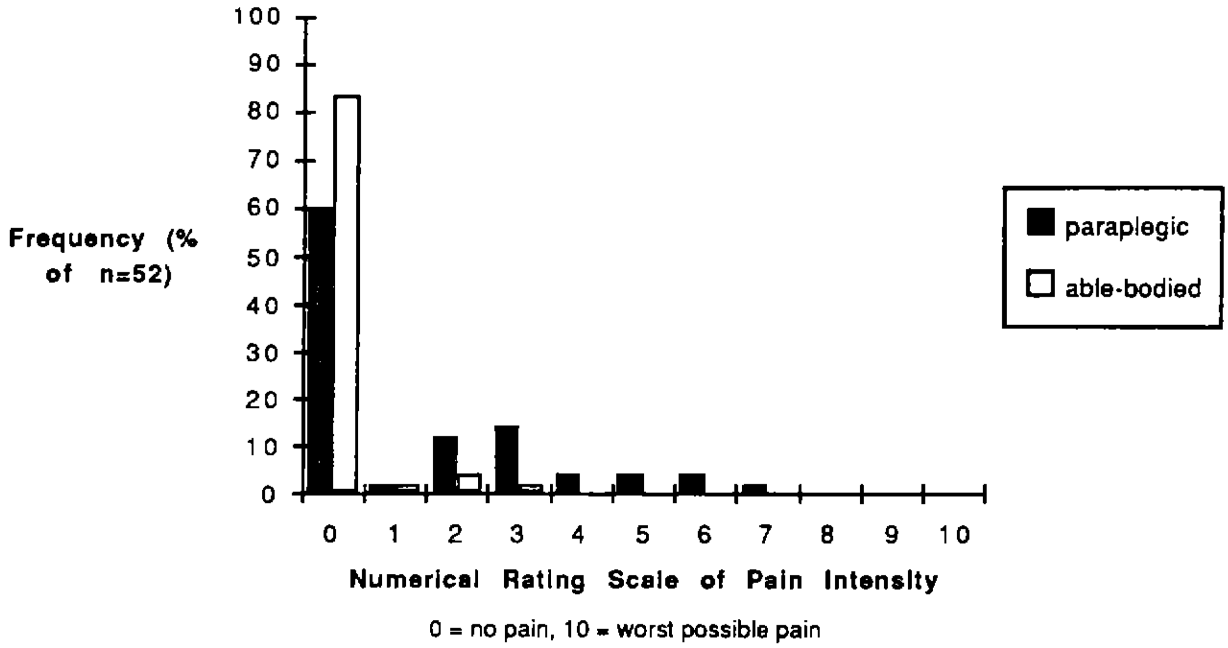
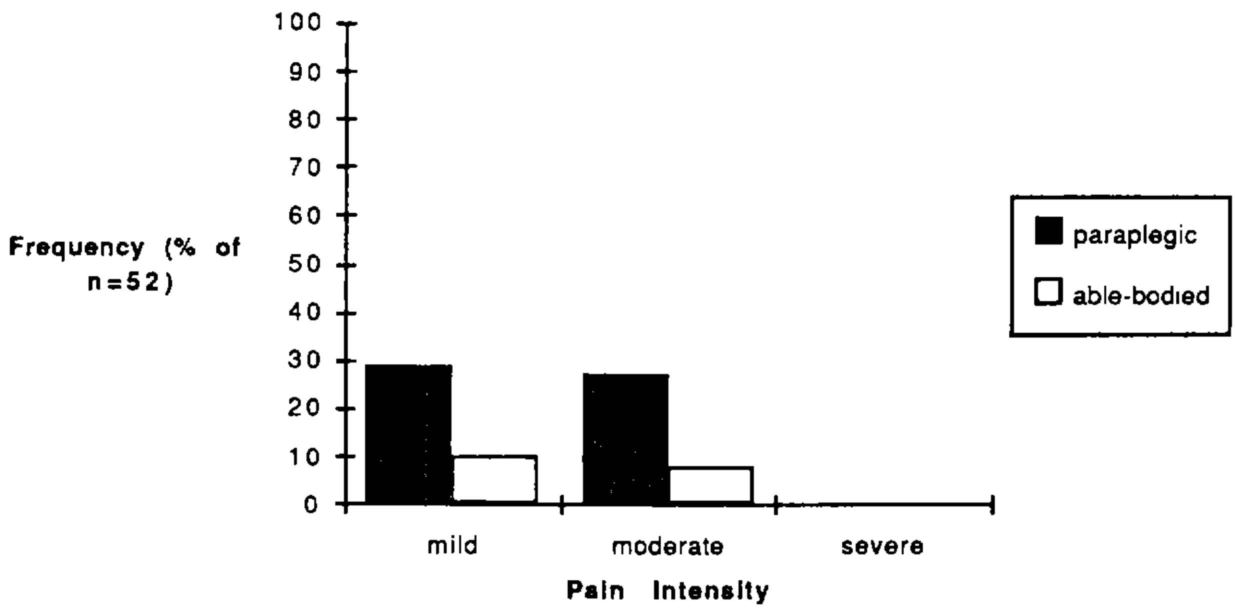


Figure 3.27: Distribution of ratings of wrist/hand pain experienced in the previous six months.



3.5. The Impact of Upper Limb Pain on Activities of Daily Living Performance in Paraplegia.

The results of the Impact of Upper Limb Pain on Activities of Daily Living Performance Questionaire are presented in four sections. The first section contains bar graphs illustrating the distribution of the questionnaire scores for all of the subjects with paraplegia. In the second and third sections, the results of the analyses of the effects of age and duration of spinal cord injury on upper limb pain during ADL are presented. To aid comparisons, the same bar graph format is repeated in each of the first three sections. The last section contains a table ranking all of the ADL tasks in order of the frequency of occurrence of upper limb pain.

3.5.1. Distribution of Questionnaire Results for All Subjects with Paraplegia

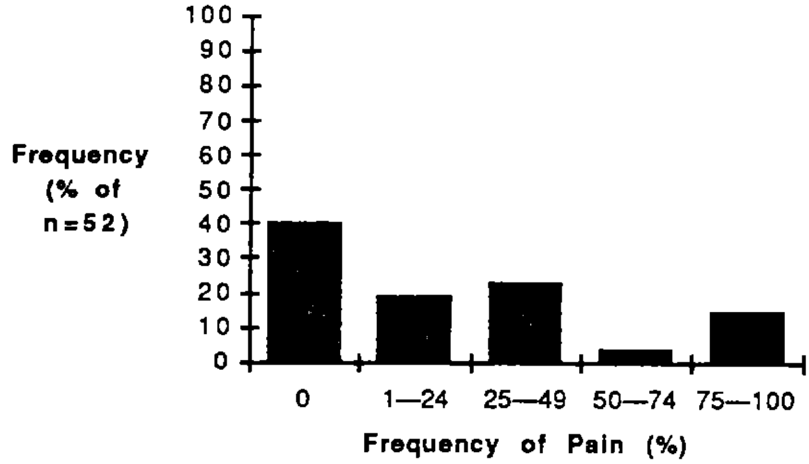
Figures 3.28 to 3.30 are bar graphs illustrating the frequency distributions of the proportion of ADL task performances where upper limb pain was reported to interfere.

a) Distribution of Mobility Scores

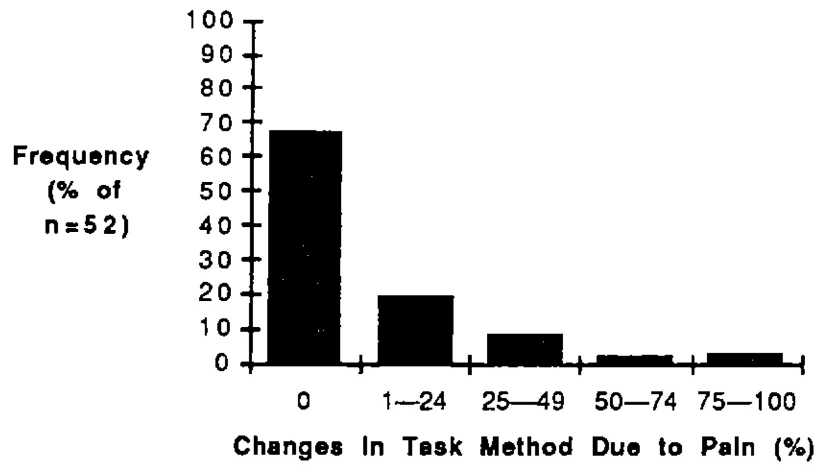
Figure 3.28a) indicates that 60% of the 52 subjects with paraplegia experienced pain when performing mobility tasks (wheelchair propulsion and wheelchair transfers). Forty-two percent (42%) reported having upper limb pain less than half of the time while carrying out these tasks, while 17% indicated that they had pain more than half of the time. Figure 3.28b) shows that 33% of the subjects with paraplegia had made changes to their methods of mobility due to upper limb pain (changes made less than half of the time = 27%; changes made more than half of the time = 6%). Upper limb pain had caused 15% of the sample to seek assistance with mobility tasks for up to half of the time that they were performed (Figure 3.28c).

Figure 3.28: Distribution of scores of upper limb pain impact on mobility tasks (n=52).

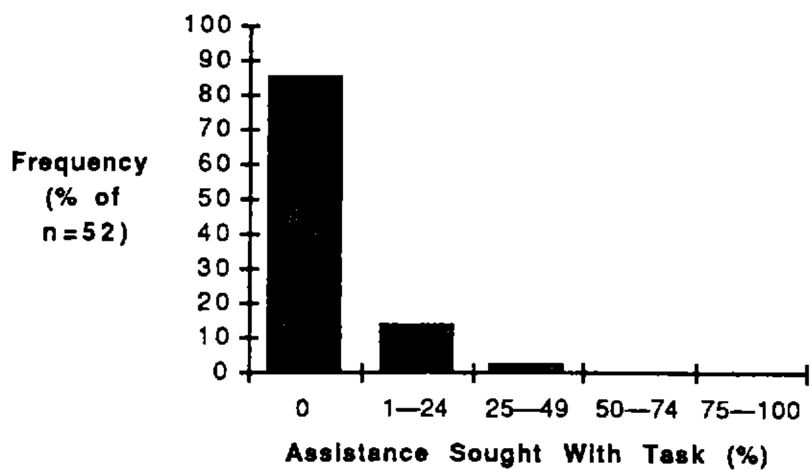
a) Percentage of mobility events where upper limb pain occurred.



b) Percentage of mobility events requiring method changes due to upper limb pain.



c) Percentage of mobility events where assistance was sought due to upper limb pain.

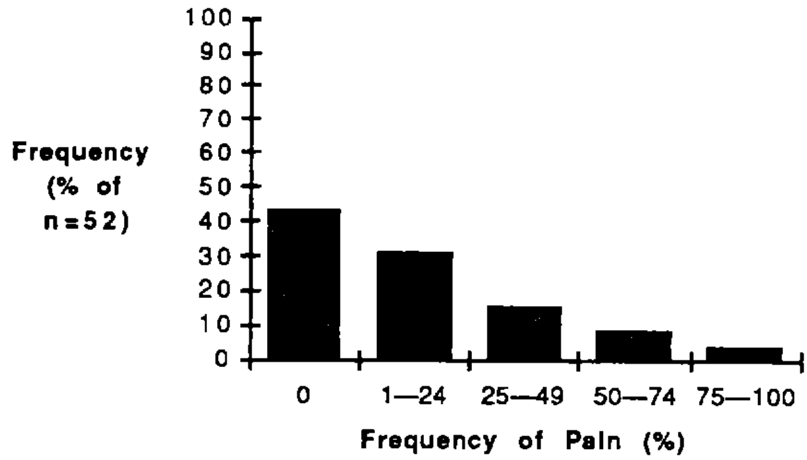


b) Distribution of Self-care Scores

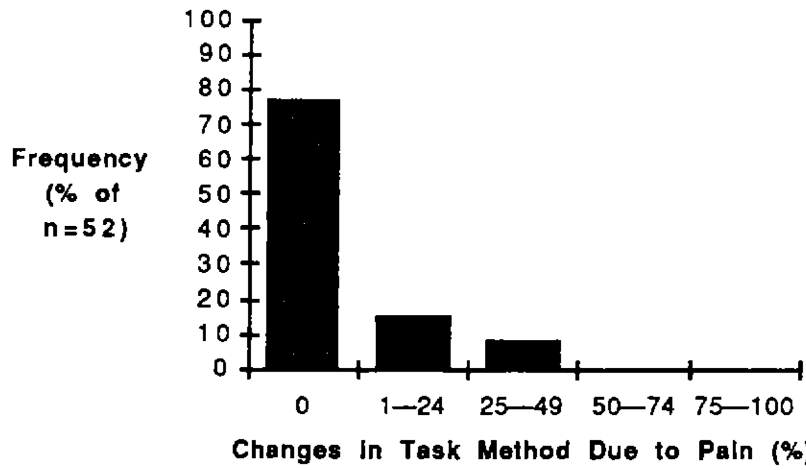
Figure 3.29a) reveals that 58% of the subjects with paraplegia reported experiencing pain in the upper limbs while carrying out self-care tasks (dressing, grooming, bathing, bowel and bladder care, reaching, sleeping). Forty-six percent (46%) indicated that the pain occurred up to half of the time during these tasks. Pain occurred more than half of the time for 12% of the subjects. Less than half of those reporting pain during self-care tasks had made changes in their methods of performing self-care due to upper limb pain (23%), and only 6% had sought assistance with these activities. These changes had been instituted less than half of the time that the tasks were performed (Figures 3.29b) and 3.29c)).

Figure 3.29: Distribution of scores of upper limb pain impact on self-care tasks (n=52).

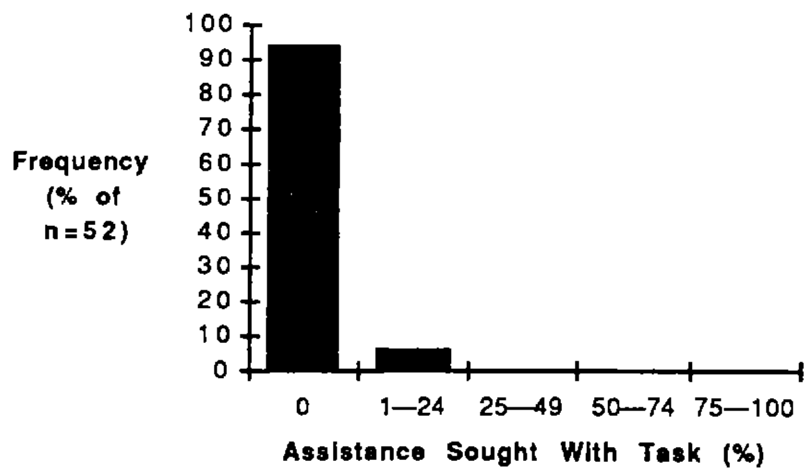
a) Percentage of self-care events where upper limb pain occurred.



b) Percentage of self-care events requiring method changes due to upper limb pain.



c) Percentage of self-care events where assistance was sought due to upper limb pain.

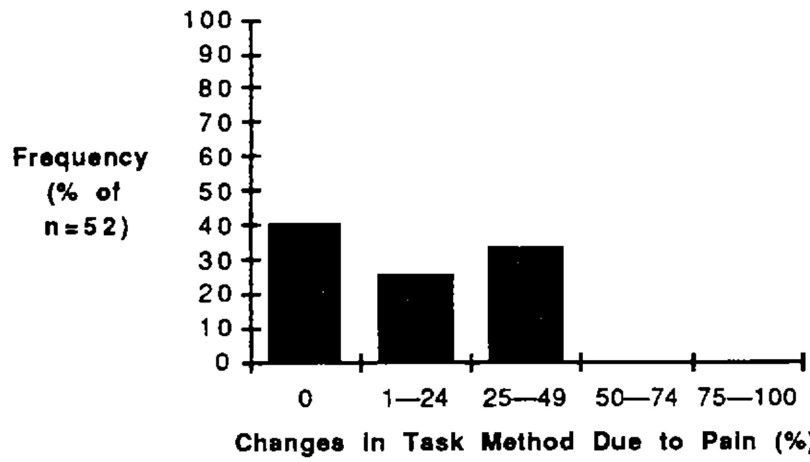


c) Distribution of General Activities Scores

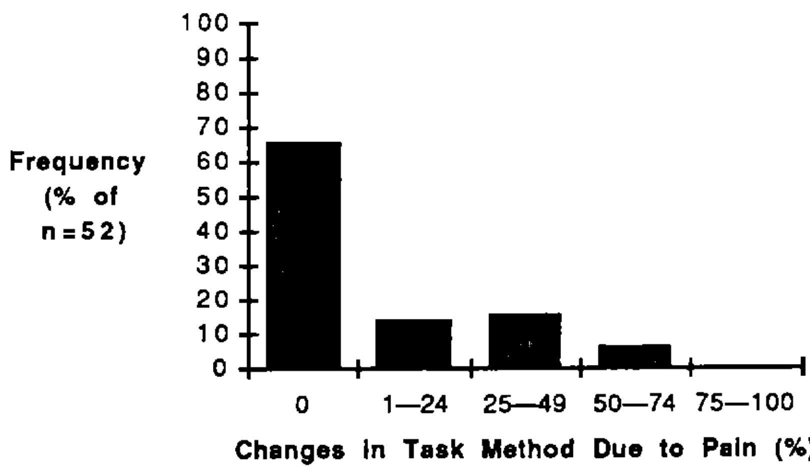
The distribution of pain experienced during general activities (outings, hobby, sport, work/school, household tasks, driving) is shown in Figure 3.30a). Sixty percent (60%) of the sample having paraplegia reported experiencing upper limb pain while performing these activities. The pain was reported to occur less than half of the time that the tasks were performed (Figure 3.30b). Changes in methods of completing general activities, due to upper limb pain, had been made by 35% of the subjects with paraplegia. These changes were made up to half of the time by 29% of the subjects (Figure 3.30b). Upper limb pain had caused 10% of the sample to seek assistance up to half of the time in order to carry out these activities (Figure 3.30c).

Figure 3.30: Distribution of scores of upper limb pain impact on general activities tasks (n=52).

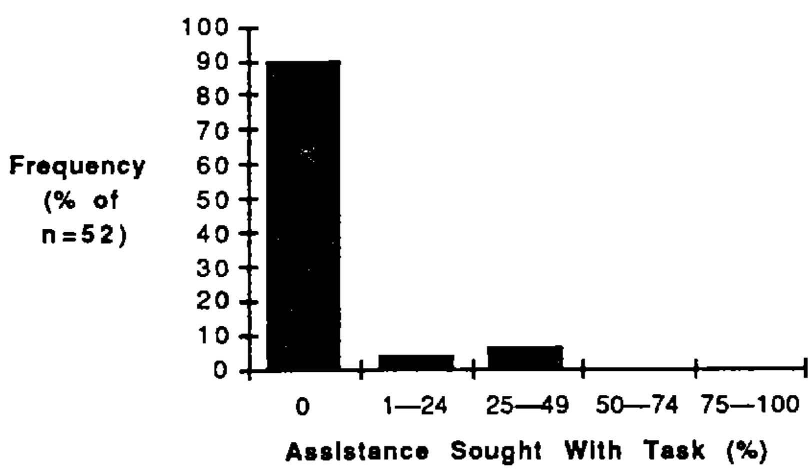
a) Percentage of general activity events where upper limb pain occurred.



b) Percentage of general activity events requiring method changes due to upper limb pain.



c) Percentage of general activity events where assistance was sought due to upper limb pain.



Review of the preceeding graphs revealed that the questionnaire scores did not follow normal distributions. A score of 0% was selected in all nine categories by between 40.4% and 94.2% of the subjects. Of those reporting pain, method changes, or assistance sought during the ADL tasks, the majority selected the 1-49% frequency categories. Thus, it was decided that, for statistical analysis, this data would be transformed to binary data. The two categories used were 0%, indicating no upper limb pain, or method changes, or assistance sought; and 1-100% indicating that pain was experienced, method changes had been made due to the pain, or assistance had been sought due to upper limb pain.

3.5.2. The Effects of Subject Age on Upper Limb Pain Experienced During Activities of Daily Living

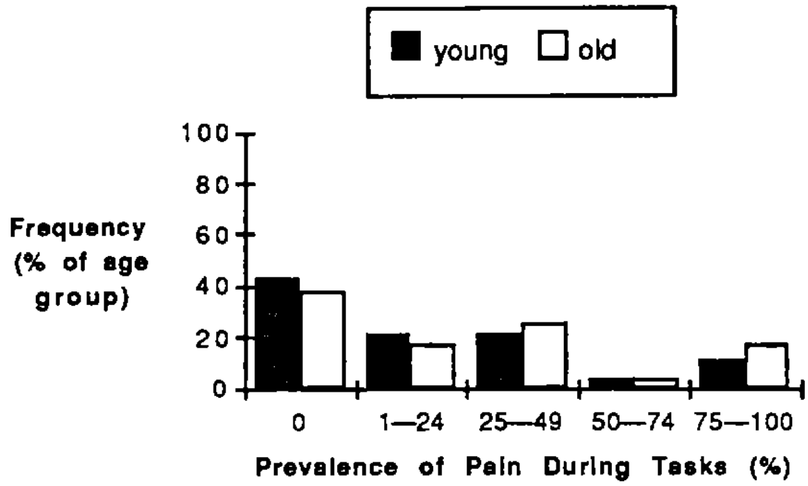
Figures 3.31 to 3.33 present and contrast the frequency distributions of the impact of upper limb pain on activities of daily living of those subjects with paraplegia aged less than 45 years (designated as Young; n=28); and those aged 45 years or more (designated as Old; n=24).

a) The Effect of Age on Mobility Scores

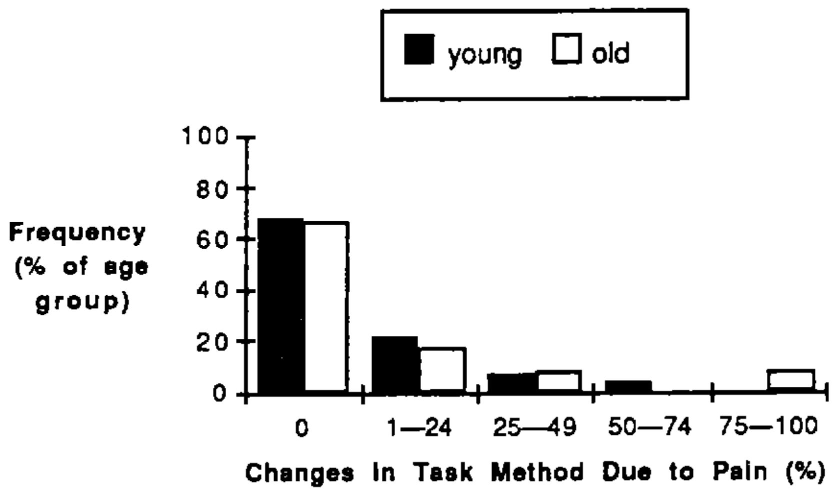
Figure 3.31a) shows that there were small differences between the two age groups in the numbers of subjects who experienced upper limb pain during mobility activities. This was also true of the numbers who had made changes in their methods of mobility due to pain in the upper limbs (Figure 3.31b)). Slightly more older than younger (21% versus 11%) reported that they had sought assistance with mobility tasks due to upper limb pain (Figure 3.31c)).

Figure 3.31: Comparison, by age group, of distribution of scores of upper limb pain impact on mobility tasks (young = age < 45 years, n = 52; old = age ≥ 45 years, n = 24).

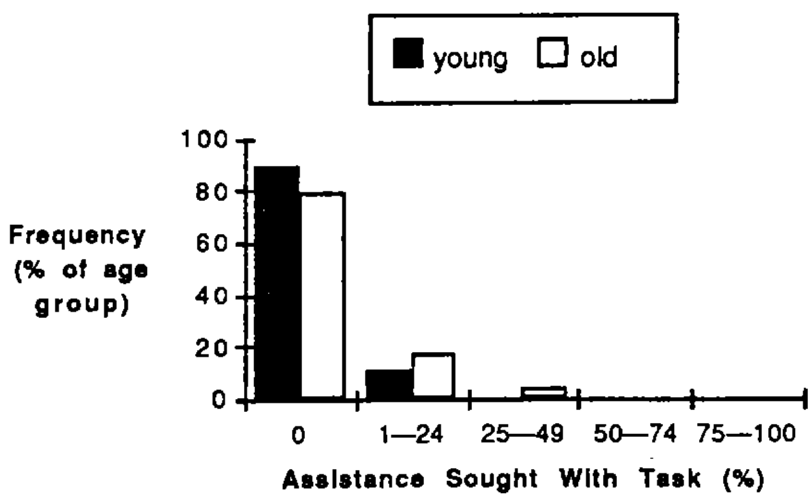
a) Percentage of mobility events where upper limb pain occurred, by age group.



b) Percentage of mobility events requiring method changes due to upper limb pain, by age group.



c) Percentage of mobility events where assistance was sought due to upper limb pain, by age group.

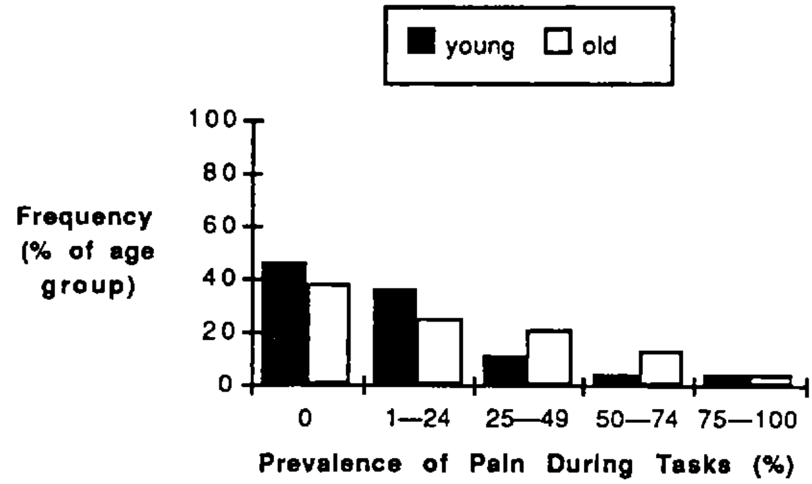


b) The Effect of Age on Self-care Scores

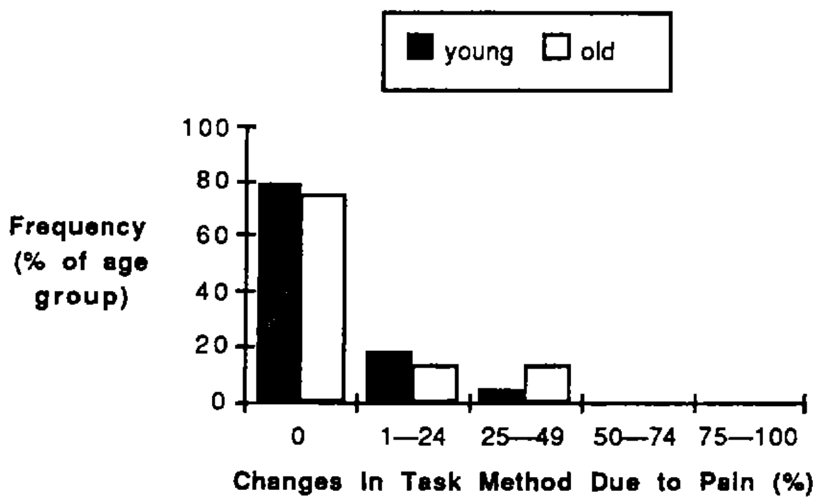
Figure 3.32a) shows that slightly more old than young subjects with paraplegia (63% versus 54%) experienced upper limb pain during self-care tasks. The pain was reported to occur less than half of the time by 7% of the young subjects, and 17% of the older subjects. The numbers who had made changes in their self-care methods due to the pain were similar (young = 21; = 25%) (Figure 3.32b)). Upper limb pain had caused 4% of the young subjects and 8% of the old subjects to seek assistance with their self-care activities. In all instances, assistance was sought less than 25% of the time that the activities were performed (Figure 3.32c).

