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THE EFFECTS OF LOWER LIMB STRENGTH TRAINING ON THE LOCOMOTOR SKILLS OF SUBJECTS WITH A TRAUMATIC BRAIN INJURY

BY

© DAYNA HIEMSTRA

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

DEPARTMENT OF PHYSICAL EDUCATION AND SPORT STUDIES

EDMONTON, ALBERTA

SPRING, 1994

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Effects of Lower Limb Strength Training on the Locomotor Skills of Subjects With a Traumatic Brain Injury submitted by Dayna Margaret Hiemstra in partial fulfillment of the requirements for the degree of Master of Science.

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Joan Loomis, B.Sc.,(P.T.), M.Ed.

December 17, 1993

To Cheryl and her family who are always an inspiration as they have endured and risen above the tragic consequences of traumatic brain injury...

ABSTRACT

The major purpose of this study was to determine [illegible] relationship between lower limb strength training and the fu[illegible] motor skills of subjects with a traumatic brain injury.

Six adults, three females and three males ages [illegible] - 58 participated in the study. Five subjects were identified as having sustained a severe traumatic brain injury as determined by their length of coma [illegible] hour) after injury. One subject did not have a traumatic brain injury, but rather was medically diagnosed as having suffered an internal brain injury caused by seizure. One female and one male withdrew from the study before the conclusion of the study. However, their data were included in the results of the study.

A single-subject, multiple baseline across subjects research design was utilized. Subjects were placed in two groups by subject preference. The time that subjects took to perform an obstacle course, consisting of a ramp, a four inch "mock curb", a set of stairs (ascending and descending) and a 25 metre flat walkway, were recorded. Strength tests were performed using the Cybex Dynamometer II every four weeks.

Intervention (B Phase) consisted of a lower limb strength training program designed to enhance the strength of the muscles of the knee flexors, knee extensors, hip flexors, hip extensors, hip adductors, hip abductors, ankle plantar flexors, and ankle dorsi flexors. Subjects trained three times weekly on Nautilus and Universal exercise machines. In addition to a generalized warm-up, subjects performed three sets of six to eight repetitions with resistance adjusted to 50 percent of their 1 repetition maximum (1RM), 65 percent 1 RM and 80 percent of their 1 RM for each prescribed exercise. Subjects were not prescribed a cool down.

Group One trained for a total of eighteen weeks after the establishment of the seven week baseline, and continued to be tested weekly on the obstacle course. Group Two began strength training on the fifteenth week and continued for a total of nine weeks. Group One continued to train during this 16-25 week period. The total duration of the study was 25 weeks.

The findings of this study revealed that there seems to be a relationship between lower limb strength training and the subjects' functional walking skills, defined by those skills needed to complete the obstacle course of this study. This finding largely agreed with the literature. The muscles that appear related to the speed of walking include the knee flexors, knee extensors, ankle plantar flexors and ankle dorsi flexors. The subjects uniformly did not increase the strength of their hip flexors, thus the importance of these muscles for performing functional skills must be queried by future research.

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Sincere thanks and gratitude to my six subjects and their care givers. Without your continual hard work, patience and endurance through the 25 weeks of study, this thesis would not have been possible. Finally, thanks to

Mary Chibuk for diligently timing my subjects through out the duration of this study.

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CHAPTER I

INTRODUCTION

Many people suffer permanent disabilities as a result of trauma to the brain. These disabilities arise from cognitive and physical deficits left after injury is sustained. Of specific interest to this study were the physical deficits that lead to the reduced ambulation capacity of this population. A study performed by Bohannon, et al. (1988) indicated that the primary rehabilitation goal of persons with a traumatic brain injury (TBI) was to improve their walking abilities.

The Rick Hansen Centre at the University of Alberta is a fitness facility for persons with a physical disability. Many individuals with a TBI participate in fitness programs similar to those offered by community facilities for able-bodied individuals. This author has observed some clients with a TBI involved in fitness programs at the Rick Hansen Centre make marked progress and some improvement in their physical function and gait.

Examples of successful clients are discussed to demonstrate these improvements. A 25 year old lady who suffered a TBI in a motor vehicle accident a number of years ago used a wheelchair as a primary means of mobility when she started at the Rick Hansen Centre five years ago. She now uses only a cane, and only when walking on difficult surfaces such as ice. A 27 year old man who suffered a TBI in a motor vehicle accident a number of years ago also began his program at the Rick Hansen Centre using a wheelchair as a primary means of mobility. He has been a participant at the Rick Hansen Centre for six years, and now walks unassisted in performing all activities of daily living. A third lady, now aged 30, also suffered a TBI in a motor vehicle accident.

Again, when she started an exercise program at the Rick Hansen Centre five years ago, she used a wheelchair to carry out all activities of daily living, but now walks with a walker for the completion of these tasks. These three individuals have also been able to transfer their improved walking skills to both the community and home environment. However, it should be noted not all clients that have entered the Rick Hansen Centre with a TBI have been as successful. For some individuals, their gait may have improved somewhat, but their preferred mode of mobility for activities of daily living remains unchanged.

Several studies in the literature indicate a relationship between strength in specific muscle groups and velocity of walking (e.g. Nakamura et al.,1985, Bohannon, 1986, Nakamura et al., 1988, Perry et al., 1993). These studies have been performed primarily on subjects who have suffered a stroke. Perry et al. (1993) performed a study on individuals with post-polio syndrome. Research on the functional outcomes of persons with TBI is limited. No research has been done on the relationship between lower limb strength and velocity of walking with persons with a TBI.

The reasons for this lack of research are unknown. However, this study will illustrate the difficulties encountered when conducting research with subjects with a TBI. Memory deficits, emotional outbursts, aggression, poor motivation, poor perception, poor conceptual skills and so on, are some of the difficulties that arise when working with this population. In addition, multiple injuries sustained at the time of the TBI, such as contractures, complicate research methodology further.

To date, no research is available on this population with specific reference to activities of daily living and the potential functional relationship with strength gains. Furthermore, this type of research is sparse in the rehabilitation literature for any disabled population.

Few studies in the literature have examined the value of physical fitness programs for persons with a TBI. Additionally, few studies have researched the potential for this population to improve their level of physical functioning after formal inpatient and outpatient therapy programs have been discontinued. If a relationship can be established where functional gains can be acquired through the participation in a regular, daily physical activity program, individuals with a TBI may continue to progress physically and functionally without reliance on costly formal rehabilitation programs. The motivated individual could access a broad range of community fitness centres that are available in both large and small communities. Finally, by undertaking a general fitness program, this population can enjoy the well documented benefits of a healthy, active lifestyle.

<u>Problem Statement</u>

The author's informal observations of clients with a TBI lead to many interesting research questions. Thus, this study investigates the following:

1. Are the functional improvements observed in people with a TBI while performing an exercise program actually due to the fitness program?
2. If so, could the prescription of a fitness program to this population serve as a long term form of rehabilitation to enhance functional independence levels?
3. Is strength training the most valuable component for enhancing functional skills, in particular, functional gait?

An attempt was made to answer these general questions by determining specifically:

4. Is there a relationship between lower limb strength training and the locomotor skills of subjects with a TBI?

Delimitations

This study was delimited to participants with a brain injury incurred a minimum of 18 months prior to the commencement of the study. The age range of subjects was limited to between 18 and 60 years. Five subjects had sustained a traumatic brain injury. One subject suffered a brain injury secondary to seizure. Subjects had to be able to ambulate without a walking device a minimum of 50 meters, and traverse stairs and ramps safely.

Limitations

There are several limitations inherent in this study. Firstly, the obstacle course was designed on the premise that the obstacles contained in the course were those faced by this population on a daily basis. However, a truly functional obstacle course would have been one that was designed from information obtained directly from the subjects. The obstacles could have been actual barriers to the individuals' life in home or other environments. Therefore, the results of this study are only truly valid for barriers in this course designed for this research.

Secondly, the strength aspect of a fitness program was researched, therefore, the overall utility of other components of a prescribed fitness program cannot be deduced. Thirdly, the optimal time at which the fitness program should be prescribed after injury was not studied. Finally, the time to walk each obstacle included in the obstacle course was not recorded. Hence, specific changes or strategies developed by the subjects to traverse the stairs, ramp, or curb were not researched. This specific information may have helped describe the results of this study.

Definitions

Traumatic brain injury (TBI) has been succinctly defined by Vogenthaler

(1987) as "damage to living brain tissue that is caused by an external, mechanical force" (p.113).

Closed Head Injury - Traumatic Brain Injury:

> "A closed head injury occurs when the head collides with another object (for example the windshield of a car) and brain tissue is damaged, not by the presence of a foreign object within the brain, but by violent smashing, stretching and twisting of brain tissue. Penetrating injuries tend to damage relatively localized areas of the brain which result in fairly discrete and predictable disabilities. In contrast, closed head injuries cause more diffuse tissue damage that results in a mosaic of disabilities that are more generalized and highly variable." (Vogenthaler, 1987, p. 113)

Difference Between Traumatic Brain Injury and Stroke or Internal Brain Injury: Stroke or internal brain injury usually occurs later in life and damage is often localized to one part of the brain. Although some survivors with stroke may require similar services as individuals with traumatic brain injury, the extent and length of time services are required differs. In addition, recovery from stroke often follows a predictable path, whereas recovery from a traumatic brain injury does not. Therefore, rehabilitation methodologies will differ.

CHAPTER II

SELECTED REVIEW OF LITERATURE

Introduction

The following literature review will focus on four specific areas. Initially, the incidence and prevalence of traumatic brain injury (TBI) will be discussed. Secondly, the specific physical and cognitive deficits resulting from a TBI and their impact on the individual's ability to carry out activities of daily living will be reviewed. Thirdly, studies on the effects of physical activity for people with a traumatic brain injury will be examined. Finally, an in depth review of the literature with respect to the relationship between gait and lower limb strength will be presented.

Background Information on Traumatic Brain Injury

The leading cause of TBI according to Rimel et al. (1982), Parkinson et al. (1985), and Wong et al. (1993) was motor vehicle accidents. This finding was in agreement with similar studies conducted in Australia and Britain (Jennett, 1990). The second and third leading causes of TBI are assaults and falls, although the order may vary.

After insult to the brain, a loss of consciousness will occur resulting in amnesia or coma. The duration of these states will vary with each individual from minutes, to months to indefinite periods of time. However, the result is always the same: permanent organic damage, with varying degrees of severity and sequelae.

The severity of brain injury is medically determined by the length of time altered consciousness persists. If a comatose state and post traumatic amnesia persists for more than 24 hours, the brain injury is classified as severe. If the state lasts less than 24 hours, TBI is considered moderate, and if less than one hour, TBI is mild (Teasdale & Bond, 1974). Wong et al. (1993) provided statistics on severity of injuries. Of the 370 patients reviewed, 22.4 percent were in coma for two to seven days, 19.5 percent in coma for eight to fourteen days, and 16.8 percent in coma for one day.

Incidence and Prevalence

The incidence of traumatic brain injury (TBI) within Canada has been reported at 200 per 100,000 population per year (Parkinson et al., 1985). Extrapolating this statistic to Alberta, there will be an estimated 4,860 people admitted to Alberta hospitals with a primary diagnosis of brain injury in 1993 (based on an Alberta population reported in June 1989 by the Alberta Bureau of Statistics of 2,429,000). A survey of Alberta hospital discharge data and death certificates indicate that this estimate is fairly accurate (Alberta Health, 1991). An additional 360 persons will die as a result of traumatic brain injury before they reach the hospital (Alberta Health, 1991). Recently, Wong et al. (1993) determined that 40,000 persons are discharged from hospitals with a diagnosis of skull fracture, or intracranial injury in Canada annually.

In the United States, incidence statistics have been reported at 422,000 per year (Anderson & McLaurin, 1980). The authors indicated that the large majority of patients sustain mild injuries, but at least 44,000 people survive with moderate or severe injuries. Prevalence was calculated by the authors as the number of people who received some form of treatment as a result of their brain injury each year. This figure was estimated to be 1 million and is 40 times the number of people with spinal cord injuries. In Britain, prevalence data were reported at 150 per 100,000 population (Jennett & McMillan, 1981). Although severity level of the injuries were not provided in these studies, clearly brain injury is becoming an increasing concern to the health care system.

Profile of the Victim of Traumatic Brain Injury

All studies reviewed to date indicated that males are two to three times more likely to sustain a TBI than females. Wong et al. (1993) found this ratio to be three to one. In the Canadian study by Parkinson et al. (1985), this ratio was given as 2.19:1.

A second consistent finding in the literature is the age group at risk. Those aged 15 to 24 were at highest risk (Anderson & McLaurin,1980, Rimel et al., 1984, Jennett, 1990). Wong et al. (1993) reported a slightly different at risk age range of 20 to 29 years. The authors indicate that this may have been due to the acceptance of only adults in their rehabilitation facility. Rimel et al. (1984) found three age groups that had higher than average numbers of brain injuries. The highest incidence rates were reported for persons aged 15 to 19 at 42 per 10,000 and persons aged 75 and over at 30 per 10,000. Children aged five to nine had the lowest rate, although a figure was not provided.

A third common characteristic within the literature is the socioeconomic status of people with TBI. Wong et al. (1993), found 38.7 percent of their patients were unemployed at the time of their injury. In the Parkinson et al. study (1985), 47.5 percent of their population with a brain injury were either unemployed or receiving welfare at the time of their injury. These statistics are striking because the welfare and unemployment rate was 11 percent of the general population at the time of the Parkinson study and 5.64 percent of the general population at the time of the Wong study. Similar disproportionate representation of this socioeconomic group was also reported by Rimel and Jane (1984) and Jennett (1990).

In summary, TBI is reaching epidemic proportions around the world. The victim of TBI is most likely to be an unemployed male aged 15 to 24. The causes of TBI are typically motor vehicle accidents, assaults and falls. The length of the comatose state will determine the severity of injury.

Sequelae of Traumatic Brain Injury

The consequences of traumatic brain injury are particularly difficult for society and the medical profession alike to manage. Statistics have indicated that TBI is likely to occur at the prime of one's life (between the ages of 15 and 24). People with TBI are expected to live a normal life span, consequently they will live 65 to 70 years with disability (Jennett, 1990). The primary challenge for rehabilitation is dealing with the complex sequelae of TBI.

The brain is a very intricate and delicate organ that controls every aspect of our being. Although scientists now have a good grasp of how the normal brain functions, there are still many unanswered questions. When the brain experiences trauma, such as going through a windshield in a fast moving vehicle, the mechanisms of the damaged brain and how it functions becomes even more complex.

The person who experiences TBI, whether mild or severe, will never be quite the same again. An overview of each of the areas affected by brain injury will be provided, with particular focus on physical deficits. One must always remain cognizant of the fact that TBI effects each individual differently. A diffuse, traumatic brain injury does not follow a predictable course of recovery, unlike stroke, or a penetrating brain injury where damage is localized (Vogenthaler, 1987).

Cognitive Deficits

The cognitive deficits that may result from TBI are numerous. Ben-Yishay and Prigatano (1990) provide a comprehensive list of 27 potential deficits.

These deficits may be further grouped into nine key areas including poor impulse control, reduced stamina, inability to control emotions, attention deficits, memory deficits, communication skills, perceptual-motor-spatial-sequential task deficits, and deficits in executive functions.

A deficit in the balance of excitatory or inhibitory processes results in reduced impulse control, stamina and ability to control emotions. Attention deficits produce an inability to concentrate and/or an inappropriate focusing of attention. To the untrained observer, memory deficits are probably the most noticeable. The patient will experience difficulty with retention of both verbal and non-verbal information, and may be unable to recall new or old information.

Deficits of more complex functions such as language and communication skills, lead to the individual experiencing difficulty with academic skills and speech. The speed with which one can process information may also be reduced, leading to difficulty with "integrative" functions. Ben-Yishay and Prigitano (1990) describe these as deficits in performing perceptual-motor-spatial-sequential tasks. Thinking disorders include difficulty with both convergent and divergent reasoning, in addition to deficits in executive functions (planning, implementing and evaluating).

A challenge for the physical rehabilitation professional is to avoid placing unrealistic expectations on a person with a TBI who has inadequate insight or awareness into his or her disability. Further challenges are encountered when the above described deficits are exacerbated by agitation and/or depression, low self-esteem and poor ego-identity.

Physical Deficits

Physical deficits as a result of TBI are as diverse and complex as cognitive deficits. Although linked to cognition, deficits in perception pose unique difficulties for physical rehabilitation. Perception, defined by Bouksa et al. (1985), is the "dynamic process of receiving (perceiving) the environment through sensory impulses and translating these impulses into meaning based on a previously developed view of the environment" (p. 252). However, as already mentioned, the person with a TBI may lose a prior memory of the environment, or it may be drastically distorted. Thus, inappropriate movements are likely to be produced (Duncan, 1990).

The lengthy duration of coma can result in a mosaic of physical deficits. Tone, defined as the "tension present within a muscle" (Singh & Doy, 1986, p. 45) can be altered, leading to contractures. When the tone is increased, the muscle continually contracts rather than returning to the normal position due to disturbances in the brain. Muscle contractions held for a long period of time often leads to reduced range of motion, and thus, deviation from normal biomechanical alignment may be observed (Duncan, 1990).

Spasticity is an increase in muscle tone and is evidenced by an increased resistance to passive or active movement. Spasticity seen on passive movement is hypothesized to be due to a hyperactive stretch reflex (Sahrmann & Norton, 1977). Spasticity observed on active movement is hypothesized to be re' :ted to abnormal regulation of the normal neuron pool (i.e. prolonged recruitment of motor units resulting in a delay of antagonistic contractions at the end of a movement), (Sahrmann & Norton, 1977).

Although sensory organs may be fully functional, damage to the central processing area may produce reduced sensation (Vogenthaler, 1987). Deficits in sensation are manifested in the patient having a limited ability to receive movement sense. As a result of this poor feedback, the individual cannot coordinate agonist and antagonist muscles. If the person is receiving incorrect visual information, balance and proprioception skills may be affected. Reduced tactile sensation will limit the patient's sensitivity to pain, temperature and texture.

Strength, defined by Fox et al. (1989, p.159), as the "force or tension a muscle, or a muscle group can exert against a resistance in one maximal effort" is frequently affected in people with TBI. Patients are unable to produce voluntary contractions or have difficulty with motor unit recruitment (Duncan, 1990). If the primary motor cortex is damaged, the patient may be unable to produce any strength response at all.

Individuals with TBI experience difficulty activating normal movement patterns or synergies and might only be able to activate primitive motor reflexive movements. Duncan, (1990) indicates that these primitive reflex movements are not abnormal reflexes, but rather, they are normal reflexes which reappear without modulation of the central nervous system following brain injury. The emergent reflexes that result may be adequate to perform gross movements as in gait, but if the patterns are limited to flexion and extension, more complex movements may not be possible. These movements may in fact be dysfunctional for the patient. Duncan (1990) explains that often, this disorder of voluntary movement is wrongfully interpreted as the result of spasticity. Ataxia (uncoordination of muscle movement) and tremor can result when the timing of the synergies are incorrect.

Many patients with TBI will experience balance difficulties. The ability to balance is a complex task. To maintain balance, sensory input, motor programs and neuromuscular functions are required. All or some of these areas may be damaged or partially damaged after head trauma. If balance is affected in the individual, often movement will not be purposeful or coordinated (Shumay-Cook & Horak, 1986).

Deficits in Activities of Daily Living

Deficits in cognitive and/or physical function will result in a reduced ability to perform activities of daily living (ADL). ADL are defined by McNeny (1990, p.193), as "those tasks necessary for an individual's daily functioning". ADL can be further reduced to "basic" ADL which includes self-care and mobility. Instrumental ADL are those tasks that are more complex, such as financial management and driving (Jette, 1985). Although cognitively the patient may be unable to perform these skills, physical function is a necessary prerequisite for performance. For most patients with TBI, these skills will have to be relearned and/or adapted for the patient to achieve pre-injury independence.

The many deficits of people with TBI have been outlined. Cognitive and physical deficits lead to reduced ability to perform activities of daily living, and often limit functional independence.

Physical Activity Studies

The first study of exercise as a form of rehabilitation for persons with TBI was performed by Torp in 1956. The author describes the positive results of a combination of physical therapy and physical activity on the rehabilitation of 206 War Veterans with TBI. The author stresses that it is important to begin treatment as soon as possible after injury to maintain morale and joint range of motion. The study is descriptive in nature with limited information provided about the impact of specific components of physical activity.

The effects of cardiovascular training of individuals with TBI was examined by Becker et al. (1978). The study was essentially descriptive, as the authors only measured variables of lung capacity. The subjects were found to have reduced lung capacity as compared to a control group of non-disabled persons. The authors concluded this reduction was due to inactivity.

A further study of cardiovascular response to exercise in patients with stroke was performed by Monga et al. (1988). Subjects were given an isometric strength test, an arm ergometer test, and a cycle ergometer test. The heart rates and blood pressures achieved during the tests were recorded and compared to a control group matched by age and gender. No significant differences were found in the mean heart rate or mean blood pressure between the two groups in either the strength test or the bicycle ergometer test. The leg ergometer test showed that the control group completed significantly more work than did the patient group. The arm ergometer test revealed that the control group attained a higher mean systolic and diastolic blood pressure than the patient group, although heart rates between the two groups for this exercise did not differ significantly. The authors hypothesize this difference in blood pressure may be due to three factors. One is the anti hypertensive medications patients were taking. A second factor may be related to the change in the centrally mediated sympathetic tone after damage to the brain. Thirdly, higher total peripheral resistance has been previously observed in normal subjects for arm ergometer exercises, as compared to leg ergometer exercises. The authors concluded that cardiovascular exercises, under controlled conditions were safe for persons who had suffered a stroke.