Figure 3.32: Comparison, by age group, of distribution of scores of upper limb pain impact on self-care tasks (young = age < 45 years, n = 28; old = age ≥ 45 years, n = 24).

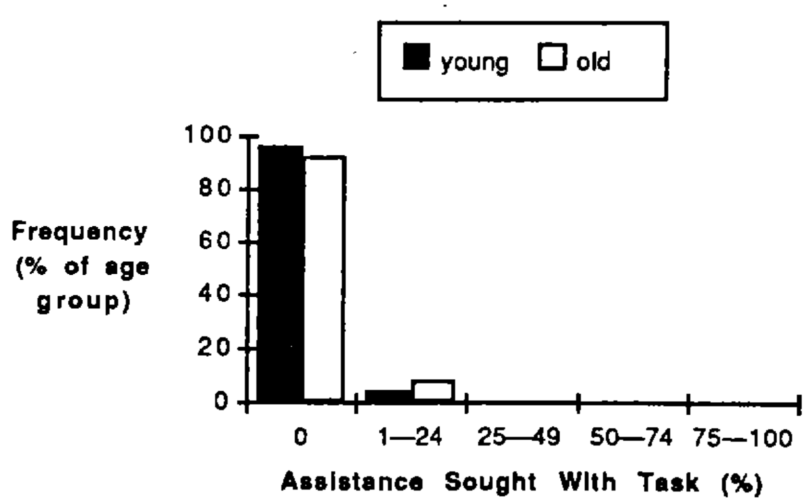
a) Percentage of self-care events where upper limb pain occurred, by age group.



b) Percentage of self-care events requiring method changes due to upper limb pain, by age group.



c) Percentage of self-care events where assistance was sought due to upper limb pain, by age group.

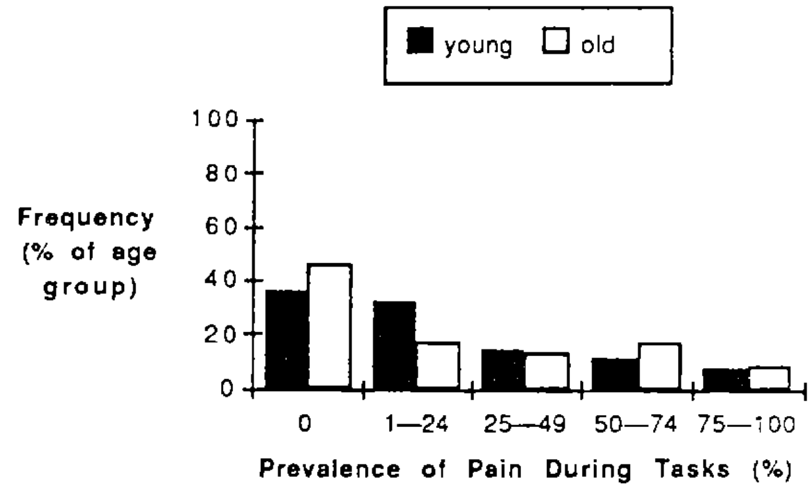


c) The Effect Of Age on General Activities Scores

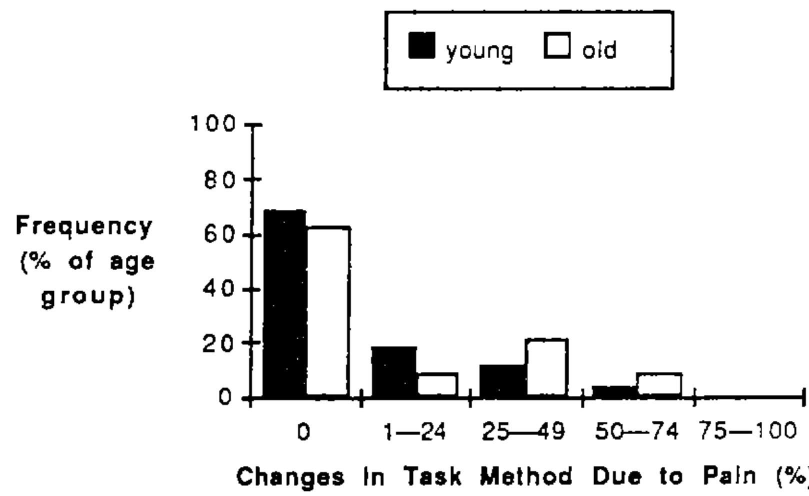
More old (46%) than young (36%) subjects with paraplegia indicated that they experienced upper limb pain while performing general activities (Figure 3.33a)). In most instances for the young subjects (32%), this pain occurred less than 25% of the time. Twenty-five percent (25%) of the older subjects experienced upper limb pain more than 50% of the time that they performed these tasks. Figure 3.33b) shows that similar numbers of young and old subjects with paraplegia had made changes in their methods of carrying out general activities (young = 32%; old = 38%). Most changes in method were made less than half of the time both groups (young = 29%; old = 29%). Assistance was sought by 7% of the young subjects and by 13% of the older subjects (Figure 3.33c)). In all cases, assistance was sought less than half of the time that the activities were performed.

Figure 3.33: Comparison, by age group, of distribution of scores of upper limb pain impact on general activities tasks (young = age < 45 years, n = 28; old = age ≥ 45 years, n = 24).

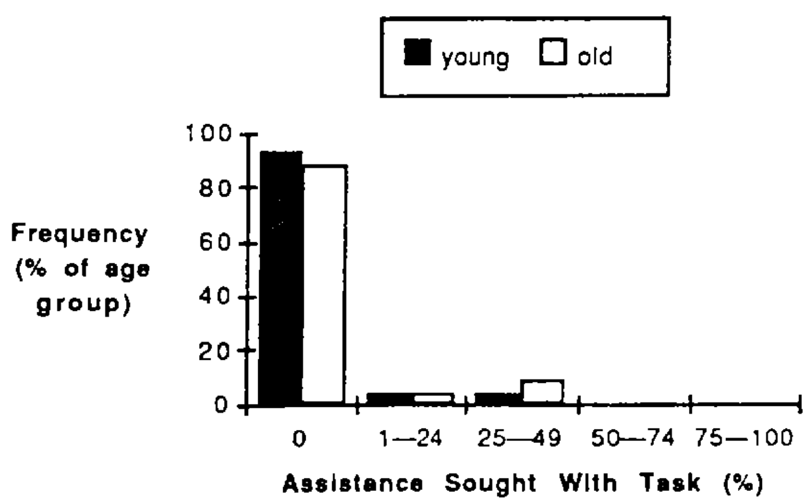
a) Percentage of general activity events where upper limb pain occurred, by age group.



b) Percentage of general activity events requiring method changes due to upper limb pain, by age group.



c) Percentage of general activity events where assistance was sought due to upper limb pain, by age group.



d) The Association Between Age and Upper Limb Pain During ADL

Following transformation of the questionnaire scores to binary data, tests of association (Fisher's Exact test 1-tailed) were performed on the three categories of activities of daily living scores (mobility, self-care, and general activities) to determine whether or not chronological age was associated with reports of upper limb pain during the tasks, task method changes due to upper limb pain, or assistance with the task due to upper limb pain (Table 3.54). No statistically significant associations were found. The same test was conducted for each individual ADL task (Table 3.55), and once again, no statistically significant associations were found.

In order to exclude duration of SCI from the effect of age on the ADL scores, the responses of the nine pairs of subjects with paraplegia who were matched for duration of SCI, lesion level, and activity-level, but contrasted in age by at least 12 years, were examined (Table 3.56). The sum of all pairs where only one subject reported pain, method changes, or the use of assistance, revealed that of 81 instances (9 pairs x 9 items), in 16 instances upper limb pain during ADL affected the young subject only, whereas in 6 instances pain affected only the old subject. Significance tests of these overall sums of the paired scores were not performed due to probable lack of independence between the individual items. However, when the individual items were tested using the McNemar test, the young paraplegic subjects, regardless of duration of SCI, were more likely than old subjects to have made changes to their methods of mobility due to upper limb pain ($p<.05$).

Table 3.54. Association of age and upper limb pain during activities of daily living (Fisher's Exact test: 1 tailed).

Activity	Association with Age		
	Young*(n=28)	Old*(n=24)	P-value
Mobility:			
Pain during	16	15	.46
Changed method due to pain	9	8	.58
Needs assistance due to pain	3	5	.27
Self-care:			
Pain during	15	15	.36
Changed method due to pain	6	6	.51
Needs assistance due to pain	1	2	.44
General Activities:			
Pain during	18	13	.32
Changed method due to pain	9	9	.45
Needs assistance due to pain	2	3	.43

* Young= Paraplegic subjects aged <45 years; Old= Paraplegic subjects aged ≥45 years.

Table 3.55. Association of age and upper limb pain during specific activities of daily living (Fisher's Exact test: 1 tailed).

Activity	Aged <45 Years with Pain* (n=28)	Aged ≥45 Years with Pain* (n=24)	P-value
Mobility:			
Bed transfer	50	46	.49
Toilet transfer	43	54	.29
Bath transfer	43	54	.26
Car transfer	43	50	.41
Load W/C to car	29	21	.38
Indoor wheeling	39	29	.32
Outdoor wheeling	46	42	.48
Self-care:			
Dressing	21	33	.26
Grooming	18	33	.16
Bathing/showering	14	25	.27
Bowel & bladder	14	21	.39
Retrieve item from shelf above shoulder	32	42	.34
Sleep	39	63	.08
General Activities:			
Outings/social activities	32	25	.39
Hobby/sport	36	25	.29
Work/school	39	42	.13
Household tasks	36	38	.56
Driving	39	38	.56

W/C= wheelchair
* = figures indicate percent of the group that performed the activity and had pain in the last six months while performing the activity.

Table 3.56. Use of matched pairs (n=9 pairs) to examine the effect of age*, excluding duration of SCI, on upper limb pain during ADL.

Activity	Paired Scores**	Summary of Pairs' Scores: Neither	Young only	Old only	Both	
Mobility:						
Pain during	+- -- ++ ++ -+ -- ++ -- ++	3	1	1	3	
Changed method due to pain	+- -- +- +- -- -- -- -- +-	5	4	0	0	S
Needs assistance due to pain	-- -- +- -- -- -- -- -- --	8	1	0	0	
Self-care:						
Pain during	++ -- ++ ++ -+ -- +- -- ++	3	1	1	4	
Changed method due to pain	-- -- +- ++ -- -- -- -- --	7	1	0	1	
Needs assistance due to pain	-- -- +- -- -- -- -- -- --	8	1	0	0	
General Activities:						
Pain during	+- -- +- ++ ++ -+ ++ -- +-	2	3	1	3	
Changed method due to pain	+- -- +- -+ -+ -+ -- -- +-	3	3	3	0	
Needs assistance due to pain	-- -- +- -- -- -- -- -- --	7	1	0	0	

* Young= aged <45 years; Old=aged ≥45 years

** -+ = negative response (e.g. no pain) by young paraplegic; positive response by old paraplegic

+- = positive response by young paraplegic; negative response by old paraplegic

++ = positive response by young and old paraplegic

-- = negative response by young and old paraplegic

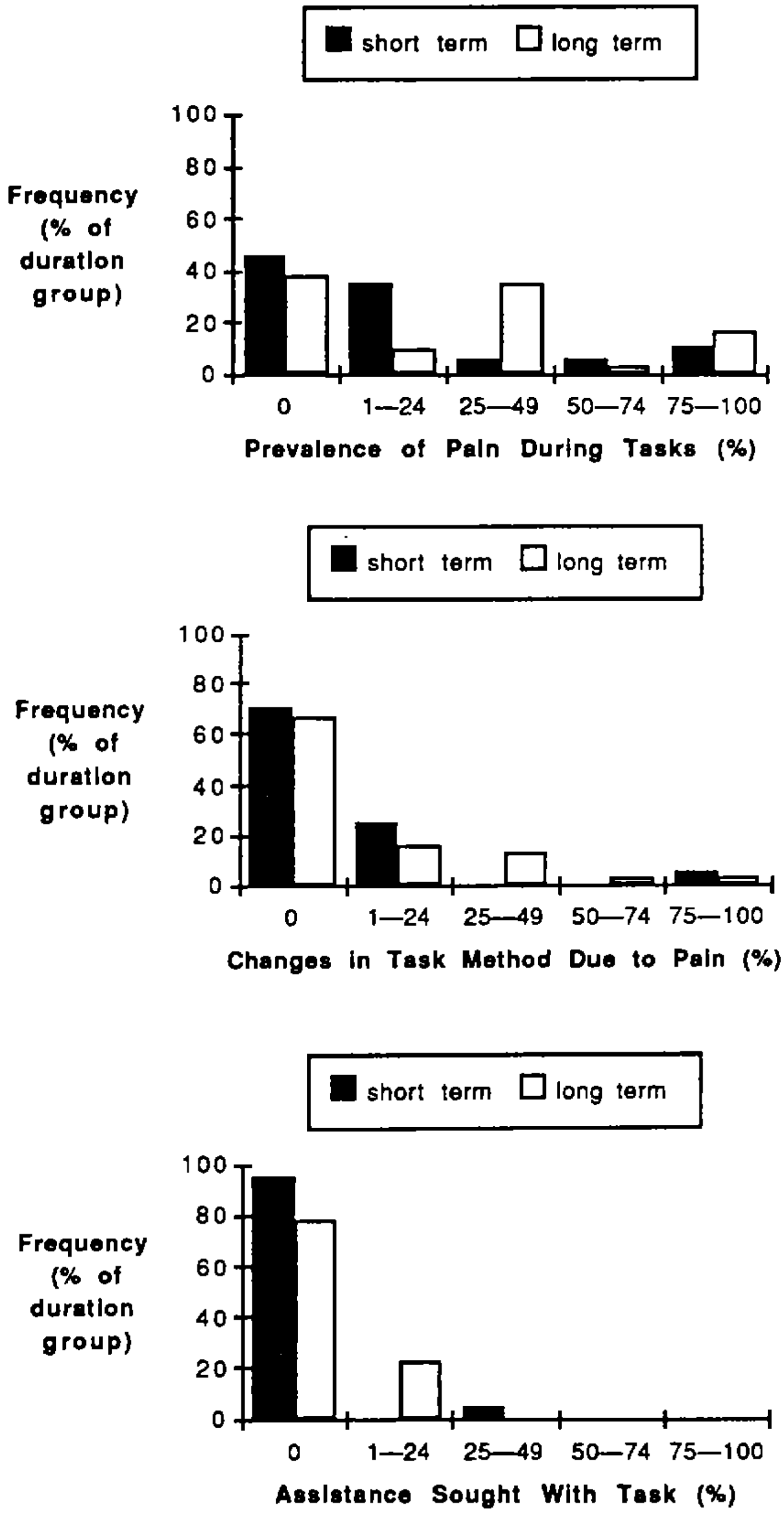
S = significant at the .05 level

3.5.3. Effects of Duration of Paraplegia on the Impact of Upper Limb Pain on Activities of Daily Living Performance

a) The Effect of Duration of SCI on Mobility Scores

Figure 3.34a) represents the distribution of pain experienced by subjects with short term (less than 15 years) paraplegia versus subjects with long term (15 years or longer) paraplegia. Upper limb pain during mobilty tasks was reported by 55% of the short term subjects and by 63% of the long term subjects. When frequency of pain was examined, the graph shows that upper limb pain occurred less than half of the time during mobility tasks in 40% of the short term group and in 44% of the long term group. The pain occurred more than half of the time during wheelchair propulsion and transfers in 15% of the short term subjects and in 19% of the long term subjects. Changes in methods of mobility due to upper limb pain were made by 30% of the short term group, and by 34% of the long term group (Figure 3.34b)). The frequencies of changes were similar between the two groups. Assistance with mobility activities due to upper limb pain was sought by 5% of the short term subjects and by 22% of the long term subjects (Figure 3.34c)). In all cases, assistance was sought less than half of the time that the tasks were performed.

Figure 3.34: Comparison, by duration of SCI, of distribution of scores of upper limb pain impact on mobility tasks (short term = SCI < 15 years, n = 20; long term = SCI ≥ 15 years, n = 32).



a) Percentage of mobility events where upper limb pain occurred by duration of SCI.

b) Percentage of mobility events requiring method changes due to upper limb pain, by duration of SCI.

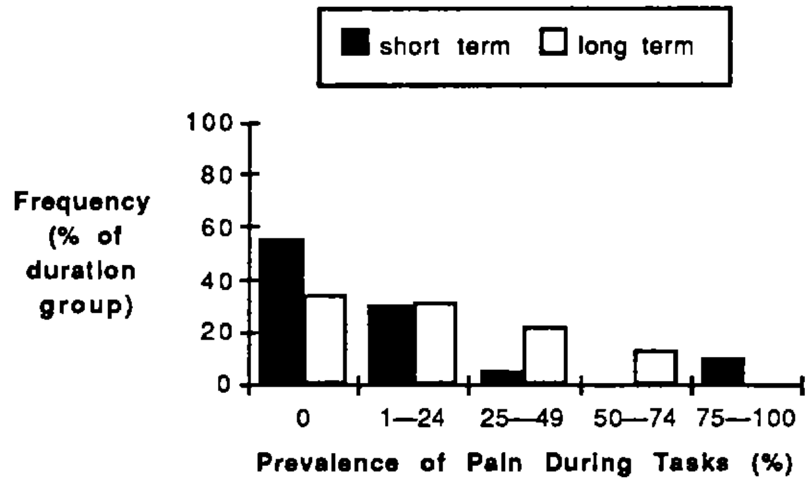
c) Percentage of mobility events where assistance was sought due to upper limb pain, by duration of SCI.

b) The Effect of Duration of Injury on Self-care Scores

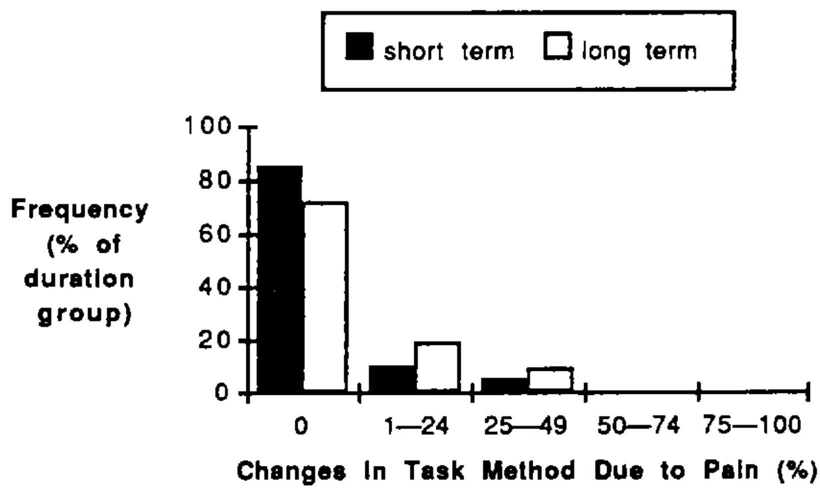
When upper limb pain experienced during self-care tasks was compared between the two duration of SCI groups, more noticeable differences were seen. Forty-five percent (45%) of the short term versus 66% of the long term SCI subjects reported pain during these activities (Figure 3.35a)). The short term group reported that the pain occurred less than half of the time. Whereas 53% of the long term group experienced upper limb pain less than half of the time, and 13% experienced pain more than half of the time that they completed self-care activities. Pain in the upper extremities had caused 15% of the short term SCI subjects and 28% of the long term SCI subjects to alter their self-care methods (Figure 3.35b)). In all cases, the changes were made less than half of the time. No short term subjects had sought assistance with self-care activities due to upper limb pain (Figure 3.35c)). Whereas, 9% of the long term group had required assistance with these tasks half of the time or less.

Figure 3.35: Comparison, by duration of SCI, of distribution of scores of upper limb pain impact on self-care tasks (short term = SCI < 15 years, n = 20; long term = SCI ≥ 15 years, n = 32).

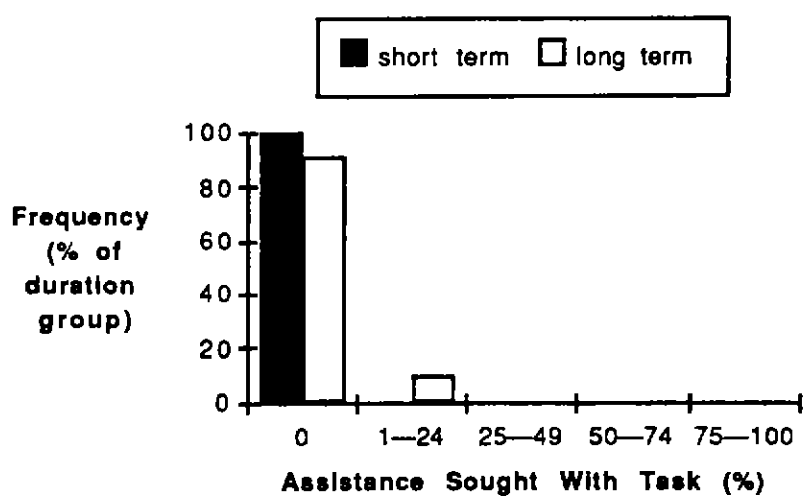
a) Percentage of self-care events where upper limb pain occurred, by duration of SCI.



b) Percentage of self-care events requiring method changes due to upper limb pain, by duration of SCI.



c) Percentage of self-care events where assistance was sought due to upper limb pain, by duration of SCI.

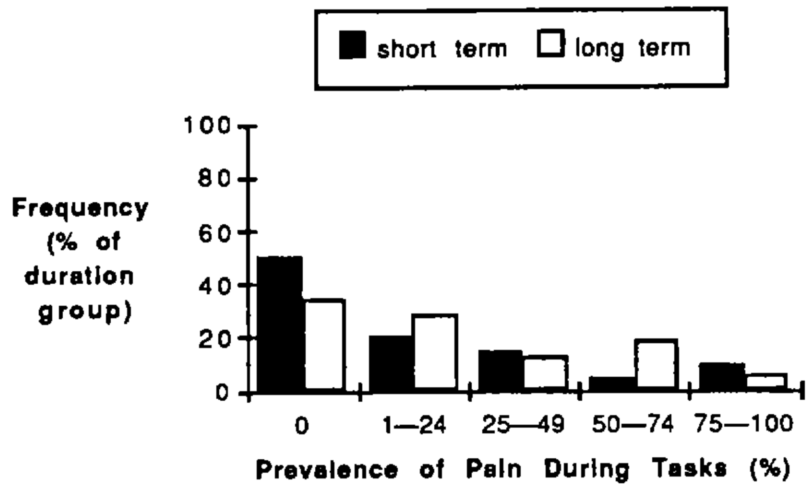


c) The Effect of Duration of SCI on General Activities Scores

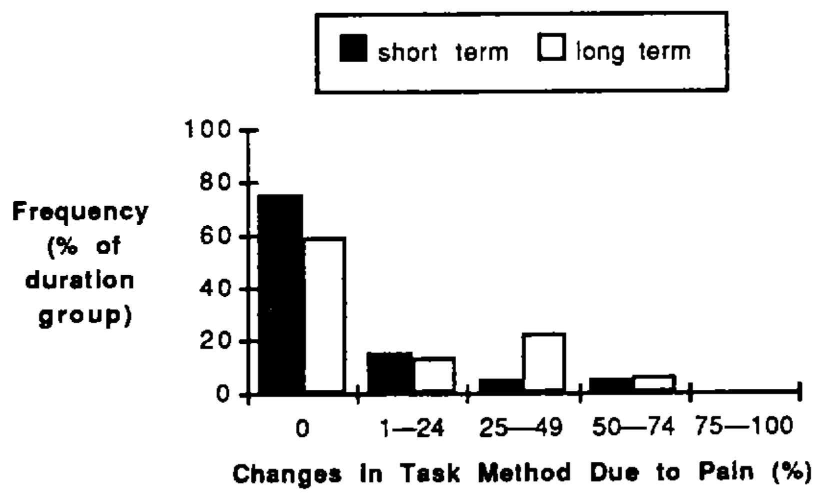
Noticeable differences were again apparent between the two duration of SCI groups when upper limb pain during general activities was examined (Figure 3.36a)). Fifty percent (50%) of the short term SCI group and 66% of the long term SCI group reported experiencing pain during general activities tasks. The pain occurred less than half of the time for 35% of the short term subjects and for 41% of the long term subjects. Upper limb pain was present more than half of the time during these activities for 15% of the short duration group and 25% of the longer duration group. Changes in methods of carrying out general activities had been made by 25% of the short term group and by 40% of the long term group (Figure 3.36b)). In most cases, the changes had been made less than half of the time (short term SCI = 20%; long term SCI = 34%). Assistance with general activities due to upper limb pain had been arranged by 5% of the short term subjects and by 13% of the long term subjects (Figure 3.36c)). In all instances the assistance was used less than half of the time.

Figure 3.36: Comparison, by duration of SCI, of distribution of scores of upper limb pain impact on general activity tasks (short term = SCI < 15 years, n = 20; long term = SCI ≥ 15 years, n = 32).

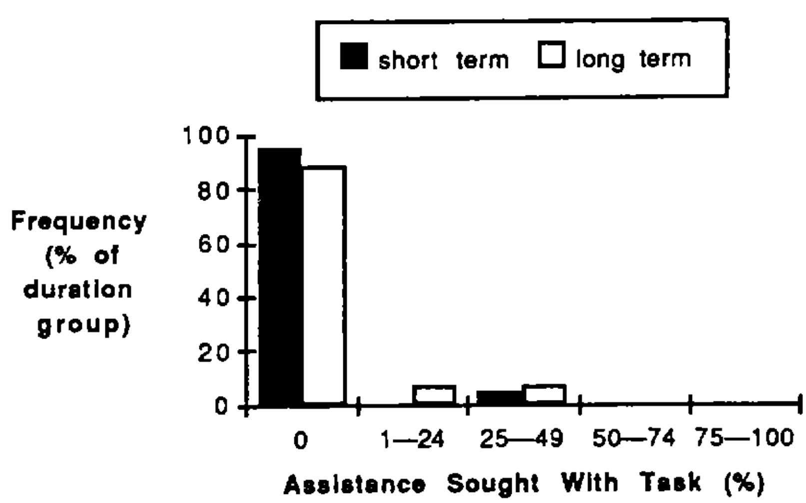
a) Percentage of general activities events where upper limb pain occurred, by duration of SCI.



b) Percentage of general activities events requiring method changes due to upper limb pain, by duration of SCI.



c) Percentage of general activities events where assistance was sought due to upper limb pain, by duration of SCI.



d) The Association Between Duration of SCI and the Impact of Upper Limb Pain on ADL Performance

The same tests (Fisher's Exact test 1-tailed) used to test for associations between age and upper limb pain during ADL, were repeated on the three categories of activities of daily living (mobility, self-care, and general activities) to determine whether or not duration of spinal cord injury was associated with upper limb pain during the tasks, task method changes due to upper limb pain, or assistance with the task due to upper limb pain (Table 3.57). No statistically significant associations were found. The same test was conducted for each individual ADL task (Table 3.58), and once again, no statistically significant associations were found.

In order to exclude age from the effect of duration of SCI on the ADL scores, the responses of the seven pairs of subjects who had been matched for age, lesion level, and activity-level, but contrasted in duration of SCI by at least 10 years, were examined (Table 3.59). The sum of all pairs where only one subject reported pain, method changes, or the use of assistance, revealed that of 63 instances (7 pairs x 9 items), in 2 instances upper limb pain affected ADL performance in the short term subject only, whereas in 27 instances pain affected the long term subject only. Due to possible lack of independence between these summed paired scores, significance testing could not be performed. However, the differences in pain impacts between the short and long term SCI groups suggest that, with age excluded, in this sample there may have been a greater tendency for subjects with long term paraplegia to report that upper limb pain affected their ADL performance. When the McNemar test was used with the individual items, a statistically significant association was found only between long duration of spinal cord injury and the experience of pain during self-care activities ($p<.05$).

Table 3.57. Association between duration of SCI and upper limb pain during activities of daily living (Fisher's Exact test: 1 tailed).

Activity	Association with Duration of SCI		
	Short*(n=20)	Long*(n=32)	P-value
Mobility:			
Pain during	11	20	.40
Changed method due to pain	6	11	.44
Needs assistance due to pain	1	7	.10
Self-care:			
Pain during	9	21	.12
Changed method due to pain	3	9	.23
Needs assistance due to pain	0	3	.22
General Activities:			
Pain during	10	21	.20
Changed method due to pain	5	13	.19
Needs assistance due to pain	1	4	.35

* Short= SCI <15 years; Long= SCI ≥15 years.

Table 3.58. Association between duration of SCI and upper limb pain during specific activities of daily living (Fisher's Exact test: 1 tailed).

Activity	Duration <15 Years with Pain* (n=20)	Duration ≥45 Years with Pain* (n=32)	P
Mobility:			
Bed transfer	55	44	.31
Toilet transfer	45	50	.47
Bath transfer	45	50	.47
Car transfer	50	44	.44
Load W/C to car	15	31	.16
Indoor wheeling	40	31	.36
Outdoor wheeling	40	47	.42
Self-care:			
Dressing	25	31	.29
Grooming	25	28	.38
Bathing/showering	15	22	.41
Bowel & bladder	15	19	.52
Retrieve item from shelf above shoulder	30	41	.32
Sleep	35	59	.08
General Activities:			
Outings/social activities	30	28	.56
Hobby/sport	30	31	.59
Work/school	25	34	.35
Household tasks	25	44	.14
Driving	25	47	.09

W/C= wheelchair
* = figures indicate percent of the group that performs the activity and has had pain in the last six months while performing the activity.
P= P-value

Table 3.59. Use of matched pairs (n=7 pairs) to examine the effect of duration* of SCI, excluding age, on upper limb pain during ADL.

Activity	Paired Scores	Summary of Pairs' Scores Neither	Short only	Long only	Both	
Mobility:						
Pain during	-+ -+ ++ -+ ++ -- ++	1	0	3	3	
Changed method due to pain	-+ -+ ++ -+ ++ -- +-	1	1	3	2	
Needs assistance due to pain	-+ -- -+ -- -+ -- --	4	0	3	0	
Self-care:						
Pain during	-+ -+ ++ -+ -+ -- ++	1	0	4	2	S
Changed method due to pain	-+ -- ++ -- -+ -- --	4	0	2	1	
Needs assistance due to pain	-+ -- -- -- -+ -- --	5	0	2	0	
General Activities:						
Pain during	-+ ++ ++ -+ -+ -- ++	1	0	3	3	
Changed method due to pain	-+ ++ -+ -+ -+ -- +-	1	1	4	1	
Needs assistance due to pain	-+ -- -+ -- -+ -- --	4	0	3	0	

* Short duration = <15 years; long duration = $\geq$ 15 years.

** -+ = negative response (e.g. no pain) by short term paraplegic; positive response by long term paraplegic

+- = positive response by short term paraplegic; negative response by long term paraplegic

++ = positive response by short term and long term paraplegic

-- = negative response by short term and long term paraplegic

S = significant at the .05 level

3.5.4. The Activities of Daily Living Identified Most Often by the Subjects with Parapelgia as Precipitating Upper Limb Pain

Table 3.60 contains a ranked list of the percentage of subjects with paraplegia who reported upper limb pain during each of the activities of daily living examined. The percentage of the sample who reported upper extremity pain during the tasks ranged from 17% to 52%. The six activities where the most subjects (44% to 52%) reported upper limb pain were work or school, sleep, wheelchair transfers, outdoor wheeling, and driving. The four activities where the fewest number of subjects (17% to 27%) reported pain were all self-care tasks (dressing, grooming, bathing, bowel and bladder care). Approximately one third (29% to 37%) of the sample experienced upper limb pain during indoor wheelchair propulsion and various general activities (household tasks, loading the wheelchair into the car, hobby, sport, outings, social activities).

Table 3.60. Percentage of SCI sample who reported upper limb pain during specific activities of daily living including overall rank by proportion (n=52).

Activity	Percent with Pain	Overall Rank
Work/school	52	1
Sleep	50	2
Toilet transfer	48	3
Bath/shower transfer	48	3
Car transfer	46	4
Outdoor wheeling	46	4
Driving	45	5
Bed transfer	44	6
Retreive item from shelf above shoulder	37	7
Household tasks	37	7
Indoor wheeling	35	8
Load W/C to car	33	9
Hobby/sport	31	10
Outings/social activities	29	11
Dressing	27	12
Grooming	25	13
Bathing/showering	19	14
Bowel & bladder	17	15

W/C= wheelchair

CHAPTER FOUR: DISCUSSION

The discussion of the study results is divided into five sections. Initially, findings related to the paraplegic and able-bodied subjects' upper limb strength, flexibility, and pain are compared to the results of previous published investigations. Following this, the similarities and differences in upper limb function between the two samples are discussed. In the third section, the discussion focuses on the effects of age on upper limb function in the two samples. The discussion in the final two sections centres on the subjects with paraplegia; specifically the effects of duration of SCI on upper limb function, and the impact of upper limb pain on the subjects' performance of daily living activities.

4.1. The Results of Upper Limb Function in this Study Compared to Those Reported in the Literature

Strength, active range of motion (AROM), and pain data from various sources must be compared and interpreted with caution since numerous factors can affect results, including sample, equipment, protocols, exercise condition, and psychological factors (Kulig, Andrews, Hay 1984; Rothstein, 1985). Prior to discussing the results of comparisons of strength, AROM, and pain between paraplegic and able-bodied samples, it was deemed important to establish that the findings for each group were consistent with previous published descriptions of strength, AROM, and pain in their respective populations.

4.1.1. Characteristics of the Strength Results in this Study Relative to Previous Studies

Shoulder and Elbow Isokinetic Strength

Kulig et al (1984) reviewed the strength literature to compile information on the typical shapes of human strength curves. A strength curve is defined as the plot of the variation in maximum strength versus joint angle (Thistle et al, 1967). While the studies that Kulig et al (1984) reviewed were based on a mixture of isometric and isokinetic protocols, they reported that there was general agreement that for the muscles tested in this study, within the ranges tested, the strenth curve shapes were:

a) shoulder flexion: descending (as joint angle increases, strength decreases);

b) shoulder extension: ascending (as joint angle increases, strength increases);

c) shoulder adduction: ascending - descending with a plateau between approximately $90\text{-}110^0$ of abduction);

d) elbow flexion: ascending - descending with peak strength at $90\text{-}120^0$ of flexion.

Inspection of the results in this study revealed that the curve shapes attained for both paraplegic and able-bodied subjects were similar and were consistent with those described by previous investigators.

Comparison of specific strength values is difficult due to the wide variety of samples, protocols, types of strength measures, equipment used, and methods of classifying, analyzing and presenting results in the literature. To see how the present results compared with those of previous investigators, some observations can be made, particularly with regard to relationships in strength between muscle groups.

The relationships of the able-bodied subjects' isokinetic average torque scores for shoulder flexion, extension, and adduction were similar to those identified by Ivey et al (1985) in their study of isokinetic shoulder strength in 18 males (average age = 17 yr). In the present sample (average age = 44 yr), the torque generated by the shoulder muscle groups, in descending order, was eccentric adduction, concentric adduction, followed by flexion and extension which were within 3% of each other. Ivey et al (1985) also reported the greatest values for the adductor muscle group. They did however report greater differences between the shoulder flexor and extensor groups, with the flexors generating, on average, 21% less torque than the extensors. The difference in flexor-extensor strength relationships between Ivey et al (1985)'s results and this study may be related to a difference in activity levels and ages between the two samples, and the observation that persons with shoulder pathology were excluded from Ivey et al's (1985) sample but were included in this study.

In a study of dominant elbow flexion and extension, isokinetic torque in soldiers (n=352), Knapik and Ramos (1980) found flexion and extension scores at 90^0/sec were positively correlated (r=.76). The results in the present study showed similar relationships, with moderate correlations between flexion and extension torque on both the dominant (r=.76) and non-dominant (r=.67) sides. Knapik & Ramos (1980) reported dominant isometric extensor strength to be approximately 82% of flexion strength. In this study, the results were similar, with dominant isokinetic extensor average torque being 75% of dominant flexor torque, and non-dominant extensor torque being 83% of non-dominant flexor torque.

No studies of eccentric shoulder adductor strength were found. Eccentric contractions recorded in this study consistently generated more average torque than concentric contractions at the same isokinetic velocity. In the able-bodied group, eccentric adduction torque was greater than concentric by 1.9 times in the dominant shoulder and 1.8 times in the non-dominant shoulder. In the paraplegic subjects, dominant eccentric adduction was also 1.9 times dominant concentric, and non-dominant eccentric torque was 1.7 times concentric in the same limb. These relationships are in agreement with the literature where eccentric torques have been reported to be close to twice that of concentric torque (Ng, 1988; Rogers & Berger, 1974; Komi & Rusko, 1974; Komi, 1970).

Correlation co-efficients between the isokinetic strength scores for the paraplegic subjects' dominant and non-dominant limbs revealed low to moderate correlations (range of r=.53-.76). Previous investigators have reported no significant differences in isokinetic shoulder strength between upper limbs in the able-bodied (McDonald, 1988; Ivey et al, 1985). It is not clear from previous published descriptions of isokinetic upper limb strength in persons with paraplegia, whether or not the authors' conclusions are based on tests of one or both upper extremities (Kofsky et al 1983; Davis et al, 1986; Davis et al, 1980). One study that did report this information, tested only the dominant limb (Kofsky et al, 1985). The present results indicated that inclusion of bilateral upper limb strength data would provide the most complete information as to upper extremity function in subjects with paraplegia.

There are very few studies of upper limb strength in persons with paraplegia and no reports of norms for upper limb strength in this population could be located. It is clear that research is needed to establish normal upper limb muscle strength and the strength relationships between upper limb muscle groups in this population in order to aid rehabilitation planning, to maximize functional independence, to prevent injuries, and to understand the process of change over time. In those studies where shoulder strength was measured, specific muscle group strength values were either not reported (Davis et al, 1980; Davis et al, 1986) or were reported as a sum of a number of muscle groups in a variable labelled upper body strength (UBS) (Kofsky et al, 1985; Kofsky et al, 1983).

In one published study that did report isokinetic elbow flexor peak torque strength values in the lower-limb disabled (Wicks et al, 1983), the sample comprised elite wheelchair athletes and included diagnoses other than paraplegia (e.g. poliomyelitis). Comparisons with the present results must be made with caution due to sampling differences and Wicks et al's (1983) use of peak torque, which is a measure of strength at a specific joint angle, as opposed to average torque used in this study which reflects strength throughout a given range. In this study, which examined primarily sedentary subjects with paraplegia, the elbow extensor muscle group generated less torque than the elbow flexor group (dominant = 82.8%; non-dominant = 93.7%). The stronger flexor versus extensor muscle relationship at the elbow was also observed by Wicks et al (1983).

In conclusion, the comparison of the strength results in this study with those obtained in previous investigations indicates that the able-bodied isokinetic strength data compares well with that reported in the literature. The test-retest reliability of the protocol used in this study was very high (r=.921 -.982), and no other reliability assurance for an isokinetic shoulder strength testing protocol could be located. It is a higher reliability than that reported for a previously published elbow isokinetic torque protocol (r= .80 -.83) (Griffin, 1987). There are few published studies of upper limb strength in persons with paraplegia. Where comparisons were possible, the present results for elbow flexor/extensor torque relationships did not differ unexpectedly from those reported for wheelchair athletes. Based on this confidence that the able-bodied isokinetic strength data reflects that of the population, and the established high reliability of the strength test protocol, data from this study can be used to further the understanding of upper limb strength in individuals with paraplegia, its relationship to that in the able-bodied, and to examine age and duration of SCI related isokinetic strength changes.

Grip Strength

The maximum isometric grip strength scores generated by the able-bodied subjects in this study were in agreement with those obtained by previous investigators. The average maximum grip strengths of the young subjects (average age = 35 yrs) in this study were 51 kg for the dominant and 48 kg for the non-dominant hand. For the old subject group (average age = 55 yrs) the maximum grip strength values were 49 kg for the dominant and 45 kg for the non-dominant hand. In one of the very few published longitudinal studies of upper limb strength, Asmussen et al (1975) found the average maximum grip strength generated by young men (n=19; average age = 24 yrs) to be 56 kg. In a follow-up assessment, when the sample's mean age was 61 years, their average maximum grip score had declined to 40 kg. (Asmussen et al, 1975). The weaker average grip strength in Asmussen et al's (1975) older subjects, versus that observed in the older subjects in this study, may be explained by the slightly older mean age of the old subjects in Asmussen et al's (1975) study.

The maximum average grip strengths in the paraplegic sample in this investigation were 53 kg in the dominant hand, and 48 kg in the non-dominant hand. Wicks et al (1983) found similar, though slightly higher, grip strength scores for n=61 wheelchair athletes in the second and third age decades (right grip = 56 kg; left grip = 53 kg). The difference in scores between Wicks et al's (1983) results and the present study likely reflects the younger mean age and higher activity-level of the subjects in Wicks et al's (1983) study. Zwiren and Bar-Or (1975) compared grip strength between two groups of paraplegic subjects (active and sedentary) and two groups of able-bodied subjects (active and sedentary), all aged less than 40 years. The maximum dominant grip strength scores were: active paraplegic: 51 kg, sedentary paraplegic: 55 kg, active able-bodied: 58 kg, and sedentary able-bodied: 48 kg. The majority of the sample in the present study were sedentary, and the young subjects' results are in agreement with those of Zwiren & Bar-Or's (1975) sedentary subjects.

4.1.2. Active Range of Motion (AROM) Results in this Study Relative to Previous Studies

Depending on the joint and movement, between 88% and 100% of the able-bodied subjects scored within the ranges defined as normal for this study (Constant & Murley, 1987). Tables 4.1 and 4.2 show that the AROM results for the able-bodied subjects in this study compared well with those published as normal scores in the literature. Table 4.1 shows both the ranges considered as normal in this study and the norms provided by the American Academy of Orthopaedic Surgeons (1965). Boone et al (1979) measured upper limb AROM in healthy (n=56) males, aged 20-56 yrs, and Murray et al (1985b) gathered shoulder AROM data on n=20 healthy males divided into two age groups. The average scores obtained in these two studies are listed in Table 4.2.

Table 4.1 Definitions of Normal AROM for this study versus those used by the AAOS*.

Movement	Study Normal Range	AAOS Normal Range
Shoulder		
Flexion	151-180^0	158^0
Abduction	151-180^0	170^0
Internal rotation	Hand to T_7	67^0
External rotation	Hand top of head, elbow held back	90^0
Elbow		
Flexion	126-150^0	146^0

* American Academy of Orthopaedic Surgeons

Table 4.2 Upper Limb AROM norms published by Boone et al (1979) and Murray et al (1985).

Movement	Boone et al (1979) (Age 20-56)	Murray et al (1985) (Ave. Age 31yr)	(Ave. Age 62yr)
Shoulder			
Flexion	165^0	170^0	165^0
Abduction	183^0	178^0	178^0
Int. rotation	67^0	49^0	59^0
Ext. rotation	99^0	94^0	82^0
Elbow			
Flexion	140^0	-	-

No studies were located that presented norms for upper limb AROM in persons with paraplegia or wheelchair users. In this study, between 67% and 98% of the subjects scored within the ranges defined as normal for the joint motions measured. The subjects with paraplegia tended to demonstrate restricted shoulder rotation AROM when compared with the able-bodied subjects. This will be discussed in a later section.

4.1.3. Upper Limb Pain Prevalences in this Study Relative to Previous Studies

The prevalences of pain in the upper limbs of the able-bodied subjects during the past week and past 6 months compared well with those reported in the literature for the general population. Reported pain prevalences in the last week and past 6 months in this study are listed below for the able-bodied subjects.

Location	Past Week	Past Six Months
Shoulder	7.6%	14%
Elbow	0%	13%
Wrist/Hand	7.6%	9%

Reports of the prevalence of musculoskeletal pain may vary remarkably depending on evaluation protocols and sample characteristics. Silverstein et al (1986) noted that reports in the literature of wrist/hand tenosynovitis prevalences varied between 1% and 50%.

Upper limb pain prevalences have been examined in the able-bodied population as a whole (Cunningham & Kelsey, 1984; Westerling & Jonsson, 1980). But more common are those investigations that examine pain in the arms in specific occupational or athlete groups thought to be at high risk of upper limb problems (Bjelle et al, 1984; Bjelle et al, 1979; Kvarnstrom, 1983; Fry, 1986a; Bollen, 1988). Since the able-bodied sample in this study was heterogeneous with respect to occupation, sports participation, and age, one would expect upper limb pain prevalences to be low relative to studies published of samples at higher risk for these symptoms. This was shown to be the case in this study. Pain prevalences at the shoulder that have been reported in anticipated high risk groups include 16% in dentists (Shugars et al, 1987); 15% in swimmers (Hawkins & Kennedy, 1980); 42% in swimmers (Richardson et al, 1980); 14% in rockclimbers (Bollen, 1988); 15% in chicken-packers (Buckle, 1987); and 30-40% in Swedish industrial workers (Maeda, 1977). Prevalences of pain reported in the elbow include 7-14% in chicken-processors (Buckle, 1987); 15% in assembly-workers (Ohlsson et al, 1989). Prevalences of pain reported in the wrist/hand include 30% in assembly workers (Ohlsson et al, 1989); 50% in musicians (Fry, 1986b); 10% in cyclists (Weiss, 1985); and 54% in music students (Fry, 1987a).

The upper limb pain prevalences in this study were similar to those reported for the general population. Westerling & Jonsson (1980) reported a 6% prevalence of shoulder pain in a random sample of Swedish men and women aged 18-65 years. In an epidemiological survey (Cunningham & Kelsey, 1984) conducted in the United States on 6,913 adults aged 25-74 years, the prevalences of upper limb symptoms and signs reported were:

Location	Symptom	Sign
Shoulder	6.7%	3.0%
Elbow	4.2%	1.2%
Wrist	3.1%	.9%
Fingers	6.8%	4.4%

In addition to similarities in prevalences, the finding in the present study that pain occurred most often in the shoulder and wrist/hand in able-bodied persons is supported by Cunningham & Kelsey's (1984) results.

Studies of upper limb pain in wheelchair users have tended to use samples that vary in age, gender, duration, diagnosis or lesion level, and method of mobility. These are all potential prognostic variables in the study of the development of overuse related musculoskeletal degeneration in the upper limbs. The heterogeneity of the samples used in these studies, as well as differing methodologies, likely accounts for much of the variability in reported pain prevalences. It also makes their results difficult to compare. In this study, where gender, lesion level, method of mobility, and previous upper limb trauma were all controlled, the reported pain prevalences were:

Location	Pain Now	Pain in Past Six Months
Shoulder	38.5%	57.7%
Elbow	30.8%	38.5%
Wrist/Hand	40.4%	59.6%

Other studies, using mixed samples (Blankstein et al, 1985; Nichols et al, 1979) and samples of relatively shorter duration of SCI than this study (Gellman et al, 1988a) have reported persons with SCI to have shoulder pain prevalences of 35 to 51%; elbow pain prevalences of 5 to 32%, and wrist/hand pain prevalences of 5 to 48%.

In general, the results of this study confirm previous investigations of arm pain in wheelchair users. The low prevalences of elbow (5%) and wrist/hand (5%) pain reported by Gellman et al (1988a) relative to this study were likely to be due to the knowledge that 65% of the sample in the present study had a duration of SCI greater than 15 years, whereas 84% of Gellman et al's (1988a) subjects had been injured less than 15 years. Gellman et al (1988a) noted in that in their sample the prevalence of wrist/hand pain increased to 40% in those with a duration of SCI greater than 25 years.

The present study also closely examined the impact of upper limb pain on a wide variety of activity of daily living tasks. Other than two published studies that reported the prevalence of shoulder pain during wheelchair transfers (Bayley et al, 1987; Gellman et al, 1988a), no studies were located with which to compare the findings of this study as to the impact of upper limb pain on wheelchair users' daily lives.

In conclusion, the observations in this study of upper limb strength, flexibility, and pain in able-bodied persons and persons with paraplegia are consistent with those reported by previous investigators. Therefore, these observations can be compared in order to identify similarities and differences in these variables between the two groups. They can also be used to determine whether or not increased age affects upper limb function in the two groups differently, and how increased duration of SCI impacts on upper limb function in persons with paraplegia.

4.2. Comparison of Upper Limb Function Between Subjects with Paraplegia and Able-bodied Subjects

4.2.1. Shoulder Function

In summarizing the differences in shoulder function between the paraplegic and able-bodied subjects, the following should be noted:

1. the groups were similar in dynamic strength except for shoulder flexion where the able-bodied were stronger;
2. AROM was similar between groups, except the subjects with paraplegia tended to have reduced internal rotation and non-dominant external rotation, and
3. significantly more paraplegic than able-bodied persons reported shoulder pain.

Isokinetic Shoulder Strength and Active Range of Motion

Perhaps one of the most unexpected findings in this study was the similarity in isokinetic average torque scores between the paraplegic and able-bodied subjects. Average torque represents the contractile ability of a muscle or group of muscles throughout a selected range of motion, as opposed to strength at a selected joint angle. Therefore it gives a more global indication of muscle strength. In the author's clinical experience, it is often assumed that wheelchair users require stronger upper limbs than able-bodied persons in order to function independently in a wheelchair, and that persons with paraplegia who use wheelchairs develop stronger upper limbs through the training effect of their daily wheelchair activities. The results of this study with regards to the shoulder musculature do not support this assumption, and the significant strength advantage of the able-bodied in shoulder flexion is directly opposite to what might be expected.

One other study located which compared shoulder muscle strength between paraplegic and able-bodied persons (Grimby, 1980), found that isokinetic shoulder abductor strength of 5 young (mean age = 28 yrs) paraplegic subjects of varied activity levels was 20-30% greater than that in moderately trained men. However, Grimby's (1980) results must be interpreted cautiously because the strength variable was peak torque, and this reflects a muscle's contractile ability at only one specific joint angle. Furthermore, the sample size was small, the paraplegic and able-bodied subjects were not matched for activity-level, and two of the more active paraplegic subjects generated 50-100% greater values, which may have skewed the results for the whole sample considerably.

In the present study, isokinetic strength was not significantly different between the two groups for shoulder extension, concentric adduction or eccentric adduction. One possible explanation for this similarity is that shoulder extension and adduction involve similar muscles i.e. latissimus dorsi, teres major, pectoralis major, posterior deltoid, and the longitudinal head of triceps (Basmajian, 1976; Daniels & Worthingham, 1972). Thus the strength relationships of both extension and adduction between two subject groups would be expected to be similar.

Since the paraplegic and able-bodied subjects were matched for upper limb activity-level (i.e. job and leisure/recreation), any observed upper extremity strength differences could be attributed to wheelchair use. The similarity of adductor strength between the two groups seems surprising. While no published research as to the muscles utilized during wheelchair transfers could be located, it would be expected that the shoulder adductors would play a primary role in both transfers and in wheelchair push-ups for pressure relief to prevent ischial pressure sores, and to therefore be stronger in persons with paraplegia. In both movements, the body weight is lifted and held briefly in this position. The adductors would be expected to contract concentrically during the lift, isometrically while holding the trunk elevated, and eccentrically to control lowering or shifting of the body weight. The subjects with paraplegia in this study reported performing an average of 15 transfers per day. In order to prevent skin breakdown, individuals with spinal cord injuries are taught to perform pressure relief push-ups, where the arms are used to lift the buttocks up off the seat, approximately every 20 minutes. This would amount to roughly 54 push-ups during 18 waking hours. Research has shown compliance is often at a rate far below this (Merbitz et al, 1985). However, evidently, even if the adductors are important in transfers and push-ups, they are not stressed sufficiently to result in a training effect in excess of that seen in able-bodied persons.

Wheelchair propulsion is another daily living activity commonly performed by wheelchair users, and might be expected to train a shoulder strength advantage in those with paraplegia over able-bodied persons. However, neither the shoulder extensors nor adductors have been shown to play a major role in this task (Harburn & Spaulding, 1986; Cerquiglini et al, 1981; Sanderson & Sommer, 1985). Indeed, during slow wheeling, none of the muscles that were involved ever exceeded moments greater than 20% of their maximum (Cerquiglini et al, 1981).

Extremes of shoulder external rotation place a stretch on the extensors and adductors. More paraplegic than able-bodied subjects demonstrated limitations of external rotation such that they could not touch the top of their head with their elbow held back. One cause of tightness in external rotation might be that the muscles under stretch (the extensors and adductors) are tight secondary to repetitive stress or to chronic soft tissue trauma (Brown, Niehues, Harrah, Yavorsky, Hirshman, 1988). This may have resulted in a limitation of extensor and adductor muscle strength in the subjects with paraplegia in this study.

The paraplegic subjects' shoulder extensor and adductor strength may have also been limited by shoulder pain. Instructions given during isokinetic testing were to perform within the limits of pain. While only four persons with paraplegia reported pain during the strength tests, the results of the pain screening tests and interviews clearly showed that the paraplegic sample experienced more shoulder pain than their age-matched able-bodied counter parts. Thus, it is possible that they may have held back during strength testing to avoid eliciting shoulder pain.