Dickstein et al. (1986) researched the effects of three exercise programs prescribed for patients with stroke to improve their ability to perform activities of daily living (ADL). One group received traditional exercises and functional activities which involved pulleys and weights. Activities were progressed by increasing the total number of joints involved in the exercises and performing

ADL as quickly as possible. A second group received proprioceptive neuromuscular facilitation (PNF) exercises. The third group received treatment using the Bobath approach of reducing abnormal muscle tone and encouraging the production of normal movements. Subjects underwent training in one of the three groups for six weeks. The authors did not describe the length or intensity of training sessions. The conclusion of the study was that the prescribed programs did not vary in their effectiveness in improving ADL. All exercises yielded similar marginal improvements in both ADL and physical function. The authors concluded that muscle tone decreased substantially, although not significantly using the PNF method. Due to a lack of information provided by the authors, the conclusions of this study must be treated with caution.

The effects of exercise overflow on electromyography results were examined by Mills and Quintana (1985). Patients with stroke performed three strength exercises (one at maximal, one at 50 percent, and one at no weight). These exercises were performed by the unaffected biceps brachii, triceps brachii and quadriceps femoris. The effects on the opposite, affected limbs were observed using electromyography. The authors concluded that training of the opposite limb will enhance the strength of the paretic limb. No long term effects of the strength training on the subjects were reported.

A treadmill training program was prescribed by Waagfjord et al. (1990) to determine its relative effectiveness on the temporal distance variables of gait of a subject with traumatic brain injury. The subject trained for ten minutes per session for a period of nine weeks. The authors found that treadmill training did not have an effect on these variables of gait for this subject.

Jankowski and Sullivan (1990) performed the only study reported in the literature on the effect of an overall physical activity program on the efficiency, capacity and fatigability of patients with traumatic brain injuries. Fourteen subjects participated. Subjects performed stationary cycling, rope skipping, jogging and stair climbing for 45 minutes, three times per week for 16 weeks to enhance aerobic capacity. Ring tossing, three pin bowling, dribbling drills, weight lifting and callisthenics were performed for 45 minutes, three times per week for 16 weeks for neuromuscular stimulating effects. Subjects improved their oxygen consumption capacity, however there were no significant changes in training heart rate or in the oxygen cost of walking. The outcomes of the study were measured by grip strength, abdominal muscular endurance and a submaximal oxygen consumption test. The authors also developed an index of fatigability based on informal observation; this measurement was not tested for reliability or validity. The amount of time spent performing each specific activity was not defined.

A summary of the possibilities for functional rehabilitation for persons with a TBI using physical activity was provided by Sullivan et al. (1990). The authors described an exercise program in adjunct to a physical therapy program. The activities prescribed for the individuals included running, walking, jogging, javelin, ball throwing and weight lifting. The authors measured the functional abilities of the patients prior to entering the program. Upon completion of the program, 45 of 51 subjects obtained the status of a walker or a jogger compared to 16 of 51 patients who held this status at the outset of the program. Although the authors described exercises as including flexibility, strengthening, coordination and relaxation activities, specific prescription information with respect to duration and types of exercises performed were not provided. However, the authors provided some insight into the potential benefits of physical activity not previously described for the TBI population.

Sullivan et al. (1990) suggested that participation in physical activity may result in a general physiological training effect for the cardiovascular system, and hence reduce fatigability and enhance ability to perform ADL. Physical activity could be used as a vehicle through which self satisfaction and improved confidence could be achieved. The authors concluded an overall improved healthy lifestyle may result from participation in physical activity.

<u>Summary</u>

Clearly the review of literature shows that the effects of physical activity on the long term functional skills of the population with a head injury are not well documented. Several gaps within the literature are evident. Subjects are generally patients with stroke even though it is well known that individuals with TBI do not follow the same pattern of recovery as patients with stroke (Jennett, 1990). Studies completed to date have generally been performed without adequate attention to scientific research design. Finally, many of the studies do not provide enough information about specific prescribed programs. Critical information about the programs is often missing preventing the reader from making appropriate conclusions.

<u>Gait and Strength Relationship Studies</u>

A study performed by Bohannon et al. (1986) indicated that the primary rehabilitation goal of persons with a TBI was to improve their walking abilities. However, studies to determine the relationship of strength with the performance of gait are limited. Most studies seek to determine if strength is a reliable indicator of gait performance. An initial study by Brandstater et al. (1983) found that time or velocity of walking was a sufficient measure of gait performance for research purposes. The velocity of walking identified deficits in the stride period, cadence, stance period and swing period. The findings of this study revealed that velocity of walking adequately assessed the gait of an individual with a brain injury and identified the stage of recovery according to Brunnstrom. Thus, the speed of walking is frequently used in the literature to describe gait performance.

Gait of patients with stroke and TBI show commonly, observable deficits. The Rancho Los Amigos Scale is an observational tool used to determine if deficits are present in these patients. By observing the seven key areas involved in gait (trunk, hip, pelvis, knee, ankle, foot and toes), underlying motor deficits can be inferred. The four primary motor deficits identified from this scale include: spasticity limiting range of motion; contractures in the hip flexors, knee flexors and ankle plantar flexors limiting the passive range of motion of the subject needed for walking; uncoordinated synergies of the lower limbs altering gait at initial contact and during the swing phase; motor control or inaccurate selective control of a joint occurring when a normally active muscle fails to activate (Bampton, 1979).

Hamrin et al. (1982) examined the relationship of muscular strength to balance in patients with stroke. Thirty seven subjects were given isokinetic torque tests of knee extension and flexion. The authors concluded that isokinetic muscle torques of both the paretic and non-paretic legs were a good indicator of locomotor ability. However, the results must be treated with caution as the authors did not indicate how locomotor ability was measured.

Nakamura et al. (1985) did a more extensive study of the above relationship. The study was performed with 11 patients with hemiplegia following a stroke. Isokinetic strength of the knee flexors and the knee extensors were measured using Cybex II, and gait was measured using time to walk ten meters. The authors found that there was a significant relationship between isokinetic muscle torque at fast velocities for both the affected and non affected side. The conclusion drawn was that reduced muscle strength required for rapid movements was a primary cause of motor disabilities in locomotion in persons with hemiplegic gait.

Bohannon (1986) examined the relationship further by looking at the effects of muscular strength on gait velocity and cadence of 20 stroke patients. Bohannon used a hand-held dynamometer to measure static strength of hip flexors, hip extensors, hip abductors, knee flexors, knee extensors, ankle dorsi flexors and ankle plantar flexors. The purpose of the study was to determine if strength in these muscle groups was indicative of gait performance as measured by cadence and velocity of walking. Correlations were established between both cadence and velocity and the strength of hip extensors, knee flexors, ankle dorsi flexors, and ankle plantar flexors. A correlation between cadence and strength was established with the hip abductor and knee extensor muscle groups. Caution in interpreting these results is recommended for two reasons. One, the hand-held dynamometer is not a sensitive measure of static strength. Second, the use of only eight meters to measure walking variables is a very short length to effectively determine the relationship between strength and gait.

A follow-up study by Bohannon (1987) was performed to determine which variables of hemiparetic gait were related to gait performance. Speed, cadence, independence and appearance of gait were measured using one trial, although this was not described. The comparison variables were motor control, balance, muscle tone, weight-bearing ratio and normalized strength (paretic and non-paretic). Several methods were utilized to measure these variables. The author concluded that balance and motor control were better predictors of gait performance than normalized strength of the paretic limbs and weight-bearing ratio. The author's limited examination of the subjects' gait and the various methods employed to measure predictor variables call into question the implications of this study.

Nakamura et al. (1988) examined the relationship between walking speed and muscle strength of knee flexors and knee extensors in patients with stroke. In this study, the authors compared the strength and walking speed of patients four and eight weeks after gait retraining. Unfortunately, the method of gait retraining was not described. However, the authors concluded that an increase in walking speed did not improve with increases in isokinetic strength. By performing regression analyses, the authors did find that the variance explained by walking speed is gradually increased with more training. Again, lack of information about the specific methods used within the study lead to difficulty in accepting the conclusions reached.

Bohannon performed a more recent study in 1990 to determine if a relationship between spasticity, muscle torque and speed of walking existed in subjects following stroke. Using Cybex II, knee extensor muscle torque and spasticity were measured. Performance of gait was measured using speed of walking over an 8 meter walkway. The author concluded that knee extensor muscle torque was significantly correlated to speed of walking, but spasticity was not correlated. Therefore, the strength of the knee extensor muscles was thought to be a good predictor of walking speed.

Some studies have been performed using elderly adults as subjects to examine this relationship. Judge et al. (1993) prescribed a strength training program for thirty males whose average age was 82.1 years. The exercises consisted of three training sessions per week. Subjects performed three sets of eight to ten repetitions at 75 to 85 percent of 1 RM to volitional fatigue. The muscle groups strengthened were knee extension, hip abduction ankle dorsiflexion, hip extension and knee flexion. A control group performed only flexibility exercises. Velocity of walking was measured at usual and maximal pace of walking. The authors found that the strength training program improved gait velocity at both speeds in the strength training group, but not in the control flexibility group. The experimental group improved their usual pace of walking by 8 percent, and their fast pace walking by 4 percent ($p<.05$). Judge et al. hypothesized that improved gait velocity as a result of improved strength will be greater in those subjects whose knee extension strength is below a threshold of weakness. In their study, they estimated this threshold to be 48 Newton Metres.

A similar study was recently performed by Perry et al. (1993) using 24 subjects with post-polio syndrome. Isometric torques were measured in the muscle groups of ankle plantar flexors, hip and knee extensors, and hip abductors. Gait was recorded at usual pace and fast pace. Through step-wise regression analysis, the authors concluded that plantar flexion torque was the best predictor of gait velocity at both usual and fast paces. For fast pace walking, the authors determined that hip abduction strength in addition to plantar flexion strength were the best predictors. In contrast to previous studies, the authors found that knee extension torque was the poorest predictor of ability to walk at both paces. The authors' use of isometric torque in determining their predictions is at odds with almost all previous studies where a form of dynamic muscle testing (most frequently Cybex) was used. As walking is a dynamic activity, the validity of using isometric torques in terms of specificity of testing is questionable. Nevertheless, the findings of Perry et al. (1993), are quite different than those of previous authors. Comparison is difficult because of the testing technique, and the subjects did not have limiting neurological factors as do persons with stroke or traumatic brain injury.

Summary

Although some studies have been performed to determine the relationship between muscle strength and gait performance, most do not provide enough information about the specific methodologies used. However, there tends to be a relationship between lower extremity strength and speed of walking or gait performance. Most studies have not use research designs to determine a cause effect relationship, but rather use Pearson Product Moment Correlations. The effects of strength training on gait performance over time has been neglected. In addition to the above limitations, all studies have been performed primarily on patients with stroke and not on individuals with TBI.

If the above described research findings are to be accepted, there might be a relationship between strength training and gait performance of individuals with head injury. From Bohannon et al. (1990), the muscles that appear to be most important for strength in gait are the ankle plantar flexors, ankle dorsi flexors, hip adductors, hip abductors, knee extensors and knee flexors. The following study will determine if indeed there is a relationship between strength training and the locomotor skills of persons with TBI.

CHAPTER III

METHODOLOGY

Sample Selection

Subjects were selected according to the following criteria:

1. Male or female between the ages of 18 and 60.
2. Sustained a traumatic brain injury a minimum of eighteen months prior to the commencement of the study.
3. Brain injury was classified as severe according to length of time in coma (>1 hour).
4. Were able to ambulate 50 or more meters with or without assistive devices.
5. Subjects must not have had any medical contraindications that would have prevented them from participating within the study.
6. Subjects had to be able to comprehend and sign informed consent forms.

Subject characteristics are outlined in the following Table:

	Age(yrs.)	TSI (mos.)	AI (yrs.)	LOC(days)	COI
S1 (BN)	43	26	41	14	Fall
S2 (JP)	58	270	35	4	Assault
S3 (GH)	22	56	17	180	MVA
S4 (SW)	34	50	30	21	MVA
S5 (WK)	27	104	18	98	Fall
S6 (LH)	29	18	27	14	Seizure

Table A - Subject Characteristics
*TSI= Time since injury
*AI=Age at injury
*LOC= Length of coma
*COI=Cause of injury

A decision was made to allow an individual to participate whose cause of injury was a seizure (and not a traumatic brain injury) because it was difficult to recruit subjects and this particular subject was exceptionally eager to participate. The causes of injury were motor vehicle accident (2), fall (2), assault (1), and seizure (1).

Subjects were recruited primarily by referral from the Rick Hansen Centre. Six subjects began the study but only four completed it. One individual (LH) dropped out on the advice of her physician as she was diagnosed with cancer. The second subject (GH) dropped out for reasons he would not state and refused to continue. After discussion with his primary care givers, it was discovered that this type of behaviour was not uncommon for this subject who had a history of not completing several other unrelated commitments. The lack of compliance by this subject is indicative of some of the difficulties previously reported in performing research with subjects with a TBI.

Subjects participated voluntarily and were not offered any incentives to participate other than anticipated improved well being. Both subjects and their primary care givers (if applicable) signed an informed consent form. The study was approved by the University of Alberta Faculty of Physical Education and Recreation Research Ethics Committee.

Procedures

Research Design

The research design utilized in this study was a single-subject, multiple baseline across subjects design. Traditional research designs of a homogeneous experimental group were rejected due to the high variability that exists between subjects with a TBI. In addition, this small sample detailed individual information with regard to the relationship between lower limb strength training and the speed of walking in people with a traumatic brain injury.

The six subjects were divided into two equal groups. Subjects were assigned to a group depending upon subject preference and convenience. Subjects one, two and three (BN, JP, GH) were place in Group 1 to foster their participation in this study. The length of time to establish baseline data was long (seven weeks) and these subjects were becoming increasingly frustrated that they were unable to begin training.

Establishment of Baseline

The criterion set for establishment of baseline was when all six subjects showed sufficient stability in their baseline walking speeds (defined as ± 10 seconds) over a minimum of three trials. However, at seven weeks (7 trials) stability was only observed in Subjects 1, 2, 4 and 5. Subjects 3 and 6 showed considerable variability and a decreasing trend in times. Attendance may have affected stability in the baseline. Subjects 2 and 6 were both absent for two trials. Subjects 4 and 5 missed one trial each while Subjects 1 and 3 were present for all trials.

Due to subject frustration with delay in the initiation of training and restrictions on researcher time, the decision was made to begin the second phase (B) of the study. Although not ideal for single-subject research, this step was necessary to avoid losing subject interest and motivation to continue. The risk was taken that the strength training program would be a sufficiently strong intervention to show improvements beyond the baseline phase of data collection.

Once Group 1 (Subjects 1, 2 and 3) began the B Phase, both groups continued to be tested on the obstacle course on a weekly basis. The ongoing collection of the data for both Groups served as an additional control. If subjects in Group 2 were not showing a trend of improvement in their walking times during this time frame, but did improve after strength training intervention, then conclusions could be confidently drawn that improved walking speeds were in fact due to the intervention prescribed.

When Group 1 began to show a trend toward improvement of time on the obstacle course (defined as a 30 percent decrease in time over a minimum of three trials from baseline average), Group 2 began their strength training program (B Phase). Group 1 had been training a total of 9 weeks when Group 2 started B Phase. Group 1 continued to strength train and were tested on the obstacle course weekly. Group 2 strength trained for 9 weeks making the total duration of the study 25 weeks.

Two groups were utilized in this study for several reasons. If the intervention had similar effects for both groups, the results of this study become scientifically stronger. Due to the varying levels of performance in individuals with traumatic brain injury, this number of people were required to allow generalizability to the population of people with TBI. Finally, the effects of subject drop-out were reduced.

Obstacle Course

An obstacle course was developed which contained one flight of stairs (ascending and descending), one ramp (with a rail), two automatic doors, a 25 metre walkway on a concrete surface, and a four inch high "mock" curb. The obstacles selected were those encountered by this population on a daily basis. Although there have been many studies conducted utilizing a walkway, no similar studies have been performed using obstacles of daily living. An outdoor course was not selected due to the unpredictability of weather conditions.

The placement of the curb and the start and finish lines were marked with permanent marker and remained consistent throughout the duration of the study. The course was placed in a low traffic area but, due to the location in a field house, noise and activity occasionally distracted the subjects. In order to simulate daily living, when distractions occurred during time trials, they were not discounted and not recorded.

Collection of Time Data

Brandstater et al. (1983) suggested that velocity of walking was an adequate measure of gait performance to identify deficits in the stride period, cadence, stance period and swing period. Thus, time in seconds to complete the obstacle course was utilized to measure subject performance. Velocity, measured in metres per second, was not used as the accuracy of the distance calculated would have been questionable due to the obstacles.

In order to measure intra-tester and inter-tester reliability of the collection of time data, a pilot study was conducted with three subjects with a traumatic brain injury not involved in the primary study. Four volunteers were selected as timers. One timer was the primary researcher, and of the three other timers, one timed all subjects in the primary study. The primary researcher did not perform the timing in the main study to avoid bias in the data collection. Three pilot test sessions were conducted in weekly trials in an attempt to simulate as closely as possible the primary study.

Subjects were instructed to walk as quickly as was safely possible. Subjects were placed behind a marked line on the floor and were given instructions to start as "go when ready". Upon initial foot movement by the subjects, the stop watch was started. The stop watch was stopped when the subject's foot crossed the plane of a marked end line on the floor one meter from the top of the stairs. All subjects received stand by assistance to ensure safety.

The reliability results of the primary study were analyzed using a Multiple

Analysis of Variance (MANOVA) employing the SPSSx statistical software package. Inter-tester reliability (reliability between testers) was found to be significant ($p<.01$) $F=.9983$ ($df=5$) and intra-tester reliability of the primary timer was found to be significant ($p<=.05$) $F=.9967$ ($df=35$). This level of reliability was deemed to be acceptable to begin the primary study.

Subjects for the primary study were given the same instructions as those in the pilot study ("go when ready") and were instructed to walk as quickly as possible. Subjects were timed on a weekly basis (Fridays) before performing their strength training program. Although subjects were timed by timer MC to avoid bias in the data collection, the primary researcher was always present to supervise and offer standby assistance.

<u>Measurement of Strength Changes</u>

Peak torque was measured using the Cybex II Dynamometer. The use of the Cybex II Dynamometer has been reported as a reliable and valid measure of muscle torque (Mawdsley & Knapik, 1982). The damping was set at 1 to avoid suppressing the true quantity of muscle torque as recommended by Sinacore et al. (1983). Gravitational effects were held constant as all subjects were tested without compensation. Calibration of the Cybex II was performed in accordance with the instructions provided by the manufacturer prior to each test session.

Research by Tripp & Harris (1991) investigated the use of isokinetic testing in subjects with spastic hemiparesis. The researchers concluded that isokinetic testing yielded reliable results on both the affected and unaffected sides. Although the researchers used a different measuring device (LIDO Activation Isokinetic System), the nature of the testing is similar to Cybex II.

Testing began at the end of the collection of baseline data and continued every four weeks thereafter for a total of five test sessions. Test sessions took place on Sundays to allow adequate recovery from the strength training session on the previous Friday. A standardized sub-maximal warm-up (consisting of three repetitions at the speed of 60 degrees per second for each muscle group tested) was provided for each subject. The muscle groups tested were the ankle plantar flexors, ankle dorsiflexors, hip flexors, hip extensors, hip adductors, hip abductors, knee flexors and knee extensors. For subject convenience the muscle groups were tested at each test session in the above prescribed order.

All tests were performed by the primary researcher. The protocols as described by the Manufacturers were followed for each test. The only modification made was the use of a wider bench for subjects 2 and 4 for safety and subject comfort. Both subjects were overweight, thus the Cybex bench was not wide enough. The data was collected using the Cybex II chart recorder. After warm-up, subjects performed six maximal repetitions. The peak torque calculated was the single highest value produced by the subject for each muscle group.

Strength Training Methods

Prior to each strength training session, subjects were required to perform a standard warm-up. The purpose was to reduce muscle soreness and prevent possible injury. The warm-up exercises prescribed were specific to the muscle groups that were to be trained. The warm-up consisted of: a ten minute bout on a bicycle ergometer (heart rate was not monitored), ankle circles (three times ten repetitions, each way, each ankle), hurdlers' stretch (three times on each leg, holding each stretch for ten seconds), sitting toe touch (three times, holding position for ten seconds) and groin stretch (three times, holding position for ten seconds). The total time for subjects to perform the warm-up was twenty minutes. Subjects were supervised during their warm-up by the primary researcher or the weight room attendant if the researcher was not available.

The exercises prescribed were those specific to the muscle groups required for walking, as recommended by Bohannon (1986). Bohannon found correlations with speed of walking and the muscle groups of ankle plantar flexors, ankle dorsi flexors, knee extensors, knee flexors, hip adductors, hip abductors, hip extensors and hip flexors.

All exercises were performed using Nautilus with the exception of the toe press (for ankle plantar flexors and ankle dorsi flexors) which was performed on a Universal apparatus. The exercises on Nautilus were as follows: Hip and Back (for the hip flexors and hip extensors), Hip Abduction/adduction (for the hip abductors and hip adductors), Leg Extension (for the knee flexors, and knee extensors), and the Leg Curl (for knee flexors).

Subjects were positioned on the apparatus according to the instructions as provided by the Nautilus and Universal Manufacturers. No modifications were required to accommodate the subjects. All Nautilus exercises and warm-ups were performed at the Rick Hansen Centre. Exercises on the Universal apparatus were performed in the University's general use weight room.