The shoulder flexion strength advantage of the able-bodied subjects was unexpected. The advantage was most notable in those over 45 years of age (dominant: 33%; non-dominant: 21%). The shoulder flexors have been shown to provide wheelchair propulsion power but in the few studies published, the proportion of that power provided relative to other upper limb muscle groups ranges from the majority (Cerquiglini et al, 1981) to minimum/moderate (Harburn & Spaulding, 1986). Based on the findings of the present study, the loads placed on these muscles are not sufficient to result in a strength training effect. This is supported by Cerquiglini et al's (1981) report that the shoulder flexor moments generated did not exceed 20% at slow wheeling or 30% during fast wheeling. Furthermore, Harburn & Spaulding (1986) found that during wheelchair propulsion, the shoulder flexors in three subjects with paraplegia did not exceed 40% of maximum voluntary contraction (MVC).

In this study, the lower strength levels of the paraplegic subjects' shoulder flexors relative to those of the able-bodied subjects, may also have been related to the finding that the majority of paraplegic subjects in the present study were sedentary. Cerquiglini et al (1981) and Davis et al (1986) have shown that higher wheeling speeds and wheelchair sports participation make the greatest differences in paraplegic persons' shoulder flexion and abduction strength. In this study, the shoulder flexor strength differences were the greatest between older subjects. In light of Cerquiglini et al's (1981) and Davis et al's (1986) findings, in this sample, the weaker shoulder flexors may reflect an age related reduction in wheeling activity-levels by the older paraplegic subjects.

Another factor that may play a role in the weaker shoulder flexor strength of the spinal cord injured subjects may be related to the habitual range of motion through which that muscle group works in wheelchair users. It may be that the habitual range of shoulder flexion motion used for daily tasks from a wheelchair is less than that used for the daily tasks by able-bodied persons. Average isokinetic torque reflects strength throughout a given range (-15^0-150^0 of shoulder flexion in this study). As a result of functioning in the environment from a seated position, individuals with paraplegia may perform fewer tasks in the outer ranges of shoulder flexion than able-bodied persons. During wheelchair propulsion, Cerquiglini et al (1981) showed that the shoulder rarely exceeded 5-10^0 of flexion at the slow speeds and 15-20^0 of flexion at faster speeds. Thus, while the paraplegic subjects may have been stronger in the small range of shoulder flexion used in wheelchair propulsion and transfers, they may not have strength trained the flexor muscles throughout the remainder of the range. Whereas in the able-bodied, it may be that by using and training their shoulder flexors through a greater range of motion, that even though their peak strength may never exceed or even equal that of persons who have paraplegia, their average shoulder flexion strength will be greater.

The greater tendency for subjects with paraplegia to report shoulder pain may have limited the strength of shoulder flexion both as a result of deconditioning secondary to reduced use, and of efforts to protect the joint during the isokinetic testing. Those with paraplegia were more likely to test positive on the pain screening test for the following items;

a) dominant acromio-clavicular joint tenderness (young only), and
b) supraspinatus tendon tenderness.

In the pain interview, particularly in the young group (aged less than 45 years), the paraplegic subjects were more likely than the able-bodied to report shoulder pain in the past week and past six months. However, there were greater shoulder flexor strength discrepancies between the older paraplegic and the older able-bodied subjects. This suggests that factors other than shoulder pain were limiting paraplegic persons' shoulder flexor torque. One factor might have been that the older paraplegic subjects had reduced their activity-levels relative to those with paraplegia who were younger.

Shoulder Pain

In this study, shoulder pain in the past week was reported by 39% of the paraplegic sample and 8% of the able-bodied sample. This difference was significant ($p<.001$). Pain at the shoulder in the past six months was reported by 58% of the paraplegic group and by 14% of the able-bodied group. This difference was also significant ($p<.001$). Since the two samples were matched for gender, and age, and as closely as possible for past and present upper limb activity-levels (jobs, sports, and hobbies), these results suggest that wheelchair use is a factor in the development of upper limb shoulder pain. It can only be speculated as to what aspects of wheelchair use might precipitate shoulder pain, since the only published literature that examines the kinematics of wheelchair use, has investigated wheelchair propulsion.

Wheelchair mobility, including both transfers and wheeling, may stress the shoulder components. The stress involved in transfers appears to consist primarily of compressive forces, possibly with some rotation. This compression may both stress joint components and cause ischaemia in the joint region (Barber & Gall, 1991; Bayley et al, 1987; Pringle, 1984). Bayley and co-workers (1987) measured the extra-articular pressures in the glenohumeral joint during transfers. They found it increased from 3.5 to 7 times, and speculated that this chronic stress on the joint contributes to the high rate of shoulder problems observed in wheelchair users. Barber & Gall (1991) reported a case of bilateral osteonecrosis of the humeral heads in an active 37 year old paraplegic subject. They could find no factors to account for the damage, other than habitual wheelchair use. They concluded that wheelchair activities stress the vascular supply and subchondral bone of the humeral head, and osteonecrosis of this region should be considered a cause of overuse shoulder pain in persons with paraplegia.

While the chronic stresses of daily wheelchair use may contribute to shoulder problems in this group, clinical experience demonstrates that there may also be an acute, traumatic risk of damage to the shoulder during wheelchair transfers. Paraplegics who must transfer in an unfamiliar or inaccessible environment (eg. washroom, automobiles) or who perform unusual transfers (eg. to and from the floor, a tractor, a docked boat) may attempt transfers with excessive height discrepancies, or across large distances. These can stress the shoulder in biomechanically weak ranges and can entail explosive, or sudden compressive forces rather than slow, controlled movements. These higher risk, more aggressive transfers are probably more common in the younger person with paraplegia, and may explain the finding in this study that young paraplegic subjects tend to report more shoulder pain relative to the able-bodied than the older paraplegic subjects.

The amount of shoulder stress due to wheelchair propulsion would vary with an individual's activity-level. Those who wheel regularly would subject the joint to repetitive stresses. Those with sporadic wheeling levels would risk damage secondary to poor musculoskeletal conditioning and muscle fatigue. Traumatic or more acute damage might occur during wheelchair propulsion over terrain to which an individual is unaccustomed (eg. curbs, grass, gravel, ramps). Wolfe (1978) showed that wheeling on carpet rather than a smooth surface increased energy expenditure by 36-56% in paraplegic subjects.

However, other aspects of ADL, besides exclusively mobility activities, may precipitate overuse problems at the shoulder. The wheelchair user interacts with the environment from a seated position. While some do have their home and work environments adapted for wheelchair use, many do not. Many public buildings and facilities are designed for the average sized able-bodied individual (eg. bank counters, telephones, elevator controls, door handles, grocery store shelves). Therefore, a wheelchair user attempting to function in an inaccessible environment is required to use more shoulder elevation and abduction relative to an able-bodied person performing the same task.

Work in shoulder elevation has been clearly linked with the development of overuse pain and damage secondary to rotator cuff compression (Nasca et al, 1984), and muscle fatigue (Herberts & Kadefors, 1976; Kvarnstrom, 1983; Hagberg & Wegman, 1987). The forces borne by the shoulder joint increase significantly as it moves into abduction. Poppen and Walker (1978) showed that at 90^0 of abduction, the glenohumeral joint must bear resultant forces amounting to .89 times the body weight. Supraspinatus and infraspinatus muscles have been shown to be particularly sensitive to the weight of objects held in the hand when it is elevated (Herberts et al, 1984). One example of a heavy and awkward task for a wheelchair user is loading a wheelchair (average weight 12-15 kg) into and out of a car. In this study, supraspinatus region tenderness on the pain screening test was significantly associated with paraplegia.

Cervical spine disorders may precipate referred pain to the shoulder (Cailliet, 1981; Wells, 1982; Hawkins, 1990). In this study, neck pain on the pain screening test was not significantly associated more with either the paraplegic or able-bodied sample. While it was not the intent of this study to diagnose the causes of pain, it is possible that the origin of shoulder pain in a proportion of subjects was cervical spine disorder or degeneration. Nichols et al (1979), based on a mailed questionnaire to wheelchair users, concluded that a proportion of the shoulder pain described by some respondents may have resulted from cervical root problems alone, or was a combination of glenohumeral joint pathology and cervical root pathology.

In those with paraplegia, it is possible that disorders at the cervical spine level may be secondary to wheelchair use. Wheelchair use is associated with poor head and trunk posture (Bergen & Colangelo, 1985; Keegan, 1953). Forward head posture has been implicated in entrapment neuropathies of the dorsal scapular nerve, resulting in muscle weakness, and shoulder and scapular protraction, which can result in compression of neurovascular components and thoracic outlet syndrome (Darnell, 1983). Shoulder protraction can stretch the suprascapular nerve (which innervates infraspinatus, and the glenchumeral and acromioclavicular joints) leading to neuropathy (Darnell, 1983).

Cervical spine disorders causing referred pain to the shoulder often improve at night (Hawkins, 1985). The observation that the paraplegic subjects in this study were significantly more likely than the able-bodied to report their shoulder pain to be worst at night suggests that their shoulder pain was not of cervical origin. Hawkins (1985) also suggested that if shoulder pain is referred from the cervical spine, local findings in the shoulder will be absent or minimal. In the pain screening test used in this study, on 3 out of 8 items related to the shoulder, the paraplegic subjects were more likely to score positive for pain than the able-bodied. During testing, a subjective observation by the investigator was that the majority of the paraplegic subjects who scored positive for pain on the test items, appeared to experience minimal to moderate pain, rather than severe pain. Based on the findings of this study, it appears that further research is necessary into relationship between long term wheelchair use, wheelchair induced head and trunk postures, and the development of cervical spine disorders.

Shoulder pain within the previous week was reported by 39% of the paraplegic subjects; which was similar to the proportion reporting wrist/hand pain (40%). Shoulder pain during the past six months was reported by 58% of the sample with paraplegia. This suggests that their pain comes and goes, or that they had since modified their lifestyle to eliminate those activities that precipitate or aggravate shoulder discomfort. Significantly fewer able-bodied subjects reported shoulder pain for both time periods (past week: 8%; previous six months: 14%).

Clearly, this study shows that the paraplegic subjects have a greater prevalence of shoulder pain than the able-bodied subjects. Those with paraplegia were also more likely to test positive for acromio-clavicular pain and supraspinatus tendon pain. The concurrent findings of weaker shoulder flexors and limited internal rotation is suggestive of rotator cuff contracture. Overuse in the shoulder region would stimulate an inflammatory response in the soft tissues, which due to its nature, would result in rotator cuff tightening. In an examination of 94 spinal cord injured subjects, Bayley et al (1987) found the most common diagnoses of shoulder pain to be:

> avascular necrosis - 5%;
> chronic impingement syndrome - 24.5%; with
> 65% of those with impingement also having a rotator cuff tear.

They found shoulder pain to be slightly more common in the younger group, which was true, but not statistically significant, in the present study.

In this study, the paraplegic subjects were more likely than the able-bodied subjects to report their pain to be at its peak at night. In a report by Nichols et al (1979), whose sample included cervical level lesions, 31% complained of sleep loss, and 7.5% of severe sleep loss, due to their shoulder pain. Their study also agreed with the present study as to the tendency for shoulder pain to be bilateral. In the present study, the paraplegic sample was significantly more likely than the able-bodied sample to report non-dominant shoulder pain. This probably reflects the bilateral nature of wheelchair mobility tasks.

4.2.2. Elbow Function

The results of comparisons of elbow function between the paraplegic and able-bodied samples revealed there to be no difference between the two groups in elbow flexor strength, but the young paraplegic subjects were significantly stronger (21-25%) than the able-bodied subjects in extensor strength. There was no difference between the two groups for elbow flexion AROM. The subjects with paraplegia were more likely to have tenderness or pain at the non-dominant lateral epicondyle and the medial epicondyles. The paraplegic subjects were more likely to report elbow pain in the past week and during the previous six months. In the sample with paraplegia, pain prevalence at this joint was less than for either shoulder or wrist/hand pain.

Elbow Flexion Strength

The similarity in elbow flexion average torque between the two samples suggests that wheelchair use does not require elbow flexor muscle contractions of sufficient intensity so as to train greater strength in this muscle group in wheelchair users than in the able-bodied population. Previous investigations into muscle activity during wheelchair propulsion support this finding. Harburn & Spaulding (1986) found biceps to generate 10-50% MVC during wheelchair propulsion in three paraplegic subjects, particularly during the initial phase of pushing. Cerquiglini et al (1981) found biceps to be more active than triceps during wheelchair pushing but the muscle did not exceed 20% of its maximum during slow wheeling, or 40% during fast wheeling. These levels would not be expected to stimulate strength training. However, while endurance training effects may follow, these were not assessed in this study. The results of this study suggest that the performance of daily living activities in a wheelchair does not result in elbow flexion isokinetic strength advantages over the able-bodied population. Persons with paraplegia may perform isolated heavily resisted elbow flexion tasks such as lifting their body weight during transfers, pulling on grab rails, and pulling pants up over their paralyzed lower limbs, but in this sample this has not resulted in an elbow flexion strength advantage over able-bodied persons.

Pain may have played a role in limiting elbow flexion strength. However, no subject with paraplegia reported pain during testing and bicep tendon pain was not associated with either the paraplegic or able-bodied group. The paraplegic sample was more likely than the able-bodied sample to report elbow region pain during the pain interview, but this also included complaints of epicondylar pain. It appears that elbow pain did not significantly limit elbow flexion strength in either group.

Elbow Extension Strength

The elbow extensor strength advantage of approximately 18% in the paraplegic sample, was not surprising since this muscle group is acknowledged as playing a major role in wheelchair propulsion, and almost certainly in wheelchair transfers. When the strength comparison was conducted by age group, it became apparent that the strength advantage (21-25%) was primarily with the young subjects. This probably reflects their higher activity-levels when compared with the older paraplegics. The elbow extensors have been shown to be only minimally active during slow wheeling speeds (Harburn & Spaulding, 1986; Cerquiglini et al, 1981). Triceps activity was reported to be highest in the final stage of wheelchair propulsion (Cerquiglini et al, 1981). However, in high speed wheeling, Cerquiglini et al (1981) found triceps brachii involvement increased, although it never exceeded 40% of its maximum. Tupling et al (1986) found that the ability to initiate wheelchair movement was directly related to elbow extensor strength more than to any other muscle group. Specific wheelchair activities demanding impulse power include ascending ramps and curbs and traversing carpet and rough terrain. The elbow extensor strength advantage noted particularly in the young subjects with paraplegia, may reflect their greater frequencies of performing these tasks.

Further supporting the premise that it is the more demanding wheelchair tasks, such as sport, which result in elbow extensor strength gains in excess of those in able-bodied persons was Taylor, McDonnell, Royer, Loiselle, Lush, Steadward's (1979) comparison of wheelchair and able-bodied athletes. Needle biopsies of triceps brachii from six wheelchair Olympic athletes showed that group to have significantly greater fast twitch (FT) fibre area than able-bodied Olympic contenders. The slow twitch fibre area of the athletes with paraplegia was also larger, but their FT area was the largest to date found in humans.

While no studies were found that examined muscle activity during wheelchair transfers and push-ups, analysis of this task suggests that the elbow extensors play a primary role in lifting the body weight. Persons with paraplegia commonly do push-up type transfers. While the young and old paraplegic subjects in this study reported similar frequencies of wheeling and transfers, the young subjects did perform significantly more of the heavier transfers (wheelchair to floor) and daily tasks (loading wheelchair to and from car). This may indicate that the younger subjects place greater demands on triceps, and therefore have a significant strength advantage over the able-bodied, but only at this age.

Despite the disappearance of the paraplegic subjects' elbow extensor strength advantage after 45 years of age, age itself was not shown to be a predictor of elbow extension strength in the paraplegic sample. This is consistent with the view that this muscle group plays a primary role in wheelchair activities and thus undergoes daily conditioning which maintains its strength with age more effectively in the wheelchair user than in the able-bodied subject. Age did not predict an elbow extensor strength decline in the able-bodied either, however. Analysis of the daily tasks normally performed by able-bodied persons suggests that the elbow extensors would not be expected to play an important role in activities of daily living in this group. However, perhaps the elbow extension is used more with advancing age in the able-bodied to assist the hip and knee extensor muscle groups to push the body up to standing from a seated position.

Pain at the Elbow

Elbow pain during the previous week was reported by 31% of the paraplegic sample and by none of the able-bodied subjects. In the paraplegic sample, elbow pain was reported least often as compared to both shoulder and wrist/hand pain. The same rank order of pain in wheelchair users was reported by Blankstein et al (1985) and Gellman et al (1988a). However, while its prevalence was low, elbow pain in the week prior to testing was reported by one third of the paraplegic subjects in the present study. Blankstein et al (1985) reported a 32% prevalence of elbow pain in a sample of mobility aid (wheelchair and crutch) users. In this study, the average numerical rating scale score given by the paraplegic subjects of their elbow pain in the past week was 3.9/10, which is indicative of moderate intensity pain. Clearly, paraplegia is more associated with significant discomfort in this region. Further research is needed to identify the source of this pain in persons with paraplegia and whether there is elbow joint overuse, or whether the pain relates more to wrist flexor and extensor origin pathology.

4.2.3. Wrist and Hand Function

A comparison of wrist-hand function between the paraplegic and able-bodied subjects revealed maximum isometric grip strength to be similar, except among the young subjects, where those with paraplegia produced 14% stronger dominant hand grip. At all ages the paraplegic subjects were significantly more likely to report wrist/hand pain than were the able-bodied subjects.

Maximum Grip Strength

There was no significant difference in grip strength between the parapelgic and able-bodied samples when compared as a whole, or in the over 45 year age group. In the less than 45 year age group the young paraplegic subjects had significantly stronger dominant maximum grip (14%) than the able-bodied subjects. Their non-dominant grip strength may have been limited by non-dominant medial epicondyle pain, for which they were significantly more likely to test positive on the pain screening test.

Only one other study was located that compared grip strength between paraplegic and able-bodied persons. In that study, (Zwiren & Bar-Or, 1975) maximum dominant isometric grip strength was compared between sub-groups of athletic and sedentary paraplegic and able-bodied persons aged less than 31 years. The age of that sample was most comparable to the young age group used in the present study (aged <45 years; mean age = 35.1 years). In contrast to the results for the young subjects in this study, Zwiren & Bar-Or (1975) reported no difference in grip strength between paraplegic and able-bodied persons. The differences in findings may have been due to the younger mean age of Zwiren & Bar-Or's (1975) sample relative to this study, and their small sample sizes ($n \leq 13$ in each of their sub-groups), which would require large differences in grip strength in order to be detected statistically.

The apparent loss of the paraplegic subjects' 14% advantage in dominant grip strength over the able-bodied between young and old age, may be explained by a combination of factors. Linear regression showed that both age and duration of SCI predicted a decline in grip strength in the paraplegic subjects. But age did not predict a decline in grip strength in the able-bodied subjects. Furthermore, it was shown that as the duration of SCI increased, the difference in grip strength between paraplegic and able-bodied samples increased slightly. In other words, over time, the paraplegic subjects' grip strength weakened at a slightly faster rate than did that of the able-bodied. This advanced rate of decline in grip strength with time in the paraplegic sample may be connected to their tendency to have a greater prevalence of wrist/hand pain with increased duration of SCI.

The failure of the paraplegic subjects to demonstrate significantly greater grip strength than the able-bodied, may have been because the daily activities of a wheelchair user do not require excessive grip strength. On the other hand, it may be that greater grip strength is required, but that it was reduced in the paraplegic subjects secondary to the significantly greater prevalence of medial epicondylar pain in this group, relative to the able-bodied subjects. Stress to the muscles inserting on the medial epicondyle (including flexor carpi radialis and pronator teres) can be caused by overloading the wrist flexors. The association between paraplegia and medial epicondyle pain in this study suggests that activities related to wheelchair use stress the wrist flexion musculature.

Pain at the Wrists and Hands

In the pain interviews, wrist/hand pain in both the past week and previous six months was significantly associated with paraplegia and not with the able-bodied sample. In the paraplegic sample, wrist/hand pain in the past week was reported more often (40%) than either shoulder (39%), or elbow (31%) pain. A similar distribution was found for the paraplegic subjects' reports of pain in the previous six months (wrist/hand 60%; shoulder 58%; elbow 39%). Thus, in this study it is the wrist/hand and the shoulder that appear to suffer the most secondary to wheelchair use by persons with paraplegia. Blankstein et al (1985) also found that wheelchair and crutch users reported wrist/hand pain most often (48%) followed by shoulder (38%) and elbow (32%) pain.

The paraplegic subjects were significantly more likely than the able-bodied subjects to report their wrist/hand pain to be bilateral, not limited to the joints (numbness, parasthesias, and hand-cramping), intermittent, and worst during the day. Other studies tended not to report information related to the character of spinal cord injured persons' wrist/hand pain. One study (Davidoff et al, 1991) did report that 23% of their subjects described their wrist pain or parasthesia to worsen at night. In the present study, the same proportion (23%) described their wrist/hand pain or numbness to be worse at night, but more (61%) indicated it was worse during the day. Thus, activity appeared to aggravate and rest appeared to reduce the wrist/hand pain reported by the paraplegic subjects in this study.

A comparison of the mean Numerical Rating Scale scores between the paraplegic (3.4/10) and able-bodied persons (2.0/10) for wrist/hand pain in the past week showed that the paraplegic subjects perceived themselves to have slightly worse pain than did their able-bodied counterparts. This suggests that the paraplegic subjects' wrist/hand related pathologies may be more severe. However, it must be considered as well, that the paraplegic sample may have experienced more intense pain in this region because wheelchair use forces them to continue using their hands despite pain, under relatively greater loads than the able-bodied. The able-bodied population may find it more convenient or feasible than wheelchair bound persons with paraplegia, to rest and protect their wrists and hands at the onset of pain.

Reports of pain, numbness or parasthesias in the wrist/hand region were recorded as pain in this study. A wide variety of sampling techniques and data collection protocols have been used by other investigators to study pain and degenerative processes in this region in subjects with spinal cord injuries. This makes comparison of the results difficult. However, it appears that the prevalence of reported wrist/hand pain in this study is in general agreement with that reported in the literature. The majority of studies in this area have focused on the prevalence of peripheral neuropathies in this group (Tun & Upton, 1987; Aljure et al, 1985; Gellman et al, 1988a; Gellman et al, 1988b). In a study of degenerative bone and joint changes in the wrist/hand in wheelchair and crutch users (Blankstein et al, 1985), 48% of the subjects reported wrist/hand pain. Gellman et al (1988a) published much lower wrist/hand pain prevalences in paraplegic subjects (wrist = 5%; hand = 8.5%). However 84% of their sample had an SCI duration of less than 15 years, and the authors (Gellman et al, 1988a) pointed out that in those subjects injured for 25 years or more, the prevalence of hand pain jumped to 40%. This is similar to the prevalence of wrist/hand pain in the past week found in this study (40.4%) which had a sample with a longer average SCI duration (61.5% injured for 15 years or more). In one other study of persons with paraplegia (Davidoff et al, 1991), wrist/hand pain, numbness and/or parasthesias were reported by 74% of the subjects. The sample was more similar in age (mean 37.9 years) and SCI duration (mean 9.7 years) to that used in this study, and yet the prevalence rate was high relative to this investigation. There is no obvious explanation for this difference. However, Davidoff et al (1991) did not give details as to the recall period that was used when they questioned their subjects regarding pain. Their prevalence rate for wrist/hand pain is more similar to the rate reported in this study for wrist/hand pain experienced during the past six months (60%).

This study supports the majority of previously reported studies of the prevalence of wrist/hand pain in persons with paraplegia. In contrast to previous investigations, the current study considered lesion level, gender, age, upper limb activity-history and activity-level, and used a matched able-bodied reference group. Thus it is able to more confidently conclude that persons with paraplegia who use wheelchairs have a particularly high prevalence of wrist/hand discomfort at all ages. This suggests that wheelchair use places demands on the wrist and hands which can eventually result in musculoskeletal damage.

4.3. Age-related Changes in Upper Limb Function in Paraplegic and Able-bodied Persons

In this section, the results for the paraplegic and able-bodied subjects will be compared with regard to age-related changes in shoulder, elbow, and wrist/hand strength, flexibility, and pain. In any comparison of two gender, age, and activity-level matched groups of healthy individuals with normal upper limbs, if one group is found to be weaker, or less flexible, or to have more pain, then it is most probably secondary to either (or combination of) habitual patterns of use, or pathology in that anatomical region. If the functional profile of the paraplegic subjects' upper limbs changes differently with age when compared to that of the able-bodied subjects, then it may suggest the need for specific prevention and management strategies to ensure continued independence and quality of life for individuals with paraplegia.

No previous studies were found that examine changes in upper limb strength over time in persons with paraplegia. Trieschmann (1988), in her ethnographic study of long term SCI persons, noted that the respondents frequently complained of increasing weakness in their upper limbs as they grew older. Of the published studies that examine changes in strength with age in the able-bodied population, by far the majority examine maximum isometric hand grip, presumably because it is convenient to measure (Burke et al, 1953; Asmussen et al, 1961; Aniansson et al, 1983; Rice et al, 1989). Other studies of age-related upper limb strength changes are all based on isometric strength at either the shoulder or elbow. Three studies of changes in isokinetic strength with age were found, but all were of the knee extensor muscle group. As a result, comparison of the results of this study with the literature will be made where possible, but much of the data expressed in this study is unique, and aging upper limb dynamic strength is not well understood in either the able-bodied or paraplegic populations.

4.3.1. Age-related Changes in Shoulder Function

Analysis revealed that shoulder function (isokinetic strength, AROM, pain) in the paraplegic and able-bodied subjects was, for the most part, not affected differently by aging. Stated another way, for both paraplegic and able-bodied subjects, age appeared to have a similar effect on the majority of the parameters of shoulder function that were examined.

As mentioned, no published studies were found that examined changes in upper limb isokinetic strength with age, with which to compare the results of this investigation. Three such studies of lower limb isokinetic strength were located. However, it has been suggested that upper and lower limb strength differ in their response to aging due to differences in their customary activity patterns (Aniansson et al, 1983). Researchers in the area postulate that in the lower extremity, the slower postural demands associated with slowed mobility recruit less Type IIb motor units, which results in a faster decline in dynamic than isometric strength, whereas continued fast and resisted manual daily living tasks retard isokinetic strength declines in the upper limbs (Larsson et al, 1979; Vandervoort et al, 1976).

The studies of age-related strength changes in the upper limb that were located were all based on isometric strength measurements at the shoulder (Murray et al, 1985; Shock & Norris, 1979), elbow (Sperling, 1980; Aniansson et al, 1983; Pearson et al, 1985; Rice et al, 1989) and grip (Rice et al, 1989; Anniansson et al, 1983; Agnew & Maas, 1982). But changes in isometric strength with age are difficult to interpret because these are measurements of strength at one joint angle, and the angle of isometric peak torque has been shown to be very variable between subjects (Knapik et al, 1983). Furthermore, comparisons between age changes in isometric and isokinetic strength must be made with caution because the relationship between the two changes as isokinetic velocity increases. The present study used an average isokinetic value based on the subjects' average torque at 60^0/s and 120^0/s, and isometric strength has been shown to be better correlated with the slower (eg. 30^0/s) isokinetic velocities (Knapik & Ramos, 1980). It is recommended that isometric strength should not be used to predict isokinetic strength (Osternig, Bates, James & 1977). However, in the absence of any isokinetic literature in the area, the results of this research will be compared with the isometric studies, in order to highlight similarities and differences in age-related changes.

Shoulder Flexion Strength

Plots of mean isokinetic shoulder flexor strength by age decade, revealed that both the paraplegic and able-bodied samples peaked in the third decade and then either plateaued or declined only slightly until age 60. Regression analysis showed that in both samples, age predicted the shoulder flexor strength decline, and was a better predictor of this decline than activity-level. Comparison of the strength losses between peak strength and strength at age 60 years or more, showed both groups declined to a similar extent (26-34%), with the able-bodied maintaining a shoulder flexor strength advantage in the old age group. Further regression analysis revealed that the difference between the paraplegic and able-bodied subjects for shoulder flexion strength did not change with paraplegic age.

These results suggest that age affects shoulder flexor strength similarly in both groups and that with age, the effect of factors that influence shoulder flexion muscle strength, such as joint pathology or pain, and customary patterns of use, change similarly in the two groups. The results of this study are similar to previous reports of the change in overall isometric shoulder strength with age, where minimal changes were observed until age 60 (Shock & Norris, 1970). Murray et al (1985) reported slightly less declines in shoulder flexor isometric strength between young (mean age = 31 years) and older (mean age 62 years) subjects, than were observed for isokinetic strength in the present study (26-34%). They recorded a loss of 19% at 0^0 of flexion and of 16% at 45^0 of flexion. This may be explained by sampling differences and/or the possibility that isometric strength declines less or more slowly than isokinetic strength in this muscle group.

Shoulder Extension Strength

The relationship between paraplegic and able-bodied subjects' shoulder extensor strength was not shown to differ statistically as the paraplegic subjects aged. Indeed, in both groups the predictive effect of age on strength in the shoulder extensors was not conclusive. Only for the able-bodied subjects' non-dominant shoulder extensor muscles was age shown to predict a strength decline (p=.03). Both groups peaked in the 20-29 years or 30-39 year age groups, and both showed a very gradual decline until age 60.

An interesting phenomenon was revealed by the calculation of the differences between peak extensor average torque and average torque at over 60 years of age. These calculations showed that the paraplegic subjects in the two age groups were noticably less different in isokinetic extensor torque (dominant 11%; non-dominant 8%) than were the two age groups of able-bodied subjects (dominant 22%; non-dominant 31%). Cross-sectional studies of strength by age decade are subject to sampling bias in that an anomalously strong or weak age group can skew the data. However, in this study it appears curious that 22% to 34% differences in torque were observed in both groups for shoulder flexion and in the able-bodied for shoulder extension, but only an 8% to 11% difference in extension was seen between the peak paraplegic age group and those over 60 years of age. This apparent discrepancy in age-related changes in the flexor-extensor (agonist-antagonist) ratio at the shoulder in the paraplegic subjects, suggests a tendency for this group to preserve extensor strength more than the able-bodied subjects with age. This reflects the strength requirements of wheelchair use for latissimus dorsi, teres major, posterior deltoid, and the long head of triceps during resisted shoulder extension, adduction, and medial rotation. This was further supported by the regression analysis that showed activity-level to best predict dominant shoulder extensor strength in the paraplegic subjects.

The failure of age to predict declines in dominant shoulder extensor strength with age in the able-bodied seemed inconsistent with the results for the other muscles about this joint. The failure of this muscle group to be affected significantly by age until age 74, may be because with age the able-bodied begin to offset the potential strength decline due to disuse, by using the dominant upper limb more often to assist the weakened lower extremity into standing from sitting or to aid in balance during mobility.

In this study, examination of the decline in strength of the shoulder extensors, flexors, and adductors from peak in the third and fourth decades, to over 60 years of age revealed the shoulder extensors to decline the least (8% to 11% in the paraplegic group; 22% to 31% in the able-bodied). Similar relationships in the declines in isometric shoulder flexor, adductor, and extensors strengths were reported by Murray et al (1985) between 31 and 62 years of age. However Murray et al's (1985) older subjects (mean age 62 years) declined much less in extensor strength (7%) than did the older able-bodied group in this study. This may be due to differences in age-related declines in isometric and isokinetic strength or to sampling differences.

Shoulder Adductor Strength

Examination of mean concentric and eccentric adductor strength by decade, again showed the two samples to peak in the third or fourth decade and to plateau or decline in strength only slightly until age 60. The regression analysis using the paired data showed that the differences between the two groups in adductor strength remained the same regardless of age. This is the more sensitive test, because it incorporates the paired data, even though examination of the effects of age on the two groups independently suggested that age affected the able-bodied shoulder adductor group (concentric adduction:

dominant p=.002, non-dominant p=.006; eccentric adduction: dominant p=.03, non-dominant p=.04) more than the paraplegic subjects, where only dominant concentric adduction was significantly predicted by age (p=.02).

Age clearly predicted both concentric and eccentric adductor strength declines in the able-bodied, and was selected as a better predictor of strength losses in this muscle group than activity-level. Whereas, in the paraplegic sample, activity-level and duration of SCI were shown to be the best predictors of shoulder adductor strength. Furthermore, declines in able-bodied adductor strength between peak to 60 years or more were two to three times those observed in the paraplegic sample. Again, in cross-sectional studies, anomalous groups of subjects can skew the data significantly. However, given the similarity of the strength declines observed in grip and shoulder flexor strength between the two samples, this exaggeration in loss of able-bodied adductor strength seems noteworthy. As in shoulder extension, there appeared to be a relative preservation of adductor strength with age in the paraplegic subjects . This may have been due to the continued stimulus for strength training of the adductor muscle group (pectoralis major, latissimus dorsi, teres major, coraco-brachialis, long head of triceps, and posterior deltoid (Basmajian, 1976) imposed by daily wheelchair tasks.

Murray et al (1985) reported a 21% decline in isometric adductor strength, tested at 45^0 of abduction, between young men (mean age = 31 years) and older men (mean age = 62 years). Once again, this decline was less than that observed in the present able-bodied sample (dominant 41%; non-dominant 28%). This difference may result from sampling differences, or it may be that isokinetic strength declines more with age than does isometric strength in this muscle group.

In a study of age-related changes in overall shoulder isometric strength, Shock & Norris (1970) reported minimal declines until age 60 years, followed by an increased rate of strength decline. In this study, where the oldest subject was 74 years, this accelerated strength decline in the 7th decade appeared to have begun in both the paraplegic and able-bodied groups. If greater declines in strength in later life, such as the 13% in the 8th decade and 30% in the 9th decade reported by Shock & Norris (1970), were to occur in the paraplegic population, wheelchair independence would likely be jeopardized. Compounding these difficulties would be the greater prevalence of upper limb pain reported by the wheelchair users in this study.

Shoulder Range of Motion

Reduced active range of motion at the shoulder was not shown to be associated with age in the able-bodied subjects. Nor was reduced range of shoulder flexion and abduction AROM shown to be associated with age in the paraplegic subjects. Indeed, very few subjects in either the able-bodied or paraplegic samples demonstrated abnormal ranges for these movements (less than 151^0).

Table 4.3 Normal ranges of motion for the shoulder for the current study as compared to previous studies.

Shoulder Motion	Normal for this study	AAOS Average Ranges of Joint Motion (1958)	Murray et al (1985) (mean age 31 yr)	Boone et al (1979) (19-56 yr)	Murray et al (1985) (mean age 62 yr)	Walker et al (1984) (60-84 yr)
Flexion	$151\text{-}180^0$	158^0	170^0	165^0	165^0	155^0
Abduction	$151\text{-}180^0$	170^0	178^0	182^0	178^0	160^0
Int. rotation	hand to T_7	70^0	49^0	67^0	59^0	59^0
Ext. rotation	hand to top of head, elbow held back	90^0	94^0	100^0	82^0	76^0

As can be seen in Table 4.3, there is a wide variation in average shoulder ranges of motion reported for all ages (AAOS, 1958), young and middle-aged men (Murray et al, 1985;

Boone et al, 1979) and old men (Murray et al, 1985; Walker et al, 1984). Based on their results of tests of 28 upper and lower limbs, Walker et al (1984) indicated that reduced range of motion can be expected in the elderly and that an age-specific set of norms should be developed for this group. Inspection of their results for the shoulder reveals that flexion and abduction ranges are less than AAOS standards by 3^0 and 10^0 respectively. It is doubtful that these limitations would cause functional difficulties.

Subject selection criteria for the studies in Table 4.3 included the absence of shoulder pathology. Clearly, in both the paraplegic and able-bodied samples in the current study, AROM of shoulder flexion and abduction were within the normal ranges for healthy shoulders identified by previous investigations. In order to detect age-related decreases in flexibility of less than 151^0, further studies would have to be done. However, from a functional standpoint, more subtle losses may be less relevant, since for example, 120^0 of shoulder abduction has been suggested as the minimum threshold for adequate function (Bassey et al, 1989).

When the effect of duration of SCI was excluded from the examination of the effect of age on AROM using the qualitative technique of pairing paraplegics who were matched for duration of SCI but contrasted in age, there appeared to be a very slight association between increased age and reduced shoulder internal rotation bilaterally. Significantly limited active and passive internal rotation have been associated with subjects with impingement (Warner, Micheli, Arslanian, Kennedy, Kennedy, 1990). This has been attributed to posterior capsular tightening secondary to repetitive microtrauma which stimulates the reactive formation of fibrosis tissue in the capsule (Pappas, Zawacki, McCarley, 1985). Thus, limited internal rotation in the older paraplegic subjects in this study may be suggestive of capsule damage secondary to overuse.

The majority of those with limited internal rotation in this study could reach to between the T_7 and T_{12} levels (Figure 3.12, page 297). Warner et al (1990) considered reaching to T_6 as marked limitation of internal rotation. Although the habitual range of motion of wheelchair users, and muscle bulk, may play a role in the reduction of internal rotation AROM, in light of Warner et al's (1990) findings of internal rotation AROM limitations of T_6 and impingement, it is possible that capsular damage may account for some of the restriction in movement in the older persons with paraplegia. Impingement has been associated with wheelchair users. Bayley et al (1987) diagnosed impingement in 24% of 94 paraplegic subjects who used wheelchairs. Warner et al (1990) also found a relative imbalance in the internal rotation/external rotation isokinetic strength ratios in subjects with impingement, but this data was not collected in the present study.

Shoulder Pain

Although the paraplegic subjects as a group were more likely to have shoulder pain than the able-bodied subjects, pain about the shoulder was not associated with age in either the paraplegic or able-bodied samples for either the pain screening test items or the pain interview. This lack of association with age probably reflects the view that overuse damage is more associated with the nature of daily activities and the inherent stresses placed on the shoulder, than with age alone.

When tests of association were performed between paraplegic and able-bodied subjects by age group, positive pain scores were more often associated with the paraplegic subjects in the young group than in the old (dominant acromio-clavicular pain, non-dominant supraspinatus pain). In other words, old paraplegic subjects and old able-bodied subjects had similar prevalences of shoulder pain on this test, whereas the young paraplegic subjects were more likely than young able-bodied persons to report pain. This further reinforces the hypothesis that it is current techniques and more active levels of wheelchair use that precipitates shoulder pain. It may also indicate that the older persons with paraplegia had altered their wheelchair use techniques and activity-level in order to avoid aggravating their shoulders.

4.3.2. Age-Related Changes in Elbow Function in Paraplegic and Able-bodied Subjects

Elbow Strength

In both the paraplegic and able-bodied samples, age decade mean isokinetic elbow flexion and extension average torque showed very small declines with increasing age. In both groups, age predicted declining elbow flexor strength, but not extensor strength. The failure of age to predict declines in elbow extensor strength in the paraplegic subjects was not surprising, since this muscle group is acknowledged as being active during both wheelchair propulsion (Tupling et al, 1986) and transfers. However, the same result in the able-bodied was unexpected. As stated in a previous section, perhaps the able-bodied subjects offset their age-related triceps muscle weakening through more frequent use of elbow extension to push up from sitting and thereby assist the quadriceps and hip extensors in raising the body to the standing position.

The decline in isometric elbow flexion and extension torque between the peak recording and in those aged 60 or over in the able-bodied was at least twice that observed in the paraplegic sample (see Table 4.4). While this may be due to sampling anomalies, such marked discrepancies seem surprising since the paraplegic and able-bodied samples were matched for age, height and upper limb activity-level. The declines observed in the able-bodied group are greater than the 10-15% losses reported for isometric elbow flexor and extensor torque between 20-30 year olds and 70 year olds (Sperling, 1980). Similarly, McDonagh et al (1984) reported declines of 20% in isometric elbow flexion at 90^0 between aged 25 and 71. The able-bodied strength declines in this study more closely resemble the 23-34% declines in isometric torque noted by Annianson et al (1983) between those aged 70 and 75 years. It may be that the greater declines observed in this study are due to an earlier or faster age-related decline in isokinetic than isometric strength.

Table 4.4 Percentage difference in elbow average torque between the decade of peak results and those subjects aged 60-74 years.

Elbow Muscle Group	Paraplegia % decline	Able-bodied % decline
Flexion dominant	-16%	-33%
non-dominant	-14%	-30%
Extension dominant	-14%	-32%
Non-dominant	- 8%	-17%

There are no studies to date of age-related changes in isokinetic strength in the upper extremity, however, Larsson et al (1979) reported greater age-related losses in higher velocity (180^0/s) isokinetic speeds than isometric strength in the quadriceps. Two possible explanations that have been suggested for the poorer performance of the elderly at the faster speeds of movement are that they have difficulty learning to perform the movement as well, or that they have a reduced proportion of Type II muscle fibres (Vandervoort et al, 1986). The knowledge that the age and activity-level matched paraplegic subjects aged 60-74 lost only 8-16% elbow flexor and extensor strength suggests that conditioning, possibly directly related to wheelchair use, can delay age-related strength declines, and thus help to maintain independent function. It also appears that, even though the paraplegic subjects were more likely than the able-bodied to report elbow pain, this pain did not appear to limit strength. This was further supported by the regression analysis that showed that the difference between able-bodied and paraplegic elbow flexor and extensor strength remained the same regardless of age.

Further studies of persons with paraplegia beyond the 60-74 year old group (the ages of the oldest subjects in the present study) are necessary to determine whether old age in this group is associated with more dramatic and potentially debilitating declines in elbow muscle strength. Rice et al (1989) found age to be the main determinant of upper and lower limb strength in 62-102 year olds. Based on existing reports, age-related strength declines do accelerate beyond the 7th decade (Shock & Norris, 1970; Agnew & Mass, 1982). Given the importance of the role of the elbow flexors in ADL and the elbow extensors in wheelchair mobility, it is important that these reported declines be countered by the maintainance of appropriate strength conditioning programs.

Elbow Range of Motion

In both subject groups, virtually all of the participants had normal ($126-150^0$) range of elbow flexion (paraplegia 98%; able-bodied 100%). Consequently, a reduction in flexion AROM was not associated with age in either group. Based on the few published studies of age-related changes in elbow flexibility in healthy adults, it appears that the active flexion range remains fairly constant. The norm for elbow flexion reported by the American Academy of Orthopaedic Surgeons (1965) is 146^0. Boone et al (1979) recorded an average range of movement of 140^0 in 19-54 year old men. Walker et al (1984) found a very similar average elbow flexion AROM of 139^0 in 60-90 year olds. Therefore, it appears that paraplegic and able-bodied persons' elbow flexion range of motion responds similarly to advancing age.

Pain at the Elbow

Neither pain reported at the elbow in the interviews, nor positive scores on the pain screeing test were associated with age in either the paraplegic or able-bodied subjects. Thus, while the paraplegic subjects as a group, were more likely to experience pain in the elbow region, that prevalence was not shown to be associated with age. More influential than age however, may be the nature of the individual's lifestyle and the stresses to which all joints, including the elbows are exposed.

4.3.3. Age-related Changes in Wrist and Hand Function in the Paraplegic and Able-bodied Subjects

Comparison of changes in maximum isometric handgrip by age decade for both the dominant and non-dominant hands of the paraplegic and able-bodied subjects showed both groups peaking in strength in the 3rd or 4th decade, followed by very slight and gradual declines to the 60-74 year old age group. This is consistent with the findings of previous investigators who have reported minimal or very gradual declines in grip strength until approximately the 6th decade (Burke, 1953; Agnew & Maas, 1982; Shock & Norris, 1970). After this, some researchers (Shock & Norris, 1970; Agnew & Maas, 1982; Burke et al, 1953; McLennan et al, 1980) but not all (Aniansson, 1983), report the decline in grip strength accelerates from, for example, 13% in the 8th decade to 30% in the 9th decade (Shock & Norris, 1970). It has been postulated that upper limb muscle strength is preserved more with age than is evident with the lower limbs, through the ongoing training associated with the performance of ADL tasks which focus on upper limb strength and ability (Sperling, 1980).

The decrements in grip strength between peak and 60-74 year old age groups in this study were 10%-16% bilaterally for the paraplegic and able-bodied samples. While comparison with other studies is complicated by sampling and age group differences, this appears to be slightly less than the declines reported by other investigators. Between peak grip and grip at age 65 or 70, declines have been reported of 21% (Burke et al, 1953), 23% (Asmussen, 1961), 25% (Sperling, 1980), 27.7% (Asmussen et al, 1975), 35% (Kellor, Frost, Silberberg, Iverson, Cummings, 1971), and 49% (Ufland, 1933).

However, all but Asmussen's (1975) investigation were cross-sectional studies and used non-random sampling, therefore, variations, particularly activity-level and age distributions, could have affected the results (Petrofsky & Lind, 1975). Clement (1974) reported that the decline in grip strength with age in longitudinal studies may be as much as 60% versus roughly 40% reported in some cross-sectional studies. He attributed this to the knowledge that there are fewer weak subjects in the older cohorts secondary to natural selection. Asmussen's et al (1975) longitudinal study results of 27.7% grip strength decline over 30 years did not bear this out.

The difference in the grip strength decline with age between Asmussen et al's (1975) investigation and the present study may relate in part to sampling differences. All of Asmussen et al's (1975) subjects were from a temperate climate with a cold winter, whereas this study was conducted in a sub-tropical climate. This may result in lifestyle differences that affect grip strength. Interestingly, one other study with findings similar to those of the present study (8% decline in grip from peak to 56-65 years) was conducted on subjects living at the same longitude, also in Australia (Agnew & Maas, 1982).

While it is of interest to contrast the findings of this study with previous investigations, many factors affect muscle strength, including height, weight, health, and socio-economic status, and it is very difficult to compare with studies in the literature (Clement, 1974; Sperling, 1980). Since this study did match for age, gender, height, weight, and upper limb activity-level, comparisons of strength changes with age between the two samples are more reliable than comparisons with the literature where such matched samples are absent.

In the current study, age was shown to be a significant though very weak predictor of grip strength bilaterally in paraplegic subjects (dominant p=.0002; non-dominant p=.002), but not in the able-bodied (dominant p=.07; non-dominant p=.2). Analysis to determine the best predictor (age, duration, activity-level, lesion level) of grip strength in the paraplegic sample showed duration of SCI to be the best predictor bilaterally (dominant p=0001; non-dominant p=.0002). In the able-bodied, activity-level was the best predictor of grip strength bilaterally (dominant p=.01; non-dominant p=.01). This was interesting because for all other muscle groups tested in the able-bodied, age was identified as the best predictor of strength. The failure of age to predict strength in the able-bodied group is consistent with the literature on grip strength in healthy adults, where declines in grip strength are more noticeable after the 6th decade (Shock & Norris, 1970; Pearson et al, 1985; Burke, 1953; McLennan et al, 1980; Agnew & Maas, 1982).

As stated above, regression analysis showed that age predicted declines in grip strength in the paraplegic subjects, but not among the able-bodied. However, when the difference between paraplegic grip strength and able-bodied grip strength was plotted against paraplegic age, the slope of the regression line was not significant. This latter analysis is a more sensitive test of whether age affects the grip strength of the two samples differently, because it incorporates the paired data. Therefore, based on these results, it can be concluded that age has a similar minimal effect of decreasing maximum grip strength in both paraplegic and able-bodied persons up to the age of 74 years.

McLennan et al (1980) found that age was the best predictor of declining grip strength in persons over 65 years. Should this apply to the paraplegic population, it would be expected that beyond the 6th decade, age-related losses in grip strength would become more apparent and could interfere with independent function. Other studies also suggest that more marked declines in strength occur after the 6-7th decades of life (Burke et al, 1953; Rice et al, 1989).

Until very recently, comparatively few persons with paraplegia have survived to these older ages. This study shows that until age 74, paraplegic subjects'grip strength declines similarly to that of the able-bodied. Should it continue to follow the same pattern as in the general population, the more significant strength losses in later life may have critical implications for independence in this group. Investigators are now emphasizing the important positive effect of activity for maintaining strength in old age, and for avoiding the reductions in functional independence due to weakness caused by disuse (Grimby, 1988; Shephard, 1986; Clement, 1974). Aniansson et al (1983) and McDonagh et al (1984) suggest that grip strength is maintained into the 7th decade because the hands continue to perform fast and forceful movements associated with ADL, which continue to recruit Type IIb motor units. If those with paraplegia are encouraged and able to continue to be as independent as possible, age-related grip and upper limb strength losses, with associated losses of independence, could be reduced.

Pain in the wrist/hand region was not associated with age in either the paraplegic or able-bodied subjects. The paraplegic subjects were more likely than the able-bodied subjects to report wrist/hand pain, and analysis showed that the pain prevalences were similar for young and old persons with paraplegia.

4.4. The Effect of Duration of Paraplegia on Upper Limb Function

4.4.1. Pain in the Upper Limb and Duration of Paraplegia

Few studies have attempted to discern the effects of chronological age versus duration of SCI on the development of upper limb pain in paraplegia (Aljure et al, 1985; Tun & Upton, 1987; Gellman et al, 1988a; Gellman et al, 1988b; Davidoff et al, 1991). All but one of these (Gellman et al, 1988a) focused exclusively on the development of compressive neuropathies in the wrist and hand. The results of these studies are mixed. Three concluded that increased duration of SCI was associated with signs and symptoms of compressive neuropathies, and three found no association. The most obvious reason for the variation among findings was the differences in clinical assessment and electrodiagnostic procedures used (Davidoff et al, 1991).

Age and duration of SCI were shown to correlate in the present study (r=.68) and it would be expected that this would be the case in most paraplegic samples. None of the studies referred to above indicated that they controlled for age in order to examine the independent effects of the duration of paraplegia. Gellman et al (1988a), examined the association of duration of SCI and pain at the shoulder, elbow, wrist and hand. Based on frequency distributions, he concluded that increased duration of SCI was associated with the development of upper limb pain. However, the confounding effects of age were not excluded from Gellman et al's (1988a) analysis.

In the present study, it was considered important to examine the independent effects of duration of injury on the development of upper limb pain. A review of the literature revealed that persons with long duration paraplegia are classified as those injured for more than 15 or 20 years. In the United States, the majority of traumatic SCI's occur in the 16-20 year old age group. The mean age of injury is 29.7 years and the modal age (most common age of injury) is 19 years (Stover & Fine, 1986). This means that, by the time these men reach the "long duration of SCI" category they will still be relatively young (34-45 years of age). Therefore, if duration of SCI, exclusive of age, is associated with the onset of overuse related upper limb pain in this population, it could begin causing problems in persons as early as the fourth age decade. This knowledge would have significant clinical implications and would direct preventative approaches to the problem.

Age was excluded from the examination of the effect of duration of SCI in the current study by selecting from the paraplegic sample as many pairs as possible of the same age and past upper limb activity-level, who differed in duration of SCI by at least ten years. Results of the tabulation of the pain interview data revealed that shoulder pain at the time of the interview and in the past six months was statistically associated with duration of paraplegia of greater than 15 years, exclusive of age ($p<.05$). Wrist/hand pain was more common in the longer duration paraplegics, but the association was not statistically significant (pain in past week $p<.2$; pain in past 6 months $p<.1$). However, the sample of seven pairs used in this study was small. Further investigations with larger samples are needed in order to draw definitive conclusions as to the independent effects of duration of SCI on the development of wrist/hand pain. Pain at the elbow was not associated with duration of SCI. The findings in this study are consistent with Gellman et al (1988a) who reported that increased duration of SCI appeared to be associated with the development of shoulder and wrist/hand pain but not with elbow pain.

The findings of this study suggest that the upper limb joints of all paraplegic subjects (and especially the young) should be carefully observed and evaluated for the possible developement of pain and/or pathological changes. Such changes may result from overuse. Werner, Waring, and Davidoff

(1989) found that persons who had had poliomyelitis who used canes, crutches, or a wheelchair, had four times the risk of developing median nerve neuropathy. Davidoff et al (1991) reported that abnormal electrodiagnostic findings can exist in subjects with paraplegia exclusive of complaints of pain. This suggests that complaints of pain (at least at the wrist), can come after degenerative changes have already begun to occur.

Tabulation of the paired results for the pain screening test items showed that more long duration than short duration paraplegic subjects tested positive for pain on most items. However, none of the tests of association were significant. This study used a small paired sample, and it is likely that a larger sample would show more definitive results. While the pain screening test was not intended as a diagnostic tool, it is interesting that the shoulder pain reported by the subjects in the interview was not always elicited by the screening test movements for acromio-clavicular pain, impingement pain, supraspinatus tendon pain, or bicipital tendon pain. Barber & Gall (1990) detected bilateral osteonecrosis of the humeral head using radiographs in a paraplegic subject who complained of increasing dull aching in the shoulders. They noted that numerous provocative manual tests about the shoulder were negative. It has been observed that even when a comprehensive battery of tests (X-ray, bone scans, electrophysiological tests, serology, and biopsy) and thorough physical examinations are conducted, occupationally related upper limb pain can be difficult to diagnose (Sikorski, Molan, Askin, 1989). In a study aimed at identifying discrete musculoskeletal diagnoses for occupationally related arm and neck pain in 204 subjects (Sikorski et al, 1989), a firm diagnosis could be made in 37% of cases, a diagnosis without the support of laboratory tests (eg. for tendon disorders) was made in 21% of cases, and in the remaining 42% the clinical pattern did not fit any definable musculoskeletal problem. The authors suggested five alternatives to explain the complaints of pain in this latter group. These were:

a) poor physical conditioning,
b) an as of yet undefined physical disease,
c) psychosomatic disorder,
d) iatrogenic disorder, or
e) that their claims were fraudulent.

While in a work setting it might be believable that individuals would fraudulently claim arm pain in order to avoid work or obtain disability benefits, persons with long term paraplegia stand to gain virtually nothing from fraudulent complaints of upper limb pain.

4.4.2. Duration-related Changes in Range of Motion

Reduced shoulder and elbow range of motion was rare in the paraplegic subjects except for shoulder external rotation (non-dominant 21%) and internal rotation (dominant 33%; non-dominant 29%). No significant associations between reduced AROM and duration of SCI, excluding age, were found using the matched pairs. While there was an association between the prevalence of shoulder pain and duration of SCI, restrictions in shoulder flexion, abduction and rotation flexibility appeared to be distributed equally among the longer and shorter duration subjects. However, results in this case are based on only seven pairs. Further investigation with a larger sample is needed before conclusions can be drawn.