Prior to commencing the strength training program, subjects came in for one session during which their one repetition maximal (1RM) for each apparatus was determined. This is defined by Delorme and Watkins (1948) as the maximal load a muscle group can lift before fatigue. Research by Berger (1962) showed that the most effective strength training program is one that is performed with three sets with six repetitions using a percentage of the individuals' 1 RM. To date, research of effective strength training protocols for subjects with a traumatic brain injury has not been performed. Therefore, the protocol as described by Berger (1962) was selected.

Subjects were required to perform three sets. The first set was six repetitions with a resistance of 50 percent of their 1 RM. The second set was six repetitions at a resistance of 65 percent of 1 RM, and the third set, six repetitions at a resistance of 80 percent of their 1 RM. During training sessions, if subjects could perform more than eight repetitions on the last set, the resistance was increased for each set by five pounds at their next training session for that particular exercise.

There was some difficulty encountered with this protocol. Subjects often indicated that the first set was too easy and demanded more resistance or did more than the required six repetitions. If the increased resistance was provided, subjects were unable to perform the final set of six repetitions at 80% of 1 RM. This was resolved by providing further education to the subjects on strength training principles and providing constant supervision either by the primary researcher or the weight room attendant.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The results of this study will be presented in two ways. Firstly, individual results will be presented. The results of the subjects' time to walk the obstacle course, Cybex data and resistance changes on Nautilus and Universal will be provided. This will be followed by a discussion of the individual's results. Second group results will be presented. The results will then be summarized in terms of the two Groups; {Group One and Group Two} at the conclusion of the individual discussion of the third subject in each group. To protect confidentiality, subjects will be identified as Subject #1 (BN), Subject #2 (JP),Subject #3 (GH) {Group 1}, Subject #4 (SW), Subject #5 (WK), and Subject #6 (LH) {Group 2}. Upon completion of these two sections, there will be a general discussion at the conclusion of the chapter.

Method of Analysis

The speed of walking on the obstacle course will be analyzed graphically and by calculating average times measured during baseline and average times achieved during B Phase (intervention). The averages will be calculated by adding up the times recorded and dividing by the number of trials completed. A percent improvement will be provided for each individual from the end of baseline to the conclusion of the study. Percent improvement will be calculated by dividing the total average times measured in baseline by the average total in B Phase and multiplying by 100.

It should be noted that the first time trial for all subjects on the obstacle course has been removed in all of the Figures of the time data presented. This point was deleted as it reflects the slowed effects of the subjects' first initiation to the course. With the removal of this data point pictorially, the trend of decrease in the subjects time to walk the obstacle course from the beginning of the study to the end is more representative of the actual changes that took place. All data points were used in all mathematical calculations of averages and percentages.

The Cybex data results will be analyzed graphically. In addition, changes will be indicated by peak torque (measured in Newton Meters (NM)) differences from the first baseline test to the final test.

I. INDIVIDUAL RESULTS

GROUP 1

SUBJECT #1: BN

Subject Characteristics

BN, a 43 year year old male was injured when a garage door he was repairing at home fell on him. BN was a labourer at the time of injury but has since retired. BN had been injured 26 months prior to the commencement of the study and was in a comatose state for 14 days post-injury. He was an eager participant in all aspects of the study.

BN had a memory deficit as evidenced by his inability to remember the primary reseearcher's name even after 17 weeks of seeing him three times per week. BN's gait deficits were minimal. BN had a slight lateral lean to the right and BN's right side was slightly stronger than his left. This data is obtained from self-report and was substantiated in the results of the Cybex data. BN's gait deficits were exacerbated at the beginning of the study when attempting to traverse the "mock curb" of the obstacle course. He appeared slightly unstable. BN had no difficulties with the stairs and in fact had to be reminded to travel them one at a time by the end of the study. BN also did not exhibit any difficulties with the ramp, going down it independently, without holding on to the rail for assistance.

After he was taught what exercises to do on each machine and how to adjust his resistance, BN was able to carry out strength training sessions independent of supervision. The primary researcher and the weight room attendant did frequent spot checks to ensure he was performing the exercises accurately with all weights at the prescribed resistance. BN commented to the primary researcher many times that he felt much better since beginning his strength training program, and has continued to strength train at the Rick Hansen Centre since the conclusion of the study.

<u>Time on Obstacle Course</u>

BN's results are displayed in Figure 1. The raw data is found in Appendix A. Figure 1 shows that BN improved his time on the obstacle course

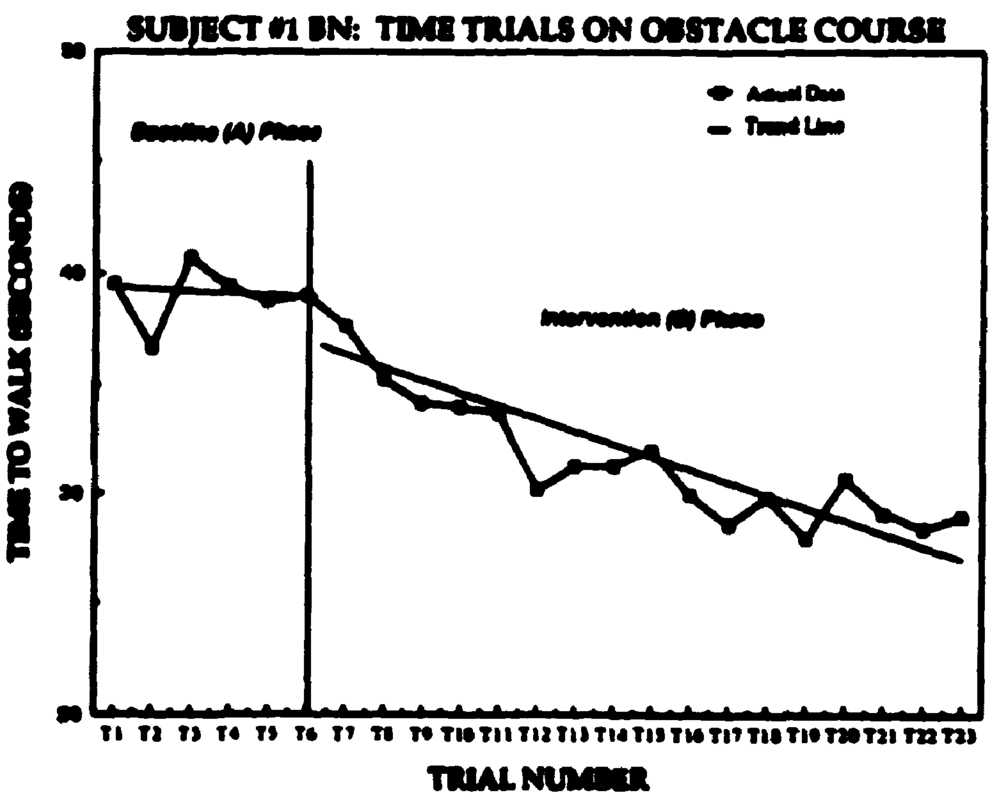

FIGURE 1-SUBJECT#1 BN: Time to Walk Obstacle Course

considerably from baseline to the conclusion of the study. His average time during baseline was 39.72 seconds and his average time was reduced to 31.33 seconds during post-intervention. From baseline to the conclusion of the study, there was an average difference of 8.39 seconds which represents a 78.88 percent improvement.

Cybex Results

BN improved on the following Cybex tests: Right knee flexion (57NM), left knee flexion (21NM), right knee extension (10NM), left knee extension (33NM), right ankle plantar flexion (15NM), left ankle plantar flexion (9NM), left ankle dorsi flexion (6NM), right ankle dorsi flexion (12 NM), right hip adduction (18NM), left hip adduction (13NM), and left hip extension (36NM). BN showed a decrease in strength in right hip extension (-10NM), right hip flexion (-11NM), and left hip flexion (-2 NM), as illustrated in Figures 1a, 1b, 1c and 1d. The raw data is located in Appendix B. Table B illustrates that BN increased all resistances on his Nautilus and Universal exercises.

Discussion

Examining Figure 1, BN had a relatively stable baseline. After Week 1 of B Phase, BN never went slower on the obstacle course than his fastest time during baseline (36.67 seconds). After the sixth week of strength training, BN recorded his fastest time to date. This result is possibly indicative of strength gains as strength gains have been reported as early as six weeks after beginning training (Frontera et al. 1988). BN's time plateaued for three more weeks but then began to show steady and continual improvement.

Perry et al. (1993) found a strong relationship between plantar flexion strength and hip abduction strength for fast walking in patients with post-polio

SUBJECT #1 BN: RIGHT KNEE AND RIGHT ANKLE CYBEX

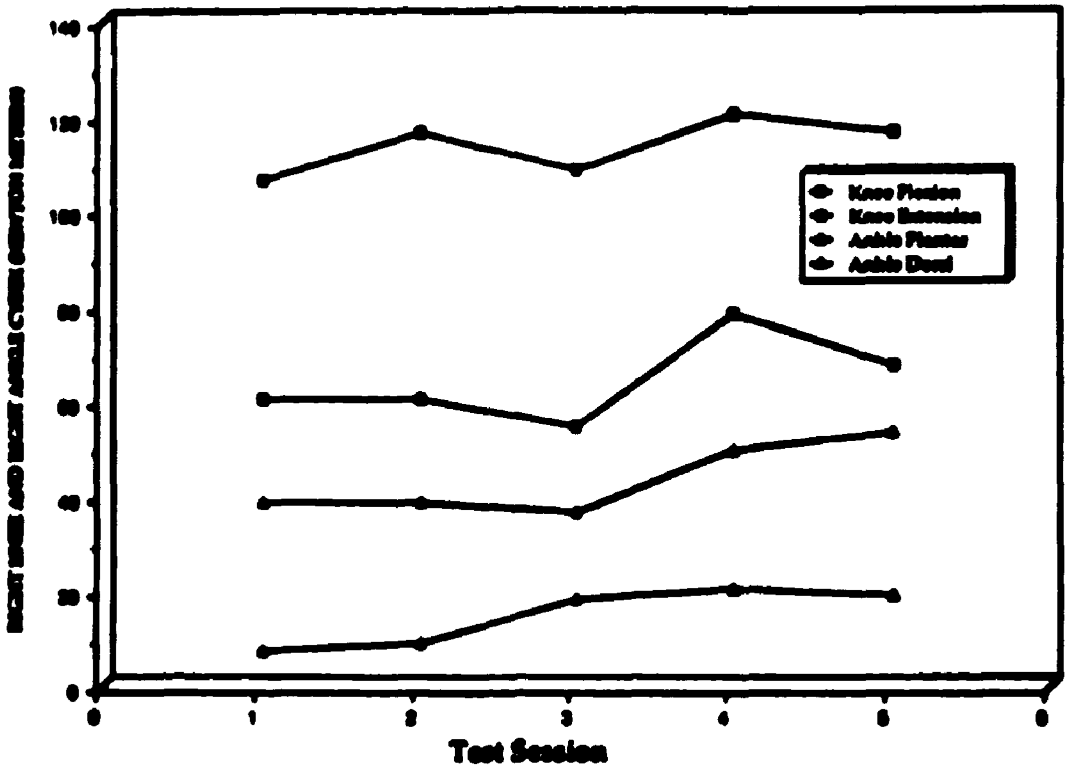

Figure 1 A-Right Knee and Right Ankle Cybex Data

SUBJECT #1 BN: LEFT KNEE AND LEFT ANKLE CYBEX

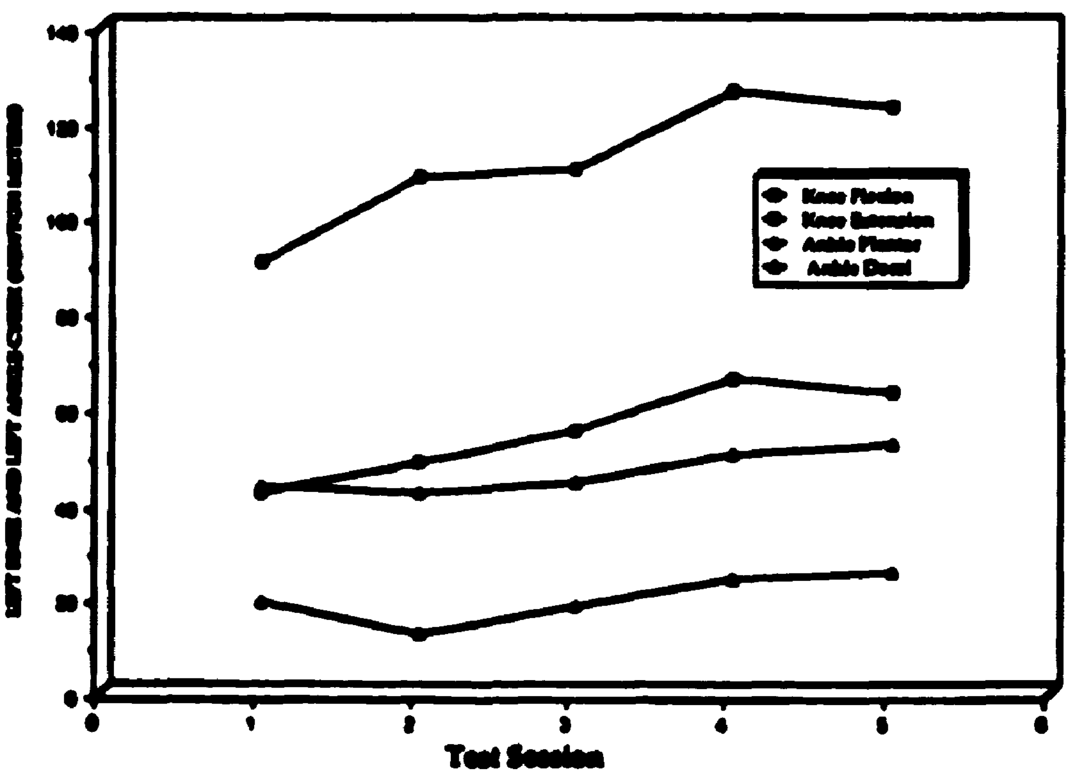

Figure 1 B-Left Knee and Left Ankle Cybex Data

SUBJECT#1 BN: RIGHT HIP CYBEX

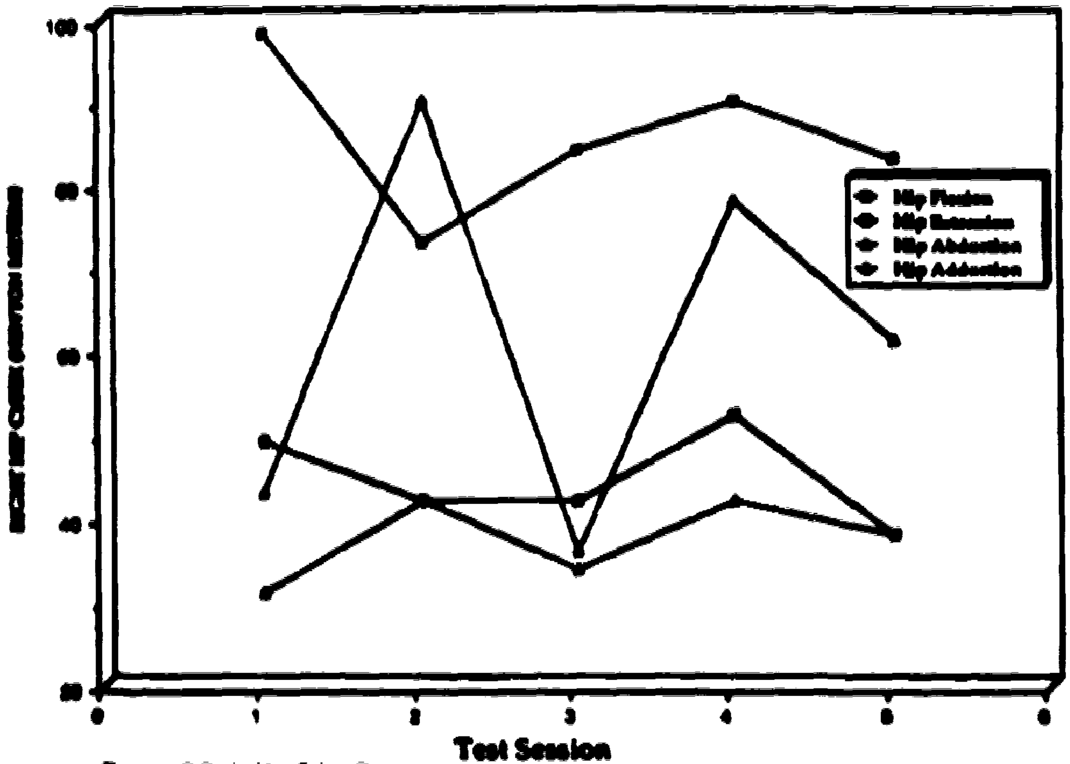

Figure 1 C-Right Hip Cybex Data

SUBJECT #1 BN: LEFT HIP CYBEX

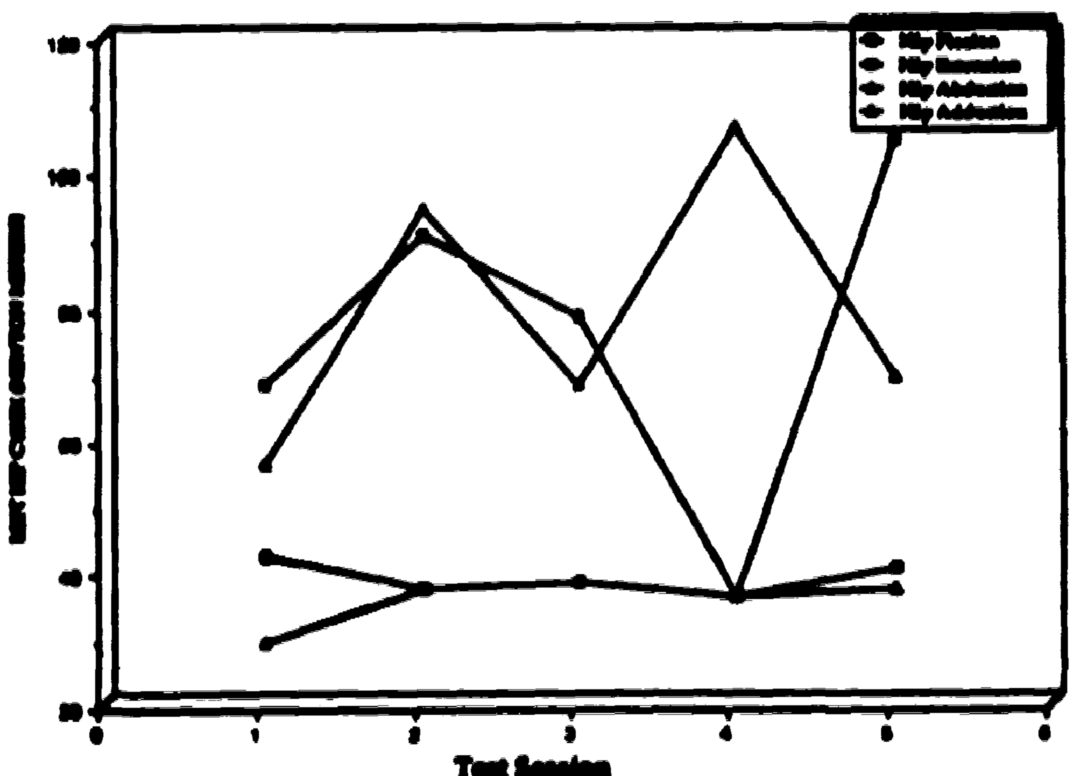

Figure 1 D-Left Hip Cybex Data

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	65 70 85	65 75 90	60 75 85	35 45 55	90 120 135	50 60 70
[illegible]	75 85 95	90 90 120	70 90 110	50 60 70	90 140 180	120 160 180

syndrome. Hamrin et al. (1982) and Nakamura et al. (1985) found a relationship between isokinetic muscle torques of knee extension and knee flexion and gait in patients with stroke. Bohannon (1986) found a relationship between cadence and velocity and strength of the hip extensor, knee flexor, ankle dorsi flexor and ankle plantar flexor muscle groups. A correlation between cadence and strength of the hip abductor and knee extensor muscle groups was also established. In a follow-up study, Bohannon (1990) further determined that knee extensor muscle torque was related to the speed of walking in patients with stroke. Finally, Lankhorst et al. (1985) did a study with patients with osteoarthrosis of the knee in relation to the tasks of stair climbing, walking, and rising from a chair. Lankhorst et al. determined that strength of the quadriceps correlated with speed of stair climbing and walking.

On Cybex, BN's largest gains were observed in left hip extension (36NM), left knee extension (33NM), right knee extension (10NM), right hip adduction (18NM), and right ankle plantar flexion (15NM). The large gains observed in left and right knee extension and the marginal gains in plantar flexion and dorsi ankle flexion agree with the literature stating that these muscles are related to the velocity of walking. The decreases noted in hip flexion in BN are also in agreement with the literature as they have not yet been previously identified as being related to the velocity of walking.

Thus, due to BN's relatively stable baseline and noticeable increases in time on the obstacle course, it would appear there is a relationship between his increased lower limb muscle strength and corresponding increase in speed of walking on the obstacle course. This increase is probably due to his improvement in quadriceps and hip extensor strength which would improve his ability to perform the stairs. However, without knowing his speeds on the stairs (split times), the strength of this relationship is difficult to discern.