4.3.3. Changes in Isokinetic Strength Related to Duration of SCI

In order to exclude paraplegic age when testing for the effects of duration of SCI on isokinetic shoulder and elbow strength and isometric hand grip, regression analysis was used. This was intended to determine whether or not paraplegic duration of SCI predicted the difference between paraplegic strength and normals (the able-bodied pairs). Statistical significance was achieved for grip strength only.

In the present study, shoulder pain prevalence was shown to increase with the duration of SCI, exclusive of age. However, range of motion and isokinetic shoulder flexor, extensor, and adductor strength were not shown to be affected by duration of injury, exclusive of age. The strength of internal and external rotation, horizontal flexion and extension, and abduction muscle groups was not tested, as these movements were deemed to be more secondary contributors in wheelchair activities. However, weakness in some of these groups may have been present and may have been related to duration of SCI. The results of this study suggest that while long duration paraplegia is associated with more shoulder pain, shoulder strength (flexion, extension, concentric and eccentric adduction) is not reduced compared to age-matched able-bodied persons.

Conversely, for the hand, the longer duration paraplegic subjects were shown to have a greater prevalence of wrist/hand pain and to also show slightly more rapid declines in grip strength over time than is normal for able-bodied persons of their age group. This may have been related to epicondylar pain secondary to inflammation of the insertion of the wrist flexors and extensors or to other degenerative changes in the hand such as SLAC wrist (Watson & Brenner, 1985) or damage to the TFCC (Palmer, 1987). Blankstein et al (1985) showed a variety of pathological radiographic findings in the wrists and hands of 50 wheelchair and crutch-users. The most common were arthroses of the trapezio-metacarpal and radio-scaphoid joints. While X-rays only indicate degenerative change or bony pathology, they are often useful indicators of potential pain sites (Pierro, Berens, Crawford, 1989). The longer duration subjects' discomfort may have also been secondary to compressive neuropathies. As stated earlier, the literature is not clear regarding the association between median or ulnar nerve compression and duration of SCI, but three studies have shown a positive relationship between these two variables (Aljure et al, 1985; Gellman et al, 1988b; Gellman et al, 1988a).

In summary, while duration of SCI does not appear to accelerate changes in upper limb strength (except for grip) or range of motion, beyond those which occur with age in the able-bodied population, in this study there was a greater prevalence of shoulder and wrist hand pain in paraplegic subjects of more than 15 years duration, regardless of their age. The extent of the impact of this pain on the paraplegics' daily functioning will be discussed in the next section. But regardless of its impact on their ability to continue to perform daily tasks, it causes many of them considerable discomfort. This suggests that regardless of age, persons with paraplegia should be watched closely for the development of over use related upper limb problems. It also points to a need for preventive management approaches for wheelchair users that may include strengthening and flexibility programs, increased attention to the ergonomics of wheelchair tasks, and to the design of their environments and equipment, and early monitoring to identify degenerative pathology and institute corrective procedures.

4.5. The Impact of Upper Limb Pain on Activities of Daily Living (ADL) Performance in Paraplegia.

In this sample of persons with paraplegia (n=52), whose mean duration of SCI was 17 years and mean age was 44 years, 17-52% reported that they experienced upper limb pain during specific ADL tasks. Average numerical rating scale scores for those reporting pain in the previous week were; shoulder 4.5 out of 10, elbow 3.9 out of 10 and wrist/hand 3.4 out of 10. This represents moderate pain levels. The proportions of paraplegic subjects reporting upper limb pain were similar for: a) mobility tasks (60%), b) self-care tasks (58%), and c) general activities (60%).

4.5.1. The Effect of Age and Duration of Paraplegia on Upper Limb Pain During Activities of Daily Living

Complaints of pain during ADL were not associated with young or old age. Before age was excluded, there was an association between duration of SCI of greater than 15 years and reports of pain during self-care ($p<.05$), but not during mobility or general activities. When age was excluded using the paired data (9 pairs) there did appear to be an association between pain during these latter groups of activities and increased duration of SCI. The questionnaire item regarding pain asked whether or not the subject currently had pain while performing the task. Thus it did account for subjects who may have stopped performing an activity that aggravated their upper limb pain. The association between pain during self-care and duration of SCI may have achieved statistical significance, even before age was excluded, because it may be be the last realm of activities that persons with paraplegia can or want to give up performing independently. The lack of association between age and upper limb pain during ADL was not surprising since the pain interview, and pain screening test analyses, did not show upper limb pain to be related to increased age in this group.

4.5.2. Specific ADL Tasks Where Upper Limb Pain Occurred

Wheelchair transfers were one of the most common causes of upper limb pain. Between 44-48% of the sample reported pain during bed, car, bath/shower, and toilet transfers. Previous investigators (Bayley et al, 1987; Gellman et al, 1988a) have reported that slightly lower proportions of their samples had pain during transfers (32.9%; 30% respectively). But, whereas in the present study complaints of pain anywhere in the upper limb during transfers were recorded, these previous studies focused only on shoulder pain. Sampling differences might also account for the higher prevalence of transfer related pain in the present study. Bayley et al's (1987) sample included over 22% of cervical lesions, and only 15% of Gellman's et al (1988a) sample had been injured over 16 years. In contrast, the mean duration of the present sample was 17 years. Gellman et al (1988a) did report that the number of paraplegic subjects complaining of upper limb pain increased dramatically after 15 years duration of SCI. The present study supports this. Based on the findings of this investigation, studies of upper limb pain in long term paraplegia should use samples of sufficient duration of SCI, for example a mean of 15-20 years.

The pain experienced during wheelchair transfers may be related to the stresses placed on the wrists and shoulders by the raised intra-articular pressures in these regions during the loading phase of a transfer (Bayley et al, 1987; Gellman et al, 1988b). During the weight-bearing phase of a transfer, shoulder intra-articular pressure has been shown to increase from between 40 and 80 mmHg to up to 280 mmHg (Bayley et al, 1987). Paraplegic subjects with carpal tunnel syndrome were found to have greater intra-articular wrist pressures than an asymptomatic group during lifting of the body weight onto the hands (Gellman et al, 1988b).

Another possible etiological factor in the development of shoulder pain in wheelchair users, that to date has not been discussed in this area of the literature, are the stresses on the shoulders during wheelchair propulsion. During wheelchair propulsion the shoulders are held in abduction while force is applied by the hands to the handrims. Abduction to 45^0 has been shown to compress the rotator cuff (subscapularis, supraspinatus and infraspinatus) (Nasca et al, 1984). This stress on the muscle tendon unit has been shown to predispose the shoulder to damage (Nasca et al, 1984). Poppen and Walker (1978) also showed that abduction stresses the glenohumeral joint, such that 90^0 of abduction places resultant forces of .89 times body weight on the joint. Presumably, the push phase of wheelchair propulsion would only exacerbate these stresses.

These studies also suggest that shoulder pain would be more likely to develop in wheelchair users who must function in environments that are designed for the able-bodied person. This would require frequent work with the shoulders in elevation in order to reach work surfaces and related items. Environments designed for the ergonomics of the wheelchair user would minimize these elevated postures.

Overall ranking of the pain prevalences during the 18 tasks on the ADL questionnaire revealed upper limb pain to occur most often during:

a) work/school (52%),
b) sleep (50%),
c) transfers (44-48%),
d) outdoor wheeling (46%), and
e) driving (45%).

At first glance, these are a diverse group of tasks. However, they have some common ground in that they are probably the most difficult tasks to eliminate, and other than sleep, all involve significant upper limb work. Furthermore, they probably are not mutually exclusive in that attending work (paid or volunteer) or school usually involves bed, toilet, bath, and car transfers, outdoor wheeling, and driving. It appears then, that not only is arm pain interfering with functional tasks during the waking hours, but it is also disturbing sleep to some extent in 50% of the paraplegic sample.

Some of the tasks where pain was experienced by fewer subjects also involve heavy upper limb work (loading wheelchair in/out of car (33%), hobby/sport (31%), outings (29%)). The lower prevalences of pain recorded here may indicate that subjects who had significant upper limb pain during these activities had begun to avoid them. A number of the respondents stated that they had purchased automatic wheelchair car loading devices, some due to upper limb pain and others for convenience.

The relatively lower prevalence of pain during many of the self-care tasks (dressing 27%; groooming 25%; bathing 19%; bowel and bladder 17%) suggests that were this group to require assistance or attendant care to relieve or rest their upper limbs, it would not be required during these activities. Indeed, the activities where upper extremity pain was experienced most often tended to include those tasks that enable interaction in the community and that are associated with roles that are important for independence and self-esteem. Thus, increased upper limb pain would possibly jeopardize independence in these activities first of all.

4.5.3. Modification in ADL Routines Due to Upper Limb Pain

More paraplegic subjects reported that arm pain had caused them to change their methods of performing mobility tasks (33%) and general activities (35%) than self-care tasks (23%). These changes included reduced frequency, using assistive devices, re-organizing workspace, and changing techniques. Self-care tasks are generally lighter in terms of upper limb work required, and upper limb pain may not have been sufficiently aggravated by them so as to necessitate lifestyle changes. On the other hand, the fewer changes may have been made to self-care routines as a result of the subjects ignorance of what modifications to make to reduce the occurence of pain.

Roughly 60% of the subjects reported pain during mobility, self-care, and general activities, but only half had made changes in their ADL routines in order to deal with this pain. The making of changes was not associated with age or duration of SCI. There are a number of possible explanations as to why so few subjects had attempted to deal with their discomfort. Firstly, the NRS scores indicated that on average, the pain was not severe. It may be that for many of the subjects the pain intensity was not sufficient to warrant or bother with changes in their usual routines.

Secondly, the subjects may have been resistant. They may have believed it to be a sign of weakness to begin to use assistive devices, or to admit to having to change techniques. A third reason may be that the paraplegic subjects lacked the resources, including information or financial, to understand the causes of the pain, or to identify and implement effective changes. Limited finances for equipment is an unlikely factor due to the existence of socialized government insurance schemes in Australia.

However, lack of knowledge of how to manage their upper limb pain did appear to be a problem. During the interviews it was clear that only a minority of the subjects had sought medical attention because of their upper limb discomfort. Many seemed to expect the prescription would be either invasive treatment (steroids or surgery) or rest. They were fearful of the former and did not see the latter as feasible. It was apparent that they were concerned about the future implications of their present upper limb pain, but they lacked the knowledge of how to prevent and manage strains and overuse. In addition to knowledge of how to manage acute strains, and exercise and movement programs to benefit joint tissues and overall physical conditioning, this group would benefit the most from information regarding preventative and alternative ADL methods. They indicated that rest was not an option since it meant depending on others and curtailing rewarding activities. With knowledge of a variety of ADL techniques, they could avoid repetitive stresses and rest painful areas by alternating methods.

4.5.4. Utilization of Assistance with ADL Tasks Due to Upper Limb Pain

While close to 60% of the paraplegic subjects reported upper limb pain during ADL, and 23-35% had changed their ADL techniques as a result of the pain, few of them had sought assistance with these tasks because of pain in their arms. It was with mobility tasks (wheeling and transfers) that the most (15%) had sought help. Review of the raw data revealed that in most cases this was assistance with outdoor wheeling and less often with transfers. This may be because it is possibly easier and more acceptable for a paraplegic to allow another person to assist by pushing the wheelchair over distances, or rough ground or up inclines, than it is to get more personal assistance such as help with a transfer. However, while the majority of the literature to date has indicated that it is the stresses of weight-bearing during wheelchair transfers that are important in the development of upper limb problems in wheelchair users (Bayley et al, 1987; Gellman et al, 1988a), the findings of this study suggest that the role of the kinematics and stresses of wheelchair propulsion may have been underestimated.

The paraplegic subjects in this study had transferred on average 14 to 18 times a day during their years in a wheelchair. Relative to the distances and terrain over which many of them might wheel during the course of a day, transfers alone may be a less significant musculoskeletal stressor. In addition, it should be considered that the source of upper limb wear and tear or damage may not be the routine transfers or the repetitive smooth terrain wheeling. It may be the unfamiliar transfers or wheeling in poorly designed environments (curbs, rough ground) that exposes the muscles and joints to sudden stresses for which they are not adapted. Further research is needed to understand the kinematics of wheelchair transfers as well as of wheelchair propulsion as performed by the average paraplegic rather than the elite disabled athlete, and over less than ideal surfaces. This would have application in wheelchair design and suggests that the planning of environments that are ergonomically suited to the wheelchair user are not only important for their convenience, but in the reduction of overuse pathologies in their upper limbs.

Upper limb pain had prompted 10% of the paraplegic subjects to seek assistance with general activities and 6% to seek assistance with self-care tasks. This statistic represents the number who had actually sought assistance due to upper limb pain. It does not represent the number who might have needed assistance but did not use it due to pride, ignorance, limited finances, or because none was available. As discussed earlier, self-care tasks are less demanding on the upper limbs than mobility related tasks. In addition, the subjects were probably less inclined to seek help with these more personal activities. General activities, such as work, outings, and household tasks involve heavier upper limb work including wheelchair propulsion and transfers.

The information that 6-15% of the subjects, depending on the task, were currently using assistance with daily activities due to upper limb pain, has implications both for their self-esteem and quality of life, as well as health care costs. Similar disadvantages and costs would be associated with ADL technique changes that required additional assistive devices such as an electric wheelchair or automobile wheelchair loading device.

4.6. Conclusions and Implications for Clinical Practice and Further Research

In conclusion, no previous study was located that has compared the prevalence and nature of upper limb pain, strength, or flexibility, in the long term wheelchair user, with matched able-bodied subjects. Nor was any research found that examined the impact of upper limb pain on activities of daily living performance by persons with paraplegia.

This study shows that upper limb strength was not significantly different between able-bodied persons and persons with paraplegia, except for bilateral shoulder flexion (able-bodied stronger, and bilateral elbow extension (paraplegia stronger). Based on this result, it appears that to live independently in a wheelchair in the community does not require significantly greater upper limb strength than normal. This suggests that current practices in rehabilitation of focusing on maximizing upper limb strength in wheelchair users, need to be questioned and re-evaluated. It is important to note, however, that this study looked only at one type of strength (isokinetic), and it did not examine endurance.

Strength changes with age were similar for the paraplegic and able-bodied groups. However, whereas age was the best predictor of strength in the able-bodied, results for subjects with paraplegia showed that duration of SCI and activity-level were more important strength predictors in nine of fourteen muscle groups tested. The findings showed persons with paraplegia to be more likely to experience pain at the shoulder, elbow, and wrist/hand, and the pain also appeared to be associated more with duration of SCI than with age. These findings suggest that persons with paraplegia may indeed experience premature aging of musculoskeletal function (decreased strength, increased pain) associated with increased durations of paraplegia. Indeed, the paraplegic sample in this study was relatively young (mean age = 44 years). They had also only been spinal cord injured for relatively short time (mean duration of SCI = 17 years), considering that the mean age of SCI is 29 years (Stover & Fine, 1986), and the life expectancy of persons with paraplegia is close to that of the able-bodied population. Statistically, this group has many years of wheelchair use ahead of them, and their already significant levels of upper limb pain and weakness may be an indication of future and more intrusive upper limb problems. This has important implications for a number of groups.

The paraplegic population needs to realize the importance of respecting and protecting their upper limbs as an essential resource to their continued independence. Service delivery planners and those who determine insurance settlements need to consider that upper limb pain and weakness, and subsequent difficulties with the independent performance of ADL should be expected to develop in this population, and that the onset appears to occur after ten to fifteen years or sooner, post SCI, regardless of age.

The findings have numerous implications both for persons with paraplegia and those working with them, including occupational therapists, physical therapists, trainers, and coaches. Limited bilateral shoulder internal rotation and non-dominant external rotation were associated with paraplegia. The subjects admitted to being ignorant of training and conditioning techniques. This group should be educated regarding joint protection and upper extremity conditioning techniques, including strengthening and flexibility programs. Strength in the muscles and tendons surrounding joints is acknowledged as having a protective effect, particularly during unusual or sudden movements (Knight, 1980; Rowe, 1988). They need to educated about the importance of warming up before stressing the upper limbs, including, for example, before the first transfer out of bed in the morning. They also need to understand that musculoskeletal training benefits are limited to the range of motions within which the training took place. Therefore, they must exercise caution or avoid sudden or unusual stresses for which their arms are not trained, such as toilet transfers in inaccessible washrooms, long distance pushes which they have not trained for gradually. Coaches and trainers need to understand the importance of ensuring that wheelchair using athletes progress their training appropriately. Unlike the able-bodied athlete, they cannot easily rest the upper limbs after a training session. This creates fertile ground for overuse injuries.

Health care clinicians need to watch for the early onset of upper limb problems while these persons may still be chronologically young, but are five to ten years post SCI. Upper limb pain during ADL was reported by the majority of the subjects with paraplegia, but relatively few had made changes or sought assistance with ADL in order to deal with the pain. There appears to be a need for both preventative and management treatments. They need to be encouraged to consult with health care service providers as soon as pain or overuse problems begin. Problem-solving and treatment strategies will have a greater chance of being effective if begun early. Early identification of overuse problems may allow intervention before the condition becomes chronic. For persons who use a wheelchair, it is important to ensure the availability of appropriate assistive devices. Of particular importance are ergonomically designed personal and public environments that minimize the stresses on the upper limbs with features such as lowered work and storage surfaces, and barrier-free entrances and facilities. There is a need to educate persons with paraplegia as to work simplification and alternative ADL methods so that they can reduce heavy or repetitive stresses on their upper limbs. The skills to perform a variety of transfer, and even propulsion, techniques would enable a person not only to avoid problems associated with repetitive use, but also to problem-solve safe movements when in an unfamiliar environment, and to be able to alternate techniques if the early signs of overuse occur.

Clinically, these results point to the need to monitor persons with paraplegia regardless of their age, for the development of overuse pathology in the upper limbs. If the upper limbs of those with paraplegia are prone to the development of overuse problems, then wheelchair users whose upper extremities are already compromised by weakness and muscle imbalance (e.g. quadriplegia, poliomyelitis, degenerative neurological conditions) may be especially at risk. The findings of this research, compared to those of previous studies with younger and more recently spinal cord injured subjects, indicates that future investigations of upper limb overuse in wheelchair users should use samples with a mean duration of SCI of at least 17-20 years.

Further research needed in this area includes information that will add to the understanding of the kinematics and biomechanics of wheelchair use by the typical user, as opposed to the elite athlete. There is a need for the implementation and evaluation of upper limb overuse prevention and management programs for persons who use wheelchairs. There is also a need for more research that examines the effects of time on persons with spinal cord injury, with consideration of both the impact of increased chronological age and increased duration of spinal cord injury.

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DEMOGRAPHICS AND ACTIVITY HISTORY QUESTIONNAIRE

Identification No.

1. Date of Birth:

2. Age a) in years:

b) in months:

3. Sex: M=1 / F=2

4. Duration of injury a) in years:

b) in months:

5. Date of Injury:

6. Age @ Injury:

7. Level of lesion:

8. Hand dominance: Right / Left

9. Marital Status: Single=1 / Lives with partner=2

10. Daily routine/Roles: Unemployed=1 School/paid or volunteer work=2

11. Have you ever had any injuries or diseases in your neck, shoulders, arms, or hands that required medical attention? (e.g. fracture, dislocation) Please describe and date.

a) Pre spinal cord injury/able-bodied:

b) Post spinal cord injury/or at the time of SCI

12. Have you ever had any pain, discomfort, numbness etc. in your arms since your spinal cord injury? No=1 Yes=2

** If YES, complete Pain Questionnaire

13. a) Are you currently receiving any treatment for problems with your neck, shoulders, arms or hands? (physiotherapy, medications, chiropractic treatments, etc.) No=1 Yes=2

** If YES, complete Pain Questionnaire

b) Lower extremity spasticity? Yes / No

14. In the last two months, what hobbies, jobs, sports have you participated in?

Activity	Frequency

15. Since your spinal cord injury, what hobbies, jobs, and sports have you participated in? (Able-bodied — since you were 16 years old)

Activity	Frequency	How many mos./yrs.

16. Prior to your spinal cord injury, what hobbies, jobs, and sports did you participate in?

Activity	Frequency	How many mos./yrs.

ACTIVITIES OF DAILY LIVING (ADL) HISTORY

Identification No. __________

In the past | Now

1. Since your spinal cord injury, on average, how many transfers do you do each day? ☐☐ ☐☐

2. Please indicate which of the following characterizes your UNASSISTED wheeling since your spinal cord injury.

In the past | Now

mainly indoors, occasionally outdoors short distances =1
indoors and outdoors, 2-3 city blocks, school, work. etc. =2
regularly outdoors long distances or rough terrain =3

☐ ☐

3. Since your spinal cord injury, on average, how often have you lifted your wheelchair into the car unassisted? (per day)

In the past ☐ Now ☐

4. Since your spinal cord injury, on average how often have you transferred on and off the floor unassisted? (per week)

In the past ☐ Now ☐

5. Since your spinal cord injury, on average, how often have you transferred to the bottom of the tub unassisted? (per week)

In the past ☐ Now ☐

6. Please indicate which of the following characterize your transfers since your spinal cord injury.

	1=No	2=Yes	In the past	Now
I use a lift for most transfers.			☐	☐
I get assistance with most transfers	1	2	☐	☐
wrists locked, hands fisted.	1	2	☐	☐
wrists extended, palms flat.	1	2	☐	☐
use sliding board.	1	2	☐	☐
pull up on overhead loops.	1	2	☐	☐
height changes of 6 inches or less.	1	2	☐	☐
height changes of 6 inches or more.	1	2	☐	☐

7. For the majority of the time since your spinal cord injury, who has done the cooking, laundry, cleaning and groceries where you live?

In the past ☐ Now ☐

Other (spouse, child, friend, attendant, etc.)
Shared equally with another
Self

PAIN INTERVIEW SCHEDULE

Ident. No. __________

(Past and/or present pain or discomfort)

1. Where is your pain? (shoulder / elbow / wrist-hand)

2. Have you had this pain in the past week? (S / E / W-H) Past 6 months? (S / E / W-H)

3. Location: uni/bilateral, joints, distribution.

4. When: initial onset, recurrences, time of day, rare, intermittent, daily.

5. Duration/Course/Frequency: at rest; on mov't; time of day or night; specific activities that elicit/aggravate/alleviate?

6. Description & Severity/Character: Change over the course of the day?: worse at night / worse during day.

   NRS if pain in the past week:

   Mild/Moderate/Severe if pain in the past 6 months:

7. Impact on daily life/routine: Any changes made due to the pain?

8. Diagnosis made? By whom?

9. Treatment received & perceived effectiveness.

PAIN SCREENING TEST

Ident. No. ____________

	RIGHT	LEFT
NECK: ROTATION LATERAL FLEXION FORWARD FLEXION		
ACR/CLAV: EXAMINER APPLIES PRESSURE THROUGH SUPERIOR ASPECT OF JOINT, SUBJECT'S ARMS FOLDED ACROSS CHEST		
IMPINGEMENT: a) ABDUCT WITH FOREARM PRONATED b) FLEX ELBOW 90°, PRONATE, SHLDR. INT. ROT & FLEX TO 90°, RAPID INT. ROT. FORCE		
SUPRASPINATUS: PAINFUL ARC SCAP. PLANE ABD TO 45 ° & RESIST 10 SEC PALPATE TENDON		
BICIPITAL: SPEED'S TEST ABDUCT IN EXT. ROTATION PALPATE TENDON		
LATERAL EPICONDYLITIS: RESIST WRIST EXT. PALPATE EXTENSOR ORIGIN		
MEDIAL EPICONDYLITIS: RESIST WRIST FLEXION, PALPATE FLEXOR ORIGIN		

Appendix E

IMPACT OF UPPER LIMB PROBLEMS ON ADL PERFORMANCE QUESTIONNAIRE

Ident. No. ______________

SELF-CARE

1. a) In the last three months, how often have you had any pain, stiffness, or weakness in your arms (shoulders, elbows, or hands) when eating meals?	0%	1-24%	25-49%	50-74%	75-100%
b) Due to this pain, stiffness, or weakness, how often do you require extra equipment or assistive devices when you eat your meals?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to pain, stiffness, or weakness in your arms, how often do you now require any assistance when eating meals?	0%	1-24%	25-49%	50-74%	75-100%

2. Since your injury have you usually dressed your lower body a) yourself, b) with some help, c) with total assistance. If usually totally assisted, proceed to item 3.

a) In the last three months, have you had any pain, stiffness or weakness in your arms while dressing your lower body?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this pain, stiffness or weakness caused you to change your method of getting dressed or to use extra assistive devices when dressing?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to the pain, stiffness, or weakness do you need more help than you used to when dressing?	0%	1-24%	25-49%	50-74%	75-100%
3. a) In the last three months, have you had any pain, stiffness, or weakness in your arms while grooming at the sink? (brush teeth, wash, comb hair, shave)	0%	1-24%	25-49%	50-74%	75-100%
b) Has this pain, stiffness, or weakness caused you to change your method or to use extra assistive devices when grooming?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to the pain, stiffness, or weakness in your arms, do you need more help than you used to when grooming?	0%	1-24%	25-49%	50-74%	75-100%

4. Since your injury, have you usually bathed (CIRCLE ONE): tub, shower, sponge, bedbath) a) yourself b) some assist c) total assist
If usually totally assisted, proceed to item 5.

a) In the last three months have you had any pain, stiffness or weakness in your arms while bathing? (once transfer completed)	0%	1-24%	25-49%	50-74%	75-100%
b) Has the pain, stiffness, or weakness caused you to change your method or to use extra assistive devices when bathing?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to the pain, stiffness, or weakness in your arms, do you now need more help than you used to when bathing?	0%	1-24%	25-49%	50-74%	75-100%
5. a) Do you have any pain, stiffness, or weakness when removing a large book from a shelf just above your head?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to use extra assistive devices to reach items stored above your head or to change where you store things?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to the pain, stiffness, or weakness in your arms, do you need help to remove a large book from a shelf above your head?	0%	1-24%	25-49%	50-74%	75-100%
6. a) Is your sleep disturbed by shoulder, arm or hand problems?	0%	1-24%	25-49%	50-74%	75-100%

MOBILITY

1. Since your spinal cord injury, have you usually required help to get into bed? No / Some / Total assistance
If total assistance, proceed to item 2.

a) In the last three months, have you had any pain, stiffness, or weakness in your arms when transferring to a bed?	0%	1-24%	25-49%	50-74%	75-100%

b) Has this caused you to change your bed transfer method, or to use extra equipment for bed transfers?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to the pain, stiffness or weakness, do you need more help than you used to when transferring to a bed?	0%	1-24%	25-49%	50-74%	75-100%

2. Since your injury, have you usually done toilet transfers a) yourself b) with some assistance c) with complete assistance.
If complete assistance, proceed to item 3.

a) In the last three months, have you had any problems in your arms when transferring to the toilet?	0%	1-24%	25-49%	50-74%	75-100%
b) Have these problems caused you to change your method of toilet transfer or to use extra equipment to get onto the toilet?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to these problems in your arms, do you need more help than you used to when transferring onto the toilet?	0%	1-24%	25-49%	50-74%	75-100%

3. Since your injury, have you usually transferred from your wheelchair into the tub/shower a) yourself b) some assist c) total assist
If total assist, proceed to item 4.

a) In the last three months, have you had any pain, stiffness, or weakness in your arms when transferring to the tub/shower?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to need extra equipment or to change your method or to get into the tub/shower less often?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to the pain, stiffness, or weakness in your arms, do you need more help than you used to to transfer to the tub/shower?	0%	1-24%	25-49%	50-74%	75-100%

4. Since your injury, have you regularly transferred on/off the floor? a) your self b) some assist c) total assistance.
If total assistance, proceed to item 5.

a) In the last three months, have you had any pain, stiffness or weakness in your arms when transferring on/off the floor?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to change your method or use extra equipment or to get on and off the floor less often?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to pain, weakness, or stiffness, do you need more help than you used to to get on/off the floor?	0%	1-24%	25-49%	50-74%	75-100%

5. Since your injury, have you normally transferred to a car a) yourself b) with some assistance c) with total assistance.
If total assistance, proceed to item 6.

a) In the last three months, have you had any pain, stiffness, or weakness in your arms when transferring into a car?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to change your car transfer method or to use extra equipment or to transfer to the car less often?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to pain, stiffness, or weakness in your arms, do you need more help than you used to to transfer to a car?	0%	1-24%	25-49%	50-74%	75-100%

6. Since your injury, have you normally put your wheelchair into the car yourself? Yes / No

a) In the last three months, have you had any pain, stiffness, or weakness in your arms when putting your wheelchair into the car?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to change your method or to use extra equipment to get your wheelchair into the car, or to do it less often?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to problems in your arms, do you need more help than you used to when putting your wheelchair into the car?	0%	1-24%	25-49%	50-74%	75-100%

7. a) Do you have any problems in your arms when propelling yourself indoors 10 metres, or manoeuvering your wheelchair around obstacles indoors?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to reduce the amount that you wheel yourself indoors, to make architectural changes, or to use extra equipment to help get around indoors?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to problems in your arms, do you need more help than you used to to get around in your wheelchair indoors?	0%	1-24%	25-49%	50-74%	75-100%
8. a) Do you have any pain, stiffness, or weakness in your arms when wheeling yourself up ramps, outdoors 4 city blocks or more, or over rough terrain (grass, gravel, broken pavement)?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to reduce the amount that you wheel yourself up ramps, over rough terrain, longer distances outdoors, or to use extra equipment to do this?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to problems in your arms, do you need more help than you used to to do the above?	0%	1-24%	25-49%	50-74%	75-100%

GENERAL ACTIVITY

The intent of this section is to find out whether shoulder, arm, or hand problems have interfered with you doing those activities that you have normally done SINCE your spinal cord injury.