SUBJECT #2: JP

Subject Characteristics

JP is female and had been injured the longest of all of the subjects. She sustained her injury as a result of an assault in 1970 and was in a comatose state for four days. She was the oldest of the subjects at 58 years of age and was somewhat obese. JP was particularly eager to be involved in the study as she had been attempting to enter the Rick Hansen Centre to train for several months prior to the start of the study.

JP, like BN, had very few noticeable gait deficits but walked with a cane. She walked considerably slower than BN. JP indicated that she had frozen her left foot several years prior to the TBI and had walked with a cane in her right hand since her brain injury. JP's most noticeable deficits were a slight trunk lean right and dragging of her left foot. At the outset of the study, JP used her cane for her timing tests. By week number five, JP no longer used her cane for the tests.

JP had some memory deficits. She had to be reminded for approximately six weeks which way to go after going through the automatic doors on the obstacle course. JP was on anti-depressant medication throughout the duration of the study. JP could not write but it is not known if this was a direct result of her brain injury as she indicated or if she was illiterate prior to her injury. JP worked as a secretary three years prior to the study but had since retired.

JP was a motivated subject for the most part. There was some difficulty with her attempting heavier resistance. If JP was not told there would be an increase in weight, she was able to lift it. If she knew there was going to be an increase, she would not be able to complete the set and would quit due to fatigue. This may have been a result of her prior inexperience in a resistance training program. JP had relatively regular attendance but would occasionally miss two to three days without a phone call.

JP could eventually set her own weights but was unable to record them due to her inability to write. JP required close supervision as she would neglect her warm-up if allowed and was required to be strapped into some of the machines. It was also important to keep JP motivated to continue to complete her strength training program on a daily basis. JP frequently indicated that she felt much better since beginning her strength training program and also continued training at the Rick Hansen Centre after the conclusion of this study. JP exudes much more confidence since commencing the study and she attributes this to the undertaking of an exercise program. JP no longer requires the use of her cane anymore.

Time on Obstacle Course

JP's results are displayed in Figure 2. The raw data is found in Appendix A. Figure 2 shows that she experienced a clear decrease in time during the gathering of baseline data. Although the trend of the data during baseline is decreasing, JP never went slower than her slowest time on the obstacle course after beginning Phase B. Her average time during baseline was 65.33

seconds, and her B Phase average was 51.56 seconds, for a total average decrease of 13.77 seconds, representing a 78.93 percent improvement. JP's fastest time during baseline was 57.44 seconds. Her fastest time recorded during B Phase was 45.77 seconds a difference of 11.67 seconds.

SUBJECT #2 JP: TIME TRIALS ON OBSTACLE COURSE

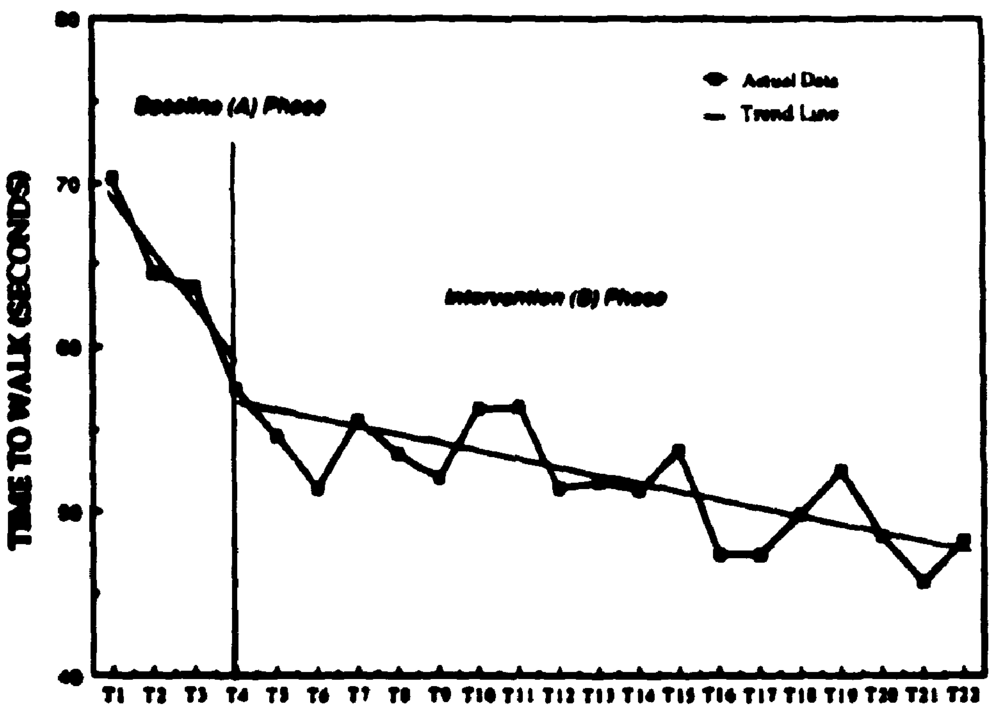

FIGURE 2-SUBJECT#2 JP Time to Walk Obstacle Course

Cybex Results

JP increased all of her Cybex measurements as follows: right knee flexion (6NM), left knee flexion (13NM), right knee extension (20NM), left knee extension (21NM), right ankle plantar flexion (17NM), left ankle plantar flexion (1NM) left ankle dorsi flexion (10NM), right ankle dorsi flexion (9NM), right hip adduction (33NM) left hip adduction (5NM), left hip extension (27NM), right hip extension (37NM), right hip flexion (4NM), and left hip flexion (10NM) as illustrated in Figures 2a, 2b, 2c and 2d. The raw data is located in Appendix B.

SUBJECT#2 JP: RIGHT KNEE AND RIGHT ANKLE CYBEX

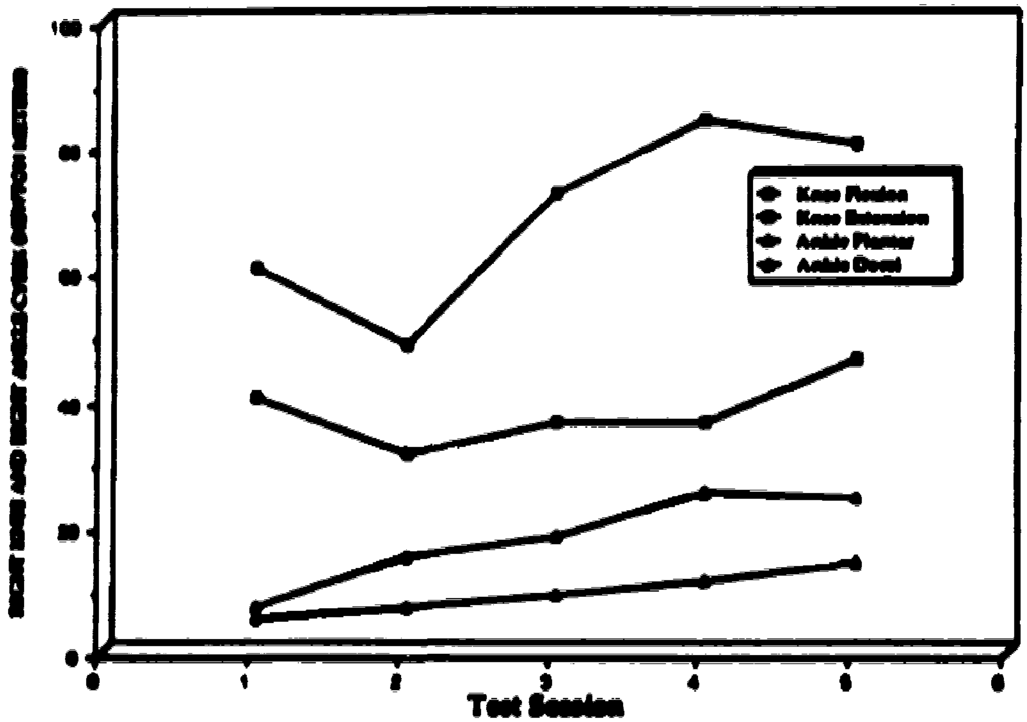

Figure 2 A-Right Knee and Right Ankle Cybex Data

SUBJECT #2 JP: LEFT KNEE AND LEFT ANKLE CYBEX

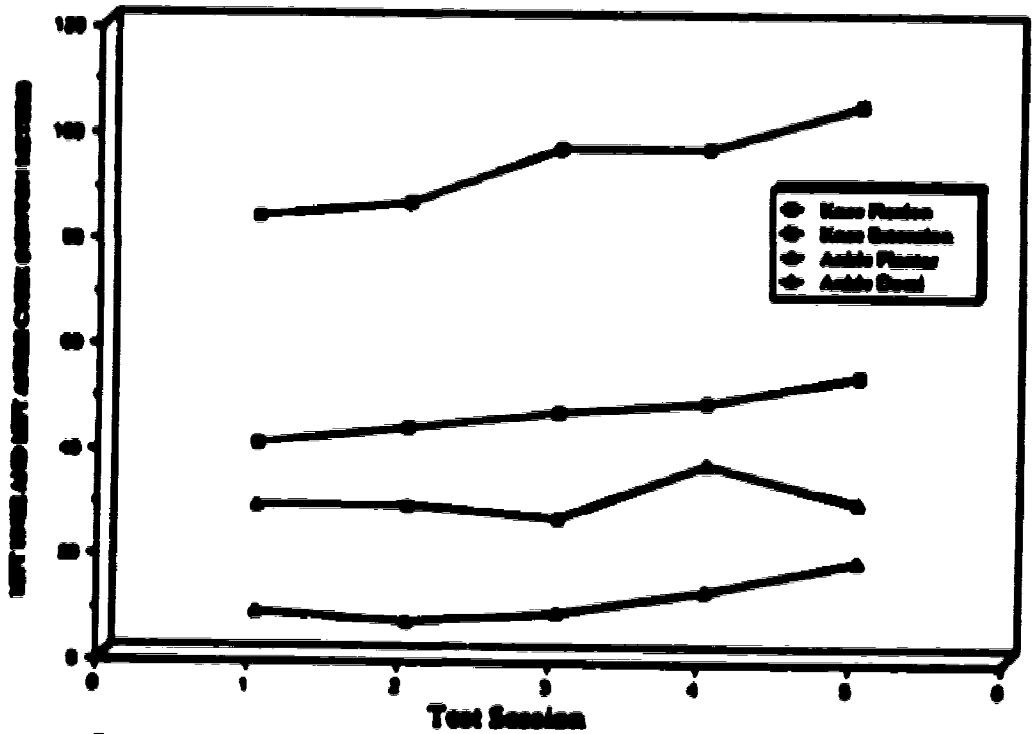

Figure 2 B-Left Knee and Left Ankle Cybex Data

SUBJECT #2 JP: RIGHT HIP CYBEX

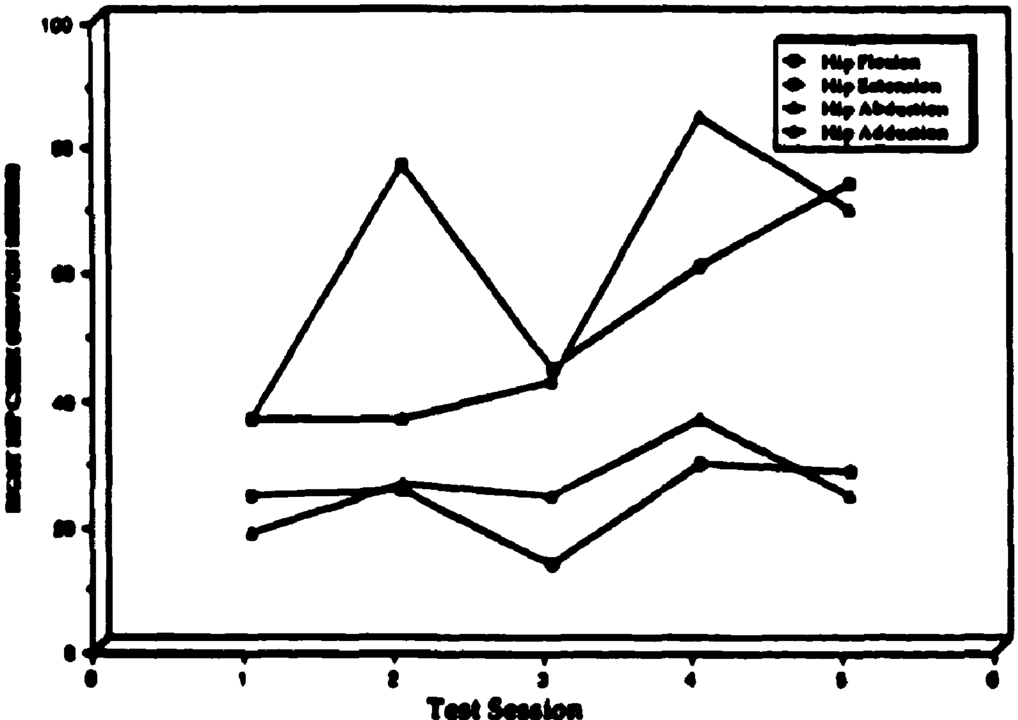

Figure 2 C-Right Hip Cybex Data

SUBJECT #2 JP: LEFT HIP CYBEX

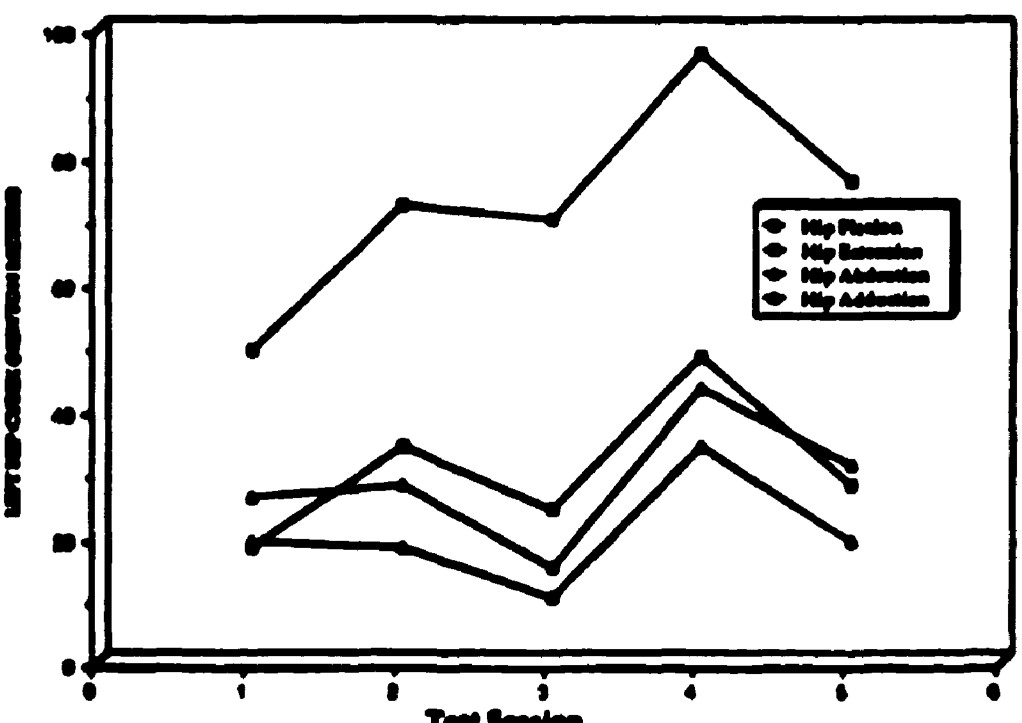

Figure 2 D-Left Hip Cybex Data

JP also increased all of her resistances on the Nautilus and Universal machines as illustrated in Table C.

JP [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	50 60 75	50 60 75	50 60 75	30 35 40	60 65 80	70 90 110
[illegible]	65 70 80	60 70 75	65 75 85	35 40 50	55 70 90	80 100 120

<u>Discussion</u>

From JP's results there seems to be a relationship between lower limb strength and speed of walking on the obstacle course. By comparing Figure 2 with Figures 2a and 2b, increases in strength seem to coincide with decreases in speed on the obstacle course. After the eighth week of strength training, increases are seen in all Cybex results excluding those of hip flexion, hip abduction and hip adduction. However, by the sixteenth week of training, these peak torques had also increased from initial measures. JP's times decreased a total of 6.02 seconds from the last baseline measurement taken after 16 weeks of strength training.

JP's results are in agreement with the literature in that there seems to be a relationship between the strength of knee extension, knee flexion, ankle plantar flexion, ankle dorsi flexion, hip adduction and hip abduction (Hamrin et al.,1982, Nakamura et al.,1985, Bohannon, 1986, Perry et al, 1993) and speed of walking. JP's moderate increases in hip flexion also support relatively little to no relationship between these muscles and speed of walking. With the exception of right knee flexion, JP's large increases in knee flexion and extension lend support to Lankhorst et al. (1988) who concluded that strength of the quadriceps femoris muscles are key to performing stair climbing and other related activities. However, as with BN, the strength of this relationship is again difficult to discern without split times measured on the stairs.

SUBJECT #3: GH

Subject Characteristics

GH is male and was injured five years prior to the start of this study as a result of a motor vehicle accident. GH was the most severely injured of the group as measured by his length of coma (180 days). GH was the youngest of the subjects at age 22. He is unemployed and had obtained a grade 11 education. GH had speech difficulties and experienced mood swings as reported by both his group home staff and personal observation of the researcher.

GH used a wheelchair as his regular means of daily mobility. GH did not use a walking device, other than his wheelchair as it would have been unsafe. GH had several gait deficits that were easily observed. Some of these included: hyper extension of the knee, excessive plantar flexion with toes first, forward lean of the trunk and poor control of all of his limbs due to spasticity. For timing on the obstacle course, GH was supported by the primary researcher. GH walked by holding onto the researcher's right shoulder for stability.

GH was initially highly motivated to begin strength training. GH was extremely frustrated during the gathering of baseline data as he did not understand why he could not begin strength training. Once he began strength training, GH would demand more and more resistance but had to be restricted as his technique was poor with increased weight. Constant reminders to GH that technique was more important than increased resistance served to only frustrate him. GH was dependent during all components of his strength training as he required assistance moving from machine to machine and could not remember how to set his weights accurately from day to day. Furthermore, GH often had to be shown how to perform each task from day to day.

Difficulties with GH were encountered in maintaining a professional relationship with him. GH began to call the researcher at home unnecessarily. As a result, the researcher was asked by the group home staff to remind him of the purpose of his involvement in the study. His altered behaviour was interfering detrimentally with his performance and cooperation at the group home.

Unfortunately, GH quit very early in the study. GH would not give reasons for quitting and refused to discuss it further with the researcher by telephone. An attempt was made to see GH in his home but GH was not home when the researcher went to his residence. However, when questioned prior to withdrawing from the study, GH had indicated several times that he felt much better since beginning strength training, and the researcher was somewhat surprised when he quit as he appeared to be improving his motor control on the Nautilus machines considerably.

Time on Obstacle Course

GH exhibited a very unstable baseline, with no apparent trend towards decreasing (Figure 3). However, after only 6 weeks of strength training, GH's time on the obstacle course seemed to decrease. GH's baseline average was 165.48 seconds and, after beginning Phase B, it was 156.68 seconds which represents an 86.09 percent improvement. GH's fastest time recorded during baseline was 162.33 seconds. Although he went slower than this time during B Phase, his fastest time recorded during B Phase was 106.44 seconds.

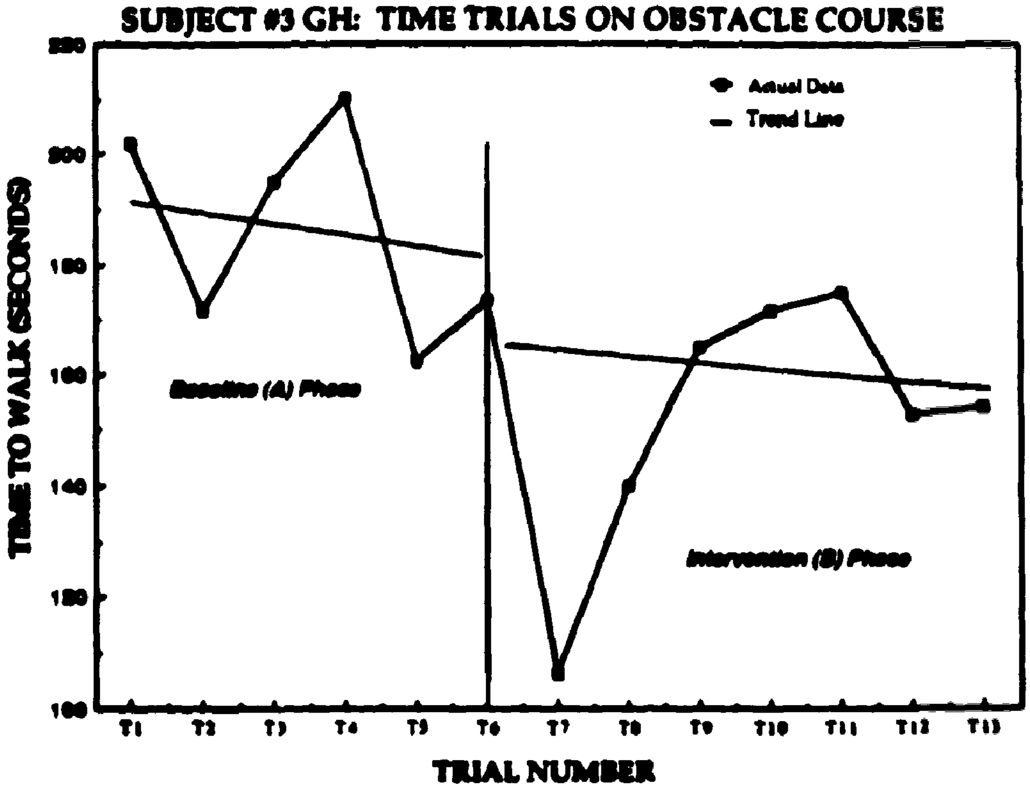

FIGURE 3-SUBJECT#3 GH: Time to Walk Obstacle Course

<u>Cybex Results</u>

Increases were observed for the following exercises: right knee flexion (26NM), right knee extension (72NM), left knee extension (3NM), left ankle plantar flexion (8NM), left ankle dorsi flexion (8NM), right ankle dorsi flexion (4NM), left hip flexion (5NM). Decreases were noted in the following: right ankle plantar flexion (-15NM), left knee flexion (-20NM), right hip adduction (-20NM), left hip adduction (-42NM), left hip extension (-48NM), right hip extension (-84NM), right hip flexion (-52NM), as illustrated in Figures 3a, 3b, 3c and 3d. The raw data is located in Appendix B. GH also improved on his Nautilus and Universal exercises as Shown in Table D.

SUBJECT #3 GH: RIGHT KNEE AND RIGHT ANKLE CYBEX

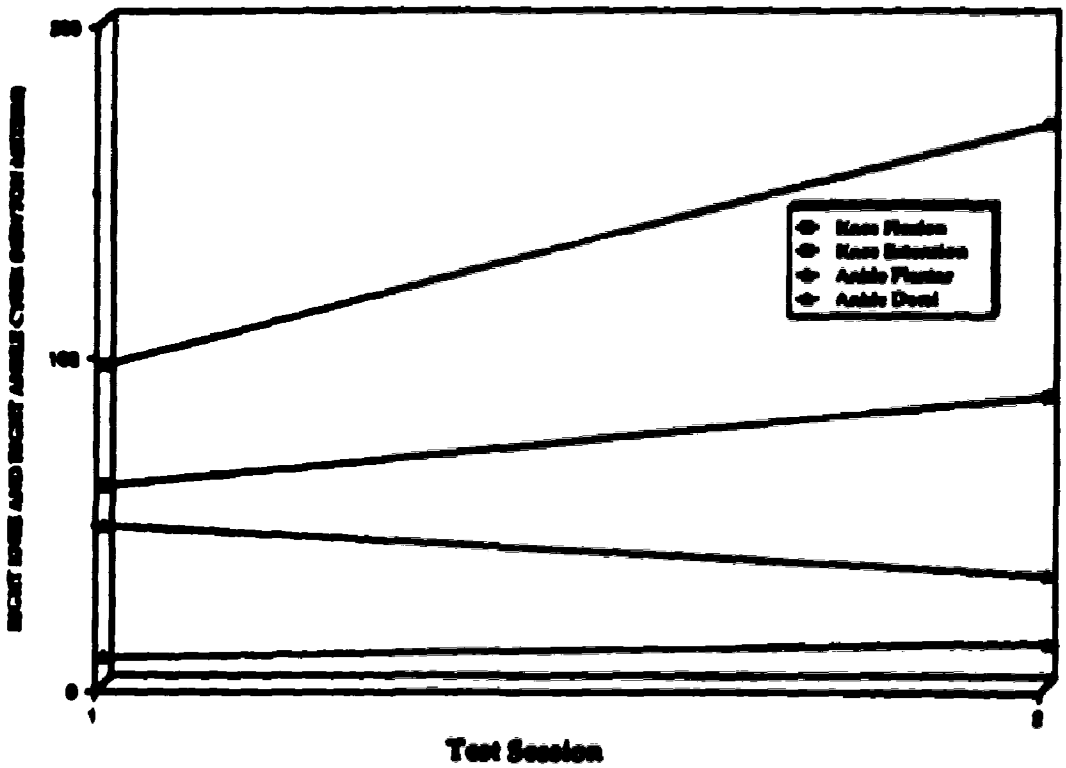

Figure 3 A-Right Knee and Right Ankle Cybex Data

SUBJECT #3 GH: LEFT KNEE AND LEFT ANKLE CYBEX

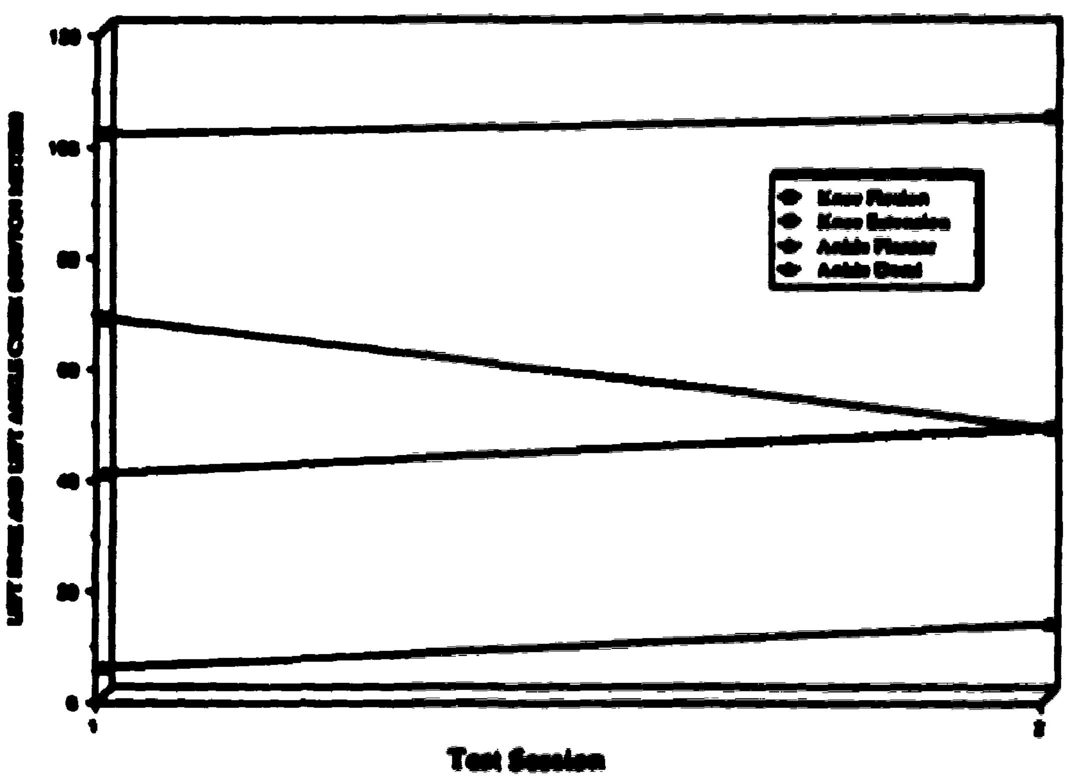

Figure 3 B-Left Knee and Left Ankle Cybex Data

SUBJECT #3 GH: RIGHT HIP CYBEX

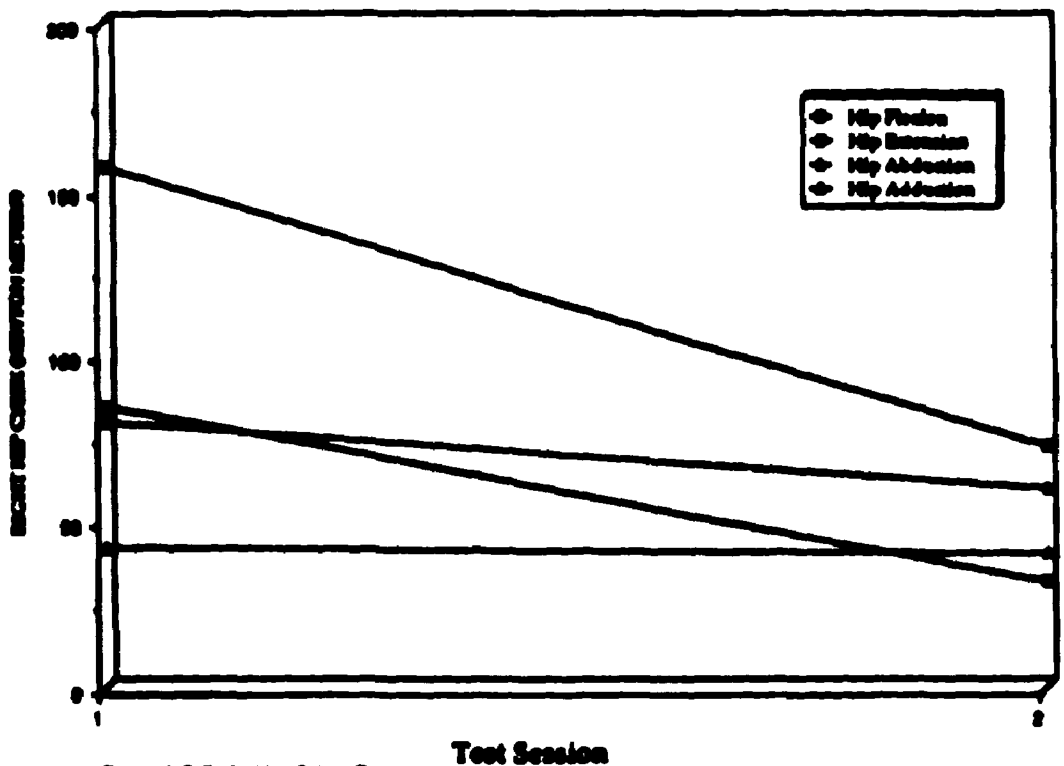

Figure 3 C-Right Hip Cybex Data

SUBJECT #3 GH: LEFT HIP CYBEX

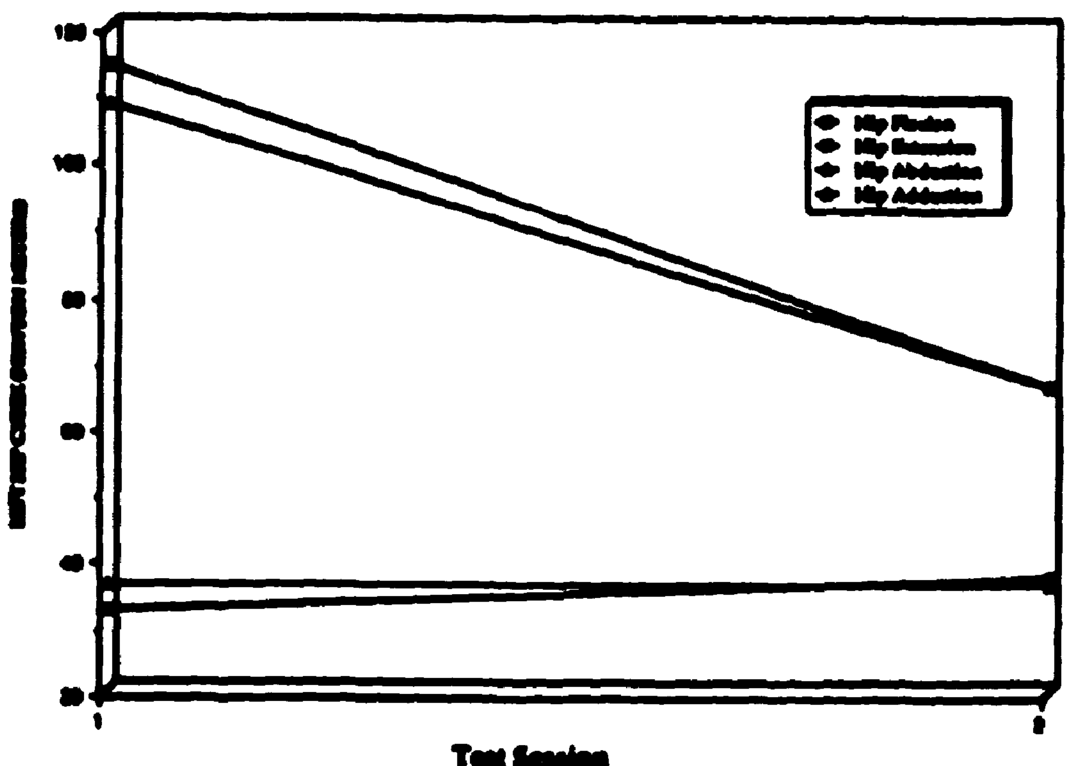

Figure 3 D-Left Hip Cybex Data

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	35 50 60	30 40 55	45 60 70	40 50 65	95 110 140	[illegible] 100
[illegible]	30 40 45	45 55 70	65 70 75	45 50 65	80 100 120	130 150 160

[illegible]

<u>Discussion</u>

After only one week of strength training, GH achieved his fastest time of 106.44 seconds on the obstacle course. As GH was highly motivated (by beginning his strength training the week earlier), perhaps this could explain his rather abrupt improvement. In examining the Cybex data (Figures 3a, 3b, 3c and 3d), GH showed large improvements only in his right knee extension and right knee flexion from baseline. The large decreases in the muscles measured could again be evidence of his declining motivation to continue with the study.

GH was difficult to test using Cybex as his spasticity interfered a great deal. He would become increasingly frustrated if he accidentally kicked the researcher as a result of his spasticity. Although conclusions can not be drawn from GH's results, there are several observations worthy of discussion.

Examining Table D of GH's Nautilus and Universal resistances, it is noted that GH made only marginal increases in his resistance throughout the six weeks of strength training. In fact, some of the weights had to be decreased so that he could perform the exercises accurately. Thus, the method of strength training as proposed by Delorme and Watkins (1962) may not have been appropriate for GH. Instead, resistances should have been initially set so that GH could perform them in a controlled and accurate manner.

A further interesting point with respect to GH's strength training was that he did increase control of the muscles of his lower limbs (although he did not increase his strength noticeably). This was observed by the researcher in his ability to perform the Nautilus and Universal exercises in a more controlled manner after six weeks as compared to when he initially started his program. Furthermore, his Cybex data was recorded much more smoothly on his second test as observed on the chart recordings. This change was most notable in his knee flexion, ankle plantar flexion and ankle dorsi flexion data. Perhaps more important than a heavy resistance training program, recommendations for GH would be to prescribe a low resistance endurance training program to acquire further control of his muscles.

GROUP 1 SUMMARY

Subjects in Group 1 (BN, JP and GH) improved their times substantially on the obstacle course. BN and JP improved their resistances on the Nautilus and Universal machines. The results of BN and JP were found to be in agreement with the literature. Most notably knee flexion and knee extension seem to be related to the speed of walking with less agreement for hip flexion. The improvement in quadriceps may have the most impact on the subjects' ability to traverse the stairs rather than on straight fast walking. It has been noted that it is difficult to confirm this relationship as seperate times were not taken for the stairs and level walking. Confirmation of the relationship of increased strength and decreased speed on the obstacle course is also difficult due to the instability of the baseline data of all three subjects. Although there appears to be a decreasing trend in this data after baseline, the decrease is too variable to be conclusive.

It is difficult to draw conclusions from GH's results. Speculatively, although GH did not make strength gains (with the exception of right knee flexion and extension), he did improve his motor control and thus performance on the prescribed resistance exercises. Therefore, perhaps what contributed to GH's improved performance on the obstacle course was a combination of motivation and improved motor control. GH's data is invaluable as his individual characteristics exemplified and highlighted the common difficulties encountered when performing experimental research with this population.

GROUP 2

SUBJECT #4: SW

Subject Characteristics

SW is female and was injured in a motor vehicle accident just over four years prior to the start of the study. SW was in a coma for 21 days. She was employed as a bank teller pre-injury but has not returned to work. SW has a sincere desire to improve her walking skills and thus was very motivated to take part in the study.

At the time of the study, SW was using a wheelchair for daily mobility. Since the conclusion of the study SW uses a walker for most activities of daily living. SW used four pronged canes for all time trials on the obstacle course, although she wanted to switch to her walker. The researcher would not allow her to switch for fear of contaminating the data. To traverse the stairs, she held the hand of her primary care giver and left her canes at the top of the stairs. Some of SW's gait deficits include: forward trunk lean, external rotation of the right hip, excessive knee flexion and toe drag of the right foot. From SW's Cybex data (Figures 4a, 4b, 4c and 4d), self-report and gait observation, her right side is clearly stronger than her left. Other deficits as a result of her brain injury include difficulty with perception, poor short term memory and some trouble controlling her emotions as she is easily tearful.

SW enjoyed strength training for the most part. She had some lack of motivation to finish on a daily basis and to push herself to fatigue, which is necessary to acquire strength gains. If the researcher was not there, SW would not complete her program. As she was considerably overweight SW was most interested in exercising on the stationary bike in her desire to lose weight,. SW remained dependent on assistance within the weight room and required help to adjust her weights as she was unable to remember from day to day her exact weights. SW continues to strength train at the Rick Hansen Centre.

A difficulty encountered in collecting the walking data for SW was that at week 6, SW obtained a new walking brace which she insisted on using for the test. The effect of the brace on her recorded times on the obstacle course was obvious. Only the week before, she had used her old brace and obtained a time of 516.10 seconds. The week she used her new brace (week 6) she recorded a time of 725.67 seconds. She again switched at week 7 back to her old brace and obtained a time of 571.22 seconds. Thereafter, she used her new brace for the duration of the study. As a result of SW switching knee braces, establishing baseline stability was somewhat difficult.

Time on Obstacle Course

As already mentioned, there were some challenges in establishing a baseline for SW. However, in examining Figure 4, specifically her third and fifth time trials, it would appear that her baseline is relatively stable. Prior to beginning B Phase, there does appear to be a moderate trend of a decrease in her times. Once beginning B Phase, the declining trend becomes even more evident. During baseline, her average time was 625.08 seconds and during B Phase her average was 455.54 seconds, representing a total of 72.87 percent improvement. During Baseline, SW's fastest time was 516.10 seconds. After beginning B Phase, SW never exceeded this time and achieved a fastest time of 379.76 seconds.

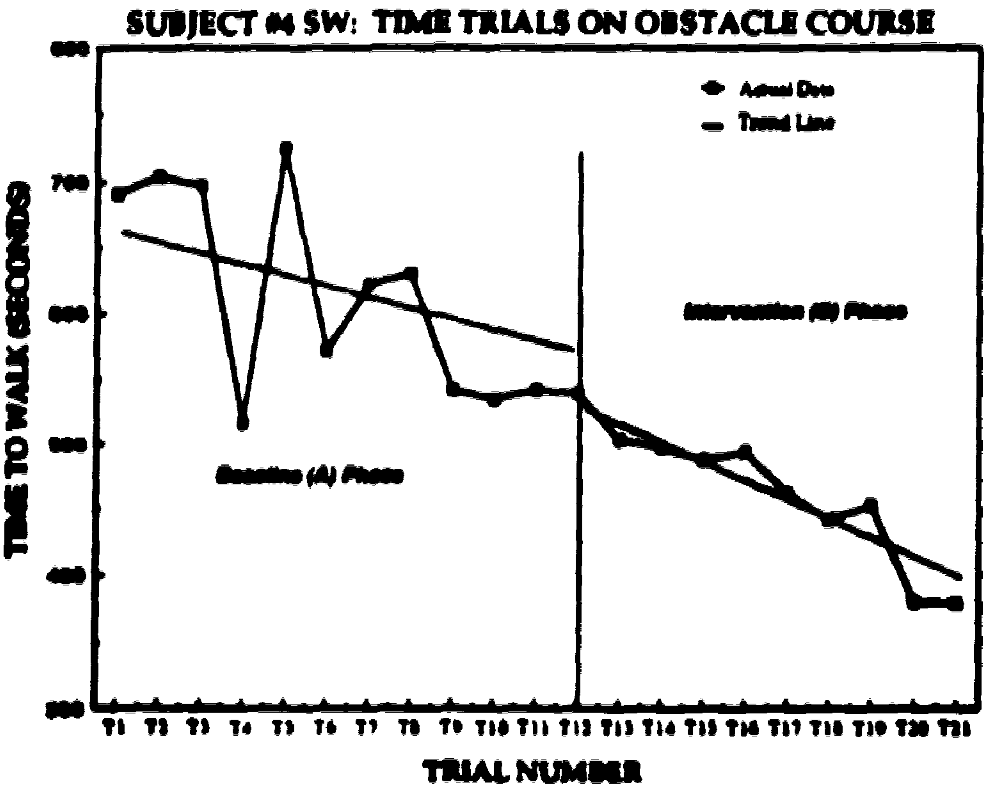

FIGURE 4-SUBJECT#4 SW: Time to Walk Obstacle Course

Cybex Results

SW's Cybex results indicate some increases. Increases were observed in the following: right knee flexion (17NM), left knee flexion (57NM), right knee extension (24NM), right ankle plantar flexion (10NM), left ankle dorsi flexion (4NM), right ankle dorsi flexion (6 NM), right hip adduction (18NM) left hip adduction (32NM), left hip extension (42NM), right hip extension (57NM), and left hip flexion (14NM). Decreases were noted for the following: right hip flexion (-5NM), left knee extension (-3NM), and left ankle plantar flexion (-5) as illustrated in Figures 4a, 4b, 4c and 4d. The raw data is located in Appendix B.