1. a) In the last three months, have you had any problems while participating in your usual outings or social activities (visit friends, shopping, spectator events, pub)?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to do less of these activities, to do them differently or to need extra equipment to do them?	0%	1-24%	25-49%	50-74%	75-100%
c) Has this caused you to need more assistance than you used to to continue these activities?	0%	1-24%	25-49%	50-74%	75-100%
2. a) In the last three months, have you had arm problems while participating in your usual recreation and sport activities?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to reduce your participation, to do the activities differently, or to need extra equipment to do them?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to arm problems, do you need more help than you used to to continue these activities?	0%	1-24%	25-49%	50-74%	75-100%
3. Do you normally work (paid or volunteer) or attend school? Yes / No					
a) In the last three months, have shoulder, arm or hand difficulties caused you problems or discomfort at work or school?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to make changes in your work or school routine, or to use extra equipment to carry out activities related to work or school?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to arm problems, do you need more assistance than you used to when carrying out activities related to work or school?	0%	1-24%	25-49%	50-74%	75-100%
4. a) In the last three months, have you had any arm problems when carrying out your usual household activities (maintenance and repair, gardening, childcare, clean, groceries, laundry, banking)?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to do less of these activities, do them differently, or use extra equipment to do them?	0%	1-24%	25-49%	50-74%	75-100%
c) Have arm problems caused you to need more assistance than you used to to do these activities?	0%	1-24%	25-49%	50-74%	75-100%
5. Have you usually driven a vehicle since your spinal cord injury? Yes / No					
a) In the last three months, have you had any problems in your arms when driving?	0%	1-24%	25-49%	50-74%	75-100%
b) Has this caused you to drive less, change your method, or use extra equipment when driving?	0%	1-24%	25-49%	50-74%	75-100%
c) Due to problems in your arms, do you have someone drive for you?	0%	1-24%	25-49%	50-74%	75-100%

UPPER EXTREMITY ASSESSMENT

IDENT

1 BODY WEIGHT TOTAL ________ - W/C WEIGHT ________ = ________ kg

2 SEGMENT LENGTHS

FOREARM	R	________	L	________
UPPERARM	R	________	L	________
TOTAL ARM	T	________	L	________

TRUNK HT (SUPINE) ________

BODY LENGTH (SUPINE) ____

3 GRIP STRENGTH R / / /
L / / /

4 Active range of motion of the shoulder

0-30 degrees	0 points
31-60	2
61-90	4
91-120	6
121-150	8
151-180	10

a) Flexion R ________ L ________

b) Abduction R ________ L ________

5 Active range of motion of elbow flexion :

0-25 degrees	0 points
26-50	2
51-75	4
76-100	6
101-125	8
126-150	10

R ________ L ________

6. Internal rotation .

Dorsum of hand to lateral thigh	0 Points
Dorsum of hand to buttock	2
Dorsum of hand to lumbosacral junction	4
Dorsum of hand to waist (L3 vertebrae)	6
Dorsum of hand to T12 vertebrae	8
Dorsum of hand to interscapular region (T7)	10

R ________ L ________

External rotation :

Hand behind head with elbow held forward	0 points
Hand behind head with elbow held back	2
Hand on top of head with elbow held forward	4
Hand on top of head with elbow held back	6
Full elevation from on top of head	8
Total	10

R ________ L ________

A BRANCH OF ROYAL PERTH HOSPITAL

6 SELBY STREET, SHENTON PARK, WESTERN AUSTRALIA 6008

Dept. Spinal

Tel. 382 7289

ERG.MG

16 March 1989

Dear

This letter accompanies a letter to you from Wendy Pentland. She is a very experienced and very well qualified Occupational Therapist from Canada, who will be doing a year's research into aspects of spinal injuries in Western Australia.

She will be working from Curtin University and has a special interest in the problems which arise in the shoulders and arms of those who have used wheelchairs for many years and develope problems later on.

I am sure you know very well that, with good arms and shoulder you can manage a wheelchair very well, but once the upper limb start giving trouble, then you get a lot more handicapped and everything becomes more difficult for you.

This really has not been looked into before in any depth at al and I am glad that Wendy Pentland has taken an interest in thi and is giving her time for twelve months looking into the prob in detail.

If you can help her in participating in this study, it could give us a lot of very useful information in treating, not only your problems, but all people who are unfortunate enough to sustain the same injuries in future.

I would be personally most interested in the ultimate results when they are assessed, and I am sure it will help us in our follow up care of all those who have been through our hands at the Spinal Unit.

Sincerely yours,

E. R. Griffiths
HEAD OF SPINAL DEPARTMENT (Retired)

Universit
Perth W

March 1989

Dear ,

I am writing to ask for your assistance with a research program I am conducting that examines the changes that may occur in arm function in people who have used wheelchairs over many years. The research will look at whether your arm strength differs from people of the same age but not in wheelchairs, and whether any problems or soreness in your arms interferes with your usual daily activities.

The testing will take approximately two hours and will be carried out at the Curtin University School of Physiotherapy, Selby Street, Shenton Park on a special strength testing machine. If you agree to participate, a time will be booked that is convenient for you.

I will telephone you in the very near future to find out whether you are interested in participating and I will give you more details at that time. The study is being carried out as part of my doctoral work and is conducted under the supervision of Professor Lance Twomey, Head of the School of Physiotherapy, Curtin University of Technology.

Thankyou very much for considering my request.

Yours sincerely,

Wendy Pentland, M.Ed.,B.Sc.O.T.(C)

Wellington Street Perth Western Australia

SERVIO

JMW:EK HR 260

MEDICAL ADMINISTRATIO

12th June 1989

Prof. L. Twomey,
Prof. and Head of School
Curtin University of Tech...
Selby Street
SHENTON PARK W A

ETHICS COMMITTEE

Dear Prof. L. Twomey,

Protocol: **UPPER EXTREMITY FUNCTION IN LONG TERM PARAPLEGIA AND IMPLICATIONS FOR INDEPENDENCE.**

With reference to the above protocol, I am now pleased to inform you th the Ethics Committee is quite happy for you to proceed with your study.

The Committee do however wish to be informed immediately of any untowar effects experienced by any participant in the trial where those effects degree or nature were not anticipated by the researchers.

The Committee also requests that researchers submit a brief summary on outcome of the project study at the completion of it or, if a long terr project, on an annual basis during the period of the study.

Yours sincerely,

JMWhite

J.M. White
CHAIRPERSON
ETHICS COMMITTEE

Correspondence Box X2213 GPO Perth Western Australia 6001
Telephone (09) 224 2244 Facsimile (09) 224 3511 Telex AA93419

08556F

UPPER EXTREMITY FUNCTIONS IN LONG TERM PARAPLEGIA AND IMPLICATIONS FOR INDEPENDENCE

Investigator: W. Pentland, School of Physiotherapy, Curtin University of Technology, Shenton Park. 381-0600

I, ______________________________ agree to participate in the above named study which should take approximately two and a half hours of my time. I understand that during this time I will be asked to perform the following tasks:

1. An interview of approximately one hour where I will be asked about my abilities to carry out my usual daily activities.
2. Measurements will be taken of my arm length, trunk height, and body height.
3. Measurement of the maximum strength in my arms using an isokinetic dynamometer and grip meter.
4. Assessment of the active ranges of motion in my elbows and shoulders using a goniometer and specific arm movements.
5. I will be asked to describe any discomfort I may have had in my arms.

I understand that slight muscle soreness is common following maximal muscle testing and I may experience this one of two days following testing. I understand that I will have to transfer form my wheelchair to the testing bench, and that assistance will be available if I ask for it. I authorize my physician,

______________________________, to release medical information about me relevant to the study to W. Pentland as part of the medical clearance process. I understand that this is important for my own safety. The information gathered in this study will be treated confidentially and will be amalgamated with information from other subjects. The results of the study will not affect me directly, but it is hoped that they will lead to a better understanding of arm function and independence in long term paraplegia.

It has been explained to me that I may withdraw my consent and discontinue my participation at any time without prejudice or penalty to my ongoing medical care. I understand that if I have questions or concerns I am free to raise them with the investigator, or Prof. Lance Twomey, PhD., Head of the School of Physiotherapy, Curtin University of Technology, Shenton Park.

Signed ______________________ Witness ______________________

Date ______________________ Date ______________________

UPPER EXTREMITY FUNCTIONS IN LONG TERM PARAPLEGIA
AND IMPLICATIONS FOR INDEPENDENCE

Investigator: W. Pentland, School of Physiotherapy, Curtin University of Technology, Shenton Park. 381-0600

I, ____ agree to participate in the above named study which should take approximately two and a half hours of my time. I understand that during this time I will be asked to perform the following tasks:

1. Measurements will be taken of my arm length, trunk height, body height, and weight.
2. Measurement of the maximum strength in my arms using an isokinetic dynamometer and grip meter.
3. Assessment of the active ranges of motion in my elbows and shoulders using a goniometer and specific arm movements.
4. I will be asked to describe any discomfort I may have or have had in my arms.
5. I will be asked to complete a life satisfaction scale.

I understand that slight muscle soreness is common following maximal muscle testing and I may experience this one of two days following testing.

I certify that to the best of my knowledge I am presently in good health and free from any diseases. injuries, or chronic illnesses. I understand this is important for my own safety.

The information gathered in this study will be treated confidentially and will be amalgamated with information from other subjects. The results of the study will not affect me directly, but it is hoped that they will lead to a better understanding of arm function and independence in long term paraplegia.

It has been explained to me that I may withdraw my consent and discontinue my participation at any time without prejudice or penalty to my ongoing medical care. I understand that if I have questions or concerns I am free to raise them with the investigator, or Prof. Lance Twomey, PhD., Head of the School of Physiotherapy, Curtin University of Technology, Shenton Park.

Signed ______________________ Witness ______________________

Date ______________________ Date ______________________

University
Perth We

Telephone
(09) 381 9

22 June 1989

Dear

Your patients listed on the attached page have expressed interest in participating in a research study at Curtin University of Technology titled "Upper Extremity Function in Long Term Paraplegia and Implications for Independence". This study is designed to evaluate changes in levels of upper extremity muscle strength, active range of motion, and pain, and their impact on performance of activities of daily living in long term paraplegia. The investigators are Wendy Pentland, doctoral candidate, and Prof. Lance Twomey, PhD., Head of the School of Physiotherapy. This research is part of the investigator's doctoral work, of which Prof. Twomey is the Supervisor.

The purpose of this medical clearance is to ensure that the subject's physician considers participation in the study to be medically appropriate for each individual. Subject participation will involve attendance at one assessment session of approximately two hours duration. During this time the following measurements will be taken:

1. Anthropometrics including body weight, and various upper body segment lengths.
2. Active range of shoulder motion using goniometry and specific composite arm movements.
3. Upper extremity muscle strength (peak torque) using the KIN/COM II isokinetic motion testing machine (subject lying supine on a padded bench) and bilateral grip strength.
4. Screening test and report of perceived upper extremity discomfort in the last six months.

All procedures will be conducted by the investigator and all testing will be done within the subject's limits of discomfort. The subject is free to discontinue participation at any time. The main risk to the subject will be possible muscle soreness one to two days following testing, of the type normally expected following maximum muscle contractions. The study design has been pilot tested at Queen's University, Kingston, Canada. The study has been reviewed and accepted by the Ethics Review Committee of the Royal Perth Hospital.

1. Please initial opposite those subjects who can safely participate in upper extremity tests of maximum isokinetic strength, active range of motion, pain assessment, and interview assessment of activities of daily living and activity level, conducted by the investigator during a 2.5 hour session.

2. Please cross out the names of those persons who have contraindications to exercise or upper extremity activity and should not participate in this study.

3. Space is provided should you wish to make any comments regarding particular subjects.

4. Please sign the page for return to me.

I would like to begin testing as soon as possible. I would appreciate it if your secretary could notify me as soon as you have completed the form so that I can make arrangements to collect it.

Your assistance in providing medical clearance for your patients to participate in the study is much appreciated. If questions arise, please feel free to contact me at 381 0600.

Yours sincerely

WENDY PENTLAND M.Ed. B.Sc.O.T.(C)
PhD Candidate, Curtin University

SUMMARY OF PAIN INTERVIEWS (PREVALENCE OF SCORES BY JOINT REGION: ____________

PARA/ABLE: ____________

1. Pain in last week | Pain in Past

2. Location: Dominant | Non-Dom | Bilateral

In joint | In Muscle region

3. When: Rare | Intermittent | Daily

Worse at Night | During day/tasks

4. Character:

NRS	1	2	3	4	5	6	7	8	9	10
Frequency	___	___	___	___	___	___	___	___	___	___

Mild (niggling, irritation, hardly notice, twinges, < 1-2/10)

Moderate (throbbing, wakens, nagging, aggravating, ≥ 3/10)

Severe (knife, stabbing, excruciating, ≥ 7/10)

Stiff in a.m.

Cold or damp seems to precipitate/aggravate

Arms ache during day | During night

Arms /upper body "feels strange"

Pins, needles, numbness in arms | Day | Night

Pain in neck/upper back

Hand cramping

Pins & needles in hands when driving

Pins & needles, numbness hands only | Day | Night

Pins & needles, numbness forearm & hands | Day | Night

5. Did you seek treatment?		Yes	No
From:	MD	Physio	Chiro
Type:	Meds	Acupuncture	Splints
	Cortisone inj.		Surgery
	Abstain from activities		CTS Surg.
Did the treatment work?		No	Partially
		Yes	
Are you on pain medication now?		Yes	No

Appendix N

RELIABILITY OF UPPER EXTREMITY ISOKINETIC TORQUE MEASUREMENTS WITH THE KIN-COM (II)® DYNAMOMETER

Wendy E. Pentland, Sing Kai Lo, Geoffrey R. Strauss

W.E. Pentland MEd, BScOT(C) is Assistant Professor, Division of Occupational Therapy, School of Rehabilitation Therapy, Queen's University, Kingston, Ontario, K7L 3N6, Canada. This study was conducted as part of her PhD. research in the School of Physiotherapy, Curtin University of Technology, Perth, Western Australia. Fax: (Canada) 613-545-6776.

S.K. Lo PhD. is Associate Professor, Department of Public Health, Chang Gung Medical College, Taiwan. When this study was conducted, he was a Lecturer in Biostatistics in the Centre for Advanced Studies, Curtin University of Technology, Perth, Western Australia.

G.R. Strauss MPE, BPE is a Senior Lecturer in the School of Physiotherapy, Curtin University of Technology, Perth, Western Australia.

Please address all correspondence to W. Pentland.

RELIABILITY OF UPPER EXTREMITY ISOKINETIC TORQUE MEASUREMENTS WITH THE KIN-COM (II)® DYNAMOMETER

ABSTRACT

This study assessed the test-retest reliability of a protocol designed to measure isokinetic average torque, peak torque, and peak torque angle. The measurements were obtained during concentric shoulder and elbow flexion and extension and concentric and eccentric shoulder adduction, at 60°/s and 120°/s, using the Kin-Com (II) dynamometer. The test and retest of 30 (18 men and 12 women) healthy subjects (mean age = 25 years) were separated by exactly one week. The results demonstrated that the protocol can be used to measure average torque (intraclass correlation [ICC] range 0.921 to 0.982) and peak torque (ICC range 0.916 to 0.980) with high reliability at the two angular velocities. Peak torque angle reliability results (ICC range 0.019 to 0.754) were considered unacceptable, suggesting that angle of peak torque, is not a reliable measure of muscle performance. This protocol has advantages for both clinical and research application in that it is time efficient, can be conducted by one examiner, and utilizes positioning methods which are suitable for both able-bodied and lower-limb disabled subjects.

RELIABILITY OF UPPER EXTREMITY ISOKINETIC TORQUE MEASUREMENTS WITH THE KIN-COM (II)® DYNAMOMETER

The measurement of muscle performance under conditions of constant velocity (isokinetic conditions) was first discussed in the literature just over twenty years ago.[1,2] Since then, a number of dynamometers have been developed to measure muscle performance under isokinetic, as well as isometric, isotonic, and passive conditions. The reliability, of isokinetic measurements is essential for clinical and research purposes if meaningful comparisons and assessments of change are to be made using isokinetic data. Factors affecting the reliability of strength measurements include subject motivation, positioning, stabilization, and consistency of adherence to the test protocol.[3,4] The literature contains reports of reliability studies for isokinetic strength testing using various dynamometers.[5-9,11] However, as Rothstein points out, reliability results are specific to the procedure used, and should not be generalized to other machines, joints, muscle actions, velocities, or protocols.[4] The Kin-Com (II)* is a micro-computer controlled dynamometer capable of measuring both concentric and eccentric torque at angular velocities of 0°/second to 210°/second. The reliability of the force, angular displacement, and angular velocity transducers of the Kin-Com have been established.[5] The majority of published

* (Chattecx Corp., 101 Memorial Drive, PO Box 4287, Chattanooga, TN 37405.)

research using this particular model of dynamometer has focused on the lower limbs, particularly the knee. Similarly, evaluations of the reliability of Kin-Com isokinetic measurements exist primarily for tests of the knee.[6-9] Reliability for this joint has generally been found acceptable although there are variations with type of muscle action, test velocities, and whether peak torque, peak torque angle, or work are measured.

While several studies have used the Kin-Com to measure shoulder and elbow strength,[10-15] the examination of the reliability of upper extremity isokinetic strength measurements has received limited attention. Griffin assessed the reliability of a test protocol designed to measure peak torque of the elbow flexors, concentrically and eccentrically, at 30°/s and 120°/s.[11] Retesting took place after 30 minutes. The intraclass correlation coefficients [ICCs] between paired concentric velocity tests and the slow eccentric velocity tests ranged from .80 to .83, but was only .72 for the 120°/s eccentric tests.[11] In an evaluation of test-retest reliability of the measurement of concentric and eccentric peak torque of the shoulder rotators at 60°/s and 180°/s using the Kin-Com dynamometer, Hageman and associates tested six subjects and reported Pearson product correlation coefficients ranging from .83 to .93.[12] In another study using the Kin-Com with the shoulder rotators, Ng and Kramer reported high trial to trial reliability for concentric and eccentric peak torque at 60°/s (ICC range = .94-.98).[13] We found no studies examining the reliability of isokinetic strength measurements of the shoulder flexor, extensor, or adductor muscle groups.

The study was conducted as part of a larger investigation that is examining upper extremity function in long-term paraplegia. The evaluation and application of published isokinetic reliability studies are complicated by the remarkable variety of protocols, lack of description of test procedures, incomplete explanations of positioning and stabilization methods, and type of experimental design, hence the form of reliability index used. A review of the literature identified very few publications that reported on upper limb isokinetic testing of the lower-limb disabled.[16-18] Furthermore, these investigations did not use the Kin-Com, and no information regarding protocol, positioning, stabilization, or reliability was provided. An upper limb strength testing protocol for the shoulder and elbow was developed that was suitable for use with subjects who had complete lower limb paralysis and for subjects of an able-bodied referent group. The purpose of this paper is to report the reliability of the protocol in able-bodied adults who were tested on two different days.

METHOD

Subjects

The sample comprised thirty healthy university students (mean age [SD] = 25.2 yr [1.2 yr]); 18 men and 12 women, who had minimal or no experience with the Kin-Com and who had never performed isokinetic upper limb strength tests. The subjects represented a relatively equal cross-section of activity levels ranging from sedentary to elite athletes. Informed consent was obtained from all participants. Dominant shoulder and elbow peak and average torque was assessed during two 55 minute sessions scheduled at the same time exactly one week apart. All testing was conducted by W.P.

Equipment

The Kin-Com (II) isokinetic dynamometer was used to measure concentric shoulder and elbow flexion and extension, and concentric and eccentric shoulder adduction. All movements were tested 60°/s and 120°/s. The gravity correction procedure required by the Kin-Com was conducted with measurement of the limb weight at a single position in the range of movement. A universal goniometer and adapted spirit-level goniometer were used for anatomical referencing and gravity calculations. The 'medium' acceleration and deceleration settings were chosen to precede and follow the isokinetic phase of movement, respectively.

A feature unique to the Kin-Com is the option to adjust the amount of force (newtons) that the muscle must generate before movement of the lever arm can occur. The preloading can be adjusted for each subject and each test. Preloads set according to the isokinetic strength capabilities of individual subjects are particularly useful when measuring average torque since an optimal preload would ideally have the muscle working close to its maximum at the point in the range where data collection begins. Preloads set too low will result in an underestimate of the average torque potential of the muscle.[19] However, the method of selecting optimum preloads has not been determined.[20] In this study, preloads were established during the warm-up phase and were set at a level that generated the expected strength curves.

Average torque and peak torque were obtained using the Kin-Com software Version 4.0 (Chattecx Co., 1987) and were based on 5-6 maximum efforts. The software was used to edit out 10 degrees from either end of the ranges tested (see below for actual ranges). The resulting values were termed selected average torque. The rationale for this step was based on evidence in our data of oscillations at the extremes of some of the test ranges. Previous investigators using dynamometers other than the Kin-Com, have observed such oscillation's at the extremes of range and have recommended that these phenomena do not represent true isokinetic movement.[21,22]

Positioning and Stabilization

Suitability requirements for this protocol included subject comfort, minimal repositioning required for the different tests, time efficiency, and the ability to be conducted by one examiner. Subjects were tested while horizontal on a hydraulically adjusted manipulation therapy table (referred to here as test table). The upper limb cuff attachment was used for all tests. Additional 2cm thickness foam was placed beneath the cuff strap as subjects complained of discomfort during pilot testing.

Standardized stabilization methods were followed for each test using 5cm nylon strapping and 5cm thickness medium density foam. For subject comfort, the examiner applied manual stabilization through a piece of 5cm foam. The sequence of testing was concentric shoulder flexion/extension; eccentric/concentric shoulder adduction; and concentric elbow flexion/extension. The decision to use a non-randomized test sequence was made in order to follow the sequence that involved minimal repositioning and transfers for the paraplegic subjects. Subjects were tested in supine and side-lying and the head was supported with 10cm thickness foam. Joint axes were first located by palpation, marked, and aligned with the axis of rotation of the machine. The axis was then checked by securing the limb to the cuff on the actuator arm, moving it passively and actively through the test range, and observing for any migration of the cuff on the limb. Cuff movement represented axis misalignment and the necessary adjustments were made. The same lever arm length was used for the test and retest. In order to avoid possible confounding due to variations in subjects' non-dominant limb strength or skills at self-stabilizing, subjects were not permitted to self-stabilize by grabbing the table with the non-dominant hand; nor were they allowed to look at the screen during efforts. For all testing, the examiner stood by the subject's head, between the subject and the head of the Kin-Com. This was the best position for manual stabilization and allowed ready access to the keyboard and screen.

Research Design

Each test was conducted at 60°/s and 120°/s. A 5 second pause was allowed between reciprocal concentric muscle actions. A 30 second pause was observed between eccentric and concentric adduction to allow for muscle recovery, and because it has been suggested that eccentric contractions potentiate subsequent concentric contractions, with this effect being inversely proportional to the time allowed between efforts.[24] Verbal encouragement was not used, however, subjects were given feedback if movements were performed incorrectly. The sequence of testing for each movement is shown in Table 1.

Table 1 Testing Sequence for each Muscle Action.

Warm-up:	4 submaximal contractions, 1 maximal contraction
Rest:	45 seconds
Test:	5-6 maximal contractions at 60°/s separated by 30 seconds rest intervals
Rest:	1 minute
Test:	5-6 maximal contractions at 120°/s separated by 30 seconds rest intervals
Rest:	5 minutes (set-up for next movement

A contraction was repeated if judged to be unacceptable due to extraneous body movements or poor stabilization. Curves were selected based on conformity with anticipated shape, absence of oscillations, and amplitude.

Shoulder Concentric Flexion and Extension

In order to achieve the test range of motion (ROM) of -25° to 125° flexion for shoulder flexion/extension, subjects were positioned in supine lying close to the edge of the test table such that their dominant shoulder and arm were unsupported over the edge of the test table. They were then strapped snugly across the chest, above the knees, and across the ankles. Pelvic strapping was not used as pilot testing showed it to cause discomfort to obese and paraplegic subjects. The limb was weighed with the glenohumeral joint at 0° flexion and rotation, and the elbow flexed to 90°. In order to keep the effects of gravity constant and to ensure smooth movement patterns, subjects were instructed to maintain the elbow flexed to 90°, the forearm supinated, and to avoid internal or external rotation during all shoulder tests. No manual stabilization was applied during shoulder flexion tests. During extension, the shoulder was stabilized anteriorly to prevent shoulder girdle movement (see Figure 2.14, p.215).

Shoulder Concentric and Eccentric Adduction

Concentric and eccentric shoulder adduction were tested between 10° and 90° abduction with the subject in side-lying (see Figure 2.15, p.216). Initial alignment was based on the sagittal glenohumeral axis, with subsequent adjustments made based on any observed sliding of the cuff along the upper arm during adduction. Chest, hip, and ankle strapping were applied. Limb weight was calculated at 25° of abduction, with the elbow flexed to 90°.

Subjects were instructed to maintain the elbow at 90° of flexion during testing. During both eccentric and concentric movements, manual stabilization was applied by wedging the examiner's forearm between the Kin-Com bench and immediately proximal to the superior aspect of the subject's acromio-clavicular joint (see Figure 2.16, p. 217).

Elbow Concentric Flexion and Extension

Concentric elbow flexion and extension were tested within the range of 35° and 130°, with the subject in supine, the head on the Kin-Com bench, and the body on the test table. The subject's head was supported with a piece of 10cm foam. Subjects were instructed to maintain 0° neck rotation during testing since work published by Deutsch et al. suggests that head-neck position may influence elbow torque production in adult subjects.[23] The lower limbs were strapped above the knees and at the ankles. The dominant upper arm was secured to the table using a strap placed over the distal section, under the trunk and non-dominant arm, and secured under the table (see Figure 2.17, p.218). A fourth strap was placed across the chest and shoulder girdles, and around and under the table. Limb weight was calculated with the elbow flexed at 45°. During warm-up trials, subjects were asked to choose a comfortable forearm position near mid-pronation/supination and then use it consistently during testing. Manual stabilization was applied over the anterior aspect of the shoulder joint during elbow flexion and extension. Subjects were instructed to "plant" the elbow joint into the table before commencing extension, and to ensure that the elbow did not lift off the table during the test. Additional manual stabilization was applied to the upper arm strap if the elbow axis still tended to shift.

Statistical Analysis

The reliability measure used was the intra-class correlation ICC(1,1) given in Shrout and Fleiss.[25] Ninety-five percent confidence intervals were also constructed. Interaction and main effects of the 2-factor (Day and Velocity) repeated measures anova were analyzed using the statistical package SPSS/PC+. All hypothesis testing was carried out at the 5% level.

RESULTS

Average and peak torque intra-class correlations ICC(1,1) are reported in Tables 2 and 3 respectively. Also included in the tables are means and standard deviations for Day 1 and Day 2 of testing, and the 95% confidence intervals for the reliability co-efficients. There were no significant interactions between the two factors of Day and Velocity. Torque measurements were not significantly different between Day 1 and Day 2, either. However, all peak and average torque values at 120°/s were significantly lower than those at 60°/s, as shown in Table 2 and 3.

All tests for average torque can be considered highly reliable as the between week reliability coefficients for the paired average torque measurements ranged from 0.921 to 0.982

(Table 2). Concentric shoulder flexion, extension, elbow extension, and eccentric shoulder adduction all had slightly lower reliability results at 120°/s. Conversely, elbow concentric flexion and concentric shoulder adduction were slightly more reliable at 120°/s. These differences, however, were not significant statistically as all the 95% confidence intervals of the corresponding measures (e.g., concentric shoulder flexion) at 60°/s and 120°/s overlapped with each other.

The ICCs for the peak torque data ranged from 0.916 to 0.980 (Table 3). Reliability indicators were similar between test velocities, except for eccentric shoulder adduction, which was slightly lower at 120°/s; and elbow extension and concentric shoulder adduction, which had slightly higher reliability measures at the faster velocity. These results again indicate peak torque measurements were highly reliable and there was no significant difference in reliability between the two velocities.

The ICCs, 95% confidence intervals, and repeated measures anova results for the peak torque angle data are presented in Table 4. Again, no interaction effects between Day and Velocity were found. Torque values at 120°/s were significantly higher than those at 60°/s only for shoulder flexion (concentric) and shoulder adduction measurements. In addition, torque values were lower at Day 1 for eccentric shoulder adduction ($p=.037$). Of the 12 reliability confidence limits, only one includes 0.9.

DISCUSSION

The high reliability estimates indicate that this test set-up and protocol can be used to reliably measure average and peak torque at 60°/s and 120°/s using the Kin-Com with subjects who are unfamiliar with isokinetic testing. The majority of other studies of reliability using the Kin-Com have involved the knee musculature,[6-9] and while comparison of some of the relationships (e.g., effect of reliability of velocity, or concentric versus eccentric contraction) can be made, reliability findings should not be generalized across joints or muscle movements. There are very few studies of the reliability of upper limb isokinetic strength tests on the Kin-Com, with which we can compare our findings.

The high reliability achieved in this study for peak torque of the shoulder flexors, extensors, and adductors, is consistent with that observed by previous authors for the shoulder rotators.[12,13] In this study, the ICC's obtained for average torque were only minimally higher than those for peak torque, and tests were not conducted to assess the significance of these differences. Griffin assessed the reliability of peak torque measurements of elbow flexor strength in 20 healthy subjects and attributed the poor reliability estimates ([ICCs] less than .83) to subject fatigue (test-retest separated by 30 minutes), and poor stabilization (no straps, and manual stabilization applied to the shoulder only).[11] The higher reliability achieved for the elbow tests in this study may be due in part to the muscle recovery time afforded by the separation of test and retest by one week, and a more thorough stabilization procedure. It may be tempting to avoid strapping in clinical settings in order to save time, however, the method of strapping used in this protocol can be applied quickly and easily and would be worthwhile since it may positively affect reliability. Another reason for differences between reliability results in the two studies may have been that the slow speed used in this protocol was 60°/s, whereas Griffin used 30°/s.[11] Osternig[21] has postulated that slower isokinetic speeds may introduce fatigue as a physiological variable and this may explain some of the inconsistency of Griffin's[11] results. The effect of change in angular velocity on the reliability of the average and peak torque data in this study is minor and not statistically significant. Previous authors have reported similar small differences between the reliability results at 30°/s and 120°/s for concentric elbow flexion,[11] and between the reliability results at 60°/s and 180°/s for concentric and eccentric shoulder rotation.[12] However, neither of these two studies reported tests for significance of the differences.[11,12]

Based on these results, the protocol described in this study should not be used to measure peak torque angle. Harding et al., in their assessment of the test-retest reliability of knee average and peak torque, and peak torque angle, also found very low test-retest reliabilities for peak torque angle.[6] In our study, reliability for peak torque angle was particularly poor for shoulder flexion and extension and elbow extension at 60°/s and for shoulder extension at 120°/s. Visual inspection of the torque plots revealed that the shoulder flexion/extension curves for certain subjects were characterized by numerous oscillations, especially at the slower velocity, and particularly early in the ROM, which is where the peaks for shoulder flexion and extension normally occurred. Insufficient joint stabilization may have played a role. The mobile nature of the shoulder joint makes it a challenge to stabilize and test, and this protocol has the joint free of the table and unstabilized on the posterior aspect. This may explain some of the oscillations, and why they were more common at the slower velocity and in the ranges where the higher torques occurred. However, we are unable to explain why the oscillations occurred in some subjects and not in others. Peak torque angle reliability did not appear to be predictably affected by velocity or concentric versus eccentric muscle action.

In summary, the low [ICCs] obtained for the peak torque angle tests suggest that angle of peak torque using this protocol is an unreliable evaluation of muscle performance. However, the results indicate that the protocols described can be used to measure average torque and peak torque very reliably in the shoulder and elbow at angular velocities of 60°/s and 120°/s. Minimal extra time is required to position and mechanically stabilize subjects during upper extremity testing and appears to be warranted based on the reliability achieved in this study. The protocols require an adjustable padded bench in order to achieve fine adjustments for joint and machine axis alignment. Otherwise, readily available and inexpensive stabilization equipment is needed. The protocols are useful both clinically and for research since they are time efficient, suitable for both able-bodied and lower-limb disabled subjects, and can be conducted by one examiner.

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Table 2. Mean (X) and Standard Deviation (SD), Intraclass Correlation Coefficients (ICC) and ICC Confidence Intervals (CI) for Average Torque Values Obtained During Testing at Two Speeds on Two Different Days (n=30).

Movement	60°/second						120°/second						
	Day 1		Day 2				Day 1		Day 2				
	X	SD	X	SD	ICC	95% C.I.	X	SD	X	SD	ICC	95% C.I.	P*
SHOULDER:													
Flexion concentric	41.0	17	41.9	18	.976	(.952, .988)	36.8	16	38.3	17	.964	(.929, .982)	.000
Extension concentric	35.4	17	35.4	17	.964	(.928, .982)	31.4	16	32.3	16	.952	(.906, .976)	.000
Adduction eccentric	80.4	30	78.9	31	.937	(.879, .968)	76.4	28	76.1	28	.921	(.848, .960)	.000
Adduction concentric	44.2	18	44.3	19	.969	(.939, .984)	41.6	18	42.2	18	.982	(.965, .991)	.000
ELBOW:													
Flexion concentric	37.0	16	36.7	15	.971	(.943, .986)	32.9	15	32.4	13	.971	(.953, .988)	.000
Extension concentric	30.3	13	30.5	14	.965	(.930, .982)	27.3	12	28.0	12	.956	(.914, .978)	.000

p-value for testing torque values between Day 1 and Day 2

All Day*Velocity interaction p-values >0.05

No significant difference in torque measurements between 120° and 60°

Table 3. Mean (X) and Standard Deviation (SD), Intraclass Correlation Coefficients (ICC) and ICC Confidence Intervals (CI) for Peak Torque Values Obtained During Testing at Two Speeds on Two Different Days (n=30).

Movement	60°/second						120°/second						
	Day 1		Day 2				Day 1		Day 2				
	X	SD	X	SD	ICC	95% C.I.	X	SD	X	SD	ICC	95% C.I.	P*
SHOULDER:													
Flexion concentric	55.0	24	55.5	25	.949	(.900, .974)	48.1	23	49.8	23	.946	(.895, .973)	.000
Extension concentric	46.0	20	46.3	22	.952	(.960, .976)	41.5	20	41.6	21	.957	(.915, .978)	.001
Adduction eccentric	88.6	34	84.9	32	.938	(.880, .969)	85.0	32	82.2	31	.920	(.846, .959)	.000
Adduction concentric	53.2	23	53.3	21	.947	(.896, .973)	48.8	22	48.7	20	.967	(.935, .983)	.000
ELBOW:													
Flexion concentric	39.3	17	40.5	18	.970	(.941, .985)	34.7	15	35.5	15	.980	(.961, .990)	.000
Extension concentric	31.1	12	31.2	13	.916	(.839, .957)	28.7	11	28.8	11	.934	(.872, .966)	.000

p-value for testing torque values between Day 1 and Day 2

All Day*Velocity interaction p-values >0.05

No significant difference in torque measurements between 120° and 60°

Table 4. Mean (X) and Standard Deviation (SD), Intraclass Correlation Coefficients (ICC) and ICC Confidence Intervals (CI) for Angle of Peak Torque Values (degrees) Obtained During Testing at Two Speeds on Two Different Days (n=30).

Movement	60°/second						120°/second						
	Day 1		Day 2				Day 1		Day 2				
	X	SD	X	SD	ICC	95% C.I.	X	SD	X	SD	ICC	95% C.I.	P*
SHOULDER:													
Flexion concentric	-14.7	6	-14.3	10	.019	(-.459, .488)	-6.9	21	-4.2	21	.754	(.435, .904)	.018
Extension concentric	94.0	27	95.2	26	.043	(.440, .506)	94.3	22	90.2	22	.186	(.315, .606)	.370
Adduction eccentric	48.4	14	50.1	14	.574	(.137, .824)	50.4	13	57.0	13	.512	(.050, .793)	.001
Adduction concentric	73.4	13	74.7	16	.543	(.093, .808)	69.7	16	72.4	15	.629	(.221, .850)	.032
ELBOW:													
Flexion concentric	75.0	24	72.8	26	.705	(.346, .883)	77.6	20	80.9	26	.331	(.169, .696)	.068
Extension concentric	92.6	25	92.8	25	.098	(-.394, .546)	94.1	26	92.9	23	.485	(.014, .779)	.748

p-value for testing torque values between Day 1 and Day 2

All Day*Velocity interaction p-values >0.05

The only significant difference in torque measurements between 120° and 60° is shoulder adduction eccentric (p=.037)

Figure 1. Positioning and stabilization for the test of concentric shoulder flexion and extension isokinetic torque.

Figure 2. Positioning and stabilization for test of concentric and eccentric shoulder adduction isokinetic torque.

Figure 3. Manual stabilization technique used during the measurement of concentric and eccentric shoulder adduction isokinetic torque.

Figure 4. Positioning and stabilization for test of concentric elbow flexion and extension isokinetic torque.

August 1992

CURRICULUM VITAE

WENDY PENTLAND

BIOGRAPHICAL DATA

Address	Assistant Professor Division of Occupational Therapy School of Rehabilitation Therapy Faculty of Medicine Queen's University Kingston, Ontario, Canada. K7L 3N6
Telephone	613-545-6723
Birth date	March 3, 1956
Citizenship	Canadian

EDUCATION

1989 - 1992	Ph.D. - Rehabilitation. Curtin University, Perth, Western Australia Dissertation: Upper Extremity Function in Longterm Paraplegia and Implications for Independence.
1986 - 1987	M.Ed (Curriculum) Faculty of Education, Queen's University Dissertation: Inservice Education in Occupational Therapy.
1974 - 1978	B.Sc.O.T. Queen's University, Kingston, Ontario.

ACADEMIC AWARDS

1990 - 1991	Ontario Ministry of Health Research Personnel Development Fellowship. $25,000.00
1990	Ontario Ministry of Health Research Personnel Development Fellowship. $11,978.00
1989	Rick Hansen Man in Motion Legacy Fund Studentship. $13,000.00
1988	Australian Federation of University Women - Queensland. Audrey Jorss-Freda Freeman Fellowship. $9,000.00
1988	Rehabilitation Therapy Society Blue Star Award for Teaching Excellence, Queen's University.

TEACHING AND SUPERVISION

1992-93	RHBS 876*	Independent Study: Tracey Gourley
	OT 351*	Occupational Therapy Application in Musculo-skeletal Conditions Fall term: 4 hrs/week
	OT 356*	Occupational Therapy Application in Gerontology and Geriatrics Winter term: 4 hrs/week
	OT 445	Independent Study: 3 students
1991-92	OT 351*	Occupational Therapy Application in Musculo-skeletal Conditions Fall term: 4 hrs/week
	OT 356*	Occupational Therapy Application in Gerontology and Geriatrics Winter term: 4 hrs/week
	OT 445	Independent Study: 3 students
1989	OT 246	Occupational Therapy in the Community. Curtin University, Western Australia
1984-85 and 1986-88	OT-141*	Introduction to Occupational Therapy, Queen's University. Winter term: 1 hr/week
	OT-245*	Planning of Treatment Programs, Queen's University. Winter term
	OT-261*	Fieldwork - Clinical Learning Centre, Queen's University. Fall and Winter term: 6 hrs/week
	OT-351*	OT Application in Musculo-skeletal Conditions, Queen's University. Fall term: 4 hrs/week
	OT-445	Independent Study - Project Supervisor (2-3 students per year), Queen's University. Fall and Winter term: 2 hrs/week (1987-88)

Graduate Student Thesis Examiner

1992	MSc. Rehabilitation, J. McDonald: Reliability of the Penny and Giles Angular Measurement System in Motion Analysis of the Wrist Complex.	Internal Examiner
1992	MSc. Community Health and Epidemiology, L. Laughland: The deinstitutionalization of persons with developmental disabilities from Rideau Regional Centre.	External Examiner
1992	MSc. Rehabilitation, D. Zheng: The validation of peak performance two-dimensional motion measurement system.	Internal Examiner

ACADEMIC AND CLINICAL APPOINTMENTS

1992 - present	Assistant Professor, Division of Occupational Therapy, School of Rehabilitation Therapy, Faculty of Medicine, Queen's University. Kingston, Canada.
1991 - 1992	Acting Head and Assistant Professor, Division of Occupational Therapy, School of Rehabilitation Therapy, Queen's University. Kingston, Canada.
1989	Lecturer, School of Occupational Therapy, Curtin University of Technology. Perth, Western Australia.

ACADEMIC AND CLINICAL APPOINTMENTS (continued)

1989 - 1991	Assistant Professor (On Leave). School of Rehabilitation Therapy, Queen's University. Kingston, Canada.
1987 - 1988	Assistant Professor (Adult Physical Medicine and Rehabilitation), School of Rehabilitation Therapy, Queen's University. Kingston, Canada.
1986 - 1987	Lecturer in Occupational Therapy (Adult Physical Medicine and Rehabilitation), School of Rehabilitation Therapy, Queen's University. Kingston, Canada.
1985 - 1986	Occupational Therapist (relief), Home Care Program. Kingston, Canada.
1985 - Present	Private Practice, Community Occupational Therapy Assessment and Consulting Services.
1985 - Present	Consultant and Member, Attendant Care Outreach Program Committee. Providence Manor, Kingston, Canada.
1984 - 1985	Lecturer in Occupational Therapy (Adult Physical Medicine and Rehabilitation), School of Rehabilitation Therapy, Queen's University. Kingston, Canada.
1983 - 1984	Supervisor of Occupational Therapy, Physical Therapy, and Speech Pathology, Home Care Program. Kingston, Canada.
1982 - 1983	Occupational Therapist (locum), Community-Based Occupational Therapy, Home Care Program. Kingston, Canada.
1981	Occupational Therapist (locum), Townsville Rehabilitation Centre. Queensland, Australia.
1980 - 1981	Occupational Therapist (locum), Adult Physical Medicine, Greenwich Rehabilitation Centre. Sydney, Australia.
1979 - 1980	Occupational Therapist, Acute Psychiatry, North York General Hospital. Toronto, Canada.
1978 - 1979	Occupational Therapist, Head Injury Service, G.F. Strong Rehabilitation Centre. Vancouver, Canada

PROFESSIONAL INVOLVEMENTS:

Member, Canadian Association of Occupational Therapists. 1978 to present.

Member, World Federation of Occupational Therapists. 1978 to present.

Member, Association of Canadian Occupational Therapy University Programs. 1987 to present.

Member, Canadian Association of University Schools of Rehabilitation. 1987 to present.

Member, Gerontological Advisory Committee, Kingston. 1991 to present.

Member, Western Australian Association of Occupational Therapists. 1989.

Member, Ergonomics Group. Queen's University. 1987 to 1990.

PROFESSIONAL INVOLVEMENTS (continued)

Member, Attendant Care Outreach Program Committee. Providence Manor, Kingston. 1985 to present.

Member, Kingston branch, Canadian Federation of University Women. 1988 to 1990.

Member, Rehabilitation Study Workgroup. District Health Council, Kingston. 1986 to 1987.

Member, Kingston Respiratory Care Society. 1984 to 1985.

Member, Longterm Care Committee. District Health Council, Kingston. 1985.

Member, Occupational Therapy Directors' Group. Kingston, 1983 - 84. 1991 - 92.

Member, Physiotherapy Directors' Group. Kingston. 1983 - 1984.

Member, Multiple Sclerosis Society Patient Services Committee. Kingston. 1983 - 1984.

Secretary and Member, Advisory Board to City Hall on the Needs of the Elderly and Disabled. 1983 - 1985.

Member, Planning Committee for Lung Association Workshop: "Update on Chronic Obstructive Lung Disease." Kingston. 1983 - 1984.

ADMINISTRATIVE APPOINTMENTS

1992	Chair, School of Rehabilitation Therapy Project Committee
1992	Member, Vice President (Health Sciences), Planning Group for Redevelopment of the Clinical Learning Centre
1991-92	Acting Head of the Division of Occupational Therapy, School of Rehabilitation Therapy
1991 - Present	Faculty of Medicine: Member, Faculty Board; Member, Curriculum Committee; Member, Progress and Promotion Committee; and Member, Women's Issues Committee. School of Rehabilitation Therapy: Chair, Occupational Therapy Division Committee (July 1991 - June 1992); Member, School Committee; Member, Faculty Committee; Member, Tenure, Re-appointment and Promotion Committee (1991 - 92); and Member, Faculty-Student Liaison Committee.
1987 - 1989	Faculty of Medicine: Member, Faculty Board. School of Rehabilitation Therapy: Member, Admissions and Progress Committee; Member, School Committee; Member, Occupational Therapy Division Committee; and Member, Student-Faculty Liaison Committee.

GRANTS RECEIVED AND (SUBMITTED)

1992	National Health Research and Development Program, Health and Welfare Canada. **The relationship between time use patterns, health, and well-being in persons with longterm spinal cord injury.** Co-investigators: M.A. McColl, University of Toronto, A. Harvey, St. Mary's University.	($78,911)
1992	Conference Travel Grant. Office of Research Services, Queen's University.	
1992	Principal's Development Fund - Category A. **Development of problem-based learning modules for two new occupational therapy courses.**	$4,000
1992	Program for International Research Linkages. **The relationship between habitual time use, health, and well-being in persons with a longterm disability.** Co-investigators: M.A. McColl, A. Harvey (Canada); I. Niemi (Finland); L. Do Rozario, J. Barker (Australia).	$5,000
1992	Canadian Paraplegic Association and Rick Hansen Man in Motion Legacy Fund. **The effect of aging and duration of disability on quality of life following spinal cord injury.** Co-investigators: M.A. McColl, T. McNair, C. Rosenthal, J. Lundgren.	$13,800
1991	Educational Centre for Aging and Health (ECAH). **An interdisciplinary problem-based learning program on falls in the elderly.** Principle Investigator: T. Vandervoort; Co-investigators: J. Puxty, K. Heslin, A. Kartha, M. Speechley.	$5,000
1991	Research Incentive Fund, Queen's University.	$28,900
1991	Principal's Development Fund - Category B. **Activity patterns in persons with severe physical disabilities.**	$3,077
1988	Conference Travel Grant. Office of Research Services, Queen's University.	
1988	Faculty Trust Fund Travel Grant. Faculty of Medicine, Queen's University.	

UNFUNDED RESEARCH

1991-92	Client education practices of Canadian occupational therapists.
1988-91	Upper extremity function in longterm paraplegia and implications for independence. Doctoral research. Curtin University. Perth, Western Australia.
1987	A description of inservice education meetings and their functions in an occupational therapy department. Research thesis completed as a partial requirement for the degree of Master of Education. Queen's University, Kingston, Canada.
1978	The Queen's University Occupational Therapy program graduates' perceptions of their level of competence during their first six months of work, and their recommendations for improving the Queen's University Occupational Therapy program. Research thesis completed as a partial requirement for B.Sc.O.T. degree. Queen's University, Kingston, Canada.

EXTERNAL GRANT REVIEWER

1992 Rick Hansen Man in Motion Legacy Fund.

PUBLICATIONS

Pentland, W.; Lo, K.; Strauss, G. The reliability of upper extremity isokinetic measurements. Isokinetics and Exercise Science. (under revision).

Pentland, W.; Pranger, B. Adult physical medicine - Improving your patient teaching skills. Canadian Journal of Occupational Therapy. (under revision).

Pentland, W.; Twomey, L. (1991) The weight-bearing upper extremity in women with longterm paraplegia. Paraplegia. 29;521-530.

Stanton, B.; Kraus, A.K.; **Pentland, W.**; Boyce, W.; Symington, D.; Wylie, J. (1988) Aging with a lifelong disability. Kingston, Ontario: Developmental Consulting Program.

ABSTRACTS

Pentland, W. Activity Patterns of Persons with Severe Physical Disability. Proceedings of the Hong Kong International Occupational Therapy Conference. Hong Kong. September 13-16, 1992. Abstract accepted.

Pentland, W.; Legg, F. Client Teaching Practices of Canadian Occupational Therapists. Proceedings of the Hong Kong International Occupational Therapy Conference. Hong Kong. September 13-16, 1992. Abstract accepted.

Pentland, W. Age-related Changes in Upper Limb Strength. (1992) Canadian Journal of Occupational Therapy. 59(suppl);38. Abstract.

Pentland, W. The Balance of Self-Care, Productivity, and Leisure. (1992) Canadian Journal of Occupational Therapy. 59(suppl);38. Abstract.

Pentland, W. Upper Extremity Function in Longterm Paraplegia and Implications for Independence. (1992) Journal of the American Paraplegic Society. 15;126. Abstract.

PRESENTATIONS AT SCIENTIFIC MEETINGS AND INVITED PAPERS

Pentland, W. (1992) Self-care, productivity, and leisure: What do we mean by "balance"? Curtin University, School of Occupational Therapy, Perth, Western Australia. September.

Pentland, W.; Legg, F. (1992) Client teaching practices of Canadian occupational therapists. Hong Kong International Occupational Therapy Conference. Hong Kong. September.

Pentland, W. (1992) Activity patterns of persons with severe physical disability. Hong Kong International Occupational Therapy Conference. Hong Kong. September. Poster.

Pentland, W. (1992) Age-related changes in upper limb strength. Canadian Association of Occupational Therapists Annual Conference. St. John's, Newfoundland. June.

PRESENTATIONS AT SCIENTIFIC MEETINGS AND INVITED PAPERS (continued)

Pentland, W. (1992) The balance of self-care, productivity, and leisure: A roundtable discussion. Canadian Association of Occupational Therapists Annual Conference. St. John's, Newfoundland. June.

Twomey, L.; **Pentland, W.** (1990) Upper extremity function and pain in women with longterm paraplegia. World Federation of Occupational Therapists International Congress. Melbourne, Australia. April.

Pentland, W. (1989) Upper extremity function and implications for independence in longterm paraplegia. Curtin University of Technology, Perth, Western Australia. August.

Pentland, W. (1989) Improving patient teaching in occupational therapy. Canadian Association of Occupational Therapists Annual Conference. Kitchener, Ontario. June.

NON-REFEREED PUBLICATIONS

Pentland, W. (1992) The weight-bearing arm: Singing the para-propulsion blues. New Mobility. Denver, Colorado: Sam Maddock Publications, 41.

Pentland, W.; Krupa, T; Lynch, S; Clark, C. (1992) Community reintegration: Working together to make it happen. National Perspectives. Canadian Journal of Occupational Therapy. 59;127-130

Paterson, M.; **Pentland, W.** (1988) Report of a clinical trial of the prototype of a battery-powered lift for disabled persons. Kingston, Ontario: Solstice Designs.

WORKSHOPS AND SEMINARS

Pentland, W. Living in the Community with a Physical Disability. Ontario Hospital Association Annual Conference. Toronto. November, 1991.

Pentland, W. Living with a Spinal Cord Injury. Lion's Club. Perth, Western Australia. October 1989.

Pentland, W. The Multidisciplinary Team Approach for Persons with Developmental Disabilities. Rideau Regional Centre, Smiths Falls, Ontario. November 1988.

Pentland, W. Occupational Therapists as Teachers. St. Marys of the Lake Hospital, Kingston, Ontario. May, 1988.

Pentland, W. The Impact of the Various Disciplines on Multidisciplinary Team Function. Refresher Course in the Developmental Handicap Field: Developmental Consulting Program. Queen's University. Kingston, Ontario. November 1987.