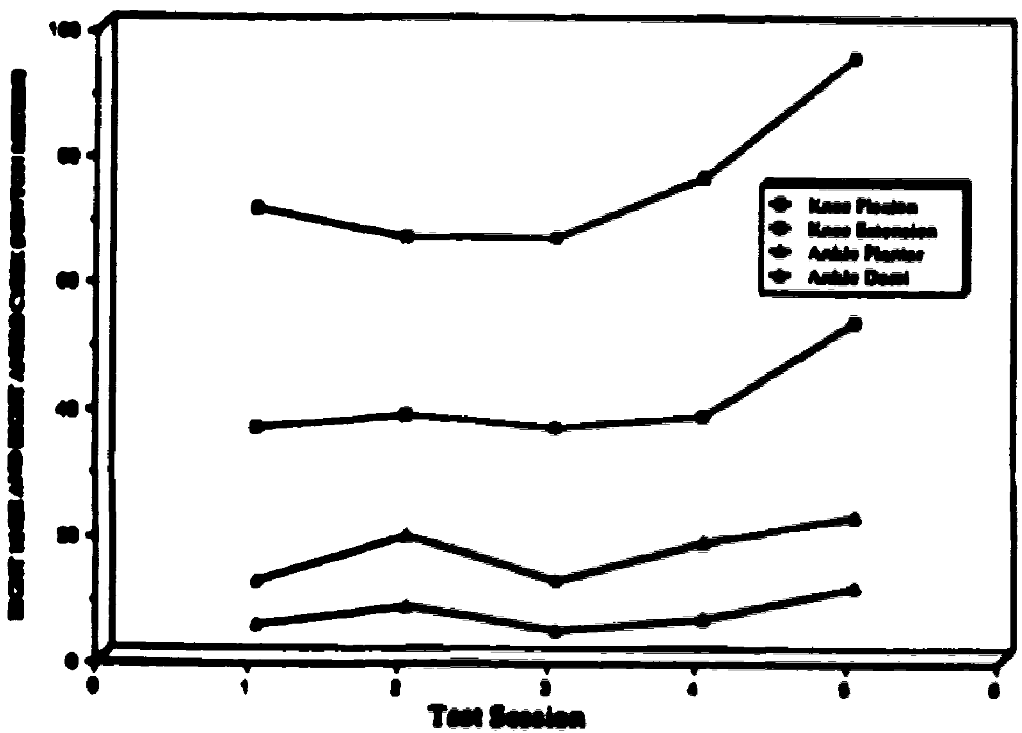

Figure 4 A-Right Knee and Right Ankle Cybex Data

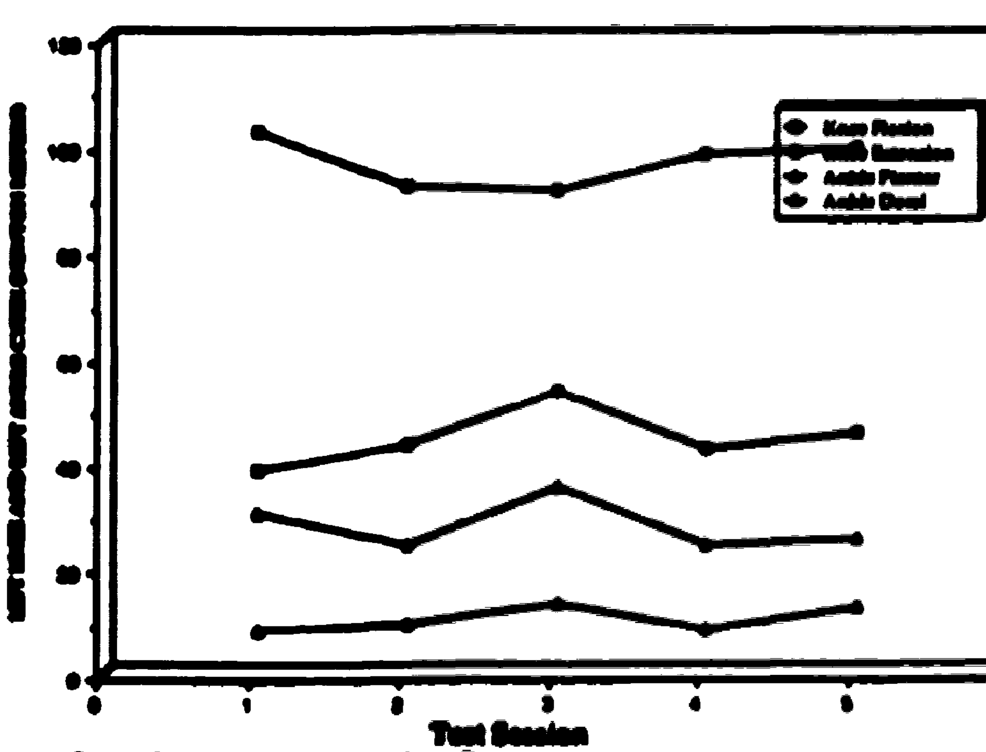

Figure 4 B-Left Knee and Left Ankle Cybex Data

SUBJECT #4 SW: RIGHT HIP CYBEX

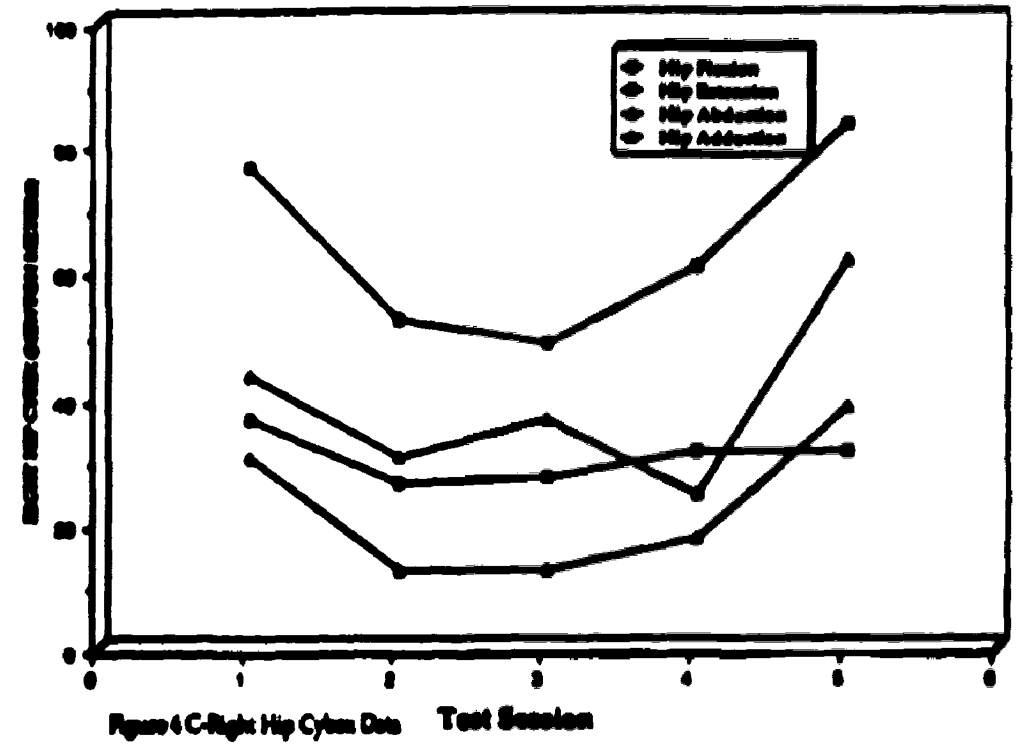

Figure 4 C-Right Hip Cybex Data

SUBJECT #4 SW: LEFT HIP CYBEX

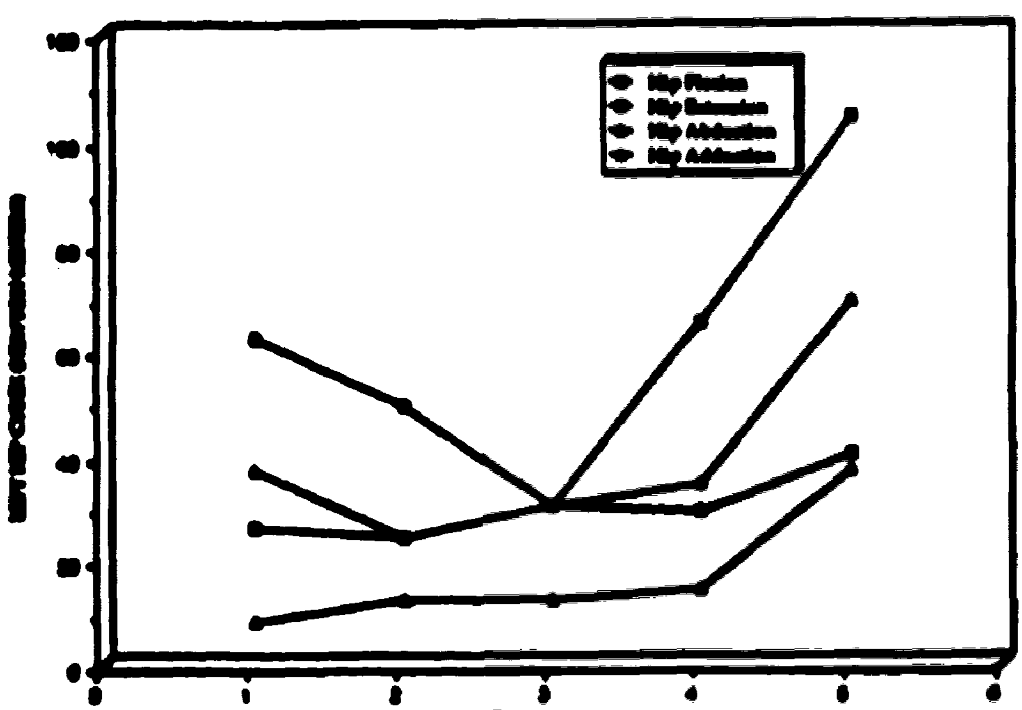

Figure 4 D-Left Hip Cybex Data

SW also increased all her resistances on Nautilus and Universal as per Table E.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] 30 40 55	[illegible] 50 55 65	[illegible] 45 60 70	[illegible] 25 35 45	[illegible] 60 75 90	[illegible] 70 80 90
[illegible]	[illegible] 45 55 65	[illegible] 60 70 80	[illegible] 65 80 90	[illegible] 40 50 55	[illegible] 110 125 140	[illegible] 90 110 120

[illegible]

<u>Discussion</u>

Although SW switched knee braces at critical times within the study, it is believed that by the time she began B Phase these effects would have been negligible. It is reasoned that this would have been adequate time to adjust to the new brace (6 weeks) as she used it to carry out all activities of daily living.

Moderate increases are seen in SW's time on the obstacle course at the beginning of strength training. After the sixth week of training, SW improved almost 60 seconds from the last measurement prior to beginning her strength training program. At the ninth week of training, SW had improved her time on the obstacle course over 120 seconds.

The results of SW's Cybex measurements and final resistances on the Nautilus and Universal (Table E) confirm that SW was indeed gaining strength. The most substantial improvements were observed in right knee flexion and right knee extension over the last four weeks of training. As indicated earlier, SW was weaker on the right side. It is believed that this increase in strength attributed to her decreased speed of walking on the obstacle course. In Figure 4, it is illustrated tha. this time period is when SW experienced the most improvement on the obstacle course.

Increases in right ankle plantar and dorsi flexion agree with the findings of Perry et al. (1993) in that they are key components required in fast walking. SW's increases in hip extension and moderate improvements in hip flexion are similar to those results of BN and JP. Again, hip flexion strength appears to have a limited relationship to the speed of walking.

The results of SW's Cybex data as displayed in Figures 4a, 4b, 4c and 4d are indicative of a possible relationship between lower limb strength training and the speed of walking on this obstacle course. In Cybex tests one to three, SW showed no strength gains with the exception of ankle plantar flexion and ankle dorsi flexion measurements. In fact, decreased strength measurements were observed on several tests. After SW began strength training on week 13 increases were seen immediately on her fourth and fifth Cybex strength tests. There would therefore appear to be a slight relationship between SW's lower limb strength training and her improved speed of walking on the obstacle course.

SUBJECT #5 (WK)

Subject Characteristics

WK is male and had been injured for eight years prior to the beginning of this study. WK was injured in an 8 metre fall and was comatose for 96 days after his injury. WK was 27 years of age at the time of the study. WK had been a previous participant at the Rick Hansen Centre but quit going three years prior to the start of the study. WK obtained grade 11 education and is presently employed part time in a video store. WK was moderately motivated to participate in the study and mostly enjoyed the socialization and the renewal of old acquaintances at the Rick Hansen Centre. WK has not continued to train at the Rick Hansen Centre since the completion of this study.

WK was able to work somewhat independently on his strength training program. He had to be closely supervised during warm-up to ensure he did all of the stretches. He has a lot of trouble counting and thus his repetitions for all exercises had to be monitored closely. Some difficulty arose when he wanted to do more than the required six to eight repetitions on his exercises. If the researcher allowed him to do as many as he wanted, he was unable to complete the full three sets due to fatigue. There were also some questions as to whether or not WK actually worked to fatigue as he gave up easily by his third set.

WK had many deficits as a result of his brain injury. WK is subject to emotional outbursts and displays some inappropriate social skills. WK has a short term memory deficit and uses a memory book to assist himself. WK walks independent of assistive devices but has fallen many times, especially on stairs and icy surfaces. WK would probably be safer with an assistive device but refuses to consider this option. Some of WK's gait deficits include: forward trunk lean, lateral lean left, external rotation of the hip (right), hyper extension of the right knee, excessive plantar flexion and toe drag of the right foot. From self-report and WK's Cybex results, he is stronger on his left side than his right.

<u>Time on Obstacle Course</u>

WK had a fairly unstable baseline as illustrated in Figure 5, but a decreasing trend is not as evident as with the previous subjects. His fastest time recorded during baseline was 69.45 seconds on his third trial. However, after his third week of strength training, his times remained below this speed. During baseline, WK's average time to walk was 77.90 seconds and during B Phase he achieved an average of 67.89 seconds, representing an improvement of 87.15 percent.

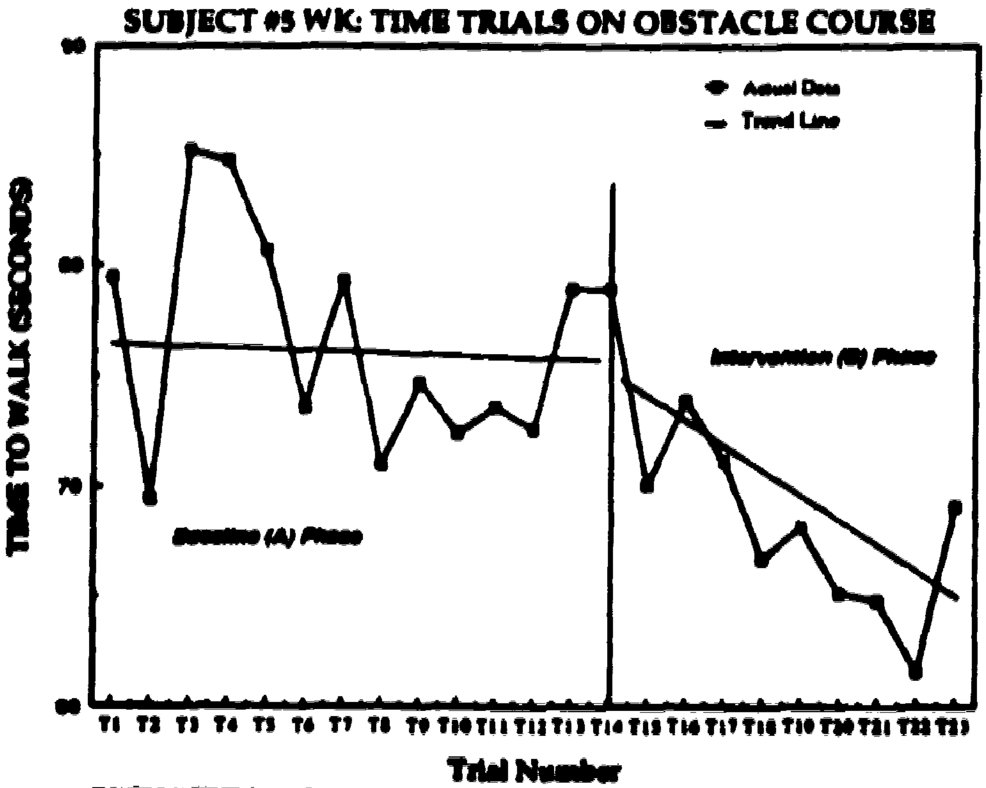

FIGURE 5-SUBJECT#5 WK. Time to Walk Obstacle Course

Cybex Results

Increases were observed in the following: right knee flexion (6NM), right knee extension (8NM), left knee extension (57NM), left knee flexion (8NM), right ankle plantar flexion (57NM), left ankle dorsi flexion (5NM), right ankle dorsi flexion (10NM), right hip adduction (25NM) and left hip adduction (24NM). Decreases were noted in the following: right hip extension (-5NM), left hip extension (-57NM), right hip flexion (-6NM), left hip flexion (-6 NM), left ankle plantar flexion (-6NM), as illustrated in Figures 5a, 5b, 5c and 5d. The raw data is located in Appendix B. Although the Cybex test results are quite erratic, strength improvements are evident because of increased resistances on his Nautilus and Universal exercises (Table E).

SUBJECT #5 WK: RIGHT KNEE AND RIGHT ANKLE CYBEX

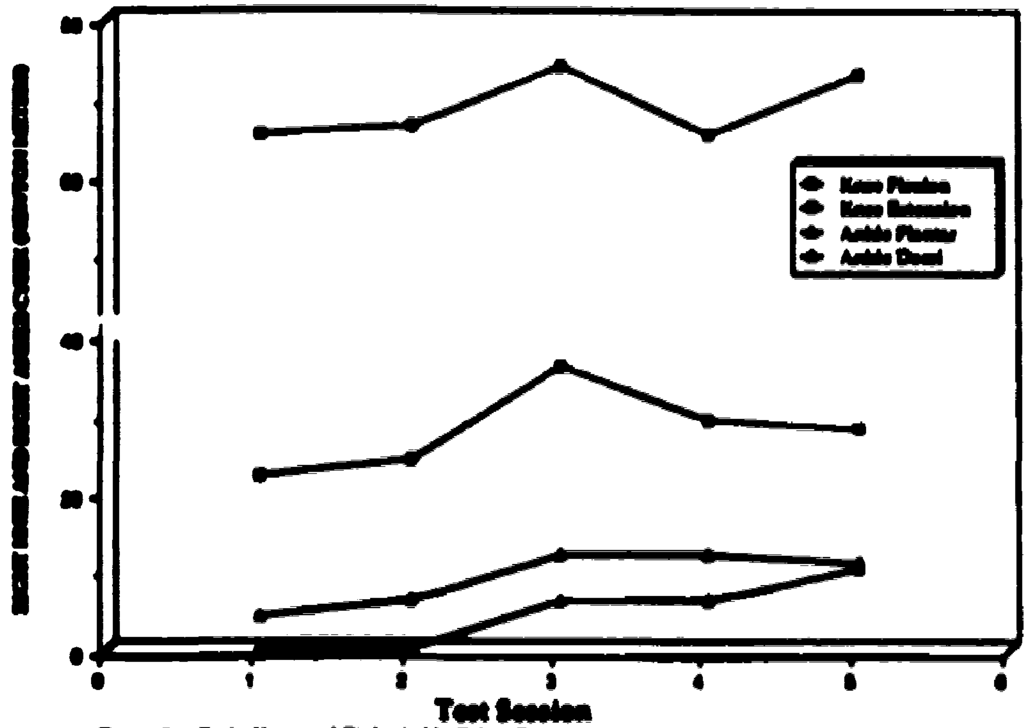

Figure 5 A-Right Knee and Right Ankle Cybex Data

SUBJECT #6 WK: LEFT KNEE AND LEFT ANKLE CYBEX

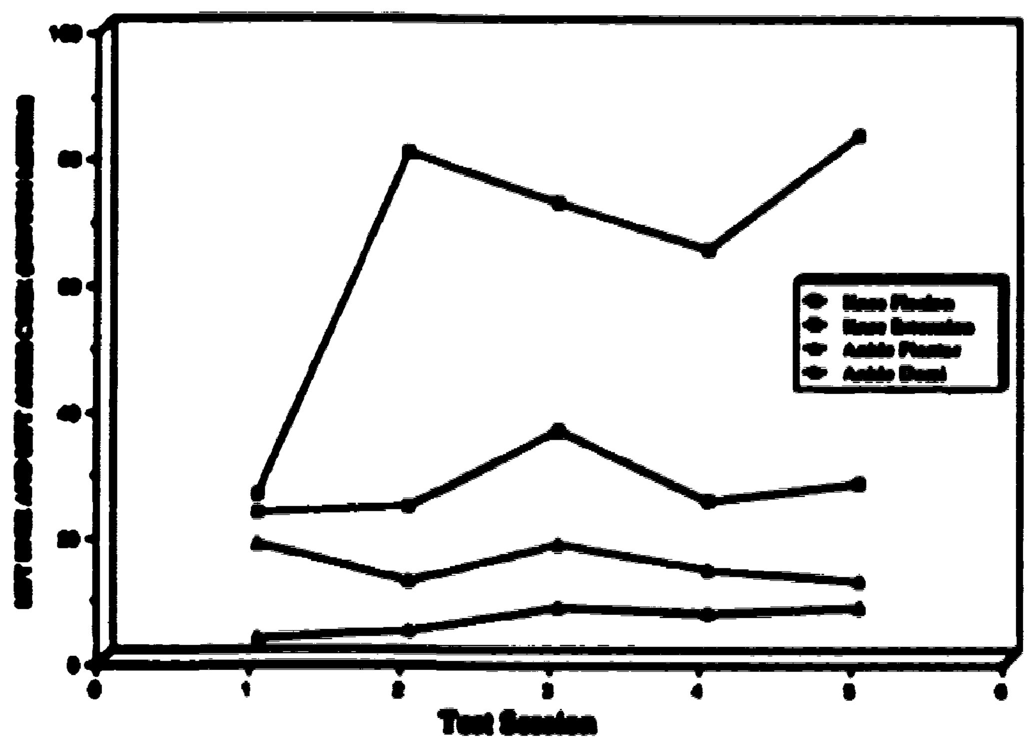

Figure 5 B-Left Knee and Left Ankle Cybex Data

SUBJECT #6 WK: RIGHT HIP CYBEX

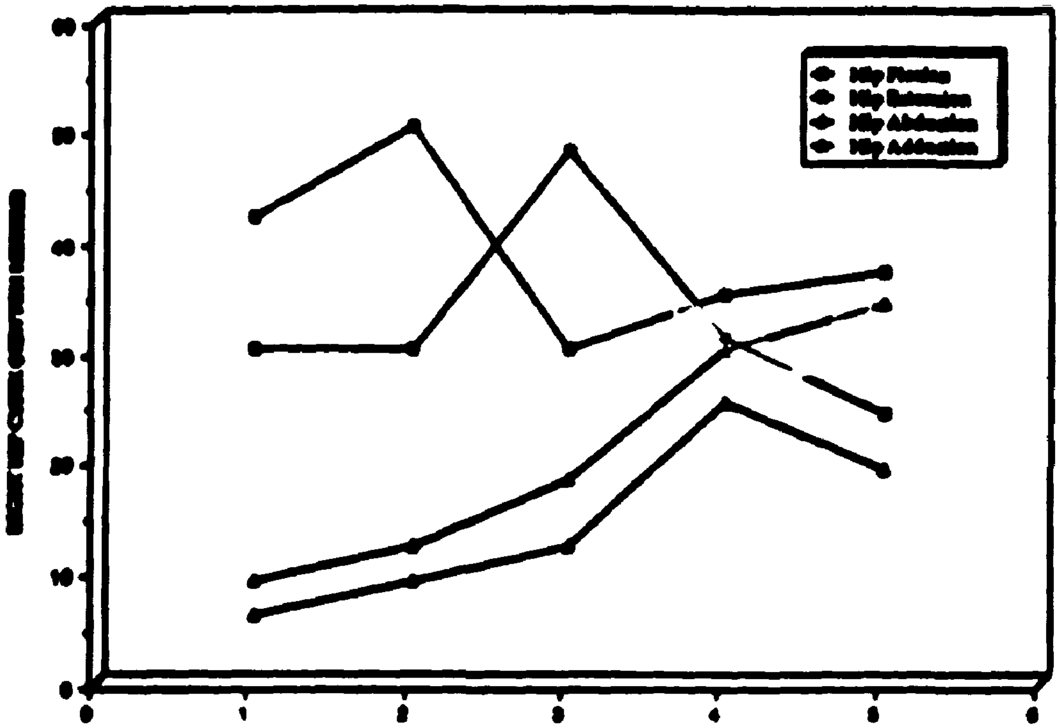

Figure 5 C-Right Hip Cybex Data

SUBJECT #6 WK: LEFT HIP CYBEX

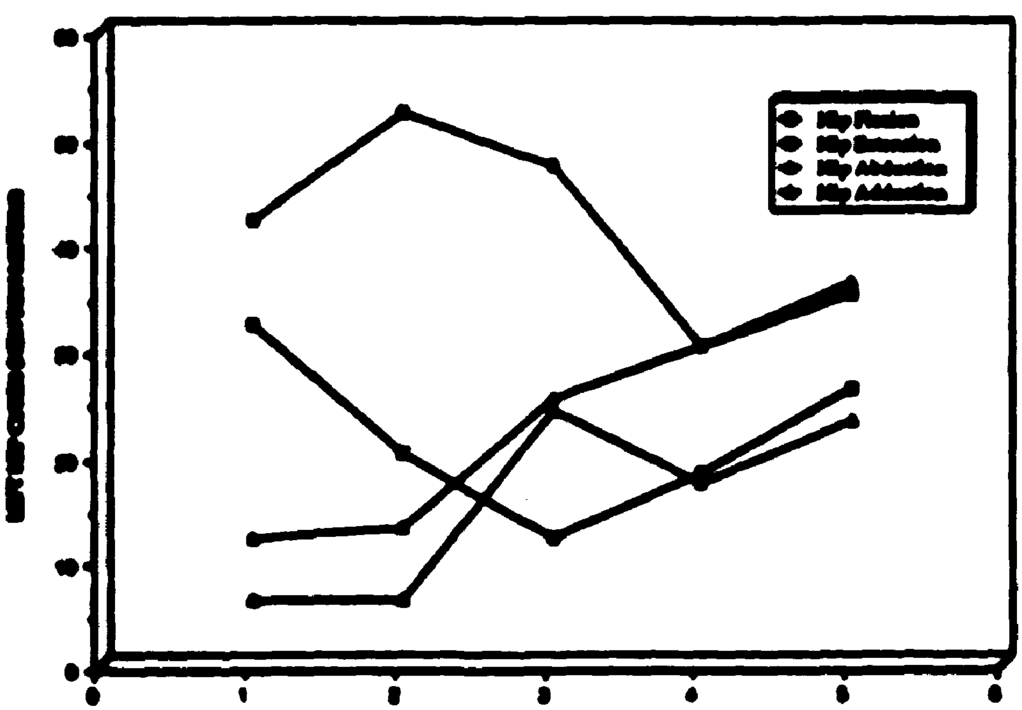

Figure 5 D-Left Hip Cybex Data

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	40 45 60	50 55 60	65 80 90	30 35 40	65 75 90	60 70 80
[illegible]	45 50 55	50 60 70	70 85 100	35 45 55	75 85 100	70 90 110

Discussion

WK's times on the obstacle course were unstable until he began his strength training program. After the second week of training, his times recorded seemed to decline in a more even manner, with the exception of his last recorded time. WK's Cybex hip extension results in Figure 5d reveal similar instability. WK seemed to increase in both right and left knee extension until he began to strength train. After four weeks of strength training, these showed moderate decreases. After eight weeks of strength training, increases were again seen in both right and left knee extension. Similar results are noted in hip adduction and hip abduction.

WK's improvement in right ankle plantar flexion and ankle dorsi flexion and a corresponding decrease in time on the obstacle course is in agreement with Perry et al. (1993) who state that these muscles are most important for the function of walking. As his right side is his weaker side, these results would further support his improved speed of walking. Other increases of note on WK's left side include knee extension, hip abduction and hip adduction. Speculatively, the improvement in knee extension supports the conclusions of Lankhorst et al. (1988) that the quadriceps are the most helpful for climbing of stairs. WK decreased in both right and left hip flexion and extension. As with the previous four subjects, hip flexion strength does not seem to be related to speed of walking on the obstacle course for WK.

Subject #6: LH

Subject Characteristics

LH was the only subject who did not sustain a traumatic brain injury. LH is female and became disabled as a result of a seizure 18 months prior to the beginning of the study. Before experiencing her seizure, LH was employed as a service worker but no longer continues with this occupation. LH had recently been discharged as an outpatient at the local rehabilitation hospital. After her seizure, she remained in coma for 14 days.

As a result of LH's seizure, she became a left hemiplegic. She walked with the assistance of a cane and used the cane for all tests performed on the obstacle course.

LH had several gait deficits which included: lateral lean to the right, circumduction of the hip, and toe drag. LH was very eager to begin strength training and was frustrated with the length of time taken to collect baseline data. LH had to drop out of the study at 12 weeks on the advice of her physician due to a diagnoses of breast cancer.

Time On Obstacle Course

As can be determined from Figure 6, LH showed a very clear continual trend towards improving her time, without experiencing B Phase. For comparison, her times were measured from the beginning of group 1's B Phase. During the seven weeks of baseline she averaged a decrease of 122.98 seconds. During the time frame in which Group 1 began B Phase, she averaged 101.6 seconds, which resulted in an 82.62 percent improvement.

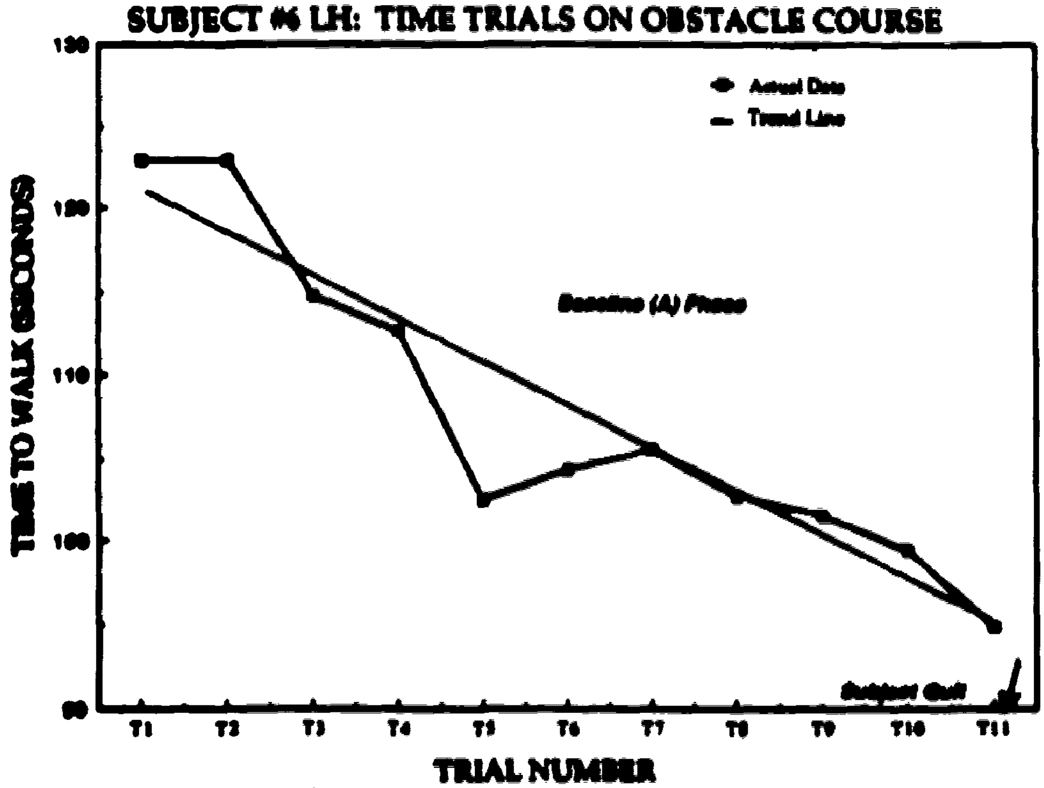

FIGURE 6-SUBJECT#6 LH: Time to Walk Obstacle Course

<u>Cybex Results</u>

Increases in peak torque were noted for the following: right ankle dorsi flexion (6NM), right hip adduction (11NM), left hip adduction (6), left hip extension (4NM), right hip extension (20NM), and left hip flexion (5NM). Decreases or no changes were noted in the following: right knee flexion (-18NM), left knee flexion (-19NM), right knee extension (-26NM), left knee extension (0NM), left ankle dorsi flexion (0NM), right ankle plantar flexion (-6NM), left ankle plantar flexion (0NM), right hip flexion (0NM), left hip adduction (0NM), as illustrated in Figures 6a, 6b, 6c and 6d. The raw data is located in Appendix B. LH had not started strength training, and thus there are no recordings provided for her on Nautilus or Universal.

SUBJECT #6 LH: RIGHT KNEE AND RIGHT ANKLE CYBEX

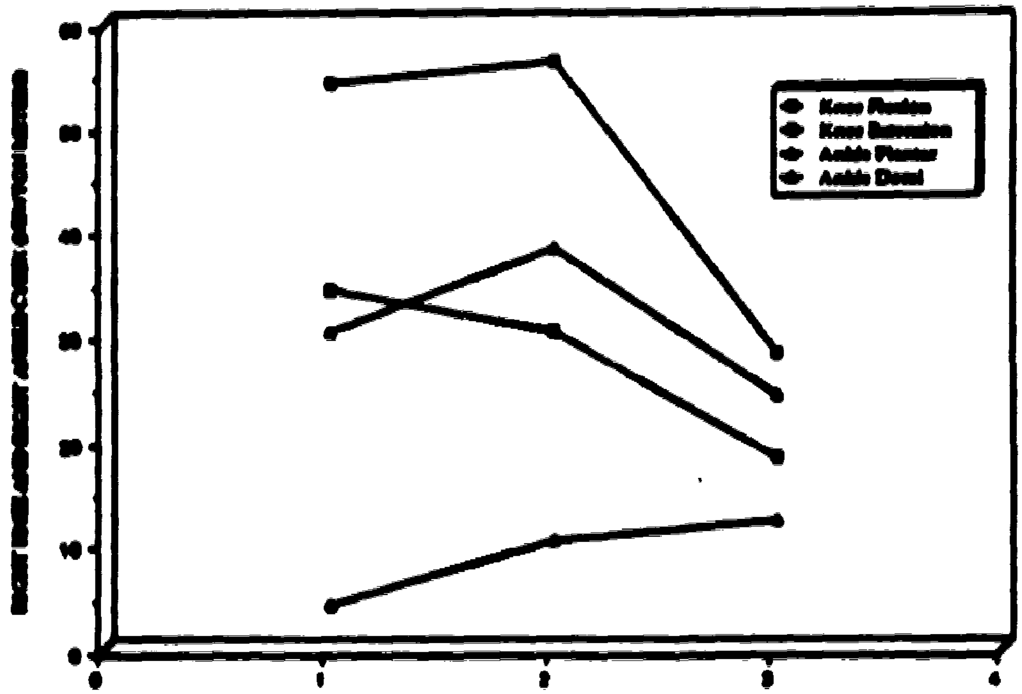

Figure 6 A-Right Knee and Right Ankle Cybex Data

SUBJECT #6 LH: LEFT KNEE AND LEFT ANKLE CYBEX

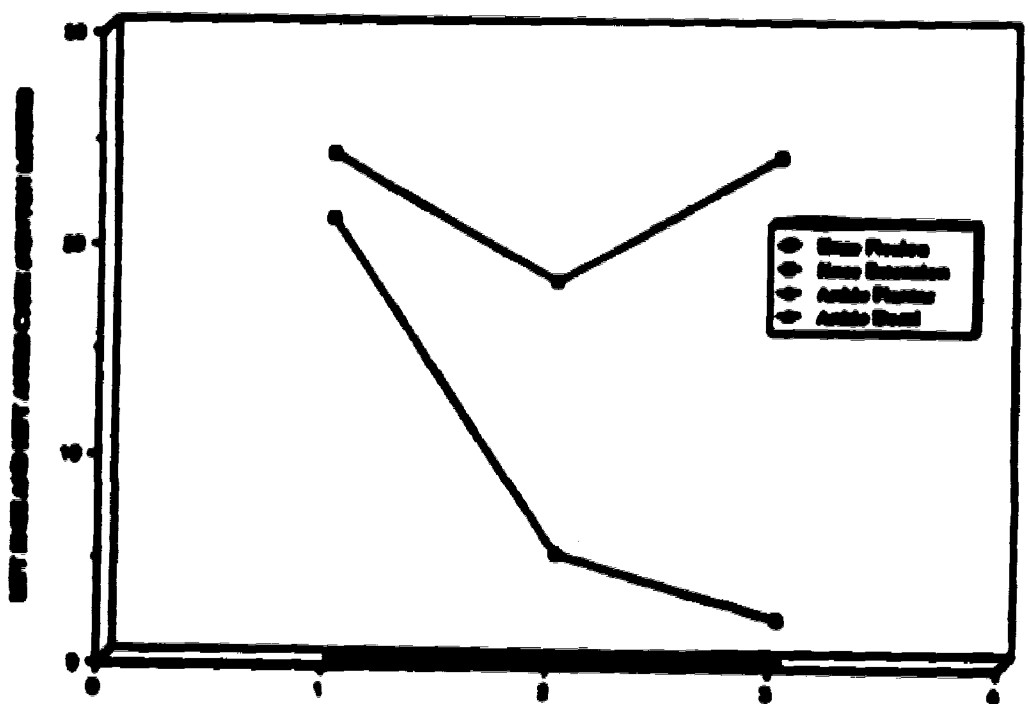

Figure 6 B-Left Knee and Left Ankle Cybex Data

SUBJECT #6 LH: RIGHT HIP CYBEX

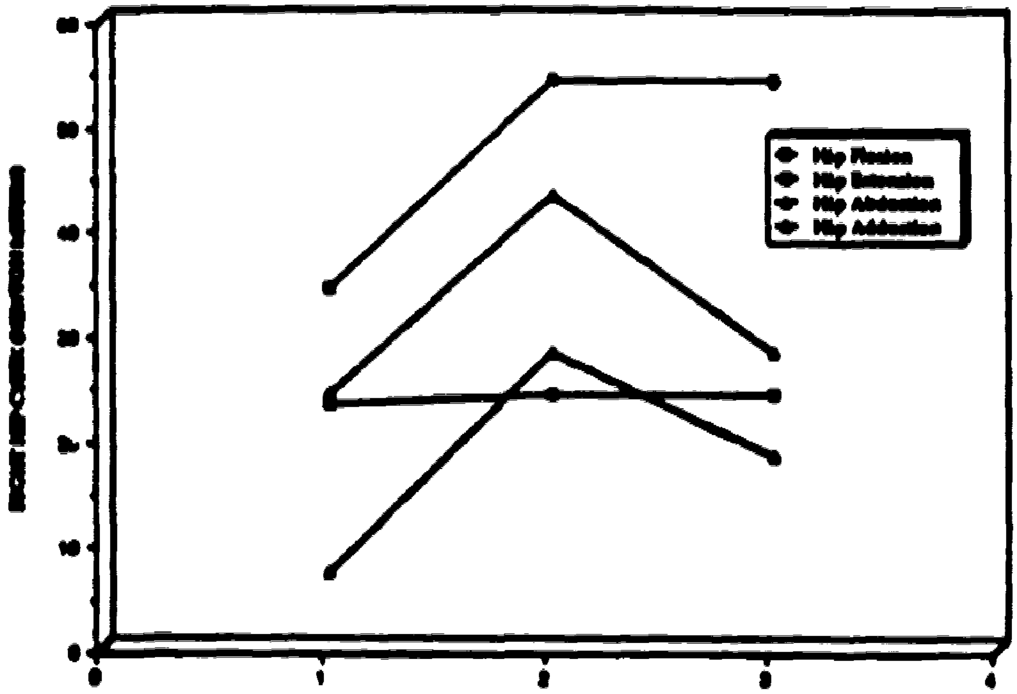

Figure 6 C-Right Hip Cybex Data

SUBJECT #6 LH: LEFT HIP CYBEX

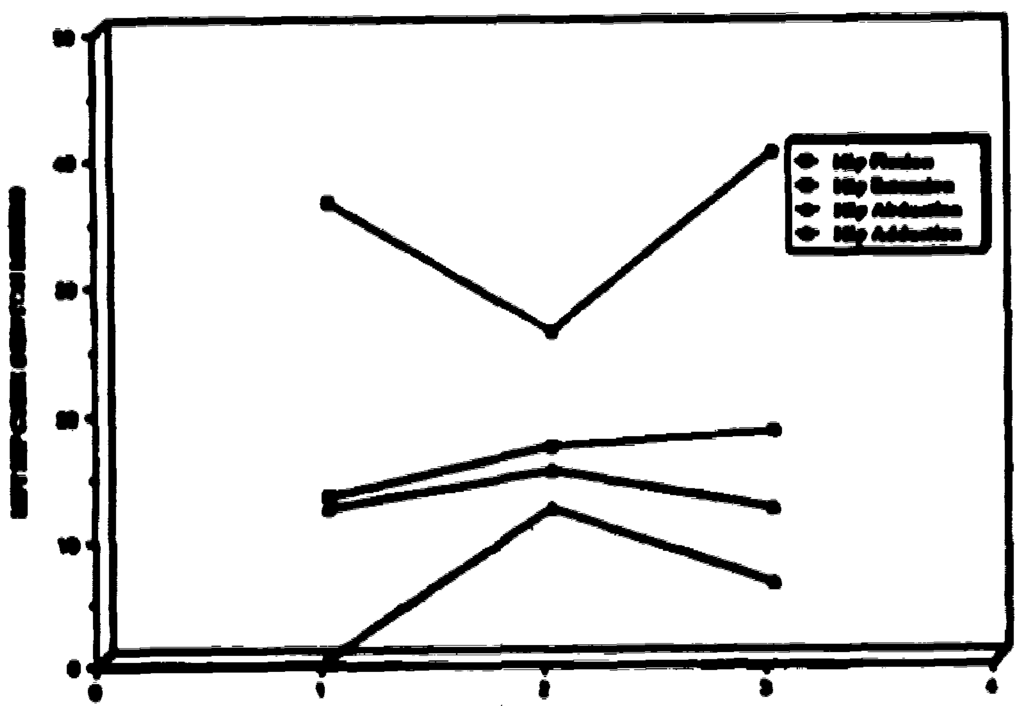

Figure 6 D-Left Hip Cybex Data

Discussion

The results of LH are perplexing. She did not make any significant strength gains and in fact decreased on most measurements. Of note are right and left knee flexion and right knee extension. Further large reductions were seen in hip adduction and hip abduction. The only large improvements were seen in left hip extension. As she did not make any strength gains, her improved time on the obstacle course can not be attributed to increases in strength.

The only explanation available is that LH may have improved her times due to practise. In addition, LH began a new volunteer position after the third week of the study. When questioned about her surprising improvements, she indicated that she was getting out more. Thus, her improvements could be attributed to increased daily walking.

The improvements observed in LH do not coincide with the results of the other subjects. The possible differences between LH and the other subjects are that LH did not have a traumatic brain injury and she had very clear hemiplegic gait. The other subjects tended to have a weaker side but did not display "true" hemiplegic gait as LH did. Another possible explanation is that, out of all of the subjects, LH had acquired her brain injury the most recently. Having just been discharged from outpatient rehabilitation, perhaps she was still experiencing some natural improvements. Without LH completing the study, conclusions are speculative at best but lead to some interesting further research implications.

GROUP 2 SUMMARY

SW and WK did not exhibit any major increases in speed of walking until the sixth to ninth week of strength training. Overall this coincided with their Cybex data, in that the most strength gains were observed during this time frame. Again, knee extension and ankle plantar flexion and ankle dorsi flexion strength seemed to be related to these gains. As demonstrated by subjects BN and JP, hip flexion appeared to be the least related to improvements in speed of walking. These findings agree with the literature that has been reviewed.

2. GROUP DISCUSSION

Improvements were observed in all subjects in their speed of walking the obstacle course. The results of subjects BN, JP, and SW revealed a possible relationship between lower limb strength training and speed of walking on this obstacle course. Although WK improved a substantial amount, his baseline data is variable and thus difficult to draw conclusions from. The results of GH revealed only a moderate relationship and no relationship was found for LH. LH's improvement in time on the obstacle course was discussed as a potential result of her becoming more active within the community and her recent injury.

From the literature, these results are generally in agreement with the conclusions drawn by Nakamura et al. (1985), Bohannon (1986), Lankhorst, et al. (1986), Bohannon (1990) and Perry et al. (1993). Although these authors used primarily stroke subjects and Perry et al. (1993) used subjects with post-polio syndrome to draw conclusions, the relationship established within this study of subjects with a traumatic brain injury supports their findings.

The use of the single-subject multiple baseline across subjects research design in this study weakens the relationship found for increased strength of the lower limbs and speed of walking this obstacle course. If this study had been designed as a traditional group pre-test/post-test design, the results would have been overwhelmingly conclusive, possibly resulting in a Type I error. The results of Subject #2 JP (Figure 2) can be used to explain the possible conclusions of this study if it was a traditional design. If JP's results were analyzed based solely on pretest/post-test, the sharp decline in the first four trials and steady decline after beginning strength training would not have been observed. The sharp decline could possibly be due to learning effects on the obstacle course. Using the first and last data point, Subject #2 would have been reported as increasing a total of 22 seconds overall. If enough subjects were used in the study, surely this finding would have been significant.

The decreasing trend observed in all subjects during baseline can be attributed to many factors. Subjects BN, JP, GH, and LH had been attempting for some time to become involved in the Rick Hansen Centre but were unable to due to long waiting lists. By being involved in this study, the subjects had to go to a novel environment where they all received individual attention which probably lead to increased self-esteem. This would especially be true of GH who resided in a group home environment with very little opportunity for recreation involvement.

All subjects reported that they felt much better overall once beginning their strength training programs. Perhaps this was due to functional improvements, but was more likely due to the enhanced well-being of an active lifestyle. Four out of the six subjects continue to strength train as a result of participating in this study. One subject did not continue due to work commitments and another is unable to continue on the advice of her physician.

Difficulties with subject motivation were encountered in all subjects with the exception of BN. Again, this may not have been determined using a group pre-test/post-test design. A further challenge for the researcher was to remain cognizant of memory difficulties which were observed in all subjects. All dates and times had to be carefully recorded for subjects. In addition, constant education with regard to research protocol was required. Difficulty of strict research protocol with the subjects was realized when SW switched braces and when LH became more active in the community. Although not desirable for research, ethically subjects could not be restricted from undertaking these activities. Finally, GH's sudden desire to quit without explanation further exemplified the difficulty of performing research with this group.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Five subjects that participated in this study had sustained a severe traumatic brain injury as defined by their length of coma after injury. The sixth subject had suffered an internal brain injury as a result of seizure.

A single subject, multiple baseline across subjects research design was utilized to determine if there is a relationship between speed of walking on this obstacle course and lower limb strength increases. Although all subjects improved substantially in their time to walk the obstacle course, only three out of the six subjects demonstrated evidence of this relationship. Two subjects withdrew from the study and the relationship is not clear for a third subject, due to variability in the data.

Agreement was found with the literature in that increased strength of the knee extensor, knee flexors, ankle plantar flexors, ankle dorsi flexors, hip adductors and hip abductors seemed to correspond with increases in strength. All subjects improved their strength in at least some of their lower limb muscle groups as was determined through Cybex measurements and increases in resistance on their Nautilus and Universal exercises.

The difficulties with performing research with this population were outlined. The multitude of deficits that this group can potentially have make this group most interesting and challenging for future research. Due to their previously relatively inactive lifestyles, the new stimulation and effects of practise were probably enhanced. Thus, for these reasons, it is thought that initial decreases in time were observed for all subjects. It is hypothesized that if a group had been used in this study who were familiar with the Rick Hansen Centre environment, the effects of strength training only may have been more clearly revealed.

Conclusions

The initial question of this thesis asked whether strength training of the lower limbs could enhance the functional locomotor skills of persons with a traumatic brain injury. As the results of the speed of walking on the obstacle course and the results of the subjects' Cybex tests and their increases in resistances on Nautilus and Universal reveal, it was determined that there appeared to be a relationship between these two variables.

The muscle groups that seemed to be related to the improvement in walking time on the obstacle course were knee extensors, knee flexors, ankle plantar flexors and ankle dorsi flexors. There was some speculation that improved muscle strength of the quadriceps lead to enhanced speed on the obstacle course due to the subjects' improved ability to traverse the stairs. This relationship was determined to be inconclusive as seperate times were not measured for the stairs, ramp, curb and level walkway.

Generally, the findings agreed with previous studies. However, Perry et al. (1993) found a poor relationship with knee extensor strength and fast paced walking in subjects with post-polio syndrome. Perry et al. did find a relationship with fast walking and strength of the ankle plantar flexors. In addition, the findings of this study also revealed that there does not appear to be a relationship between hip flexor strength and speed of walking on the obstacle course.

A further question this thesis set out to answer was whether or not the functional improvements informally observed in persons with a traumatic brain injury performing in exercise programs were due to the exercise program. After analyzing the results of testing using single-subject, multiple baseline across subjects research design, there appears to be some support for this idea. Subjects in Group 2 who remained at baseline while subjects in Group 1 performed strength training, showed very little improvement in their speed of walking on the obstacle course. Once subjects in Group 2 began their strength training program, decreases in their time to walk the obstacle course were observed. These decreases were most noticeable at the sixth to ninth week of resistance training. This is important as, according to the literature, it is well known that this is the time frame in which strength gains are recorded.

In conclusion, the prescription of a fitness program to this population could possibly serve as a long term form of rehabilitation to enhance the functional independence levels of people with a traumatic brain injury; in particular a strength training program. The results of this study indicate that at least one component of a fitness program can lead to enhanced functional skills for this population. Further research is required in order to fully answer this question.

Recommendations

The use of a single-subject multiple baseline across subjects research design in this study revealed many implications. The variability between the subjects in many areas including walking ability, severity of injury and time since injury, exemplify the true difficulties of designing a homogeneous group of people with a TBI for traditional research designs. The results of Subject JP were reviewed to illustrate the danger of making a Type I error if traditional pre-test/post-test designs are used. Thus, it is highly recommended that future research with this population be conducted using a single-subject design when possible.

As a result of this study, several further research implications arose. With specific reference to GH, are traditional strength training regimes appropriate for this population? Related to this question is to further determine the role of the other fitness components of muscular endurance, cardiovascular conditioning, and flexibility in improving this population's overall functional abilities. With reference to LH, would practise in the community have more of an effect than strength training on this population's functional skills? Through subjective observations, all subjects reported an enhanced feeling of well-being. The psychological ramifications associated with an increase in a feeling of well-being reported by the subjects could be further researched.

Tests of specific functional skills and their relationship to physical fitness should be further investigated. Although an attempt has been made with this study to examine this question, research of these effects should be taken out of the laboratory and into the community. Although these subjects improved their speed to traverse a set of stairs and a ramp, can they now reach a bus stop quicker, or answer a phone in their basement more efficiently? It is highly recommended that an attempt be made to answer these questions in future research endeavours.

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APPENDIX A

SUBJECT TIMES ON OBSTACLE COURSE (SECONDS)

BN (Subject #1)
Baseline

5 March, 1993	44.06
12 March, 1993	39.52
19 March, 1993	36.67
26 March, 1993	40.70
2 April, 1993	39.36
9 April, 1993	38.70
16 April, 1993	39.02
B Phase/Begin Str. (04/19)	
23 April, 1993	37.70
30 April, 1993	35.20
7 May, 1993	34.18
14 May, 1993	33.97
21 May, 1993	33.71
28 May, 1993	30.15
4 June, 1993	31.28
11 June, 1993	Absent
18 June, 1993	31.25
25 June, 1993	70.13
2 July, 1993	29.89
9 July, 1993	28:55
16 July, 1993	66.77
23 July, 1993	27.89
30 July, 1993	30.67
6 August, 1993	29.14
13 August, 1993	28.37
20 August, 1993	28.95

Baseline Average = 39.72 Seconds
B Phase Average = 31.33 Seconds
Percent Improvement = 78.86%

JP (Subject #2)
Baseline

5 March, 1993	Absent
12 March, 1993	70.85
19 March, 1993	70.36
26 March, 1993	64.42
2 April, 1993	63.58
9 April, 1993	Absent
16 April, 1993	57.44
B Phase/Begin Str. (04/19)	
23 April, 1993	54.61
30 April, 1993	51.48
7 May, 1993	55.58
14 May, 1993	53.53
21 May, 1993	52.06
28 May, 1993	56.22
4 June, 1993	56.38
11 June, 1993	51.42
18 June, 1993	51.86
25 June, 1993	51.34
2 July, 1993	53.70
9 July, 1993	47.42
16 July, 1993	47.45
23 July, 1993	49.91
30 July, 1993	52.55
6 August, 1993	48.61
13 August, 1993	45.77
20 August, 1993	48.30

Baseline Average = 65.33 Seconds
B Phase Average = 51.86 Seconds
Percent Improvement = 78.93%

APPENDIX A

SUBJECT TIMES ON OBSTACLE COURSE (SECONDS)

GH (Subject #3)	
Baseline	
5 March, 1993	183.29
12 March, 1993	202.11
19 March, 1993	171.54
26 March, 1993	195.27
2 April, 1993	210.35
8 April, 1993	162.33
16 April, 1993	173.50
B Phase/Begin	**Str. (04/19)**
23 April, 1993	106.44
30 April, 1993	139.89
7 May, 1993	164.90
14 May, 1993	171.67
21 May, 1993	174.84
28 May, 1993	152.74
4 June, 1993	154.07
11 June, 1993	Injured
12 June, 1933	Quit

Baseline Average = 186.46 Seconds
B Phase Average = 150.08 Seconds
Percent Improvement = 86.09%

SW (Subject #4)	
Baseline	
5 March, 1993	Absent
12 March, 1993	813.87
19 March, 1993	690.10
26 March, 1993	704.57
2 April, 1993	696.30
8 April, 1993	516.10
16 April, 1993	725.67
23 April, 1993	571.22
30 April, 1993	Absent
7 May, 1993	Absent
14 May, 1993	620.82
21 May, 1993	630.06
28 May, 1993	542.08
4 June, 1993	534.25
11 June, 1993	542.08
18 June, 1993	538.95
B Phase/Begin	**Str. (06/21)**
25 June, 1993	502.64
2 July, 1993	496.29
9 July, 1993	487.39
16 July, 1993	494.31
23 July, 1993	462.43
30 July, 1993	443.27
6 August, 1993	452.65
13 August, 1993	381.04
20 August, 1993	379.76

Baseline Average = 625.06 Seconds
B Phase Average = 456.54 Seconds
Percent Improvement = 72.87%

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #1: BN

KNEE FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		ExtenSion	
Right	60	Right	106
Left	42	Left	90

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	60	Right	118
Left	48	Left	108

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	54	Right	108
Left	55	Left	110

TEST 4 (18 JUL.93)

Flexion		Extension	
Right	78	Right	120
Left	66	Left	126

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	67	Right	116
Left	63	Left	123

ANKLE PLANTAR/DORSI

TEST 1 (18 APR.93)

Plantar		Dorsi	
Right	38	Right	7
Left	43	Left	19

TEST 2 (16 MAY93)

Plantar		Dorsi	
Right	38	Right	9
Left	42	Left	12

TEST 3 (14 JUN. 93)

Plantar		Dorsi	
Right	36	Right	18
Left	44	Left	18

TEST 4 (18 JUL. 93)

Plantar		Dorsi	
Right	49	Right	20
Left	50	Left	24

TEST 5 (20 AUG.93)

Plantar		Dorsi	
Right	53	Right	19
Left	52	Left	25

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #1: BN

HIP FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	49	Right	98
Left	42	Left	68

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	42	Right	73
Left	37	Left	90

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	42	Right	84
Left	38	Left	78

TEST 4 (18 JUL.93)

Flexion		Extension	
Right	52	Right	90
Left	36	Left	36

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	38	Right	83
Left	40	Left	104

HIP ABDUCTION/ADDUCTION

TEST 1 (18 APR.93)

Abduction		Adduction	
Right	31	Right	43
Left	29	Left	56

TEST 2 (16 MAY93)

Abduction		Adduction	
Right	42	Right	90
Left	37	Left	94

TEST 3 (14 JUN. 93)

Abduction		Adduction	
Right	34	Right	36
Left	38	Left	68

TEST 4 (18 JUL. 93)

Abduction		Adduction	
Right	42	Right	78
Left	36	Left	106

TEST 5 (20 AUG.93)

Abduction		Adduction	
Right	38	Right	61
Left	37	Left	69

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #2: JP

KNEE FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	40	Right	60
Left	40	Left	83

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	31	Right	48
Left	43	Left	86

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	36	Right	72
Left	46	Left	96

TEST 4 (18 JUL.93)

Flexion		Extension	
Right	36	Right	84
Left	48	Left	96

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	46	Right	80
Left	53	Left	104

ANKLE PLANTAR/DORSI

TEST 1 (18 APR.93)

Plantar		Dorsi	
Right	7	Right	5
Left	28	Left	8

TEST 2 (16 MAY93)

Plantar		Dorsi	
Right	15	Right	7
Left	28	Left	6

TEST 3 (14 JUN. 93)

Plantar		Dorsi	
Right	18	Right	9
Left	26	Left	8

TEST 4 (18 JUL. 93)

Plantar		Dorsi	
Right	25	Right	11
Left	36	Left	12

TEST 5 (20 AUG.93)

Plantar		Dorsi	
Right	24	Right	14
Left	29	Left	18

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #2: JP

HIP FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	24	Right	36
Left	18	Left	49

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	25	Right	76
Left	34	Left	72

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	13	Right	44
Left	24	Left	70

TEST 4 (18 JUL.93)

Flexion		Extension	
Right	29	Right	60
Left	48	Left	96

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	28	Right	73
Left	28	Left	76

HIP ABDUCTION/ADDUCTION

TEST 1 (18 APR.93)

Abduction		Adduction	
Right	18	Right	36
Left	19	Left	26

TEST 2 (16 MAY93)

Abduction		Adduction	
Right	26	Right	36
Left	18	Left	28

TEST 3 (14 JUN. 93)

Abduction		Adduction	
Right	24	Right	42
Left	10	Left	15

TEST 4 (18 JUL. 93)

Abduction		Adduction	
Right	36	Right	84
Left	34	Left	43

TEST 5 (20 AUG.93)

Abduction		Adduction	
Right	24	Right	69
Left	19	Left	31

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #3: GH

KNEE FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	60	Right	96
Left	68	Left	101

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	86	Right	168
Left	48	Left	104

ANKLE PLANTAR/DORSI

TEST 1 (18 APR.93)

Plantar		Dorsi	
Right	48	Right	8
Left	40	Left	5

TEST 2 (16 MAY93)

Plantar		Dorsi	
Right	33	Right	12
Left	48	Left	13

HIP FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	84	Right	156
Left	32	Left	114

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	32	Right	72
Left	37	Left	66

HIPABDUCTION/ADDUCTION

TEST 1 (18 APR.93)

Abduction		Adduction	
Right	42	Right	79
Left	36	Left	108

TEST 2 (16 MAY93)

Abduction		Adduction	
Right	40	Right	59
Left	36	Left	66

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SUBJECT #4: SW

KNEE FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	36	Right	71
Left	38	Left	102

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	38	Right	66
Left	43	Left	92

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	36	Right	66
Left	53	Left	91

TEST 4 (18 JUL.93)

Flexion		Extension	
Right	38	Right	76
Left	42	Left	98

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	53	Right	95
Left	45	Left	99

ANKLE PLANTAR/DORSI

TEST 1 (18 APR.93)

Plantar		Dorsi	
Right	12	Right	5
Left	30	Left	8

TEST 2 (16 MAY93)

Plantar		Dorsi	
Right	19	Right	8
Left	24	Left	9

TEST 3 (14 JUN. 93)

Plantar		Dorsi	
Right	12	Right	4
Left	35	Left	13

TEST 4 (18 JUL. 93)

Plantar		Dorsi	
Right	18	Right	6
Left	24	Left	8

TEST 5 (20 AUG.93)

Plantar		Dorsi	
Right	22	Right	11
Left	25	Left	12

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #4: SW

HIP FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	36	Right	76
Left	26	Left	62

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	26	Right	52
Left	24	Left	49

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	27	Right	48
Left	30	Left	30

TEST 4 (18 JUL.93)

Flexion		Extension	
Right	31	Right	60
Left	29	Left	65

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	31	Right	83
Left	40	Left	104

HIP ABDUCTION/ADDUCTION

TEST 1 (18 APR.93)

Abduction		Adduction	
Right	30	Right	43
Left	8	Left	37

TEST 2 (16 MAY93)

Abduction		Adduction	
Right	12	Right	30
Left	12	Left	24

TEST 3 (14 JUN. 93)

Abduction		Adduction	
Right	12	Right	36
Left	12	Left	30

TEST 4 (18 JUL. 93)

Abduction		Adduction	
Right	17	Right	24
Left	14	Left	34

TEST 5 (20 AUG.93)

Abduction		Adduction	
Right	38	Right	61
Left	37	Left	69

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #5: WK

KNEE FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	22	Right	65
Left	80	Left	26

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	24	Right	66
Left	24	Left	80

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	36	Right	74
Left	36	Left	72

TEST 4 (18 JUL.93)

Flexion		Extension	
Right	29	Right	65
Left	25	Left	65

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	28	Right	73
Left	28	Left	83

ANKLE PLANTAR/DORSI

TEST 1 (18 APR.93)

Plantar		Dorsi	
Right	4	Right	0
Left	18	Right	3

TEST 2 (16 MAY93)

Plantar		Dorsi	
Right	6	Right	0
Left	12	Left	4

TEST 3 (14 JUN. 93)

Plantar		Dorsi	
Right	12	Right	6
Left	18	Left	8

TEST 4 (18 JUL. 93)

Plantar		Dorsi	
Right	12	Right	6
Left	14	Left	7

TEST 5 (20 AUG.93)

Plantar		Dorsi	
Right	11	Right	10
Left	12	Left	8

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #5: WK

HIP FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	30	Right	42
Left	32	Left	42

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	30	Right	50
Left	20	Left	52

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	48	Right	30
Left	12	Left	47

Flexion		Extension	
Right	31	Right	35
Left	18	Left	30

TEST 5 (20 AUG.93)

Flexion		Extension	
Right	24	Right	37
Left	26	Left	35

HIP ABDUCTION/ADDUCTION

TEST 1 (18 APR.93)

Abduction		Adduction	
Right	6	Right	9
Left	6	Left	12

TEST 2 (16 MAY93)

Abduction		Adduction	
Right	9	Right	12
Left	6	Left	13

TEST 3 (14 JUN. 93)

Abduction		Adduction	
Right	12	Right	18
Left	24	Left	25

Abduction		Adduction	
Right	25	Right	30
Left	17	Left	30

TEST 5 (20 AUG.93)

Abduction		Adduction	
Right	19	Right	34
Left	23	Left	36

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #6: LH

KNEE FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	34	Right	54
Left	21	Left	24

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	30	Right	56
Left	5	Left	18

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	18	Right	28
Left	2	Left	24

ANKLE PLANTAR/DORSI

TEST 1 (18 APR.93)

Plantar		Dorsi
Right	30	4
Left	0	0

TEST 2 (16 MAY93)

Plantar		Dorsi	
Right	38	Right	10
Left	0	Left	0

TEST 3 (14 JUN. 93)

Plantar		Dorsi	
Right	24	Right	12
Left	0	Left	0

APPENDIX B

CYBEX RAW DATA /PEAK TORQUES (NM)

SUBJECT #6: LH

HIP FLEXION/EXTENSION

TEST 1 (18 APR.93)

Flexion		Extension	
Right	24	Right	34
Left	13	Left	36

TEST 2 (16 MAY 93)

Flexion		Extension	
Right	24	Right	54
Left	17	Left	26

TEST 3 (14 JUN.93)

Flexion		Extension	
Right	24	Right	54
Left	18	Left	40

HIP ABDUCTION/ADDUCTION

TEST 1 (18 APR.93)

Abduction		Adduction	
Right	7	Right	24
Left	0	Left	12

TEST 2 (16 MAY93)

Abduction		Adduction	
Right	28	Right	43
Left	12	Left	15

TEST 3 (14 JUN. 93)

Abduction		Adduction	
Right	18	Right	28
Left	6	Left	12